Global Issues in Water Policy 30

Mahmood Ahmad *Editor*

Water Policy in Pakistan

Issues and Options

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Global Issues in Water Policy

Volume 30

Global Issues in Water Policy is now indexed in SCOPUS.

Policy work in the water sector has grown tremendously over the past two decades, following the Rio Declaration of 1992. The existing volume of water-related literature is becoming dominant in professional outlets, including books and journals. Because the field of water resources is interdisciplinary in nature, covering physical, economic, institutional, legal, environmental, social and political aspects, this diversification leads in many cases to partial treatment of the water issues, or incomplete analysis of the various issues at stake. Therefore, treating a whole host of a country's water resources issues in one set of pages will be a significant contribution to scholars, students, and other interested public. This book series is expected to address both the current practice of fragmented treatment of water policy analyses, and the need to have water policy being communicated to all interested parties in an integrated manner but in a non-technical language. The purpose of this book series is to make existing knowledge and experience in water policy accessible to a wider audience that has a strong stake and interest in water resources. The series will consist of books that address issues in water policy in specific countries, covering both the generic and specific issues within a common and pre-designed framework.

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Other than my family, who stuck with me during two years of manuscript preparations, my dedication goes out to two prominent names in the water sector. The first happens to be my late father, Dr. Mushtaq Ahmad, Director of the Irrigation Research Institute and bestowed with a Sitara-e-Khidmat (the Star of Service—an award marking the services to those in need) from the government of Pakistan and a number of gold medals from the Engineering Congress. In fact, he did believe in me as a member of the water family; perhaps with his prayers, I can carry forward the light he showed. I dedicate this book to the late Shahid Ahmad, who was a distinguished expert, a contributing author to this book, and who provided the needed support and direction to turn this book into a reality. I wish he was with us to share the outcome.

Foreword

This book sets itself an ambitious agenda. On the one hand, it seeks to be an encyclopedic review of the complex and complicated constellation of water policy challenges facing Pakistan. On the other hand, it aspires to identify alternative approaches and agendas on how to re-conceive the water policy landscape of Pakistan. The ambition is bold, maybe even foolhardy, but it is most timely and very welcome.

The authors are to be congratulated for compiling a much-needed compendium of key water policy issues in Pakistan, but even more for helping their reader come to the realization that we need to not only rethink the *content* of water policy in Pakistan, but the very essence of *what we mean* by water policy in Pakistan. It is not simply the emergence of new and pressing challenges such as climate change but the accumulated evidence of decades of ineffective policy interventions that should alert us to the necessity of reimagining just what sort of a ‘resource’ water is. The same realization was brought home, in tragically dramatic fashion, during the 2022 floods in Pakistan.

A subtext of many of the chapters in this volume is that water is nowhere – and certainly not in Pakistan – simply a sectoral economic input in sectors such as agriculture or energy. As much as it is an economic resource, quite separately from being that, it is also very much a political resource, a social resource, a cultural resource, and, certainly in the Indus Basin, a civilizational resource.

For this reader, at least, the lesson is that in a society as defined by its water profile as Pakistan is, water policy is just too important to be constrained and compartmentalized into the suffocating confines of traditional ‘water institutions.’ Water policy will – as it always has, and as it should – seep into other areas of policy; possibly into *all* other areas of policy. That is the nature of water. And that need not be a bad thing at all.

In fact, if this book’s prescription of moving beyond the obsession with supply-side water policy, of contextualizing water as a ‘governance’ challenge rather than just a ‘management’ problem, and of addressing the inevitable surprises that climate change has begun to bombard us with are ever to be taken seriously, they will demand a much broader institutional palette for policy than is currently available. This discussion – on how to reconceive water policy in Pakistan – that many chapters in this volume provide insights into, needs to be continued beyond this present work, especially by a new generation of water policy scholars in Pakistan. Indeed, the 2022 floods in Pakistan may become the seminal tragedy that forces this change. It would be pity compounded if it does not.

Such a transformation is all the more important because of the way climate change is already impacting countries like Pakistan in what I have been calling 'The Age of Adaptation.' While all now realize the importance of climate change in water policy, too many are still stuck in a rather narrow conceptualization centered around 'what climate change might do to the water *sector*.' Important as this is, it misses the essence of what living in 'The Age of Adaptation' will inevitably look like in Pakistan: water becomes the frontline face of climate impacts in Pakistan. In glacial melt, in floods, in droughts, in sea-level rise, in ecological destruction, in extreme heat events, in potable water stress, and much more, climate change is being and will continue to be *felt* in Pakistan primarily through the medium of water. The 2022 floods in Pakistan have also alerted us to the importance of 'climate justice' in a water context and, possibly, that 'water justice' is the other side of the coin we are calling 'climate justice.' All evidence suggests that climate change is not only changing the water profile of the country, but will change – may already be changing – what we mean by water policy in Pakistan.

Clearly, now is the time for ambitious and bold thinking. One is thankful that chapters in this book begin investing in such a conversation and one hopes that it will inspire many others to build on this and add more.

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October 2022, Boston

Preface

This book sets out to address the pressing challenges in Pakistan's water sector – both old and new. The old challenges – a perception of growing water scarcity and the continuous search for supply-side solutions in the water sector and water governance – are well-documented. The new challenges include climate change impacts that can be observed in the form of too little water (droughts) or too much water (floods) along with much more.

Written under this backdrop, this book tries to formulate Pakistan's water policy for the twenty-first century. In our view, this requires a major shift from the classic paradigm currently employed in water resource management (supply enhancement, command-and-control water allocation) to an adaptive approach – that is, based on demand management and economic incentives. Each chapter follows a balanced approach in seeking and evaluating alternate solutions to water management issues, especially improvements in water governance and tackling new challenges emerging from climate change in both the short and long term. We have placed a strong emphasis on moving from a culture of pilot projects to one that prioritizes actual implementation on an impact-oriented scale in order to have a sustainable future. We also highlight that most solutions to water challenges are not just limited to the water sector – they also lie in the domains of agriculture, population, economy, etc. Post-COVID-19 policies are exploring solutions within the new food, water, and health nexus, which calls for nature-based solutions to ensure food and water security and sustainable development. Pioneering work that is underway in Pakistan has been documented to show how new policies can reduce water use in agriculture and save enough water for other competing purposes without the need to invest in expensive water technology and infrastructure.

This book is timely and aims to change old mindsets and create a policy space for new and innovative ideas that address the country's water woes. The main goal for this book, therefore, is to present readers with a coherent and up-to-date analysis regarding major water policy issues in Pakistan, written by distinguished technical specialists in the field, bringing together ongoing policy debates in all their dimensions and perspectives with a greater focus on implementation. It should be noted that Pakistan is an archetypal case for readers both nationally and internationally, since the management of the Indus Basin Irrigation System (IBIS), the world's largest irrigation system, means that a plethora of technical and policy lessons can be documented.

The main theme of the book is centered on a transformative process. This process underpins the need to change the narrative, which will change the outcomes, as the political economy of water continues to dominate policy discourse, as discussed in Chapters 1 and 2. In the next chapters, an agenda for transformation is proposed. Chapters 3, 4, 5, and 6 present a detailed accounting and auditing of water resources in Pakistan with the conclusion that our supply is finite but demand is open-ended – leading to a growing consensus that business as usual is not an option. Furthermore, deteriorating water quality affects both supply and demand. Chapters 8, 9, 10, 11, 12, 13, and 14 make a case for moving from supply to demand management; from emphasis on canal and surface irrigation to groundwater management or an integrated approach; from high-cost projects to low-cost nature-based solutions in both agriculture and water; from low-value to high-value crops; and from management to governance. We recommend that this proposed transformative framework be organized as a major policy shift to promote demand management, even in an era where policies continue to push supply-side development – as reflected in the building of large dams and also how adding water storage has become such a highly politicized activity that it leaves almost no room for considering several other viable options. It was also important to focus a chapter on the "food, water, and energy nexus" to look at sectors from an interconnected lens to make the transformative process a "win-win-win strategy." Not using the nexus approach often results in sub-optimal investments. For example, the present global wheat crisis, caused by regional conflicts (the ongoing Ukraine war), reminds us of the need to delink food production and pricing from the international price of fossil fuel, which is seriously affecting the food security of both developing and developed countries.

The last chapter of the book elaborates on the cross-cutting role of knowledge capacity in Pakistan's water resources, a theme that can be found in all previous chapters of this book. As in the Circle of Justice, most of the policy issues facing Pakistan's water sector can only be addressed by developing the ability of all actors and stakeholders to adopt holistic thinking and bridge critical knowledge gaps. These twin aspects of knowledge and capacity, holism and strategic innovation, and the need to balance them in ethical ways are addressed in this chapter through the rich metaphor of irrigated garden traditions and associated knowledge capacity in Pakistan. Most importantly, some policy implications of this approach are articulated.

This book provides an insight into the country's current narrative on water and also identifies and addresses its gaps for possible future developments. Every chapter has the mutual goal of initiating a different conversation on water policy in Pakistan.

Lahore, Pakistan Mahmood Ahmad

Acknowledgments

I would like to express my gratitude and appreciation to all the contributing authors for their time and dedication to preparing the chapters and participating in the round table conference to provide suggestions for strengthening the overall manuscript. The last two years have been difficult with the pervasiveness of COVID affecting us all one way or the other; I acknowledge and deeply appreciate the efforts of authors for completing the work during these times.

In the preparation of this book, I would like to acknowledge the support and guidance received from Abubakr Muhammad (LUMS), James Wescoat (MIT), Sanval Nasim (LUMS), and Simi Kamal (Hisaar Foundation). I have gratefully incorporated many of their comments, observations, and work on water policy into the relevant chapters. My gratitude also goes to Professor Ariel Dinar, who has been supportive throughout the entire process and who also attended our round table conference.

My thanks to Moshin Hafeez (IWMI) for providing extensive comments, editorial suggestions, and encouragement. I am indebted to the late Shahid Ahmad (Ex-Member Natural Resources, PARC), a dear colleague and distinguished expert who we lost last year, for being a constant source of support and encouragement when I took on this project.

I am truly thankful to Nakasha Ahmad, who has been a great assistance in preparing the manuscript for delivery and ensuring that everything is in order, and more specifically for editing, composing, and finally putting in the publisher's format.

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Mahmood Ahmad is an internationally renowned expert on agriculture and water policy. He received his Ph.D. in Resource Economics from the University of Massachusetts (1979). He carries an experience of around 40 years, including 24 years with the Food and Agriculture Organization of the United Nations, working in more than 15 countries. He carries extensive experience in water policy issues with focus on water demand management. Dr. Ahmad is presently working as Professor of Practice (Adjunct Faculty) at Water Informatics Centre, Lahore University of Management Sciences. He is leading the center in undertaking innovative research on economics of developing climate smart agriculture and water development. He has provided leadership in developing FAO program on agriculture policy for the Near East countries and supported preparation of agriculture strategies under water scarce conditions. He has published a large set of papers and is a chapter author in three books and now editor for preparing a large set of case studies on agriculture and water policy issues in the region. He has also lead the Capacity Building program with FAO HQ for the Near East (38 countries) region in the area of agriculture and water policy reforms. Also, he supported member countries in developing agriculture strategies and policy advice with donor support.

About the Contributors

Simi Kamal is a geographer with 38 years of experience in establishing institutions, building platforms and developing programs around the nexus of water, poverty and gender. As a water professional, her work has covered water policy, water rights, groundwater, irrigation, agriculture, food sectors, environment, climate change, land and water systems and conservation. As a poverty alleviation practitioner, she has focused on inclusive development, public goods (including water systems) and poverty graduation models. As a women's empowerment advocate, she has promoted gender equity and equality, especially in the water sectors.In addition to her in-depth experience in Pakistan, she has worked in South Asia, the Asia Pacific region, the Middle East, Europe and Africa. Her expertise ranges from projects in local communities to major national and international programs, transnational dialogues, track two engagements where governments find it hard to talk, research geared to actions and academic endeavors. She is the author and co-author of over 180 research, evaluation and impact assessment reports. She has headed over 200 assignments and postings as Chief of Party, Head of Programs, Team Leader and lead consultant. She is the author of over 30 handbooks and training modules, several book chapters and over 450 articles, papers, podcasts and presentations. She is the recipient of international and national awards.

Tabeer Riaz graduated from the Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden. Her master's thesis was centered around investigating behavioral patterns related to sustainable water resources, particularly focusing on developing countries. In conjunction with her master's program, she took on the role of a Research Assistant at the Nordic Africa Institute (NAI) based in Sweden and served as a teaching assistant at SLU. Before this, Tabeer contributed her expertise as a research assistant in Pakistan for approximately 5 years, collaborating with both international and national organizations such as the Shahid Javed Burki Institute of Public Policy (BIPP), the Centre for Water Informatics and Technology (WIT) and the International Water Management Institute (IWMI). Her academic pursuits and professional experience are reflective of her interest in topics such as sustainable development, water resource management, agricultural development, food system, and food security.

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Mohsin Hafeez joined IWMI Pakistan as a Country Representative and Principal Researcher on 24 May 2019. He has more than 25 years of management experience with various world-class research and academic institutes, CGIAR Centers, donor agencies (DFID, USAID, AusAID and GIZ), operational agencies, major clients, water utilities and international consulting companies dealing with integrated water resources management and modelling for urban and rural sectors in more than 14 countries (Australia, Burkina Faso, Germany, Ghana, China, the Netherlands, Pakistan, Philippines, Sri Lanka, Lao PDR, Uganda, UK, USA and Uzbekistan). He earned his Ph.D. in Water Engineering in Water Resources Management from Rheinischen Friedrich Wilhelms Universitat of Bonn, Germany, and Master of Engineering from the University of Engineering and Technology, Lahore, Pakistan. He has an excellent scientific publication record with over 200 publications and has supervised 2 M.Sc. and 13 Ph.D. students in the field of water resources management, agricultural water management, food security and rural development. He has also been working as an Adjunct Professor (Water Resources) with the Institute of Water and Hydraulic Research (IWHR) since April 2016 and as Adjunct Professor (Environmental Science) with Hubei University in China since 2008. His innovative scientific work in irrigation and water resources has led him to winning many prestigious research and industry awards in Australia and internationally.

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Mr. Zakir is member of different national and international professional organizations like Pakistan Engineering Council-Registered Professional Engineer (RPE); Institution of Engineers Pakistan; European Water Resources Association (EWRA); Pakistan Engineering Congress; AIT Alumni Association; Australia Awards Alumni Association-Pakistan; National Groundwater Association (NGWA) USA; International Association of Hydrogeologists (IAH); International Water Resources Association (IWRA). Presently, he is contributing at Charles Sturt University, Australia, as Vice President for Postgraduate Student Association (PGSA), member of Higher Degree by Research (HDR) Committee of the University and member of the Social Club (TSC). Mr. Zakir has earned a number of gold medals, awards, distinctions and scholarships during his professional and academic journey.

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Lee Baumgartner designs, supervises and undertakes research into various aspects of the biology and ecology of freshwater fish and systems. His interests are fish passage and fish migration, the impact of human disturbance on aquatic ecosystems, developing solutions to global challenges in water resource management and the connections between people and inland fish. More recently, he has developed a series of short-courses which aim to help organizations build capacity in specific areas of water management. Much of his work is applied and has fed back into adaptive management strategies which have resulted in state, national and international water policy development. His main geographic areas of expertise are South-Eastern Australia, the Murray-Darling Basin and the Lower Mekong, but he also has active collaborations in South Africa, Europe, North America and Indonesia.

Daud Ahmad has to his credit a Ph.D. in Civil Engineering (Hydraulics) from Colorado State University, USA. He is a senior development professional and practitioner who worked for nearly 35 years with the World Bank on large-scale international development projects in different countries, mostly in Asia. Since his retirement from the World Bank in 2000, Dr. Ahmad has been working as an independent International Development Consultant. He is also a member of BIPP's Board of Directors. He wrote a chapter on supply side of water management in Pakistan, with extensive review of the past and present role of large dams in Pakistan. Some key assignments and accomplishments include: Associated with the Lahore based Burki Institute of Public Policies (BIPP) as a Managing Director. Contributed to the Pakistan's Water Sector Overview of the 2017, 2018 and 2019 BIPP annual report. His distinguished portfolio includes Deputy Division Chief, Urban and Water Supply Division, EAP Region: 1981-87 and Chief Transport Operations Division, China and Mongolia Country Department, EAP Region: 1990-93. In Harza Engineering Company, Chicago (1971-72), he worked on various aspects of the hydraulic design of the Tarbela Dam, Pakistan.

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Asif Khan has more than 13 years of professional field and research experience. Dr. Khan is currently working as Lead Author for IPCC AR-6, working as Chairman and Associate Professor at CED Jalozai of UET Peshawar, Member of the Upper

Indus Network, Member of Indus Basin Knowledge Forum, Member of Cambridge Philosophical Society, Member of British Hydrological Society, Member of European Geophysical Union, Member of American Geophysical Union and Member of several other international Forums has carried out research on Water-Energy-Food Nexus under climate change for the Indus Basin during his Post-Doc at IIASA, Austria, and secured his Ph.D. degree in the field of hydro-climatology from Cambridge University, UK, where his research topic was "The hydro-climatology of the Upper Indus Basin: a critical analysis of data and modelling needs in a complex mountain environment." He has produced 18 international journal publications and 2 book chapters related to hydro-climatology of the Indus Basin. He has also been working as reviewer in the field of hydro-climatology for more than 20 well-reputed international journals since 2012. Dr. Khan's expertise are snow-glacier hydro-climate modelling, MHVRA, CRVA and Water Resources and Project Management and wants to bridge research and industry to practice his professional and research skills in a better way.

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Sanval Nasim is an Assistant Professor (Tenure Track) at the Department of Economics (MGSHSS). His primary research and teaching field is environmental and natural resource economics. Dr. Nasim obtained his Ph.D. in Environmental Sciences from the University of California, Riverside, USA, in 2015. His Ph.D. research explored the effects of institutional constraints on the efficient allocation and optimal management of groundwater in Pakistan's Indus Basin. Dr. Nasim is interested in discovering how human behavior contributes to the long-term degradation of natural resource systems and how local institutions shape and inform economic policies for a sustainable environment and a healthy resource base. He first became fascinated by the field of environmental economics as an Undergraduate student at Colby College, USA, where he double majored in Economics and History. Prior to that, he completed the International Baccalaureate at the United World College, USA.His research interests include Water Management, Sustainability and Conservation; Air pollution mitigation; Climate Change.

M. Kalim Qamar earned an M.Sc. (Plant Breeding and Genetics) from W. Pakistan Agricultural University, an M.S. (Extension) from American University of Beirut and a Ph.D. (Extension) from Cornell University, USA. He has been Instructor at W. Pakistan Agricultural University, Assistant Professor at the University of Massachusetts, resident Advisor on Rural Development and Non-formal Education in Papua New Guinea, resident Team Leader/Advisor on Agricultural Extension in Indonesia, resident Extension Communication Specialist in Nepal and resident Chief Technical Advisor in Iraq. Dr. Qamar served as Country Project Officer in the Operations Division and later as Senior Officer in Research, Extension and Training Division at Food and Agriculture Organization of the United Nations, Rome. He has done consultancies for the World Bank, UNDP, USAID, FAO, and Asian Productivity Organization. His professional activities covered countries in South, Central and South East Asia and the Pacific, Africa, Middle East, Europe, Caribbean, North America and Central America. Dr. Qamar has authored many FAO publications in English, of which some have been translated into other languages. Dr. Qamar presently lives in the USA.

Asif Sharif can be variously described as an Imaginer, Innovative Farmer, Businessman, Engineer, Inventor and Philanthropist. Mr. Asif Sharif collaborated with Cornell University and FAO on unification of three diverse technologies known as System of Rice/Crop Intensification (SRI/SCI), Conservation Agriculture (CA) and Organic Farming (OF), a sequel named "Paradoxical Agriculture." He is globally recognized as an activist for no-till, raised bed cropping, no inundation of soil, input optimization and maintaining organic soil coverage for enhancing agricultural profitability and sustainability.He has served as President of Pakistan-Belgium Business Development Forum, Honorary Consul for the Republic of Poland, Member Board of Directors Zarai Taraqiati Bank (Agri. Dev. Bank) in addition to his membership of advisory boards of various governmental and private sector bodies. He has been trained in the USA, Australia and Europe and visited countries in five continents for study, training, business and leisure. He has developed major projects and presented technical papers on crop production processes and methods and practically transformed many farms by implementing sound programs for mechanization, management, operations, farm design, irrigation and production systems, knowledge-based skills development and timely provision of resources for higher productivity.

Hamid Jalil is currently working as Member National Food Security and Climate Planning Commission, Government of Pakistan. Previously he was working with the Ministry of Agriculture Canada as well as providing intermittent technical services to GIAD Industrial Group Sudan. Dr. Hamid Jalil has more than 25 years of experience in promoting Halal economy, developing agro-livestock sectors and trade promotion in Pakistan, Sudan and Canada. He has worked with national/international public/private sector organizations, such as Government of Pakistan, Punjab Agriculture & Meat Company, Punjab Halal Development Agency, International Centre for Agriculture Research in Dry Areas (ICARDA), IFAD, European Commission, USAID and Government of Canada.

Amina Bajwa is an economic policy professional with 14 years of experience in the public and the private sectors and development agencies. Her primary area of interest is agriculture policy and she works at the Prime Minister's Office through which she supports several ministries in the implementation of their reform agenda. Amina is also engaged in short-term consulting assignments with organizations such as the ADB, IFAD, World Bank, etc.She holds a Master's degree in Policy Economics from Williams College, USA, and has a Bachelor's (honors) degree in Economics from the Lahore University of Management Sciences (LUMS).

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Sher Jamal Khan is a Professor of Environmental Engineering at the Institute of Environmental Sciences and Engineering, National University of Sciences and Technology (NUST), Islamabad. He has an M.S. in Civil and Environmental Engineering from Portland State University, USA, and a Ph.D. in Environmental Engineering and Management from the Asian Institute of Technology (AIT), Thailand. His research interests include conventional membrane biological reactors (MBRs), Hybrid MBRs, Quorum Quenching MBRs, Forward Osmosis-MBRs for wastewater reclamation and reuse, and Forward Osmosis, Reverse Osmosis and Membrane Distillation for water desalination. He has published more than 55 articles in peer-reviewed international journal articles and 5 book chapters. As a principal investigator, he has supervised many research and consulting projects for national and international agencies.

Syed Azeem Shah has over 10 years of experience working on the water governance, institutions, transboundary water management and instrumentation for flow measurement in the large-scale irrigation systems. Dr. Shah is working at International Water Management Institute (IWMI) as Senior Regional Researcher: Governance of Water Institutions for the last 9 years.Dr. Shah has led various projects at national and regional level. He has demonstrated excellence in research and development sector through wining multiple grants, delivering on the international donor-funded projects, advising government on the policy issues and delivering invited talks and capacity building trainings on the water governance challenges across the globe. He has published journal articles and book chapters and co-authored a World Bank report and multiple conference papers during his service with IWMI. Dr. Shah holds a Ph.D. Management degree (specialization in water governance) from Lahore University of Management Sciences (LUMS) with his Bachelor's and Master's degrees from the University of Engineering and Technology (UET) Lahore.

Abubakr Muhammad is an Associate Professor and Chair of Electrical Engineering, the founding Director of the Centre for Water Informatics and Technology (WIT) and the Lead for NCRA National Agricultural Robotics Lab at LUMS. He received his Ph.D. in Electrical Engineering in 2005 from Georgia Institute of Technology, USA, winning an institute-wide best Ph.D. Dissertation Award. He received Master's degrees in Mathematics and Electrical Engineering from Georgia Tech and was a Postdoctoral Researcher at the University of Pennsylvania and McGill University. Since 2008, his research group at LUMS has worked on applied research in robotics, automation and AI with applications to water, agriculture and environmental issues. He serves on various advisory panels to government agencies and industry in Pakistan on water, climate and agricultural policy, especially on the use of emerging digital technologies for these sectors.

James L. Wescoat Jr. is an Aga Khan Professor Emeritus at the Massachusetts Institute of Technology. His research concentrates on water systems in South Asia and the USA from the site to river basin scales. At the site scale, Professor Wescoat has focused on historical waterworks of Mughal gardens and cities in India and Pakistan. He led the Smithsonian Institution's project titled, "Garden, City, and Empire: The Historical Geography of Mughal Lahore." At the larger scale, Professor Wescoat has conducted water policy research in the Colorado, Indus, Ganges and Great Lakes basins, including the history of multilateral water agreements. He led a USEPA-funded study of potential climate impacts in the Indus River Basin in Pakistan with the Water and Power Development Authority (WAPDA). His current water research includes studies of urban water planning in Maharashtra, India, and water-energy-food nexus in Punjab Pakistan and the Indus River basin. His current landscape research includes studies of Indo-Islamic waterworks and gardens in Delhi, the Deccan and Lahore, and collaborative work with the Aga Khan Trust for Culture and Aga Khan Agency for Habitat. He is a fellow of the American Society of Landscape Architects, and a lifetime member of the US National Research Council.

Abbreviations

AWS	Alliance for water stewardship
B	Boron
Ba	Barium
BOD	Biological oxygen demand
Cl	Chlorine
COD	Chemical oxygen demand
Cr	Chromium
Cu	Copper
DO	Dissolved oxygen
EPS	Extracellular polymeric substance
E. coli	*Escherichia coli*
FAO	Food and Agriculture Organization
FATA	Federally administered tribal areas
Fe	Iron
GB	Gilgit Baltistan
GDP	Gross Domestic Production
GIS	Geographic Information System
Hg	Mercury
HRT	Hydraulic retention time
IUCN	International Union for Conservation of Nature
Kpa	Kilopascal
KPK	Khyber Pakhtunkhwa
KRB	Kabul River Basin
LMH	Liter per square meter per hour L/m^2h
MBR	Membrane bioreactor
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile solids
Mn	Manganese
MPS	Membrane Package System
NEQS	National Environmental Quality Standards
Ni	Nickle

OLR	Organic load rate
Pb	Lead
PCRWR	Pakistan Council of Research in Water Resources
PEPA	Pakistan Environmental Protection Act
PEPC	Pakistan Environmental Protection Council
pH	Potential hydrogen
PLCs	Program logic controllers
PVDF	Polyvinylidene fluoride
PWSN	Pakistan Water Stewardship Network
SCARP	Salinity Control and Reclamation Projects
SMEs	Small and medium enterprises
TDS	Total dissolved solid
TMP	Transmembrane pressure
TSS	Total suspended solid
WASA	Water and Sanitation Agency
WASH	Water, sanitation and hygiene
WHO	World Health Organization
WWF	World Wide Fund for Nature
WWTPs	Wastewater treatment plants
Zn	Zinc

Part I
Setting the Stage

Pakistan's economy is a 'water economy', with 60% of the population directly engaged in the agricultural sector, which uses approximately 95% of surface water and almost all fresh groundwater. And this agricultural sector is source of 80% of foreign exchange earnings

The question is, who benefits? We know that 39.2% of the total population of Pakistan lives below the national poverty line – 88 million people. They survive largely outside the domain of water subsidies, projects, and programs. Another new challenge is the direct impact of climate change on water. The shifting of seasons, natural regions, ecosystems, and agro-ecological zones are the new emerging realities affecting Pakistan's water regime. These challenges are often swept aside in the obsession with irrigation-based agriculture and more infrastructure development.

A transformative framework for water in Pakistan must look at the intersection of water, agriculture, poverty, access, and use, while taking into account the devastating impacts of climate change on water. Many economic outcomes are closely linked to social outcomes, given strong connections between the water regime, agricultural economies, and social trends. These include rural to urban migration, human health and well-being, water-related conflict, environmental degradation, severe threats to freshwater ecosystems, loss of biodiversity, increasing pollution, and the loss of productive areas because of waterlogging and salinity. Without strong local government, it is becoming increasingly difficult to reach the poorest zones and the poorest people.

Pakistan requires a fundamental shift in its political, economic, and social relationship to water. At the national level, investment decisions seem relatively fixed on building large dams to rid Pakistan of its increasing water and electricity stress, with the aim of constructing 10 large dams over the next 10 years. However, a different kind of policy discourse is also emerging, one that calls for the conjunctive use of surface and groundwater, which would, for instance, aid the downstream province of Sindh by offering a way out of the relatively intractable positions of the federating units – with continuing mistrust because of the claims and counter-claims flying in all directions. Second, there is growing agreement that a lopsided focus on supply side interventions has resulted in fewer net gains compared to demand management options that would have cost much less. Most of these agricultural interventions require a major policy shift, but would result in net benefits.

Despite a significant amount of irrigated land, Pakistan has not been able to build on its agricultural endowment in at least two significant ways with the result that current export earnings are suppressed but also does not build on the endowment it has to lift more of its population out of low economic value agriculture as a source of livelihood. In the short to medium term, serious efforts at national poverty alleviation will demand no less than working on both fronts with dual policy objectives in mind (i) ensuring that those employed in agriculture have the chance to obtain decent livelihoods; (ii) ensuring that the agricultural base of the economy can be harnessed to create both enough economic surplus such that there are requisite other industries for people to move to when they are forced or transition out of relying on agriculture as their primary source of livelihoods. The current equilibrium between these policy objectives and competing forces is significantly misbalanced. For instance, during 1970–2014, econometric analyses of the link between the country's agricultural exports and GDP growth show that agricultural exports have a negligible impact on overall economic growth. This is because of the un-competitiveness (higher prices combined with lower quality) of the country's agricultural commodities vis-à-vis competitors' exports. What this means is that far too many resources (both in the form of subsidies to keep agricultural commodity markets operable as well as in the number of people who are kept absorbed in economically low-value agriculture) are locked and unable to be tapped for the purposes of personal as well as national economic development.

Pakistan should, therefore, have a long-term view of its water requirements for all segments of its people, and define a roadmap in a climate-challenged world. Pakistan's Vision 2025 states the goals of increasing water storage capacity, improving efficiency in agriculture by 20% and ensuring clean drinking water to all Pakistanis. It speaks of water security that includes technologies to minimize wastage, more effective allocations, establishment of institutional mechanisms and a minimum quantum of water to every person in Pakistan.

Maintaining and enhancing the integrity of the Indus Basin is a serious and important responsibility of the Federation as well as the provinces, including all other administrative units. This means concentrating on the repairs and replacement, and not build new infrastructure with a leaky downstream. The funds invested in this way would save almost 50% losses of water in the system – much more than the 'new' water that is supposed to be 'produced' by new dams.

Decades of stalling over a national water policy, low levels of debate and discussion, the politicization of water discourse and the low priority afforded to water issues in the government and in the country as a whole, means that the hard decisions about water have not been taken in a timely manner. Science, technology and policy need to merge for action. This requires political will, trained person power and financial resources. The government must provide clear leadership and take responsibility. However, the new water policy provides a good platform to transform idea into actions through policy reforms both in water and agriculture at the provincial levels.

Pakistan needs a different conversation around water and different ways of developing the water transformative narrative that will lead to clearly laid out actions that are required in the twenty-first century. Pakistan water woes and solutions largely lie outside the sector domain (population growth and agriculture policies to name a few). The way we think about water influences how we define the challenges and the solutions that are put forward. This transformative narrative needs to rest on global trends and be anchored in the ground realities of Pakistan in each province.

Chapter 1
Pakistan's Water: Changing the Narrative, Changing the Outcomes

Simi Kamal

Abstract Water is Pakistan's lifeline and has had a profound influence on the civilizational development in the region. The river Indus (also known as the river Sindhu) affects the psyche of people living in Pakistan to mythic proportions. In the same way, a huge part of the glaciers of the Third Pole lies in Pakistan and are held almost with reverence by people who live on the roof of the world. This new century has brought new challenges including the direct impact of climate change on water—the unexpected and intense changes in water regimes and water cycles, shifting of seasons, distortion of natural regions, and loss of ecosystems. Yet in Pakistan these crucial conversations are swept aside in the obsession with irrigation-based agriculture and more infrastructure development. Pakistan's water policy of 2018 is a long wish list and does not contain a coherent contextual narrative within which this wish list can be understood. This chapter outlines priority actions and responsibilities largely missing from the water discourse: water conservation at all levels from homes to the agricultural sector as a whole, new water subjects to train and engage young people, water services to rural areas to stem rural-urban migration, urban water management, new water technologies, building the capabilities of people and institutions to manage the effects of global climate change on water supplies, moving to smaller and more manageable water infrastructure, building the physical health of rivers, lakes, groundwater, springs, and glaciers.

Keywords Water economy · Loss of ecosystems · De-growth models · Indus River Basin · Circular economy · Water policy in Pakistan

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1.1 Water—Pakistan's Lifeline

Water is Pakistan's lifeline and has had a profound influence on the civilizational development in the region. The river Indus (also known as the river Sindhu) affects the psyche of people living in Pakistan to mythic proportions. In the same way, a huge part of the glaciers of the Third Pole lie in Pakistan and are held almost with reverence by people who have lived on the roof of the world for centuries.

1.1.1 Old and New Challenges

The geographic and hydrological changes in the Himalayan region and the changes in the water cycle associated with the monsoons are projected to have catastrophic effects on Pakistan's water regime and its water balance in the coming years. Pakistan's rain-fed, coastal, metropolitan, and drought-prone areas each have their own huge water challenges. Groundwater continues to be overused and mined and how it interacts with surface water is still not much understood.

A new challenge this century is the direct impact of climate change on water. There are new emerging realities as the water regime of Pakistan is affected—the shifting of seasons, natural regions, ecosystems, and agro-ecological zones. These old and new challenges are often swept aside in the obsession with irrigation-based agriculture and more infrastructure development.

In the absence of meaningful debate on the full range of water challenges and solutions, there is disproportionate emphasis on water politics, water governance, water entitlement, and allocations. Constitutionally, water is largely a provincial matter in Pakistan. However, relevant policies, institutions, and legal provisions have been distributed across the national and provincial levels. These policies often overlap with each other. The legal framework for each province includes its own laws and regulations overlain by relevant national provisions. This plethora of water-related ministries, institutions, and organizations means little action on the ground, creating unrest among the federating units, within provinces, between canal-side and tail-end farmers, and between cities and rural areas.

Therefore, Pakistan needs a different conversation around water and different ways of developing the water transformative narrative that will lead to the clearly laid out actions that are required in the twenty-first century. How we think about water influences how we define the challenges and the solutions that emerge. This transformative narrative needs to rest on global trends but be firmly anchored in the ground realities of Pakistan.

Given that the current water policy is a long wish list, this chapter outlines priority actions and responsibilities. The areas missing from the current narrative on water are covered in particular: water conservation at all levels from homes to the agricultural sector as a whole, new water subjects to train and engage young people, water services to rural areas to stem rural-urban migration, new water technologies and their appropriate use, building the capabilities of people and institutions to manage the effects of global climate change on water supplies, moving to smaller and more manageable water infrastructure, building the physical health of rivers, lakes, groundwater, springs, and glaciers.

1.1.2 The Global Scenario and How It Affects Pakistan

Humanity is currently using nature 1.75 times faster than our planet's ecosystems can regenerate. The costs of this global ecological overspending are stupendous and affect the nine billion people who have to live within the limits of the planet. The last century was about unbridled growth and putting carbon into the atmosphere, resulting in the climate emergency we are facing today. Climate change directly impacts the water cycle and we have observed increased incidents of massive storms, floods, droughts, and sea rise across different climatic zones. In Pakistan we are seeing extreme heat, late monsoons, erratic rainfall, changed snowmelt regimes, earlier harvest seasons, and both floods and droughts.

The OECD Environmental Outlook for 2050 has projected that global demand for water will increase by 55%, while the demand for energy will increase by 80% (OECD, 2012). In addition, FAO (FAO, 2014) estimates a 60% increase in food demand over the same period.

Globally, agriculture accounts for 70% of total global freshwater withdrawals, making it the largest user of water. In Pakistan, however, it is 97%, according to Pakistan's Water and Power Development Authority (WAPDA) figures over the last two decades. Water is used for agricultural production, forestry, and fishery along the entire agri-food supply chain, and to produce or transport energy in different forms (FAO, 2014). At the same time, the food production and supply chain consumes about 30% of total energy used globally(Conforti, 2011). Energy is required to produce, transport, and distribute food as well as to extract, pump, lift, collect, transport, and treat water. Cities, industry, and other users, too, claim increasingly more water, energy, and land resources.

Population growth, economic development and climate change are all accelerating competition for food, water and energy. While Pakistan does not have a street population in cities as seen in Calcutta or Dhaka, we do have high levels of malnutrition and child stunting. Pakistan's Demographic Health Survey indicated that 38% of all children under five are stunted (NIPS & ICF, 2019).

Young people across the world have risen up in protest and defiance, calling for the developed world to halt its extraction and use of fossil fuels and give reparations to the rest of the world for the way it has poisoned the earth, the atmosphere, and water bodies.

In the wake of these movements, we are now discussing what no one would have dared just a few years before. *The Guardian* recently listed 'the 20 fossil fuel companies whose relentless exploitation of the world's oil, gas and coal reserves is directly linked to more than one-third of all greenhouse gas emissions in the modern era,' the oil company ARAMCO topping the list (Taylor & Watts, 2019). The capitalist model claims that earning huge profits is good, as it then makes funds available for charity. But *Forbes* magazine has reported recently that the 120-plus richest individuals in the world spend only 3.76% of their net worth on charity. So this is clearly not how the funds to combat the effects of climate change on water will be generated. The developing world is rightly calling for commitments from developed countries (and presumably from these 120-plus captains of industry) to contribute to a Loss and Damage Fund to alleviate the impacts of climate change and to safeguard water resources in the countries most affected by climate change.

Case Study 1: Glasgow Loss and Damage Facility

'A proposal to establish the "Glasgow Loss and Damage Facility" as a standalone facility under the financial mechanism of the convention was developed by the Association of Small Island States (AOSIS) with support from the Least Developed Countries Group. It was later adopted by the G-77 and China. The facility would "provide support to avert, minimize and address loss and damage… and to undertake work in 2022 with the aim of providing recommendations to the next climate conference (COP27) on its operationalization."

'The US, along with Australia, Canada and the EU, strongly resisted the demand… there were acts of solidarity pledging financial support to affected communities in poor countries. But a bloc of developed countries scuttled the idea of the facility and instead insisted on a '"dialogue" to be conducted between 2022 and 2024 to "discuss the arrangements for the funding." This language was eventually adopted in the Glasgow Climate Pact.'

Small island states could do nothing. In the interest of reaching a consensus, AOSIS had to accept this 'dialogue'. The AOSIS statement talked of a "clear understanding that this dialogue is a key step towards the creation of a loss and damage finance facility. We firmly believe that the dialogue should lead to a conclusion that the new loss and damage finance facility will be adopted at the next COP."

Source: (Singh, 2021)

The world is spiraling out of control because we refuse to change the way we think and act. A major shift is needed to throw away the capitalist mantras that have brought us to the brink of annihilation—"greed is good," "amassing and exercising power over millions," "winner takes all."

It is time to lay these destructive goals to rest and move to a culture of long-term survival for the human race as a whole—and to free water from class, gender, race, ethnicity, patriarchy, and the strangulation of capitalism. A new way of thinking is required for the painful transformation that humanity must go through; and it applies to the way we view water, use water, and extract water from water bodies. A move to 'de-growth' models is essential if the human race is to survive this century and beyond.

Case Study 2: Commission of Small Island States on Climate Change and International Law
In 2021 the prime ministers of Antigua and Barbuda and Tuvalu, signed an agreement that would allow developing countries to bring cases against both developed countries and corporations before international courts.

"The agreement establishes a Commission of Small Island States on Climate Change and International Law, for the development and implementation of fair and just global environmental norms and practices." This commission can then "request advisory opinions from the International Tribunal for the Law of the Sea, an independent intergovernmental judicial body, on the legal responsibility of states for carbon emissions, marine pollution and rising sea levels."

Source: (Singh, 2021)

Transformation must happen in Pakistan as well—we must act now to safeguard our water resources, move to a more equitable distribution of water for all its users, learn to value water and internalize its significance in economy, society, and culture.

1.1.3 Pakistan's Water Economy Within a Pattern of Inequalities

Although Pakistan is a middle-income country, it has the social, human, and gender-development indicators of the least-developed economies. The distribution of income is highly unequal. In 2018–2019, the poorest 1% of the population held only .15% of the national income, while the richest 1% had a 9% share in the national income (UNDP, 2020). The allocation and utilization in the budget for social sectors is low. For instance, the health budget was only .4% of the total national budget in 2021–22, despite an increase of 11% in the overall budget (Mirza, 2021). In addition, there is a toxic power structure fueled by patriarchy, masculinity, and tribal and feudal norms that purportedly has the final word on every subject—including water. This means that many water challenges are not even at the table. Women, young people, landless farmers, city dwellers, people who live in marginal areas and downstream communities have no voice. They have few forums to share their concerns and are largely absent from the water debate, currently waged by ill-informed TV "anchors" and their largely irrelevant guests, social media "influencers," and many water "experts" who are not actually known in the water sector.

Pakistan is home to nearly 220 million people—a near seven-fold increase since the formation of the country in 1947. "Over 67% of the population lives in rural areas and depends—directly or indirectly—on agriculture for their livelihoods. It contributes around a quarter of the country's gross domestic product (GDP), employs 44% of the labor force, and contributes significantly to export earnings" (Young et al., 2019).

Land and water are the inheritance of Pakistan's people. Land and water are the main resources providing people with a source of livelihood, of **development, of dignity and prosperity for all citizens** (Hisaar Foundation, 2016)**.** Pakistan has committed to Agenda 2030 and to Sustainable Development Goals (SDGs) where Goal 6, among others, calls for ensuring availability and sustainable management of water and sanitation for all, water use efficiency, and integrated water resources management.

Pakistan has always been a 'water economy'. As mentioned in other chapters, 95% of water is being used in agriculture, with 60% of the population directly engaged in agriculture and livestock and 80% of Pakistan's exports based on these sectors. About 95% of surface water (Ministry of Planning, 2014) and almost all fresh groundwater in Pakistan is currently used in agriculture. But who benefits? **We know that 39.2% of the total population of Pakistan could be living below the national poverty line—that makes 88 million people** (World Bank, 2021). They are largely out of the domain of water subsidies, projects and programs.

As the Hisaar Foundation has noted, farmers—not landowners—are central to the agricultural system. They are the very foundation of the water economy (Hisaar Foundation, 2016). In the same way, the poor health and sanitation conditions of the urban poor have to be recognized when we discuss the circular economy of water in urban areas.

Case Study 3: Pakistan's Water in Numbers

- Only 20% of Pakistan's people can access safe drinking water. The remaining 80% are forced to use unsafe drinking water because there are not enough safe water sources.
- 40% of Pakistan's people die from waterborne diseases.
- One quarter of total Pakistan's population do not have access to improved sanitation facilities.
- 95% of Pakistan's water is used for agriculture.
- Contamination from bacteria, pesticides, and metals (such as arsenic, iron, cadmium, nickel), and in some cases, nitrates and fluorides, significantly threaten water quality in Pakistan.
- An estimated 70% of Pakistani households drink water that is bacterially contaminated.

Sources: WASH: Water, sanitation and hygiene, 2021; Daud et al., 2017; Kundi, 2017; Rasheed et al., 2021; UNICEF, 2019; Zahid, 2018

1.2 Transformative Framework

A transformative framework for water in Pakistan must look at the intersection of water, poverty, access, and use, while also taking into account the devastating impacts of climate change on water. Many of water's economic outcomes are closely linked to social outcomes, given strong connections between the water regime, the agricultural economy, and social trends. These include rural to urban migration, human health and well-being, water-related conflict, environmental degradation, severe threats to freshwater ecosystems, loss of biodiversity, increasing pollution, and loss of productive areas due to waterlogging and salinity. Pakistan has had several years-long eras in which it had to do without local governments (largely coinciding with democratically elected governments), such that it is becoming increasingly difficult to reach the poorest zones and the poorest people. Unfortunately, elected governments in Pakistan usually choose to keep spending under the control of elected members of parliament and either do away with, or continue to delay, local government elections.

A market economy, however 'hybrid' it may be in Pakistan, does not serve the interests of the poor. Without owning land, the poor in both urban and rural areas of Pakistan have no direct right to water or water services. As per current water laws, both in rural and urban areas, one has a right to water when one owns land (or leases it). All the subsidies and engineering works on canals, for example, raise the value of the land for the landowners, who become richer.

Pakistan should, therefore, have a long-term view of its water requirements for all segments of its people (landowners and landless), and define a roadmap in a climate-challenged world. Pakistan's Vision 2025 states its goals of increasing water storage capacity, improving efficiency in agriculture by 20% and ensuring clean drinking water to all Pakistanis (Ministry of Planning, 2014). It speaks of water security, which includes technologies to minimize wastage, more effective allocations, establishment of institutional mechanisms, and a minimum quantum of water to every person in Pakistan (Ministry of Planning, 2014).

The cost of replacement of the Indus basin system was estimated in 2005 at approximately US $300 billion (Briscoe & Qamar, 2005). As the Hisaar Foundation has pointed out, "The Indus basin system is our asset and we must leverage it to generate local investment from within Pakistan for repair and maintenance of this infrastructure" (Hisaar Foundation, 2016). While we can continue to build new infrastructure, it is not necessary that the infrastructure only be big dams. We can also build a million ponds to hold flood and rain water, and millions of moisture and rainfall harvesting systems.

In recent decades, water in Pakistan has become part of the security narrative both inside the country (which makes open discourse on water use quite difficult) and with neighboring countries, where politics has erected barriers against any regional solutions which may be feasible. **In a transformative framework we must 'de-securitize' the discourse on water, just as the world must move to 'de-growth'.**

1.2.1 Building Pride in Pakistan's Hydrology and Geography

Pakistan is an incredibly diverse country with a complex geography and hydrology. There are distinct physical, climate, and ecological zones that have given rise to the natural regions we can identify easily. These natural regions have given rise to distinctive economies and cultures that remain somewhat unique in spite of the sprawl of cities and demands for more food production.

The most distinctive feature of Pakistan is the mighty River Indus. Therefore, the first cornerstone for transforming the water sectors in Pakistan is to build pride in the river Indus, its sources, its watershed, its tributaries, and its delta. The river Indus should unite Pakistan—its evolution, the historic civilizations it has spawned, the cultures it has nurtured, the economy it has propelled and the country of Pakistan it is evolving. This means finding perspectives that include, but are much more than, economic and physical infrastructure.

A positive narrative around this theme will help place emphasis on all the other natural regions as well, and move discourse away from constant federal and provincial tensions. Defining water challenges according to these regions will help find the right and appropriate solutions. This will lower the temperature of inter-provincial bickering, resolve conflicts within Pakistan, and build some commonalities in South Asia for positive discourse (Fig. 1.1).

1.2.2 Maintaining the Integrity of the Indus Basin

Pakistan has the largest contiguous irrigation system in the world, and the infrastructure built on it forms Pakistan's leading asset. Warsak Dam, the Sindh barrages, and many weirs were constructed in colonial times to extract as much value through just a few crops to export to the mother country—England. The breadbasket was further developed after the Indus Waters Treaty in the 1960s. Mangla Dam was built in 1967 and Tarbela Dam in 1974, and they were part of the Green Revolution. The Water Apportionment Accord of 1991 established an agreed-upon formula to divide the surface waters of the Indus among the four provinces. The Indus River System Authority (IRSA) was established in 1992 to oversee the division of water in the *kharif* and *rabi* planting seasons (Fig. 1.2).

While the infrastructure and canal system are part of our water heritage, there are limits to how much more infrastructure we can build on the Indus. We need to acknowledge and tackle the many problems caused by large-scale irrigation and monoculture.

For example, salinity is a major concern for irrigation and agriculture: "Pakistan has lost 3.2 million hectares in the canal command area to water logging and salinity. Thirty-three million tonnes of salt are coming in annually and we are only capable of discharging 9 million tonnes per year, leading to net accumulation of salt in

Fig. 1.1 Regional map of the River Indus. (Source: Grid-Arendal, released CC BY-NC-SA 2.0)

the system. However, there is still a potential to achieve a favorable salt balance in the Indus basin through effective drainage management" (Hisaar Foundation, 2016).

Pakistan is experiencing heat waves, floods, droughts, and extreme weather events more and more frequently—and we are witness to the direct impact of climate change on water resources and water availability (Table 1.1).

The seepage and field losses in the agricultural sector have remained the same for decades and the water governors and managers have not been able to tackle this beyond limited interventions. The agricultural sector is largely tax-free, so there is little revenue to pay for repairs, maintenance, and replacement.

The understanding of the fast-changing surface-water and groundwater "nexus" is also a challenge. We need to assess how decades' worth of seepage from the irrigation system has fed the growth of groundwater reserves and whether these now need to be brought under water-sharing arrangements among the provinces. Most of the groundwater is in Punjab (over 50 million acre-feet), while that in Sindh is mostly saline.

The integrity of the Indus Basin is crucial and the joint responsibility of the Federation, the provinces, and the lower administrative units. This means concentrating on the maintenance, repairs, and replacement of what we have, and not

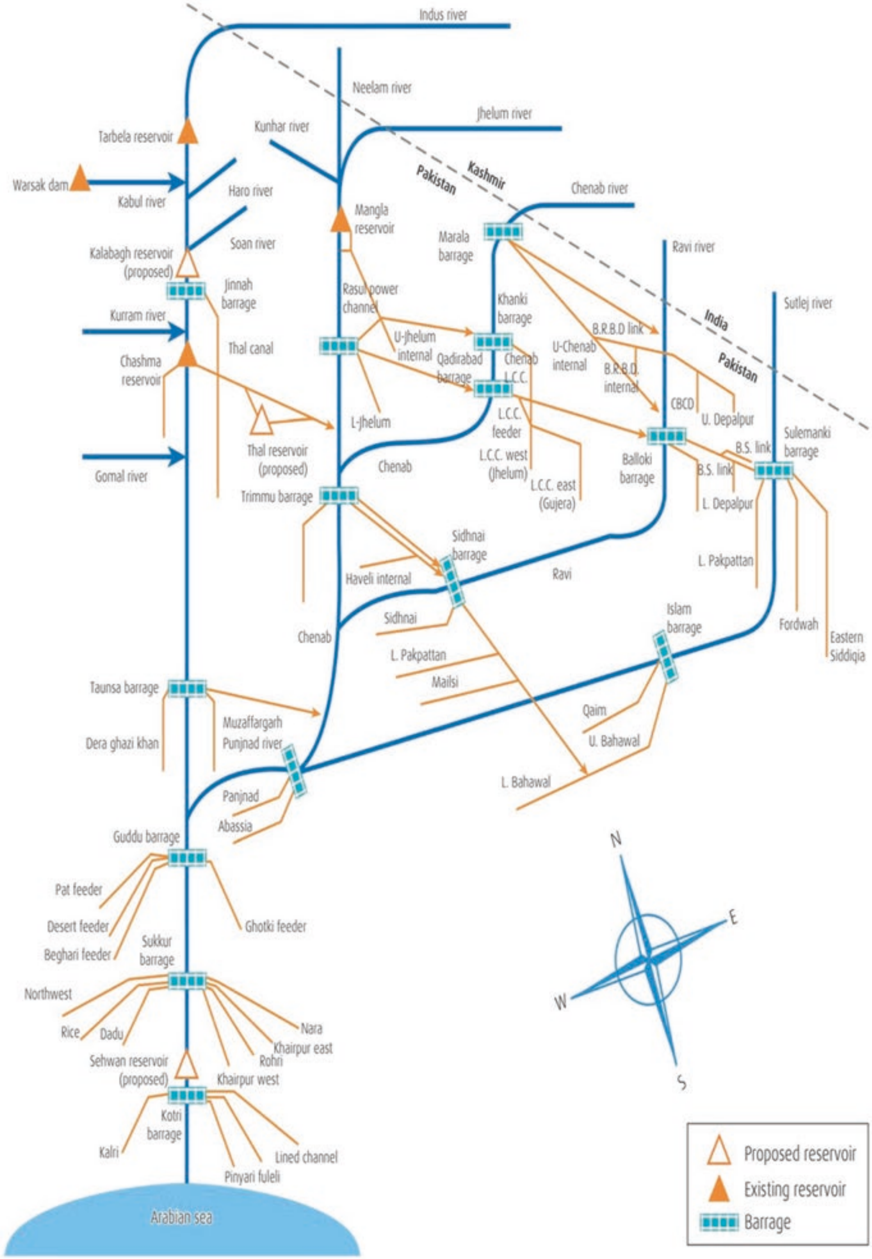

Fig. 1.2 Irrigation system of Pakistan. (Source: Young et al., 2019. Released under CC-BY-3.0)

Table 1.1 Water availability in Pakistan. (Source: Rajput, 2015)

Water Availability in Pakistan	
Surface Flow	145 Million Acre Feet (MAF)
Rainfall	8 MAF
Groundwater	56 MAF
Surface Flow Variation	
Maximum (1959–60)	186.79 MAF
Minimum (2001–02)	95.99 MAF
Seepage Losses	
Canals & Branches	15%
Distributaries & Minors	8%
Water Courses	30%
Losses in fields	
Losses in field applications	30%

building new infrastructure. The funds invested in this way would save almost 50% of the water losses in the system—much more than the "new" water that is supposed to be "produced" by new dams.

It also means keeping the rivers flowing as much as possible, given the infrastructure already in place, respecting the waterways and ensuring there is sufficient flow for all of them, whether it be the Ravi in Punjab or the downstream part of the Indus in Sindh.

We need to guarantee a consistent and controlled minimum flow to the sea each year if we want to protect all parts of the Indus basin—including the delta areas and the coastline.

Pakistan has already tried large-scale storage and constructed some of the biggest dams in the world. The benefits and problems of these dams are well-documented, as are the effects on the health and flow of the river Indus itself. The integrity of the Indus basin has to include measures to ensure environmental flows to the sea. If we take less from the river, more can flow to the delta area to rejuvenate and bring it back into balance. There are so many more methods to store and use water in the Indus basin that don't require the building of more hugely expensive and ecologically harmful dams. We can turn to smaller storage that can together hold as much water as a single dam. We can build millions of small, medium, and large ponds. Indeed, ponds have been an historical, reliable, and economical source of water in the Indus basin in the past. With the aid of satellite data, Pakistan can easily identify the best spots for ponds that can store rainwater, spring water, and flood water, which can then be used to tide over drought times. Development of this small storage capacity is low-cost and can be directly available to local communities, reducing their long wait for their share of water from large storage sites that are far away.

The integrity of the Indus Basin cannot be guaranteed without rejuvenating the ecology of the region. We must move to a mix of crops that helps the soils to breathe, take steps to stop further deterioration from invasive water-guzzling species and restore the ecological balance of the basin.

1.2.3 Understanding and Regulating Groundwater Use

With over 56 million acre-feet in underground reserves, Pakistan is the third-largest user of groundwater for irrigation in the world. The province of Punjab has 50 million acre-feet of groundwater and uses more than 90% in agriculture. In 2020 there were 1.2 million private tube wells installed in Pakistan, out of which 85% were in Punjab, 6.4% in Sindh, 3.8% in Khyber-Pakhtunkhwa, and 4.8% are in Baluchistan (Qureshi, 2020).

In Punjab, more than three million farmers have access to tube wells and one in four farming families owns a tube well (Qureshi, 2020). Approximately 76% of the cultivated area in Punjab relies on groundwater in some way to meet its irrigation needs. And water-intensive crops such as wheat, rice, and sugarcane—which together use 80% of abstracted groundwater—rely on this abundant supply of groundwater (Qureshi, 2020).

Farmers' free access to groundwater has helped them increase yields and diversify crops, and enabled them to grow water intensive crops (which also include non-native fruits along with the above-mentioned rice and sugarcane) (Qureshi, 2020). However, these benefits have come with a considerable environmental cost: "The unregulated groundwater exploitation has resulted in an excessive lowering of groundwater levels in some irrigated areas of Punjab and Baluchistan" (Qureshi, 2020).

We have long extolled the conjunctive use of surface and ground water in irrigation, but there has sprouted what can only be called the "circular debt of water" in Punjab, where most of the groundwater is—water leaks out in copious amounts from the ill-maintained surface irrigation system; it becomes groundwater; high amounts of expensive energy (mostly diesel and, in a very few cases, electricity) is used to abstract this water to bring it back to the surface and put it back into the on-farm surface water channels. Adding more dams for surface irrigation in this scenario will technically mean more seepage, more groundwater, and higher energy requirements to abstract it.

1.2.4 Recognizing the Barani (Rainfed), Watershed, Desert and Coastal Areas Outside the Indus Basin

There is a tendency in Pakistan to treat the irrigated areas as the favored child and bypass the areas outside the Indus basin. Building the physical health of non-perennial rivers, lakes, groundwater, springs, ponds and glaciers is ever more critical.

"The water sources, basins, catchments, groundwater and coastlines of Pakistan have to be secured and safeguarded from degradation, over-exploitation and destruction so they continue to be available for multiple and sustained uses and remain the backbone of Pakistan's economy and social well-being" (Hisaar Foundation, 2016). The arid districts of Eastern Sindh, Southern KPK, Eastern Baluchistan, and Southern Punjab are especially vulnerable.

1.2.5 Rationalizing the Value of Water

While the price of water reflects only the amount it takes to treat it and transport it, its actual value includes social, psychological, cultural and economic considerations. For one thing, lowering the price of water (or subsidizing it) is necessary if the human right to water is going to be met. In addition, water is also necessary in both industry and agriculture, should be properly priced as such, just as electricity and gas are (Hisaar Foundation, 2016).

Drinking water, domestic water, and sanitation are social entitlements of each Pakistani and each one must receive a fixed amount in this context. Per capita water entitlement should be fixed and used for calculating and supplying water for domestic use to rural areas, cities and towns. This means that everyone will get free water up to an established entitlement. Over and above that, people would have to pay. It also means that when any person moves to another part of the country, he or she takes his or her water entitlement with them. This is one innovative way of solving water supply problems when huge numbers of people are moving to cities; the water entitlements in these migrants should be supplied to the respective city or province as part of their water supply share (Hisaar Foundation, 2016).

Most importantly, access and right to water for agricultural or other activities will have been separated from ownership of land. Therefore, a comprehensive set of water laws that define water rights, uses, value, conservation, and principles of pricing, subsidies, licenses, and polluter penalties are needed.

1.2.6 Financing and Protecting the Water Value Chain

Pakistan needs to protect its water value chain so that water can be used efficiently and benefits can be shared equitably. In order to institutionalize that sharing of benefits, better links need to be established between agriculture, pastoral outputs, and industry. This needs to be done in a way that allows younger farmers to continue farming the land while also giving them an amenable lifestyle (Hisaar Foundation, 2016).

This requires improving both productive and allocative efficiency all along water value chains. This can be done by changing the cropping pattern or creating or developing potential value chains based on the productivity of each zone. Such a policy would incentivize commercial banks to finance the initiative. Not only will this boost economic opportunities for farmers and support rural businesses, it would also be beneficial for the banks that lend to them.

1.2.7 Building a National Investment Base for Water

A transformative narrative calls for less reliance on international donors and more focus on building a national investment base where Pakistani banks, financial institutions and investors are the investors and "owners" of the water value chain, from hydropower to agriculture to infrastructure (Hisaar Foundation).

In 2017 a consortium of Pakistani Banks, led by HBL, became the first to invest in building a dam—the Dasu Dam—a run-of-the-river hydropower project. This was the first time that funds were raised from local banks to support the financing of hydropower projects (Duddu, 2019).

Pakistan's financial sector can and should become an integral part of financing water infrastructure and the water value chain. For example, Pakistan can raise "water bonds" and other similar instruments.

Pakistan has also tried another 'first' in the world of water—the creation of a "Dam Fund" (see Case Study 4) created by the Chief Justice of Pakistan, later redubbed the Prime Minister's Dam Fund and finally carrying both titles. While the use of this fund is not clear, the ads for donation remain as banners outside many banks and continue to appear on ATM machines. This Dam Fund is an example of what not to do to raise funds for water infrastructure!

Case Study 4: Pakistan's Dam Fund—Where Is It?

In 2018, a bank account for the 'Diamer-Bhasha and Mohmand Dam Fund—2018' was opened on the order of Chief Justice Saqib Nisaar to raise funds from the public constructing two dams to deal with Pakistan's water crisis. He personally deposited one million Pakistani rupees ($8120) to initiate the drive. This was followed by donations from some other judges, armed forces officials, bureaucrats, media houses, and other public and private organizations.

However, this option was not well-received by analysts, economists, and water experts who thought it "unviable." One of the major criticisms was that such big projects cannot be completed by raising funds in this way and a more innovative solution was required. The estimated cost of the project was $12.6 billion in 2006, and now rounds up to approximately $16 billion.

Currently, questions have arisen about how the dam funds have been used. As per the claims of the Minister of Water Resources, the entirety of the dam fund was not spent on the construction of the Diamer Bhasha and Mohmand Dam. According to media reports, the dam fund was invested on treasury bills. It is clearly stated on the official fundraising webpage that investments in market treasury bills were made by the National Bank of Pakistan. More than 12 billion were raised, but the account currently stands at 799,358. This information must be made transparent to the general public by the concerned authorities.

Source: (News Desk, 2021); (Khan, 2021); (Latif, 2018); (Azeem, 2018)

1.2.8 Zoning to Improve Water and Crop Productivity

Crop zoning is practiced in many countries as a policy instrument to regulate cropping patterns. A study estimating the comparative advantage of each crop or crop rotation of a region is long overdue. This will help develop investment portfolios for newly created agriculture ecological zones. The last extensive policy in estimating the comparative advantage of growing crops in each farming system, work supported by the World Bank way back in 1993. Policy instruments such as water pricing can also be used to discourage the farming of water intensive crops such as rice and sugarcane (see Chap. 11 on demand management). Such an analysis would also enhance both land and water productivity.

In short, we need to focus on growing crops that need less water, reduce the production of water intensive crops, and get those who are growing water intensive crops to pay more for water. Essentially, water must be treated as a production cost. Once this happens, both the market and cropping patterns will naturally adjust (Hisaar Foundation, 2016).

1.2.9 Instituting Circular Economy of Water in Urban Areas

"Water recycling, wastewater management, water treatment, water conservation, greening, water harvesting from rain and atmosphere and innovation" have become realities in many cities and towns across the world (Hisaar Foundation, 2016). In so far that there are some water treatment facilities in Pakistan, they are haphazard, unregulated and inequitable.

The circular economy of water is a relatively new concept but encapsulates what needs to be done to manage urban water in Pakistan. The premise of the circular economy of water is that "there is enough water to meet growing needs, but the statistics and projections highlight that it will not be achievable without dramatically changing the way water is used, managed and shared. System level change, including the use of new water enterprise models, will be necessary to maximize the extraction of value from water cycles at all scales (river basin, city, industrial unit, building), increase effectiveness in the use of water resources and prevent further degradation of the environment" (CEO Water Mandate, 2019).

"Adopting a circular economy approach, based on the three principles of circular economy, presents a tremendous opportunity for businesses, governments and cities to minimize structural waste and thus realize greater value from industry and agriculture while regenerating the environment" (CEO Water Mandate, 2019).

This is the way that management of urban water needs to move, so the ever-rising demands can be met from within the water allocations of cities.

"Application of circular economy principles will require mapping the interactions of the water cycle, how it is used, and where within the river basin and urban water cycles value can be extracted and new enterprises established" (CEO Water Mandate, 2019).

Case Study 5: Karachi's Water Woes

The city of Karachi, Pakistan's industrial and financial centre, has approximately 16.1 million people and is home to almost 60% of industries. In fact, it contributes 12–15% to Pakistan's GDP.

Located on the coast of the Arabian Sea in the south of Pakistan, Karachi's water supply depends on both surface water and groundwater sources. Surface water sources include Lake Haleji (Plate 1), Lake Keenjhar (Plate 2) and Hub Dam (Plate 3), while the groundwater sources include the Dumlottee wells. However, these wells only supply 1.4 million gallon per day (MGD) of water after the rainy season and are dry the rest of the year.

- The Karachi Water and Sewerage Board (KWSB) supplies approximately 665 MGD to Karachi. Since demand is about 820 to 1200 MGD, there is a shortfall of 155 to 535 MGD.
- Approximately 210 MGD of the supplied water is unfiltered.
- The city's water supply system is at least 40 to 45 years old. An estimated 35% (232 MGD) of the water is lost en route, so the actual amount of water available is not 665 MGD, but rather 433.
- There is no metering for retail customers and only 25% of commercial and industrial customers have a metered supply. Hence water consumption data for these sectors is not available.
- Almost 60% of homes are connected to the water supply network and water availability ranges from two hours after every two days to two to four hours every day.
- In order to fulfil the demand gap, there are both regulated and unregulated water hydrants throughout the city. After the shutting down of 948 unregulated water hydrants since 2009, six regulated and metered hydrants supply water to the city. Despite this, the issue of unregulated hydrants needs attention.
- K-IV project phase-I, designed to supply an additional 260 MGD of water, was to be completed by 2018, yet only 20% of the work has been completed till date.
- Most surface and drinking water sources (88%) have lead levels that are higher than the World Health Organization's (WHO) recommended value. A study in 18 towns of Karachi showed high levels of lead in blood in 89% of the samples.
- Pakistan Council of Research in Water Resources (PCRWR) reports that 86% of water sources are contaminated with Coliform and are considered unsafe to drink.
- According to an estimate, less than 60% of people have access to sewerage facilities and almost 40% of the city's population lives in slums with limited water supply and poor sanitary infrastructure.

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Case Study 5 (continued)

- Karachi's sewerage system consists of 5670 kilometers of sewers, six major pumping stations, 32 minor pumping stations, and 250,000 manholes.
- A total of 475 MGD of sewage is generated in Karachi. Out of this, approximately 54 MGD is treated at Sewage Treatment Plant-I Site and Sewage Treatment Plant-III, Mauripur, while a third treatment plant remains non-functional.
- Over 12,000 industries of 65 different types exist in Karachi, including tanneries, foundries, metal processors, manufacturers of plastic, rubber, glass, ceramics, tiles, cement, textiles, pharmaceuticals, soap, fish processing units, producers of fertilizers, pesticides, and other chemicals.
- A Combined Effluent Treatment Plant has been installed at Korangi Industrial Area, originally designed to treat wastewater from tanneries in the area and domestic sewage from KWSB Pumping Station-II. However, it does not run at full capacity and also receives waste from 280 or so other factories, affecting its performance.
- 420 MGD of untreated sewage (municipal and industrial) is disposed of into the Lyari and Malir rivers, ultimately ending up in the Arabian Sea. This is causing coastal pollution and environmental degradation
- Due to changing climatic conditions, torrential rains are becoming more common resulting in urban flooding. Lack of planning, ineffective drains, and wastewater channels further aggravates the situation. There is a dire need to include storm water in the overall water management plan for Karachi.

Sources: (WWF, 2019); Pakistan Bureau of Statistics, 2021; KWSB, 2021

The water entitlement of each urban area needs to be determined and supplied by provincial governments from their share of water. Municipal governments will have to manage this water under equitable systems and control of wastage, charging as per entitlement and use.

1.2.10 Water Conservation

Pakistan has embarked on ambitious tree planting and recharging campaigns, but the correct focus on water as the key to managing threats to life, and the recognition of water conservation as a multi-faceted set of actions, is yet to be adopted by the government.

Since agriculture, is the major water consumer, saving water use in this sector is the starting point. Cities use only 3% of all of Pakistan's water, and while water conservation is required for all of Pakistan, so far there has been little effort to tackle the larger land owners who are entitled to the bulk of agricultural water because of their large landholdings.

A full chapter on agriculture and water highlights three main initiatives at the global and local levels that promote water saving in agriculture. The equation is simple: if we save even 5–10% of the water used in agriculture, there can be enough water to meet other demands from other sectors. Furthermore, Pakistan has large untapped amounts of rainfall that can be harnessed through conservation farming and supplementary irrigation (Kay, 2011). Supplementary irrigation is often referred to as adding limited amounts of water to rainfed crops to improve and sustain crop yields by providing optimal soil moisture. The practice is widely used in dry land agriculture in the Middle East and North Africa. In promoting climate-smart agriculture, one of the prime technologies is to set up water storage at the farm or community level to enhance wheat yields in rainfed areas.

Traditional water harvesting systems such as ponds, the *tonka* system, Rod Kohi agriculture and *Karez* systems need to be preserved as part of the solution. They are invaluable in conserving water in dry lands and harsh ecologies.

In our view, sustainable crop intensification is key to the transformative process of conservation agriculture. This has recently been more supported by a new theme called "Grow and Save" which looks at both technical and economic aspects in addressing the above problems and developing climate smart and resilient agriculture. "Climate Smart Agriculture (CSA)" is also gaining momentum, centered on three pillars which are productivity, adaptation, and mitigation. On the global stage, Regenerative Agriculture (RA), a farming method that allows food to naturally regrow on its own, is getting a huge following.

Case Study 6: Rainwater Harvesting in Thar

Tharparkar, in the southeastern province of Sindh, is frequently subject to droughts. While overall it has an arid climate, annual rainfall can fluctuate widely, with some places getting less than 100 mm of rain per year. In addition, it ranks lowest in Sindh on the Human Development Index. Ponds are a part of the hydrological landscape of the Thar region and are suited to the climate of Pakistan. These ponds are built on multiple levels—the village level, the community level and the individual level. The village and community level ponds are surface ponds whereas the individual ponds', or "*tonkas*", are built as underground tanks. In a good rainy season, once the ponds are filled, they can provide water to the villages for up to 6 months or more in the dry season. Water collected in these ponds are used for both drinking and domestic purposes.

The underground tanks are a centuries-old method, while ponds on the surface in a cascading relationship is something more recent: the largest pond can usually hold up to a million litres of water, while the medium pond can

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Case Study 6 (continued)

hold up to 40,000 litres. When drought begins, the water from the big pond is used first by surrounding communities. Then the medium ponds (usually inside single villages) are used, and when that is gone, then the individual underground tonkas are opened.

Source: (Hisaar Foundation, 2016)

There is very little work on coastal erosion, massive marine pollution and the dumping of dangerous materials along Pakistan's coastline.

A widespread media campaign is needed to cover all these critical areas. By sharing information and knowledge related to water, the public becomes more informed, and more aware of their own responsibility in protecting this vital resource. In addition, a public campaign can simultaneously build consensus while reducing polarization.

1.3 Entitlements Based on All Available Water

"In order to improve sharing of water resources and sharing the benefits of water resources, **all the water sources available to a province** must be taken into account. This will improve trust and transparency, and will also be fairer" (Hisaar Foundation, 2016). This is a very radical idea which the bigger province will likely oppose and the others endorse. But this discussion must happen.

In addition, all provinces must cooperate to determine exactly how much water is available from all sources **(surface water, groundwater, and precipitation)** and list all the ways in which it is used in each province and then allocate water shares accordingly. Moreover, this process will have to happen not just at the provincial level, but also at the district level and even at the village level (Hisaar Foundation, 2016).

Case Study 7: Punjab's Available Groundwater

The four provinces of Pakistan reached an agreement regarding the distribution of water of the IBIS in the shape of the Water Apportionment Accord (WAA) in 1991. The two important features of this accord are: (1) it protects the existing uses of canal water in every province and; (2) allocates the balance of river supplies, including flood surpluses and additional supplies from the future storages between the provinces. However, it does not mention groundwater in the provinces. At the time it was signed, groundwater might not have been given that much importance. However, in recent decades, it has become the centre of debate due to rapid increase in its use.

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To deal with the shortage of surface water availability, the exploitation of groundwater resources is happening. Due to limited understanding of groundwater dynamics on a provincial level, an effective groundwater management policy in Pakistan is absent. The use of groundwater varies in each of the provinces. Sindh has minimal groundwater exploitation because of its poor quality. In Khyber Pakhtunkhwa and Baluchistan, there are high costs because of greater depths and aquifer characteristics. Punjab has groundwater at shallow depths with relatively good quality, resulting in its widespread use. It has 50 million acre-feet of groundwater and accounts for 90% of total groundwater pumping in Pakistan. The number of installed tube wells gives an estimate of groundwater use in agriculture, but it does not sufficiently address domestic and industrial usage. Since these two sectors generally have high usage, an uncertainty exists in measuring groundwater extraction in major cities such as Lahore.

The excessive use of groundwater by farmers has environmental costs. The groundwater levels in irrigated areas of Punjab have decreased because of unregulated groundwater exploitation. From 2008 to 2018, there was a 35% decrease in areas with a groundwater table between 0–150 cm, while there was a 15% increase in the number of areas that have a depth less than 600 cm. It is estimated that groundwater table depth is below 600 cm in half of the total cultivated area in Punjab. The small pumps are less efficient at depths below 500 cm, so many farmers have installed higher-capacity pumps. Due to the increase in groundwater use over the years and issues related to the supply-based canal system, an integrated management of water resources is needed in Punjab.

Sources: (Lytton et al., 2021); (Qureshi, 2020); (Khan et al., 2017); (IUCN, 2010)

1.4 Building a Base for Science, Technology, and the Social Aspects of Water

Much of the literature on water in the past two decades has been more about "elite capture," "allocation of water" (which is about the tussle for water among the big landowners), "water governance," "poor management," and "capacity building." There is little primary research on key questions: how much water is in the system now, and how much will there be in 10 or 20 years? How many acres are waterlogged now? How many are saline? What is the rate of sedimentation in the irrigation system and in our dams? How much groundwater is there? How much of it comes from seepage? What are the main pollutants and can they be extracted? What are the parameters of the different qualities of water needed for different uses?

'Linkages are essential between science, research and practice, and between the sociology and psychology of water use and water behavior to bring water studies into the modern era and prepare the water professionals of the future' (Hisaar Foundation, 2016).[1]

Young women and men need to be trained in emerging water technologies, management skills and knowledge base, to manage water in Pakistan in all its manifestations: the hydrology and geography, the engineering and sociology of water working together, the psychology and behavioral sciences around water use, the conservation and stewardship of water bodies, new methods and models, managing the effects of climate change on water availability, and making water knowledge accessible to all.

The link of academia with government, the business sector, and civil society needs to reflect the principle that water is everyone's business, with each group playing its rightful role. Cutting-edge specialized water research from primary sources is essential, as is re-packaging academic research, science, and knowledge of water for the general public, media, and water user groups. All citizens need to understand what they have to do to conserve and better use water, so that we can continue to use our water resources as best as possible and avoid the catastrophe that awaits us. But the neo-liberal emphasis on individual action and Malthusian ideas has to be pushed back to allow for the larger sweeping actions that government and water institutions must do—water pricing, taxing the rich, making polluters pay, tackling big industries and big agricultural tycoons.

The bottom line is that we all have to learn to live with less water, and advances in water science and technology will tell us how this can be done. We need research, teaching, training and dissemination to each sector of society as needed—whether it be recycling methods, micro-irrigation, changing the crop mix in different water regimes, water laws, or reworking the right per capita allowance in times of water stress and water scarcity.

Case Study 8: One Foot in Academia and One in Practice—Panjwani-Hisaar Water Institute

The Panjwani-Hisaar Water Institute (PHWI), at NED University in Karachi, is a collaborative effort by NED University, the Panjwani Charitable Foundation (PCF), and the Hisaar Foundation (HF). PHWI is designed to play a pivotal role in new ways of thinking about water, developing theory and practice, doing applied research, and undertaking scientific investigations. It aims to stimulate and inculcate innovative water education, research and training that is interdisciplinary and multidisciplinary in nature and integrates the currently isolated nodes of engineering, water sciences, and the economic and social sciences in Pakistan's water sector, and which recognizes all the

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[1] Adopted from the concept paper of the Panjwani Hisaar Water Institute (PHWI), 2018.

Case Study 8 (continued)

linkages between water users, water uses, and different stakeholder groups to promote informed policy and actions at all levels.

The multidisciplinary approach to water education, research, and training at PHWI integrates 'information, data, techniques, tools, perspectives, concepts and theories from many disciplines to advance fundamental understanding of the complexities of water challenges and their solutions' (Hisaar Foundation, 2016). It brings together the engineering stream, which includes hydrology, hydraulics and infrastructure; the water science stream, which includes hydrology, geography, geology, and environmental sciences; the macro and micro economics stream; and the social sciences stream which includes sociology, social work, politics, and community-based approaches. The link between ways of thinking, psychology, and behavior in patriarchal society as it affects water use, water rights, and water entitlements, is also being explored at PHWI.

PHWI is designed for research and academic programs offering MPhil and PhD degrees, credit hours for undergraduate degrees, and short diploma courses and certificate courses designed specifically for industry, agriculture, and the built environment. The Institute has five laboratories which are being equipped with the latest water technologies.

- Water Ecology & Remediation
- Coastal & Riverine Hydraulics
- Water Psychology & Behavioral Sciences
- Total Water Quality (a range of water testing facilities)
- Water Data Analytics and Water Modelling

1.5 Inducting Talented Young Women into the Water Sector

Pakistan's water sector sensibilities about women's leadership and involvement are archaic. Fetching, carrying and managing domestic water, community-based sanitation work and water-related hygiene continue to be seen as the "women's domain," while national discussions, debates, decisions, infrastructure and initiatives on water are still seen as "men's domain."

"Women remain largely invisible in the water institutions of the country, water-related ministries and department, water NGOs and water businesses. They are seen mostly as 'affectees' of the water crises and climate change and therefore, are bracketed as part of the problem" (Kamal, 2018).

Women account for 48.76% of the population of the country, but they are referred to only once in the Govt of Pakistan's Water Policy of 2018, and that in the context of stakeholder participation in section 18.3 where "women population will be promoted in domestic water supply and water hygiene." (GoP Ministry of Water Resources, 2018). This absence of women from Pakistan's guiding policy document on water, reflects the prevalent attitudes of a patriarchal society in general and the very masculine water institutions in particular.

"By several estimates, women provide at least half the agricultural workforce, even if not remunerated or accurately counted. Women in Pakistan are not only careful users of water but also the custodians of water knowledge and practice. They carry the heavy burden of walking several kilometers a day in many parts of rural Pakistan to fetch water for household and livestock use, and continue to face many gender-based discriminatory practices which often determine their access to, and their participation in water-related narratives when it comes to claiming entitlements to water. Pakistan law does not directly address 'water rights,' and land ownership is usually a proxy for access to or entitlement to water. Because women in Pakistan own land in a far smaller proportion than their numbers, their 'water right' is also limited" (Kamal, 2018).

While women's role as domestic water managers is extolled and the hazards they face in the context of walking long distances to fetch water barely acknowledged, women have been quietly becoming water visionaries, academics, scientists, and researchers. They are now recognized in this context. But the doors of decision-making bodies on water and the premier water institutions of the country remain largely closed to them. Those that have broken the glass ceiling face biases and challenges that discourage them and prevent their upward movement.

Pakistan needs a plan to systematically bring in young women into the water sector, as there have been successful actions to induct women in the IT sector and in entrepreneurship development.

1.6 Demonstration of Leadership by the Government

Decades of stalling over a national water policy, low levels of debate and discussion, the politicization of water discourse and the low priority afforded to water issues in the government and in the country as a whole, means that the hard decisions about water have not been taken in a timely manner. While there is a plethora of water related government departments and institutions, the locus of authority is not clear. This has given rise to a situation where the recent Recharge Pakistan program and the very big Living Indus program spearheaded by UN agencies has gone to the Climate Change Ministry rather than the Ministry of Water or one of the other water institutions.

Case Study 9: The Plethora of Water Agencies of Pakistan: Who Is Actually in Charge of Pakistan's Water?

- Ministry of Water and Power (MoWP)
- Indus River System Authority (IRSA)
- Water and Power Development Authority (WAPDA)
- Federal Flood Commission (FFC)
- Pakistan Meteorological Department (PMD)
- Provincial Irrigation Departments (PIDs)
- Provincial Irrigation and Drainage Authorities (PIDAs)
- Provincial Agriculture Departments (PADs)
- Area Water Boards (AWBs)
- Farmer Organizations (FOs) and Water User Associations (WUAs)
- Pakistan Council of Research in Water Resources (PCRWR)
- Pakistan Council of Scientific and Industrial Research (PCSIR)
- Federal Flood Commission (FFC)
- Pakistan Commissioner for Indus Waters (PCIW)
- Provincial disaster management authority (PDMA)
- Pakistan Space and Upper Atmosphere Research Commission (SUPARCO)
- Water and sanitation agency (WASA)
- World Meteorological Organization (WMO)
- National Disaster Management Authority (NDMA)
- National Disaster Management Authority
- The Punjab Agricultural Marketing Regulatory Authority (PAMRA)
- Sindh Coastal Development Authority
- Karachi Water and Sewerage Board (KWSB)
- Balochistan Water and Sanitation Authority Act

Source: (WWF, 2012)

Interestingly, while Pakistan's Water Policy was rather unheeded by the public without an implementation framework and the Dam Fund was still open, Pakistan's Judicial Academy and its Chief Justice sought answers to Pakistan's water problems by organizing an international symposium. Its declaration is wide ranging but far more focused than the National Water Policy document (LJCP, 2018).

In conclusion, the government of Pakistan must allow its various levels to be assisted by experts, academics and professionals in water, climate change, environment, and food sectors. The world is already paying dearly for ignoring what scientists and thinkers have been saying for the past 50 years about climate breakdown, and Pakistan is no exception. The government of Pakistan must assign top priority to water and related sectors, and the federal government must provide clear leadership to take the difficult decisions needed today. These difficult decisions include protecting the integrity of the Indus basin and all other basins (rather than continue to promote and build more and more expensive infrastructure), defining water entitlements of all Pakistanis (not just land owners), moving from irrigation-based monoculture to building on the local agricultural heritage and promoting local solutions of water supply and management.

While irrigation water distribution, drinking water and sanitation have been in the ambit of provincial governments, the federal Ministry of Water and federal government as a whole must exercise an overall benevolent authority focusing on conservation and safeguarding. This does not mean commandeering the infrastructure development budget and dictating what provinces must do, but building consensus and agreed actions. Platforms and forum exist already where such consensus, however painful, can be evolved.

Provincial governments have to exercise the same restraint in their jurisdictions, so that the transfer of subsidies, benefits and power relating to water can be steered away from entrenched landowning interest groups and generalized to the public. This can only happen when suitably empowered and resourced local governments begin functioning in the districts of Pakistan. The local arena is where the nexus of water-climate-environment-food can be seen to be operational and where good policies and programming can actually make a difference.

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Chapter 2
The Political Economy of Water

Erum Sattar

Water is the petroleum for the next century.

—Goldman Sachs Global Investment Report, 2008

Abstract The political economy of Pakistan's water is a complex interplay of interests that in the modern era, beginning in the nineteenth century, emerged from within the context of colonialism. The foundation of the irrigated economy that was laid during British rule privileged particular norms of water control that, to large extents, persist and shape current policies. Given the rising and changing demands on the uses of water that have naturally arisen through the passage of time, coupled with a rapidly changing climate, prevailing water policy and allocation are hard-pressed to meet evolving societal, environmental, and economic goals. Particular and longstanding challenges arise from the political economy of interprovincial water-sharing and are further compounded by the changing geopolitics of transnational infrastructure finance within the prevailing narrative that privileges increasing supply over reducing or managing demand. Within and across sectors, a host of challenges arise from the failure to value water for its proper and integrated environmental, social, economic, and political uses. Meanwhile, the growing role of the private sector, in areas such as commercial groundwater extraction for drinking water as well as in beverage and industrial production more broadly that significantly impair water quality and the environment, remains a largely under-governed space. Since the British era, agriculture remains the foundation of the economy and with rising demands from a growing population, food and commodity security for both crops and dairy and livestock production within the context of global food production and trade flows have become ever more complex. These forces are playing out within the context of global climate change and evolving norms of water storage that take into account methane emissions from large dams as part of international climate pledges, further compounding Pakistan's overall water, food and

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energy security goals. An improved understanding of local contexts as they interact with global trends will need to be developed to improve Pakistan's political economy of water.

Keywords Valuing water · Food security · Water allocations · Climate change · Private sector · Irrigation

2.1 Introduction

2.1.1 A Broad Overview of Pakistan's Political Economy of Water

This chapter aims to focus on a host of complex and interconnected political economy factors that together impact the overall water economy and water governance in Pakistan. Some key areas include factors that will be familiar to readers of work on the political economy of managing water as a resource in other basins and contexts (Dinar & Tsur, 2021). These include but are not limited to issues of the preservation of the status quo, in the context of present-day Pakistan, stretching back to the British colonial era in the nineteenth century through its implementation of a system of land and water-use rights allocation that continues to have a lasting pull on the continuation of the status quo while also indicating the forces of policy pull (e.g. adding more water storage/supply) towards the privileging of certain specific types of the country's policy pathways. Any change in direction must account for the fact that—both individually as well as collectively—when groups work together because of aligned interests as opposed to overarching societal interests, within the context of climate change and a dramatically and rapidly altering resource scenario both in the present and the future, the decisions being made today are entirely rational. However, taken together and with a longer-term view, I suggest that at a minimum they fail to protect societal interests, much less advance them in virtuous ways that would signal and create their own self-propelling pathways. From an efficiency perspective—a concept dear to planners across a swathe of disciplinary domains—the current system of water rights and governance leaves much to be desired. The question of interest to us then is, how, in the context of an ever-stressed resource base, can it persist? As we will discuss through a broad detailing of the challenges to remaking Pakistan's troubled relationship with the political economy of its water resources, the hurdles emerge from a set of interconnected facets that make any change in one domain necessarily dependent on another, and so on and so forth in a complex web of connectivity which leaves planners with the conundrum of identifying the precise points within the overall political economy of water to begin a program of long-delayed and much-needed reforms.

It is hoped that with this broad identification of a complex set of interconnected factors that—instead of valuing water close to its real economic, social, cultural, environmental, and political values –commonly underprice or misprice water in the fuller senses of value (Alam, 2018), that we will advance the conversation. The hope is that we move beyond how meetings with Pakistan's water planners tend to end: with the identification of the problems and hurdles to any reform effort all attributed to "a lack of political will."

Water, when used and managed properly, can be a critical driver of Pakistan's economic growth. But, as the resource has been and continues to be managed, water is a significant retardant to Pakistan's economic as well as environmental sustainability and stability. While there are several interconnected reasons for why water is not yet the driver of growth and ecological thriving that it could be if understood and managed properly, we must start with identifying that the misunderstanding starts with the prevailing mental mind map that understands Pakistan as a water-short country. It is not. Pakistan instead is a water-rich country that has abundant annually renewable freshwater supplies (Young, 2017). Saying this fact aloud is important for several reasons. One is that the country must move beyond the hyper-prevailing discourse and mindset of shortage that guides present policy into making sub-optimal policy choices. Acknowledging this fact needs to be the starting point of any discussion on the country's water resources and changing this perception is an important first step. Instead of a water-short country, Pakistan is a water-rich country with a significant quantity as well as many sources of water. Even when assessed on a per capita basis, with the country's growing population representing a challenge to planners, Pakistan's daily per capita water use remains downright profligate, especially when compared to dozens of countries with lower per capita water use (Water Use Statistics—Worldometer, 2022) Interestingly, a host of countries manage to be both more responsible per capita users of water while being much richer and more developed. As may be expected, these countries include Luxembourg and the United Kingdom, but even Sri Lanka, India, and Bangladesh in the broader South Asian region fall in this category, indicating that it is not water availability per se that is the restricting limitation to a country's overall levels of well-being and economic development.

2.1.1.1 The Politics of Narrative: Reducing Demand vs. Increasing Supply

Pakistan requires a fundamental shift in its political, economic, and social relationship to water. While the discourse at the national level that drives investment decisions seems relatively fixed on the importance of large dams to rid Pakistan of its increasing water and electricity stress, with a goal to make 10 large dams over the next 10 years (Zaman, 2020; White, 2021), a different kind of policy discourse is also emerging. This calls for the desirable conjunctive use of surface and groundwater to aid, for instance, the downstream province of Sindh in finding a way out of the relatively intractable positions of the federating units that continue to breed mistrust with flying claims and counter-claims in both upstream and downstream directions (Mustafa et al., 2017). The goals of a more virtuous path are multiple: first, it would increase yields by reducing waterlogging as during the drought of 1999–2002 (waterlogging also contributes to surface salinity through plant capillary action); secondly, it would provide significant potential groundwater recharge—up to 80% is lost through non-beneficial evaporation. The current system of non-conjunctive use disincentivizes farmers to manage water more efficiently as well as more sustainably (van Steenbergen et al., 2015).

2.1.1.2 Valuing Water

Understanding that all human civilization is centrally situated in and emerges from its management of water is an increasingly influential argument (Boccaletti, 2021; Narisetti, 2021). The idea that collectively society must come together to attach the right value to water in a way that affects investments in water has been a growing trend (McClain, 2013). Importantly, these investments must link together the necessary water infrastructure that needs to be built and maintained in such a way that it contributes to long-term social, human, and ecological health.

Pakistan remains, to a significant degree, an agriculture-based economy approximately two centuries after the British rulers of a then-united India laid the legal, institutional, and physical foundations of canal irrigation in what became Pakistan's share at Partition in 1947.

2.2 Demand Sectors

2.2.1 Irrigation and the Structure of the Economy

With a country with overall 50 million acres under cultivation, of which approximately 41 million acres are irrigated via canal networks, more concerted focus is needed to bring together several relevant integrated questions and domains. Namely, the percentage of the population that is sustained through and employed by the rural agricultural economy; how much of Pakistan's food as well as agricultural commodity crops are produced through existing water diversions and allocations for agriculture; and what are some potential metrics that would help us gauge both what we know and don't reliably know (and thus need to know) to be able to set verifiable goals.

Thus, in Pakistan, it would not be too far from the truth to say that food and agricultural commodity crop production is a function of irrigation, and they thus should be a key concern of overall water policy. On this front, water policymakers need to not only know the financing needs of the agricultural economy but also make them a prime focus in a way that allows them to work together towards integrated goal setting. Rough estimates indicate that the running finance needs of the agricultural economy are approximately $1.2 billion annually (or 2 trillion PKR). The rural economy relies on informal credit markets to access its annual required financing needs and herein lies the crucial determinant of rural farm policy in the form of, for instance, farmers' crop choices. No government can claim to have an effective farm policy if it does not have the ability to set policy goals and then affect necessary action towards their attainment. This means that for the most part, farm policy is privatized as what farmers plant and their overall crop planning is determined by the silent diktats of creditors. While the urge to lay blame at their door may be an easy response–rural providers of credit (the *arthis* or middlemen) are blamed for a whole host of social ills such a holding farmers and landless agricultural workers "hostage" through never-ending debt bonds—their real power lies in the fact that while potentially exploitative, they serve a crucial and beneficial role by turning the wheels of rural credit markets. It may be time to acknowledge that despite a long-term policy focus, the government has been unable to incentivize the banking sector to offer rural credit. Only with this acknowledgement will there be a turn to develop policy that has a better chance of helping solve the interlinked problems of rural financing: the lack of formal banking credit, the crucial role of middlemen as the providers of credit and the need to shift towards more formalized banking credit provision and more regulated rural credit markets in ways that build knowledge about rural collateral to unlock needed financing (Nizamani, 2021a). Of course, the very high interest rates they charge have their own stifling effects on all aspects of agricultural development, limited not only to giving them an outsized role in the crops that farmers plant. If the situation is—as the Athenians made clear to the Melians in Thucidydes' *Melian Dialogue*—that the strong do what they can while the weak do what they must, then in the context of rural Pakistan, the extenders of credit are akin to the Athenians as the dictators of debilitating terms. The way out of this impasse may be unlocking new forms of financing to rural credit markets, for example, by fixing the long-term inability of formal banks to provide agricultural credit. In particular, the global development of tech in the agricultural credit space may be the most promising to pursue (Nizamani, 2021b).

Despite its significant endowment of irrigated land, Pakistan has not been able to build on it in at least two significant ways that together suppress not only current export earnings but also do not build on it to lift more of its population out of low economic value agriculture as a source of livelihood. In the short to medium term, serious efforts at national poverty alleviation will demand no less than working on both fronts with dual policy objectives in mind: ensuring that those employed in agriculture have the chance to obtain decent livelihoods while also ensuring that the agricultural base of the economy can be harnessed to create enough economic surplus such that there are requisite other industries for people to move to when they are forced or transition out of relying on agriculture as their primary source of livelihoods. The current equilibrium between these policy objectives and competing forces is significantly disbalanced. Between 1970–2014, for instance, econometric analyses of the link between the country's agricultural exports and GDP growth show that agricultural exports have a negligible impact on overall economic growth. This is because of the un-competitiveness (higher prices combined with lower quality) of the country's agricultural commodities vis-à-vis competitors' exports (Mahmood & Munir, 2018). What this means is that far too many resources (both in the form of subsidies to keep agricultural commodity markets operable as well as in the number of people who are kept occupied in economically low-value agriculture) are locked and unable to be tapped for the purposes of personal as well as national economic development.

2.2.2 The Political Economy of Food Security

The ongoing pandemic continues to raise significant challenges to nutritional security and to the resilience of food systems around the world. Pakistan too, with the world's largest contiguous irrigation network, is in the midst of rising inflationary and import pressures to meet its production gap. As per the Pakistan Bureau of Statistics (PBS), the food import bill in the first two months of fiscal year 2021–22 has risen by 50% as compared to a year ago, from $0.980 billion to $1.473 billion (Bokhari, 2021). In addition to increasing the country's import bill because of the need to import key items such as wheat, sugar, pulses, and palm oil, the growing clamor around food inflation and its impact on household budgets cannot be underestimated (Trading Economics, 2021). While the Government of Pakistan (GoP) has responded through an expansion of the social safety net, whether the scale of the response adequately addresses growing social vulnerability remains questionable.

Of course, there are also small victories that, it is hoped, will in time affect the overall political economy of water governance and the economic and social development to which it gives rise. At the beginning of 2021, the Sindh provincial assembly recognized that women would have the right to be included in the formal institutions of participatory water governance and irrigation management. This significant policy shift recognizing female participation in farm work and attendant water management has taken nearly two decades to accomplish after legislation recognizing farmer organizations was first adopted in the province in 2002 as part of national policy reform. The share of farm labor and management that falls on women has grown over the last two decades as a share of total farm work (FAO, 2014), especially because of disruptive internal migration of men from rural water-stressed areas at the tail end of canals to urban areas in search of jobs (Genani, 2021). The water stress suffered by smaller farms in marginalized areas as a result of larger upstream landowners taking more than their allocated share of water—what first prompted men to move to urban areas as a way to supplement family income—now falls squarely on women's navigational skills.

These results underscore a need to reduce labor-intensive agricultural workload demands during pregnancy, especially in cotton harvesting, to reduce the risks of negative maternal energy balance and poor growth outcomes in early infancy (Pradeilles et al., 2019).

The focus on supply side water provision—the language of addition and of building big dams as the foremost answer of how to address water stress in Pakistan that is advanced at official levels is the first challenge to a holistic understanding of what actually causes and perpetuates water stress in the country. Here, we make an effort to situate the discussion within its broader contexts.

2.2.2.1 Agricultural Participation and Relations

The fundamental shift in agricultural participation that is underway particularly as it relates to female participation in both uncompensated and compensated labor on farms is another factor that must be evaluated within the interplay of several other factors such as efficiency and a shift in the existing status quo of farm work. Importantly, while women provide a significant share of farm labor particularly in the care of domestic dairy animals, their lack of access to training in the operation of machines disadvantages them when it comes to a greater role within the framework of more heavily mechanized labor—a model that is growing in particular in the rice and wheat cropping belt of Punjab (Mohiuddin et al., 2020). This means that through the process of greater mechanization, women will lose out in continuing to be able to claim a share of agricultural labor provision as well as a greater share of potential earnings and in decision-making related to farm work and farm operations. If greater consolidation and greater mechanization will further squeeze out women's participation in the rural agricultural economy, this shift should be of interest to policy makers in relation to agriculture's role in several of the SDGs, particularly in relation to gender, poverty, and decent work and economic growth.

The underlying exit from farming that is playing out in the country as part of a livelihoods coping strategy at the nexus of a growing population and the move to bring ever-more marginal lands under cultivation to cope with higher food and income demand means that families are continuously engaged in evaluating whether moving away from farming is a sensible livelihood strategy. Recent data from Sindh province, Pakistan's second largest agricultural province, shows that 19% of families have completely shifted from farming to off-farm livelihoods, a high exit percentage (Ahmad et al., 2020). Given that nearly 60% of the country's population remains food insecure, the combined force of people moving away from farming as both a livelihood as well as a lifestyle must be evaluated and addressed to minimize the impacts on overall food security. Importantly and more recently, the unfolding impact of COVID-19 has only made this situation graver with a growing gap between financial need and available resources (World Food Programme, 2021). This overall shift from agriculture may have broader food security and policy implications. Further, from both the perspective of a family as well as a consideration for policymakers, moving away from farming towards urbanized livelihood strategies often fails to deliver more security (Imai et al., 2017), raising questions about both food security as well as broader poverty alleviation strategies and the potential to meet SDGs targets.

Stakeholder Participation and Influence in Policy Making

To make progress on the range of suggestions offered here it will be important for policymakers to explicitly make room for an overall atmosphere that engages with users in new ways while also creating a regulatory and governance framework that creates room for meaningful engagement from a broad swath of society, including users and those broadly affected by water projects. Such efforts will need to go beyond consultative practices adopted in more limited forms (Global Water Partnership, 2015). While examples abound in how to meaningfully undertake stakeholder participation, changing the ethos towards one of listening to users and those affected from current exclusionary institutional structures will be an uphill task. One virtuous way forward is to put in place structures that can leverage natural disasters and changing climate trends to move towards the adoption of more inclusive decision-making (Carr et al., 2014). Given the increasing reliance of the agricultural economy on tapping groundwater resources in Pakistan—currently providing 50% of irrigation water—the importance of inclusive user participation is clear for the long-term sustainability both of agricultural livelihoods as well as of the environment and ecosystems (Baig et al., 2018).

2.2.2.2 Adapting Crops to Water Shortages and Saline Soils

A significant new global study shows that since the 1960s, global agricultural productivity has fallen by approximately 21% due to rising temperatures, likely far outpacing efficiency gains from any other means such as seed development and water and fertilizer application, etc. (Milman, 2021; Ortiz-Bobea et al., 2021). To adapt crops to water shortages as a result of changing weather patterns in the overall context of climate change necessarily proceeds slowly in experimental and incremental steps, as examples of ongoing efforts from agricultural powerhouses such as California demonstrate (Cart, 2021). In such jurisdictions, farmers and policy makers are turning to science and technology to help solve several interconnected problems that affect tree crops such as almonds that have yearlong water requirements. These crops need more reliable water supplies to justify the costs of large-scale commercial tree-crop production. Given that fruit and nut trees need more than 20 years to mature, a longer-term outlook and planning is imperative. Further, even in California, with a $50 billion agriculture market, driving down water use while keeping yields high can take decades. However, between 1980–2015, a period of 35 years, farmers reduced water application by 14% while increasing crop production by 38%, demonstrating that while change may be hard, it is possible (California Farm Water Coalition, 2019). Given that decades can be required for plant breeding and the work of plant geneticists, agricultural experimentation, innovation, and it is clear that we need to start sooner rather than later. Pakistan needs to prepare for a less benevolent water future. A good first step would be to significantly expand the research budgets and capacities of its network of agricultural universities with the help of important stakeholders, such as the Centre for Agriculture and Bioscience International ("CABI"), whose old roots and networks on the ground can conduct research complemented by meaningful extension and outreach services (Asad, 2021).

Importantly, using biochar on crops has been shown to reduce the need for irrigation by 40% (Bryce, 2020), which given the declining availability of irrigation water as well as the impact of rising temperatures that reduce the ability of soil to trap moisture, would be an important policy response for Pakistan to move towards. Investigating the potential benefits for Pakistan's different growing zones would also be helpful, especially within the context of the overlaps from benefits to farming and the country's climate change commitments. Because the use of biochar enhances carbon sequestration, its use would have twin benefits in the overall water, food, agriculture and climate contexts that are key to inculcating sustainable practices—and when farmers see the commercial benefits of climate sustainable farming practices they are more likely to adopt them. As with other policy interventions, these too should be fostered by a whole-of-government approach working across federal, provincial, and local levels in tandem. Given that approximately 95% of freshwater is diverted towards farming in Pakistan, and the risks from dwindling supplies in an era of glacial melt and a warming climate, Pakistan must pivot to more sustainable and certainly less financially prohibitive ways that do not require the building of large hard infrastructure.

2.2.2.3 The Price of Essential Commodities and Their Link to Water Allocation Policies

Further, through policy innovation and design, the private sector should also be incentivized to play its attendant and beneficial role in agricultural innovation in the crop and water value chains through the convening capacity of such institutions as the Pakistan Agricultural and Research Council ("PARC") and a whole-of-government approach (Mirza, 2021). In some countries, for instance, this has been done by creating a regulatory framework such that private actors can easily locate the best opportunities available throughout the value chain and intervene where they deem best and in Pakistan, this process needs to be further incentivized through PARC's Agrotech arm. This kind of enabling regulatory and legal framework needs to be strengthened to further tap companies' creative and entrepreneurial skills throughout the agricultural value chain. One advanced model for the country to look to is that of the Netherlands where the confluence of original research work and the training of the next generation of scientists at gold-standard institutions such as Wageningen University has led to land and water poor Netherlands to become the second largest exporter of crops in the world. This makes it second only to the United States and ahead of all other countries with far greater land and water resources and a higher percentage of the population dedicated to farming, such as Australia, Russia, and China (Viviano, 2017).

In the context of food security, a significant issue is the increasing cost of food subsidies such as those for wheat release and procurement in federal and provincial budgets (DAWN Editorial, 2021). The stress this factor places on provincial and federal budgets and its effect on the government's rising overall circular debt commitments is clear. The government's flagship *Ehsaas,* or Compassion, program includes a focus on nutritional food security (based on the earlier lauded Benazir Income Support Program or BISP) for overall poverty alleviation. This program, through bulk commodity procurements and their distribution, is a vehicle for targeted food subsidies. While it addresses acute social needs, the longer term task of water and food security policy must be to lay the foundation of sustainable economic growth in a way that enables farmers to grow and for a greater share of the population to be able to access a nutritious diet. For such an outcome, sustained work and collaboration across the network of public sector agricultural universities along with the full cooperation of the private sector through industry networks. For example, the firms represented in the PFVA—All Pakistan Fruit and Vegetable Exporters, Importers and Merchants Association will be critical. The procurement value chain for key food and commodity crops such as wheat is also beset with inefficiencies that hamper the ability of growers to easily sell their stocks to government warehouses. This compels them to sell to middlemen, which they can do far more easily (Haque et al., 2021).

A major aspect of the justification to divert close to 95% of the country's available freshwater resources for irrigated agriculture is that this long-standing practice helps maintain the country's food security. While this may at first seem plausible, nevertheless the claim needs to be examined. As the World Bank has found in its latest study of the country's water resources, Pakistan diverts approximately 80% of its water supplies towards the production of four main crops: wheat, cotton, sugarcane, and rice (Young et al., 2019). While the importance of wheat in the local diet is certainly an important element in the overall calculus of water diversion and food security, it is also the case that a significant proportion of this water is used in non-food producing crops, namely, cotton and sugarcane. In addition, while rice is a mainstay of local diets, the bulk of rice produced in the country is exported, making it a major part of Pakistan's primary and processed food exports. This exemplifies the next point of relevance to the political economy of water which is that irrigated agriculture also undergirds the country's exports.

While the government claims that the impact of a rise in global food prices has been relatively checked and have not been passed on to consumers (DAWN, 2021a), nevertheless, the problems of a rise in food prices that has severe negative impacts on food security overall have only been exacerbated during the Coronavirus pandemic (Khan, 2021; DAWN.COM, 2021). In particular, to ensure that wheat stocks do not run low in the local market, further pushing up prices, the government had to import sufficient wheat stocks on an emergency basis given that wheat support prices were no longer effective. Essentially, as far as the prices of wheat are concerned, this is linked to shifts in global commodity prices and therefore highlights the fact that far from ungirding staple food production in the form of wheat, local production contributes a portion of annual wheat requirements. This less-than-optimal allocation of water to produce 70% of the country's annual wheat requirements means that a serious revision of the reasons for low wheat yields coupled with the strain that local wheat production puts on available water resources must be examined for the overlaps between current water allocations and the economic and other values that water is currently providing to the economy.

A major issue for Pakistan is the country's increasing reliance on imported food to guarantee a minimum amount of food security for the growing population

(Ahmed, 2021). This growing recognition in policy circles that staples such as wheat and sugar will need to be imported to keep food prices affordable at a time of growing inflation is compounded by the pressure such essential imports place on an already rising import bill overall thus, creating pressure on the domestic currency vis-à-vis the USD. In the realm of food, of course the country also imports other essentials such as pulses, oils, milk, and tea. Given the place of these items in domestic diets, it is hard to envisage a scenario in which their imports can be stopped or slowed in the short- to medium-term, while if there is a policy commitment to increase their production as much as possible, that such success may only materialize in the longer term with serious policy, and only with a commitment of resources. This difficulty in fact is illustrated by the very rise in production of a range of crops such as wheat, rice, potato and onion as per official data for the current year—the increases have not been enough to neutralize the need for food imports that now stands at over 16% of the country's total import bill. Thus, there is a fundamental conundrum of demand rising higher than domestic supply can meet and without significant additional resource commitment is likely to ensure that for the foreseeable future at least, water resources and agricultural resources may not be mobilized at a rate that will displace or indeed significantly reduce the need for food imports.

During the pandemic, while the international price of wheat has risen by 51%, the domestic price of wheat has only risen by 32%, demonstrating the importance of wheat to the country's social stability and overall food intake. While these are important steps taken as part of the social safety net, nevertheless, the impact on the country's balance of payments is significant with the government having to absorb an additional $500 million in food import bills, taking the total import expenditure on wheat alone to $1 billion. As may be clear, this is a significant impact both on the country's food import bills as well as a major contribution to overall imports.

For the purposes of overall food inflation as experienced by consumers, it is important to note, of course, that wheat is not the whole story. While important for overall human welfare, because other food crops have a more limited impact on the country's water resources, they will remain outside the purview of this focus on Pakistan's political economy of water. Despite this overall exclusion, it is important to note that while lentils remain a staple part of overall diets, because they are for the most part imported, they have an impact on the country's overall food import bill while having a marginal impact on the country's water resources. One of the suggestions this present intervention makes is that agricultural policy must address the factors that impede the greater indigenization of lentil production in the country (Ullah et al., 2020).

Aside from the prices of food stocks such as wheat, the global price of palm oils too can have significant impacts on household food budgets given that cooking oils are an essential ingredient and are, for the most part, imported. This means that given the reliance on imported food items used in local diets, the country can rethink its current allocation of water to irrigated agriculture particularly in the crop and commodity mix that is supported.

In particular, there are ongoing political controversies about both the wheat and sugar trades that have resulted in official inquiry commissions issuing reports implicating the entire agricultural value chain from procurement—resulting in hoarding for profit—through to processing and point of sale. The serious governance issues at play include price monitoring, lack of quality, standardization and weight compliance as well as significant issues of interprovincial coordination that potentially disadvantage farmers for a host of structural reasons such as lack of storage facilities to take advantage of ideal selling times and the operation of rural credit markets more generally (Ahmed, 2015).

While Pakistan's current annual exports range between $22–25 billion (Attarwala, 2021), clearly there is significant potential to achieve growth in agri-based exports by moving up the processing chain. One of the main challenges to increasing exports remains the limited inflows of Foreign Direct Investments (FDIs), particularly in sectors that could then either lead to the development of domestic markets or to the growth of exports. One reason that has been identified for Pakistan having been unable to benefit from either FDI inflows or the glut of global savings due to the ongoing pandemic is the relative underdevelopment of the legal system (Rehan & Usman, 2021). For a country with an estimated population of 220 million, that even domestically is a huge market, FDI flows of $2.3 billion in the past four years indicate that investors are staying away. Given the size of the domestic market and of the country's irrigated land area, investments in the entire value-chain of agricultural development and processing (both domestic as well as for export) should be high-priority areas for attracting investments. The bulk of discussions in this area remain focused on issues such as the lengthy period of time that litigation and dispute settlement take as reasons that deter commercial investors. But the flaws needing redressal in the legal system have been present from the very outset, and manifest in slow or non-existent law-making. These need to be fixed in ways that are focused on putting Pakistan's legal system on the right footing to meet the increasingly complex challenges of the twenty-first century.

2.2.2.4 Dairy Cattle and Water Impacts

Livestock has a whopping 60% share in agricultural production and contributes approximately 12% of Pakistan's GDP (Pakistan Economic Survey, 2020). The equity aspects as they pertain to water use in the domestic and commercial livestock sector, however, are understudied and raise significant challenges both to how water is currently managed as well as to any potential adaptation efforts for more equitable water distribution across size of farm holdings. While the total volume of water used for livestock rearing and maintenance likely remains low as a percentage of total water used in irrigated agriculture, nevertheless the important thing to note is that while just over half of all farmers use motorized pumps to access groundwater for their livestock, nearly 29% of small farmers rely on hand pumps to access water (Ashfaq et al., 2015). Significantly, the role of women in the livestock sector is recognized to be an important component of overall efforts for poverty reduction as their labor is a major contributor to family earnings (Hashmi et al., 2007). This means that there should be a significant push to expand the concept of rural poverty alleviation and its overlap with women's labor and the economics of water access more broadly. It is important to recognize that while access to adequate water supplies and sources is an important indicator of a farm's overall access to financial resources, small dairy farmers in Pakistan operate within an increasingly challenging environment in which 'development' is synonymous with the forces of commercialization and consolidation as evidenced through the network and operations of large milk procurement and marketing companies, which instead of alleviating rural poverty has had a negative impact on the potential survival of small farms (Sattar, 2021).

Importantly, with approximately 47% of Pakistan's landmass devoted to agriculture, its role in the provision of rural livelihoods, employing approximately 42% of the country's overall population, cannot be underestimated. Rising global and local temperatures, however, pose a significant threat to rural livelihoods in both agriculture as well as to the threatened pastoral way of life. In particular, approximately 700,000 people migrate internally annually from rural to urban areas as a result of deteriorating livelihood opportunities while an estimated 1.2 million people have migrated from the Indus delta putting increasing pressure for all resources on urban areas (Khan, 2020). When these significant challenges to rural livelihoods and overall national and food security are coupled with Pakistan's strategic pivot to geoeconomics, it becomes ever-more important that the country tackle growing heat stress as the very fundamentals of a stable climate are what broader geoeconomic and geostrategic ambitions rest on (Aluko et al., 2021).

It is imperative that Pakistan begin to engage with and build on the work of international working groups focused on building the knowledge base for digital climate services and their effective delivery to small and medium-sized farmers to ensure that the gains from improved knowledge reach them to raise yields as well as become better custodians of soil and water resources (Ferdinand et al. 2021a, b).

2.3 The Political Economy of Interprovincial Water-Sharing

A major source of discord about water is the transboundary water-sharing arrangement, especially as it continues to structure relations within the federation. For the purposes of this chapter, we will not touch upon the international transboundary water-sharing arrangements as they affect relations with neighboring countries (Kadurugamuwa, 2014) but will highlight the in-country disputes about water-sharing that affect the levels of overall agricultural as well as economic and social development. While the history of the contestation between Pakistan's federating units predates Partition in 1947, they nevertheless, despite the Interprovincial Water Accord in 1991 ('Accord'), continue to affect relations nearly 75 years on after Partition and 30 years after the Accord in familiar as well as new ways (DAWN, 2021c). While the controversies are ongoing, our focus here is on the fact that in making interprovincial water-sharing, even three decades after reaching an Accord to settle provincial water shares, there has been a deeply negative impact on the country's overall agricultural and economic development. To take one example, there is fundamental disagreement about the proper kinds of water storage infrastructure—essentially, the debate remains mired between proponents and opponents of large dams that may reduce downstream flows with some who advocate for increasing groundwater storage and a little talk about reducing usage and thereby 'adding' water through water savings, reuse and recycling. Experts have also made the case for conjunctive management of surface and groundwater in a way that could enhance food security as well as lead to more equitable and sustained economic development (van Steenbergen et al., 2015). While taken together it is extremely helpful to have a range of options open to policy-makers, the overall noise in the system prevents progress towards the most beneficial way forward and groundwater remains exceptionally poorly understood, akin to an invisible resource (Ebrahim, 2021).

A key issue causing mistrust in interprovincial water-sharing is that canal water shares are not managed in an integrated manner (relying on a combination of surface and groundwater supplies) such that they are not balanced or reallocated within different canal commands both between and within provinces. Early twenty-first century satellite-driven irrigation performance in the world's largest system: Pakistan's Indus Basin irrigated system (Peña-Arancibia & Ahmad, 2020).

The interprovincial politics of water-sharing raise significant political economy considerations (Mustafa et al., 2017). While these primarily raise controversies between the two major water-sharing provinces, upstream Punjab and downstream Sindh, water-sharing between other provinces also remains complicated (Cheema et al., 2007). For instance the greenbelt on Balochistan's eastern side—the country's largest province by land mass–continues to suffer, receiving less than its share of water from Sindh under the Inter-Provincial Water Accord signed in 1991 ("Water Accord") coupled with large landholders within the province who access more than their allocated shares thus also exacerbating drinking water availability in rural communities, where smaller landholders also depend on canal water supplies for their domestic requirements (Notezai, 2021). In the thirtieth year of its adoption, the politics of the Water Accord remain complex and contentious, without clarity on its operating rules or its actual allocations to the provinces (Anwar & Bhatti, 2018). For our present purposes within a political economy framework, this means that without water, small farmers will be unable to earn their livelihoods from farming and this unviability is giving rise to significant internal migration pressures (Barrech & Ainuddin, 2018). It is in this context that the Government of Pakistan's application to UNESCO to recognize the ancient *karez* irrigation system as having Outstanding Universal Value (UNESCO World Heritage Centre, 2016) becomes salient. As has been shown, *karez* are climate appropriate water sharing technologies that are embedded within strong social organizational structures such that they are much more equitable, sustainable, and climate appropriate compared to tubewells, especially in areas without adequate recharge where modern immersible pumps mine aquifers for profit (Mustafa, 2014).

The Geopolitics of Transnational Infrastructure Finance
China's massive infrastructure project, the Belt and Road Initiative ('BRI') aims to connect Asia, Africa and Europe by building on the historical legacy of the famed Silk Road (Chatzky & McBride, 2020). While it was launched in 2013 and will be built over decades, adding more countries and projects as opportunities become available, including a potential expansion into Afghanistan as it undergoes a significant process of political change (Jun & Daye, 2021), its flagship collaboration launched in 2015: the China-Pakistan Economic Corridor ("CPEC") (Sacks, 2021). The initial focus has been on large infrastructure development such as ports, roads, energy, and hydropower projects. These projects have been challenging to undertake and have been subject to significant delays (Hillman & Sacks, 2021). Some of these are more challenging in terms of their security implications, such as the loss of lives of staff and engineers working on a major hydropower project, Dasu in Khyber Pakhtunkhwa (KP) province (Syed & Khan, 2021). The construction of the Dasu hydropower project is a significant collaboration between Chinese firms and the Pakistani parastatal Water and Power Development Authority ("WAPDA") with significant initial funding from the World Bank (World Bank, 2021). The 4320 MW project will be undertaken in two phases, with the project adding half its total expected capacity at the completion of each phase (Haddad, 2019). While construction on the project's electro-mechanical works is slated in the first phase, the second phase will lead to the planned installation of a power station that will add the full projected generating capacity of the project (Kiani, 2017, 2019).

After the emphasis on large built infrastructure, the plans have also focused on attracting Chinese investment and significant experience in agro-processing to formalize Pakistan's agricultural commodity exports as well as develop local food and commodity processing chains. While these projects are still in the discussion and planning modes, the fact that they are envisaged and may eventually begin to materialize is nevertheless of concern to the present discussion.

2.3.1 Valuing Groundwater

As in the rest of the world, the challenge of managing groundwater in an integrated and sustainable way remains critical (Fienen & Arshad, 2016). Given Pakistan's significant reliance on groundwater for both domestic consumption, industrial supplies, and irrigation, placing a meaningful value on water—recognizing its social, environmental, physical, and economic importance— is going to be increasingly necessary. While Pakistan has a long history going back to the start of the Green Revolution of trying to address the integrated nature of withdrawing groundwater for irrigated agriculture and its attendant linkage with increased soil salinity and waterlogging (Mohammad, 1964; White House, 1964), it must develop new tools to address the changing nature of emergent challenges (Greene et al., 2016).

The late Professor John Briscoe called the management of salinity the single biggest long-term challenge to the health of the Indus Basin, a grave assessment indeed (Briscoe & Qamar, 2008). As British colonial irrigation engineers knew, canals would raise the salinity level of soils in areas of canal construction (Ali, 2014), and in the intervening century and a half, this has come to pass, particularly in areas in which groundwater has been further tapped to overcome shortages in surface water supplies.

Drinking Water Extraction and Sales

The political economy of the growing provision of drinking water by private water bottlers is another ongoing shift that must be probed for its long-term impacts, particularly for its broader impacts on public health as well as for affordability concerns. For instance, how is the growing push for understanding water and sanitation as a human right—which the United Nations recognized in 2010 (International Decade for Action 'Water for Life' 2005–2015. Focus Areas: The human right to water and sanitation, 2014)—impacted when those who can pay for better drinking water are able to access it while those who are unable to pay must endure the negative health impacts that accompany such lack of widespread public provision. An estimated 20% of the population has access to a safe drinking water source while the remaining 80% are forced to rely on unsafe water for their drinking water needs. Even more significantly, unsafe drinking water is responsible for causing 80% of disease as well as being responsible for 33% of deaths—a grave harm that falls on the most vulnerable: those who are young and malnourished to begin with (Daud et al., 2017). For all intents and purposes, the provision of safe drinking water must become an immediate priority given the harmful effects that flow from the lack of such provision. Conceptually even more importantly for our focus on the political economy of water, we must advocate for broadening the scope of water policy to address such ongoing harm, as not doing so and staying narrowly focused on increasing irrigation supplies as a matter of high policy means that identified harms continue to be perpetuated through such neglect and lack of policy focus. Importantly and relatedly, while it is clearly the case that bottled drinking water companies (large multinationals as well as national smaller regional firms) fulfil the clean drinking water needs of a greater share of the population than obtains clean drinking water from a public source, the discourse about the proper role and environmental impacts of such firms remains limited. In particular, provincial governments do not have the requisite mechanisms in place. Water and agriculture are provincial subjects as per Pakistan's federal constitutional structure and are also impacted by the passage of the 18th Amendment in 2010 (Pasha, 2011). However, significant challenges to actual devolution to the provincial governments remain even after the long passage of time, given the lack of fiscal transfers to provinces and the perpetuation and continued existence of parallel structures at the federal level in overlapping domains (Research, 2020).

Water Quality and Pollution

The treatment and disposal of waste and effluents, which are currently disposed of through either surface waterways or allowed to seep into the ground untreated, does not exist at anywhere nearing sufficient scale in either the larger metropolitan or the mid-tier and smaller cities (Alam et al., 2021). Another interconnected problem is the lack of information about industrial impacts on water quality and the lack of treatment thereof. Heat, for instance, has significant effects on water quality and the behavior of the contaminants it contains (Handbook of Industrial Water Treatment SUEZ, 2007).

As water becomes more scarce and polluted globally, countries and cities around the world are racing to capture, purify, and reuse water with the aid of both the development of old-school municipal infrastructure but also through cutting edge sensors that monitor the changing composition of discharges through the course of the day. If Pakistan is to truly gain a proper valuation of its stressed water resources, this is the direction it will have to move in. Given the overall economy's reliance on the private and the general desire to boost its role in the country's national development objectives, incentives should be put in place to help attract, develop locally and deploy such innovation and technology through the water-valuation chain. Countries such as Brazil and Singapore are at the forefront of such efforts and there is much that needs to be done to reach out to them for the acquisition of such with the attendant adaptation to Pakistan's local conditions (Freedman et al., 2015).

Climate Change and the Challenges to Pakistan's Water Supplies

According to the fifth report of the Intergovernmental Panel on Climate Change ("IPCC"), ongoing warming will have a significant impact on managing water in South Asia for the region's vast population. This will require all kinds of adequate adaptive improvements to better manage watersheds as well as improve the legal, regulatory and governance frameworks to better manage available and dwindling water resources (CKDN & ODI, 2014). These recommendations about the relative underdevelopment of the legal system as a reason for Pakistan's relative inability to attract FDI as well as the need to harness the legal system to tackle the threats from global climate change must be put together and recognized as a call to action.

It will be no mean task to pivot an economy facing such dire threats from climate change, especially when at present approximately 95% of freshwater goes to low-value irrigated agriculture that continues to produce close to 20% of the country's GDP such that approximately 65% of the population relies on an agricultural income. At the same time as the nearly 150-year old colonial-era Canal and Drainage Act 1873 ('CDA') regressively governs surface waters (by *warabandi* or fixed time allocations of water that have very little to do with actual crop water requirements and that privilege larger landowners who have land closer to the heads of canals), groundwater remains unregulated. This is a significant regulatory gap especially as, since the advent of the Green Revolution in the 1960s, groundwater use represents approximately a third of irrigation water in addition to being a significant source of drinking water as well as meeting the needs of industry. Given these multiple uses, groundwater quality, especially for drinking water purposes, remains dangerously unregulated—a significant gap. Recent studies have found that approximately 60 million people may be exposed to arsenic poisoning through their underground drinking water supplies and 70 million have drinking water contaminated by bacteria. Further, environmental and ecosystem concerns remain entirely unregulated as does the issue of the loss of coastal areas due to significantly reduced freshwater flows to the Arabian Sea Delta and the rising threats from saltwater ingress into low lying lands and to coastal lands from sea level rise. The country faces significant institutional and regulatory gaps in both surface and groundwater quantity as well as quality and the overall management of its water resources. On the critical link between water quality and public health, the World Bank estimates that the Pakistani economy loses US$4.9 billion a year because of productivity losses and treatment costs from water-borne diseases. In addition, there are significant challenges from childhood malnutrition and stunting and women's malnutrition and anemia, such that, as the chapter will explore, the political economy of water and the laws and institutions that govern it need to pivot from a heavily supply-side focus on infrastructure towards a more holistic understanding of water as a key input in both economic as well as the health and nutritional and food security of citizens. This means that developing water policy should no longer be the narrow preserve of a few select professions such as civil and irrigation engineers but should move to consult and tap the legal, economic and social sciences more broadly as well as actual users and those who rely on getting water policy right. Policies, laws and institutions will need to be redesigned; for instance, the long-delayed National Water Policy, finally approved in 2018, while a step forward, remains sadly inadequate and has to date not been followed up with actionable plans to build on its goals. Pakistan is getting close to the time when it needs to fundamentally reformulate its reliance on the waters of the Indus—before time runs out and deeply unsettling changes are forced upon it.

Meanwhile, despite experts' attempts to highlight the true economic and ecological costs of large planned and under construction dams in Pakistan such as the Diamer-Bhasha Dam in Gilgit-Baltistan, the country's policy commitment to build them continues (Abbas & Hussain, 2021). One of the significant areas of concern is that a true and more accurate accounting of such commitments must also be undertaken, in light of the submitted and revised NDCs to COP26. Pakistan's reliance on building 10 large dams in 10 years is likely holding it back from significant investments at larger scales of more sustainable and affordable renewable energy investments—especially so as its regional neighbors India and China have committed to installing large-scale solar capacity. Doubling down on a commitment to the construction of large infrastructure perhaps, somewhat ironically, has a back-to-the-future feel, harking back to a nineteenth-century belief in large command-and-control water diversion infrastructure similar to what British colonial rulers laid down in united Punjab (Ali, 2014). The idea is not that large or small dams do not need to be built where they are appropriate, but that projects must be designed from the start for multiple purposes in addition to the provision of irrigation water and hydropower, such as habitat protection and broader environmental considerations.

Monsoon variability in the Indo-Gangetic plains has had significant impacts on socio-political developments throughout South Asian history (Kathayat et al., 2017). By no means should planners underestimate the impacts fast-moving climate changes such as rising temperatures and their effects on river discharges and rainfall patterns. While our abilities to manage and adapt to variability and changing conditions are no doubt more than those of the Indus Valley Civilization, nevertheless, so too is the challenge from our greater reliance and social dependence of vastly larger population systems on the environment.

If an encompassing lesson were needed in the interrelated impacts of climate change, we need look no further than the year 2022. A hotter spring brought with it a punishing heatwave contributing to faster and earlier glacial melt which transitioned into a summer of devastating river floods and significant rainfall events (Andreoni, 2022) with the country overall receiving three times the national average of the past thirty years; Balochistan received five times its normal amount; and flat southern Sindh province received nearly six times the average (OCHA, 2022). Beyond the immediate devastation, with water inundating vast tracts of farmland and destroying standing rice and cotton crops, upcoming winter wheat planting is threatened, imperiling already tenuous food security for the most marginalized as well as potentially contributing to biting food inflation (Goldbaum & Ur-Rehman, 2022). The U.N. Secretary General Antonio Guterres, on a visit to the country to survey the damage with Pakistani authorities, spoke about what he saw: "I have never seen climate carnage on the scale of the floods here in Pakistan" (António Guterres [@antonioguterres] 2022). He went on to say, "As our planet continues to warm, all countries will increasingly suffer losses and damage from climate beyond their capacity to adapt. This is a global crisis. It demands a global response." This is undoubtedly true and even within Pakistan, it is a crisis of poverty, inequality, and inequity, with the poor and already climatically vulnerable—living in floodplains and earning their incomes from agriculture, forestry, animal husbandry, and fishing—who are directly in the line of devastation. (Atlantic Council, 2022) Both globally as well as nationally, surely, climate justice is the need of the hour (Sathar, 2022).

The monsoon and floods are undoubtedly colossal, with the lives, livelihoods, houses, and livestock of the already poor and the most marginalized impacted the most (Atlantic Council, 2022). Yet it is unclear whether, beyond the immediate humanitarian aid, any fundamental commitments to both changing the long-term trajectory of global emissions from historically high emitters—(if this is even possible) and strengthening the immediate mechanism for loss and damage financing, as needed as they are, may be forthcoming. While much-needed progress has been made on the initial $100 billion a year pledge by developed to developing countries, a significant gap remains (OECD, 2020), with each passing year opening up a further gap between needs and financing available for those who need it the most. This means that for the most part, when a calamity like this strikes, as unjust as it is, a country like Pakistan has to tackle the attendant financing and reconstruction challenges—including the building of new resilient infrastructure to protect against future harms—from its own resources. (DAWN Editorial, 2022; DAWN Report 2022) Surely, the world can do better to meet this collective action challenge.

2.4 A New-ish Consideration: The Overlapping of Water, Energy, and Climate Policy

The costs of deferring actions to reduce emissions until mid-century are being assessed as rising by 150%, as compared to timely action sooner (Lemoine & Traeger, 2016). Importantly, while the growing recognition of climate tipping points is advancing with ever greater sophistication, the methods to quantify the cumulative effects of getting water policy wrong, akin to the climate's "tipping points", remain underdeveloped.

For the bulk of Pakistan's history of water management, environmental considerations have not featured explicitly in matters of policy A major component of Pakistan's NDC's is focused on 10 large dams to be constructed in 10 years—an ambitious target—but also one with significant ecosystem impacts including resettlement issues, which the government assures (at recent international forums such as COP26) have been accounted for and will be taken care of during the implementation stages (White, 2021).

Given that at the G20 meeting in Rome in 2021 before COP26, richer countries were unable to make progress on their previously agreed goals (in 2015) to make available $100 billion a year in climate financing to developing countries, it remains a significant challenge for countries like Pakistan to attract the necessary funding for its climate goals.

Given that, as Pakistan's lifeline, the Indus River receives approximately 65% of its flows from snow and glacial melt and its two tributaries, the Jhelum and Chenab rivers, rely on glacial melt for 50% of their flows, a warming global climate that reduces Asia's water towers will have dramatic effects on future water flows into the country. Thus, the government's strategy of building large reservoirs to tackle this anticipated reduction in flows and the strength of public finances in combination with multilateral development financing to actually deliver on the planned construction of 10 dams in 10 years is being doubted by experts (Husain, 2021). As has been highlighted, cost overruns from delayed projects are par for the course from projects financed under the Government of Pakistan's Public Sector Development Program ("PDSP"), thus raising the need to finance projects through other means such as private markets—for instance, by offering green bonds as WAPDA undertook in 2021 (Bondevalue, 2021; Hasnain, 2021b). Going forward, Pakistan's continued reliance on international capital markets may be more challenging due to a host of interlocking reasons. For example, rising interest rates around the world and the regional geo-strategic situation in neighboring Afghanistan have converged in WAPDA's decision to defer issuing its second green Eurobond for financing under-construction dams to between 2022–23, depending on international borrowing rates and overall conditions (Hasnain, 2021a).

As researchers have warned for years, the water used for power production is a huge challenge to energy and water security that will only get worse over time and will face a critical limit by 2040 (Aarhus University, 2014; Lewis, 2014). Importantly, if current withdrawal and demand trends continue, by 2030 there will be a 40% gap between available water and water needed for electricity production As Pakistan races to provide electricity to a greater percentage of its population amidst the rising energy demands of more affluent countries, it must think about the sheer scale of the water used to cool power plants, with coal and nuclear being particularly water intensive sources of energy. Given this, Pakistan must begin to explicitly take account of the impact of its energy production strategy and overall energy mix on stressed and dwindling water resources. This means that the political economy of water is inextricably linked with the political economy of energy production. This would be a critical shift in policy developing paradigms given that the bulk of the current conversation is centered on developing more water resources, mainly through the production of large storage dams. But the other side of the equation—about actual water use and what its purposes are and should be—also needs to become an explicit part of the development conversation. The energy pathways of countries will need to adapt to the fact that after 2040, business as usual will cease to be possible as there will be an explicit tension between other uses of water (such as for food production and urban uses) and the water needed in high-carbon energy production processes (Lewis, 2014). Importantly, since this kind of explicit accounting of water used in energy production is missing from current frameworks, Pakistan will have to inculcate such practices within dominant sectors, and bringing such a water focus within the energy sector will require a significant shift in awareness. In addition to a shift in government-sector policy circles, a shift will also—it is hoped—be made within the country's private sector firms as there is a growing global demand for enhanced Environmental, Social, and Governance ("ESG") compliance accompanied by legal and regulatory disclosure requirements especially in the oil and gas and electricity sectors (Sewell et al., 2021; Zigelman et al., 2021). Given the global nature of trade, such a shift may affect domestic firms trading internationally as well as help firms target domestic markets. Given that there is also a parallel growth to quantify and sustainably use water in industrial production, moving in this direction of explicitly accounting for water use through a broad range of industries and processes would seem to be both a prudent and virtuous path forward (Aquatech, 2019). In Pakistan, these issues are particularly salient for its cotton and textile economy, a major crop producing and processing sector that makes up nearly half of its manufacturing base as well as accounts for nearly 60% of export receipts (Cororaton & Orden, 2008).

Pakistan's water policy is at a crossroads. Specifically, in the context of climate change, it submitted a revised Nationally Determined Contribution ("NDC") plan for its COP26 pledge with a commitment to deliver a detailed plan for COP27 in Egypt. While a push to renewable energy is in the offing, large hydropower development and the construction of attendant infrastructure is a key component of the ambitious commitments that aim for reductions in greenhouse gas ("GHG") emissions defined previously for Paris 2016. That is one consideration. For the purposes of financing its planned development pathway, this means that the country must both commit its own financial resources and also attract significant international finance for the construction of large hydropower that will need to be developed to achieve its planned reductions (Sheikh, 2021a, b).

There is a growing recognition that the energy needs of developing countries are set to rise for years to come, which will require significant funding and technology transfer and development (Bordoff, 2021a, b). Considering Pakistan's defined policy pathway, the political economy of the development of water infrastructure as it overlaps with climate adaptation becomes clear. As has been pointed out, while the government is planning on the development of large hydropower for its energy transition, the country's Alternative Renewable Energy Policy of 2019 does not contain hydropower in its definition of renewable energy—clearly, if the government wants to count hydropower as renewable energy, more needs to be done to align its incentivizing policy frameworks. Further, on the push to develop and count hydropower as renewable energy, there is significant internal stakeholder pushback with both a civil-society policy coalition, the Rural Development Policy Institute ("RDPI") and a coalition of lawyers, academics, and representatives of lower riparian groups, the Alternative Law Collective ("ALC"), who have submitted detailed comments raising questions and objections to the government's stated plans for the development of large hydropower (Jamal, 2021). The groups' analyses point out that the plans for hydropower development fail to take account of the implications of probable cost overruns, particularly changing climatic conditions as they will reduce glacial melt into built reservoirs as well as fail to take account of negative impacts on downstream and delta communities, fisheries, and ecosystems more broadly. Further, experts continue to warn that categorizing hydropower as clean energy just because it does not release carbon emissions is increasingly problematic. This is because large reservoirs may still contribute to emissions in the form of methane instead of carbon. Methane is a potent greenhouse gas ("GHG") that may offer more a greater opportunity to limit climate change in a shorter time span. The Global Methane Pledge was signed by more than 100 countries in the leadup to COP26 who agreed to limit methane releases by 2030 (McGrath, 2021). Given that context, large reservoirs that are significant emitters of the potent gas (St. Louis et al., 2000), and up to 25%more than previously estimated when calculated with newer methodologies (Cornwall, 2016) may become harder to justify as a source of green energy (Deemer et al., 2016).

The 2020 Human Development Report has called for humanity to acknowledge that existing pathways to economic growth adopted by the world's largest economies have failed to take account of their impacts on natural resources and that we must explicitly turn away from continuing to exert destructive influence on the very ecosystems that support life on the planet (Baumann, 2021).

Floods

Pakistan's water economy is built on perhaps a Faustian bargain such that not only is it prone to significant forces of underdevelopment, it is also periodically adversely affected by significant flood events that may themselves be caused or at a minimum exacerbated by the very same canal irrigation network that is itself a backbone of the economy (Mustafa & Wrathall, 2010). The periodic flood-related destruction that rural populations in particular have to endure should be a much bigger wake-up call for the conscience of the nation than it is at the moment (Bashir, 2020). The negative effects from losing lives and livelihoods, already meagre possessions swept away and the significant push of forces that are created to unleash rural to urban migration mean that the lingering effects of floods that come and recede remain etched in society for long after the waters have receded. When people have to share drinking water with their farm animals and cattle, a reckoning may be imminent.

It is important to understand that the kinds of shifts that need to be made in the structure of the rural economy are not just important for humanitarian reasons, which are often strong motivators for action. There are other significant reasons why Pakistan needs to shift away from this structure: the pattern of flooding and its link to the kind of irrigated economy that has been built needs to be understood clearly for any move towards charting another kind of course for the economy as a whole.

2.4.1 Water Policy: Legal and Regulatory Considerations

Pakistan has an overarching governance structure for water management that it inherited from British colonial rule of the Indian subcontinent. In the seven intervening decades since Independence in 1947, the country has undertaken no significant reform of its nineteenth century structure of water governance, leaving it with an existential challenge as it approaches the twenty-first century. In short, Pakistan's political economy of water governance is fundamentally unfit for purpose as it faces two classic political economy forces of demand and supply that are in direct tension and will, without significant retooling of the economy, be potentially disastrous for the country. The first is rising demand from a dramatically growing population expected to be around 350 million by the mid-century mark and increase to 400 million by 2100. From its current estimated population of 220 million, this is a very steeply rising trajectory. Given that the population is also expected to be urbanizing and consequently will demand a higher quality of life, the country faces both an increase in demand from the absolute number of people as well as from the higher quality diets as well as the consumption of a greater number of consumer goods that will accompany the rise of a more affluent population. The opposite countervailing pressure that the country will face at the same time is the decreasing supply from melting glaciers and reducing snowpack (which in the shorter term will lead to destructive flooding) that under low-, medium-, and high-climate change scenarios are expected to decrease by between one-third, one-half, or two-thirds. Thus, the country is incredibly vulnerable to global climate change and will have to learn to adapt to a much less forgiving overall water budget than it has historically relied on to build its economy. What this means is that essentially under even the most optimistic and now increasingly unlikely to be achieved voluntary contributions to reducing reliance on carbon releasing fossil fuels under the Paris Agreement, a third of the glaciers and annual snowpack the country relies on is expected to disappear by the turn of the century, now only 80 years away. Given that approximately 60% of the country's annual water supply is dependent on this flow of the combined

Indus rivers, policy-makers need to take these scenarios incredibly seriously and adapt water-use policy accordingly to build a different kind of economic model. Pakistan is even more vulnerable than most because approximately 40% of the watershed of the Indus rivers is outside its territorial control thus, without significant regional transboundary coalition-building, it will be unable to build a water-secure base for its economic well-being.

Incentivizing the Private Sector and Protecting Public Health

Given the complex interplay of forces that will require balancing between regions and sectors as well as significant efforts to rationalize demand and supply dynamics, one of the approaches that the government should also explore is working to incentivize a role for the private sector in helping address some of the significant problems. These can include the deployment of technology throughout the water value chain and can include but not be limited to water recycling and reuse, connecting universities and the private sector to develop local context specific technologies appropriate to the smaller scale of Pakistan's irrigated economy, and helping build up rural livelihoods in non-irrigated areas through improved forest management and tourism-based livelihood development (Alam, 2018).

One other relevant and growing area is that of incentivizing farming practices that also help sequester carbon such that they are a part of the country's overall carbon capture and storage framework. There are at least two aspects of this work to be considered: one is the beneficial and sustainable traditional farming practices that contribute to an overall improved global climate change scenario while helping the country meet its climate commitments. The further step is to unlock lending and finance to farmers who manage their farms through the adoption of such sustainable practices or those who have always done so and can now tap a new revenue stream. This is the direction that other countries such as Australia are moving in, where carbon farming is allowing pastoralists as well as farmers to access a secondary income stream as a result of their sustainable practices (Tracey, 2021). Pakistan has much to learn from places with developing and advanced frameworks and given the lack of formal credit access in the overall rural economy, the ability to develop another beneficial route of sustainable finance access is to be welcomed. This will be an added impetus to develop a legal and regulatory framework that enables formal lenders to move into green finance while also expanding the reach of formal credit markets into the rural economy. The fact that at the same time it could also prove beneficial to the advancement of sustainable carbon farming practices is a bonus. Given the duration of contracts that banks and other lenders operating in the carbon farming markets (especially as they attract foreign investors) require, farmers need to know that for them to be able to obtain the requisite certifications they must demonstrate a longer-term shift and commitment to sustainable practices that outside investors can trust are worthy of their buy-in.

In many ways, given the focus on absolute water quantities, the focus on the quality of available water in the overall policy discourse is sidelined in Pakistan. This has a negative impact on important sectors such as the quality of irrigation water, given the widespread use of untreated water used in manufacturing for growing vegetables, for instance, on the outskirts of cities. Another area affected is drinking water availability, which has a significant detrimental impact on overall quality of health given the prevalence of common ailments such as diarrhea and Hepatitis A. The fact that there is also a near-total lack of focus on the fact that new high-tech manufacturing sectors that the country may want to incentivize for growth—given the lack of export diversity and the grave need to move up the manufacturing and processing value chain—require high quality clean water for their processes. While a focus on the requisite quality of water required for different manufacturing processes is important, so too is an understanding of the impacts of water currently used by industry across a diverse range of manufacturing areas, such as in textile production and apparel manufacturing which account for approximately 60% of the country's exports and employ 40% of the labor force (Cororaton & Orden, 2008)). Cement manufacturing also has significant negative impacts on the quality of water that is discharged and may seep untreated into waterways and underground aquifers (Aquatech, 2019). The long-term health impacts of these industrial impacts on water resources must be studied and addressed so as to ensure health and wellbeing.

Recycling and Reuse

One aspect that has increased in importance over the years in countries around the world is the recognition that available water must be captured after use, recycled, and reused in sectors across the economy. While the level of purification that captured water undergoes will depend on the uses to which it needs to be applied in any particular context, significantly, this has become a way to address growing water scarcity around the world. Despite a growing climate of water stress in Pakistan's policy discourse, direct use of treated municipal wastewater as well as direct use of agricultural drainage water is yet to be tapped as a source of additional water supplies (FAO, 2011). While this does not mean that there is not significant and reported use of water through potentially unsafe practices such as the application of water used in industry to grow vegetables (Natasha et al., 2020), nevertheless, the prevailing discourse remains centered on building dams to capture "new" water instead of on creating more water through capture, recycling and reuse. This lack of focus on recycling and reuse is unfortunate, especially as it is an important way to tap into the innovative capacities of the private sector and companies who are keen to deploy the latest technology to the problems of water scarcity, particularly as it plays out in large urban centers (Freedman et al., 2015).

2.5 The Political Economy of Urban Water Supply and Land Settlement

According to reliable estimates, in just the city of Karachi alone, residents spend an estimated $350 million every year to acquire water through informal water suppliers or through the "water tanker mafia," as the trade is locally known (Rahman, 2008).

The detailed locality-based surveys undertaken by dedicated teams under the leadership of the indefatigable Parveen Rehman (Sarwar, 2013) at the Orangi Pilot Project ("OPP") have created a wealth of information for an improved policy response. However, despite her tragic and yet unsolved murder having come as a wakeup call to the city's conscience, better policy and actionable results that eliminate the network of illegal hydrants has been slow to emerge. While it is clear that supplying water to areas without connections to formal water systems is one aspect of the problem, networked areas too remain without actual water supplies. And the policy reforms that have emerged have in some ways led to a form of co-option by the informal of the formal, such that the city's water suppliers have partnered with the very same networks of official government sanctioned tankers (Ebrahim, 2019) and water suppliers to supply a portion (up to half of the city's demand) of water at official government rates leaving them free to sell the remainder to those who can afford to purchase better quality water at higher commercial rates (Hadid & Sattar, 2018). Given these arrangements also proliferate in other large cities of developing countries (Sethi, 2015) and are less than ideal, a key concern of policy makers should be on the inability of the formal sector to tap the significant financial resources that are sucked up by the informal sector, rather than being potentially tapped for the provision of improved formal services. The key question remains of financing—if the informal sector can generate lucrative returns on meeting water demand across the urban scale from informal settlements to large bungalows with swimming pools, how can the formal sector begin to tap the revenue that the sector is already generating? The Global Water Practice of the World Bank Group has evolved tools and learnings based on case studies of utilities from around the world that have undertaken significant reform efforts as captured in the Water Utility Turnaround Framework that could be an important starting point for Pakistan's urban utilities as they work to turn around the existing unvirtuous financing and operations cycles of the country's urban water supply (Goksu et al., 2019). Importantly, the Bank notes that while there is no recipe for turnaround, nevertheless, utilities that have undertaken a significant reform effort have done so in identifiably similar ways.

2.5.1 The Emerging Politics of Land Acquisition

The politics of land acquisition that affect water availability are longstanding, trenchant and ongoing. A particular example of a contestation (parts of it now paused through a legal order) is over the announced plans for the Ravi Riverfront Urban Development Project that pits large scale landscape transformation by re-imagining revising the Ravi River as a freshwater source (the Ravi is one of the three eastern rivers diverted to India under the Indus Waters Treaty 1960) for residential, commercial, industrial and recreational use against approximately 80,000 farmers who own fertile farmland around the outskirts of Lahore. While there is an old standing goal to remake the Ravi river into the image of global development (Malik, 2014), there is an upsurge of energy and commitment to the same under the country's present government. The announced approach of acquiring close to 100,000 acres on the outskirts of Lahore for the project, meant to cater to an additional 10 to 12.5 million people, will double Lahore's (Pakistan's second largest city) current population by 2030. The impacts of changing land use as well as the conversion of currently used agricultural land on water resources, overall food security, the channelizing of the river, as well as the shifts to farmer livelihoods, are expected to be significant. For our present purposes, focusing on the political economy of water, we must highlight that the project aims to revive the Ravi River as a freshwater source by making barrages and lakes upstream of Lahore to revitalize the waterbody. The attendant revived waterbody will be the focal point of significant urban, residential, industrial and recreation zones. While focusing on the current and planned political economy, it is important to note that the original reason the Ravi riverbed is locally referred to as old or black Ravi (referring to its degraded state), is an outcome of the diversion of the three eastern rivers to India under the terms of the IWT1960.

2.5.2 An Emergent Positive Development—A Land Registry

The overall political economy of land allocation in Pakistan, whether for agricultural production or for residential construction, is one that is mired in historical patterns with antecedents in the British colonial era and that continue to generate current controversies as well as significant economically and politically regressive outcomes (Mehmood, 2021). Pakistan's meaningful new push to formalize and digitize land titles in the country is a step in the right direction that must be pursued for the sake of greater transparency as well as to facilitate both the financing of agricultural livelihoods and to enable the ease of agriculture-related transactions. As a next step from the formalization of land titles in cities (in the first phase of the project, the land titles in the country's three major cities, Karachi, Lahore, and Islamabad are aimed for digitization) (DAWN, 2021d), the country must move to formalize land titles for agricultural lands. The greater resulting transparency is also likely to ease the enablement of formal financing to flow into the agricultural value chain—a goal that policy must aim for (DAWN, 2021b). While not an explicit focus here, we must reiterate that given the role that livestock plays as a share of rural livelihoods (between 20–25%), as well as a percentage of agricultural value addition (approximately 56%) (Ashfaq et al., 2015), the overall formalization of land titles may also help drive investment to improve dairy practices such as in animal care and reduce disease burden in the overall dairy value chain.

2.6 Tentative Concluding Thoughts

Pakistan's fundamental challenges of water governance arise from a complex interplay of historically contingent factors. While these were adequate to meet the needs of the moment, they have also raised significant challenges to sustainable development, particularly in the context of rising demands and climate change. For the country, laying the foundation for a robust and progressive political economy of water such that it meets the challenges identified here will make the fundamental difference between long-term societal and environmental well-being and a less integrated response that will fail the aspirations and potential of its people. Given the vast human reliance on the importance of getting water policy, incentives, and governance right, Pakistan must rise to the challenge and recognize that in doing so it will unleash a host of beneficial outcomes across sectors, ranging from irrigation and agricultural water use, drinking water supply, and incentivizing the private sector amongst others, all within the context of climate change. Importantly, through virtuous and experimental internal policy innovations, it will be able to share its knowledge and experience of fundamental political economy reforms with the world in a way that sets it apart as a leader in global water policy innovation. As the fertile rivers and plains of the ancient Indus Valley civilization gave birth to a sophisticated and regionally integrated and food secure urban culture, so too must modern-day Pakistan seek to tap into its vaunted history of water management and update it for the twenty-first century.

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Part II
Resource Stocktaking and Emphasis on Moving from Surface to Conjunctive Water Use

In 1977, Pakistan's history of water-centric policies started with a discussion on creating a water conservation and environmental protection strategy. Since then, while a series of policies and strategies have been rolled out, very few have been adopted by lawmakers. In 2018, the National Water Policy of Pakistan (NWPP) was the first water policy established by Pakistan, with the goal of recognizing the looming water shortage and creating an overarching policy structure and guidance for a robust action plan. Pakistan is governed by a federal structure, with provinces enjoying significant autonomy because of the 18th Amendment to the Constitution. As a result, this policy acts as a national framework for provinces to develop their own action plans for water resource development and management.

Most of the chapters on this theme take stock of water resource supply and demand over time. On the supply side, the Indus River and its tributaries contribute 175 BCM of water annually, including 165 BCM from three western rivers (Indus, Jehlum and Chenab) and 10 BCM from the eastern rivers (Ravi, Sutlej and Beas). The majority of the water (approximately 128 BCM) is used for agriculture; 35 BCM goes to the sea; and 12 BCM is wasted because of inefficiency. The Indus River flows have a high degree of variability, with minimum and maximum flows of 114.3 and 256.2 km^3, respectively, and an average flow of 182.3 km^3. Because of this variability in the Indus Basin Irrigation System (IBIS), storage is necessary for regulated flows. Further, it is now well known that Pakistan's per capita availability of water supply has already declined from 5000 m^3 in the year 1951 to just 1100 m^3 per capita in the year 2005, and is predicted to drop to 800 m^3 by 2025 in spite of the fact that overall, supply has actually increased after the completion of Indus Basin projects.

Annual variability is also observed in river flows downstream from the Kotri barrage, which is located on the Indus River between Jamshoro and Hyderabad and feeds the Fulleli, Pinyari, and Kalri Baghar canals. The probability of river flows downstream from the Kotri Barrage show that, in a normal year, the river flows were 33.2 km^3 for the 1975–2013 period. Annual downstream flows decreased after the Kotri Barrage was constructed because of enhanced canal diversions, and the

Mangla and Tarbela dams only exacerbated the shortfall in flows More canal diversions at the upstream commands has led to more zero flow days downstream of Kotri during the 1975–2013 period.

On the demand side, a whopping 96% of water is used on agriculture, with a lot of it wasted at the farm level. The agricultural sector accounts for 25% of GDP, 75% of total export earnings, and as a source of livelihood for two-thirds of the country's population. Pakistan's main agricultural exports consist of cotton, rice, and sugarcane, which are all water-intensive; sugarcane consumes 60% more water than rice, 170% more water than cotton, and almost 580% more water than wheat. Pakistan is the 10th largest producer of sugarcane, which accounts for 4.8% of the cropped area and 11% of the value-added from all crops. If water is priced at its opportunity cost, the cultivation of rice and sugarcane do not have a comparative advantage. It is also interesting to note that in the post-Tarbela period, the seasonal and annual flows show significant deviations from the average. In absolute terms, the deviations of flows during the *kharif* season range from 1.0–3.8 km^3, 1.2–11.6 km^3 during the *rabi* season, and 1.2–15.4 km^3 annually. Additionally, there has been an increase in the cultivated area along with the cropping intensity which has reduced the canal water availability per unit of irrigated land.

Pakistan's agriculture and economy at large relies heavily on its water infrastructure, but that infrastructure is now in decay because of neglect and lack of maintenance. The government allocates only 5–10% of the required amount for repair and maintenance, resulting in 30% lower delivery capacity of canals than designed. Therefore, immediate investment is required to restore the capacity of the water infrastructure and develop new storage to ensure future sustainability.

The Indus Basin Carries a groundwater aquifer that commands an area of 16.85 mha, of which 14 mha of the area is cultivable. Before the canal irrigation system was developed, the aquifer was in hydrological equilibrium, i.e., the inflow to the aquifer was balanced by the outflow and crop evapotranspiration. Groundwater governance in Pakistan is an emerging challenge which has largely been neglected in the past. Its recent surge in priority is due to its on-demand availability, adaptation options under climate change, reliability, and high productivity. Indeed, farmers with access to groundwater can cultivate 90% of their total land compared to 63% for farmers who only rely on canal water. Moreover, farmers with access to groundwater and canal water have five times more income than farmers who can only access canal water. Other water scarce countries show that sustainable ground water management is a prudent policy option to manage droughts.

Aquifer management is another effective way of balancing discharge and recharge, has been practiced in Germany, Switzerland, the USA, the Netherlands and Sweden, where interventions were used to artificially increase recharge to the aquifers. The proportion of artificial recharge to the total groundwater use ranges from 15–25% in these countries. Even India has taken steps to harvest rainwater to recharge its aquifers. Thus, the government needs to consider strategies related to rainwater harvesting to recharge depleted groundwater resources.

Those who advocate for increasing supply, given the limits on how much water can be conserved and how much more groundwater can be tapped, think the most only option is to construct more storage reservoirs. But the downstream impacts of storage, such as sea intrusion and other environmental, ecological and social impacts as a result of any reduction in surplus flows, need to be studied in detail. According to the Water Apportionment Accord further studies have to be undertaken to establish the minimal escape needs downstream Kotri. Both Sindh and Punjab have carried out these separate, studies reportedly with different results. So as there is still no consensus on this issue, the balance river supplies, which can be shared by the provinces as per provisions of the Accord, remain undefined.

Storage reservoirs would also have the significant additional benefits of providing hydropower and controlling floods. In recent years the development of large dams has been looked upon unfavorably because of the significant environmental, social, and cost implications. However, most of Pakistan's are within the Indus system and large storage is the only realistic option, given the size of the Indus.

It is an established fact that water quantity and quality are closely interlinked and reduction in water quantity has a direct bearing on overall water quality. Because of growing climate change, the increasing spatio-temporal variations in surface water supplies are putting more pressure on groundwater, with the risk that irrigated areas will become salinized. The disposal and use of untreated wastewater from municipal, industrial, and agricultural activities is one of the major sources of pollution for the entire ecosystem. This section of the book also describes the water quality situation—surface and groundwater, the implications of deteriorating quality on ecosystems, the underlying issues and suggests the way forward.

Groundwater contamination is worrisome. The Indus Plain, covering about 20 million hectares (Mha), possesses one of the largest volumes of groundwater in the world. Disposal of untreated industrial and domestic waste in open ponds and water bodies And indiscriminate use of heavy amounts of fertilizers and pesticides/herbicides are major sources of pollution. Solid municipal waste sites in all cities are a permanent source of organic and biological pollution. Liquid and solid domestic waste not only cause environmental hazards but also for all kinds of epidemics. Cleaning the Ravi has lately garnered interest, but land developers want to move quickly and have thus ignored the option of rehabilitating the river with relatively clean water.

Chapter 3
Water Resource Potential: Status and Overview

Mohsin Hafeez and Usman Khalid Awan

Abstract Water security imposes serious challenges for the social and economic development of Pakistan, which is the eight-most climate-vulnerable country in the world. This extreme climatic variability (drought/floods) has highlighted the need to manage Pakistan's water resources more sustainably. In 2018, the Government of Pakistan developed a National Water Policy (NWP) to provide an overall policy framework and guidelines for a comprehensive plan of action leading to the development of sustainable water management solutions. This chapter will briefly review past water policies and take stock of available water resources and their sectoral uses, water use options under climate change, and water governance. It will also include data on available water (surface and groundwater) and sectoral uses by basin. In addition, it will comprehensively review Pakistan's current water resources, the challenges faced by irrigated agriculture, and possible future strategies to overcome these problems and ensure the sustainability of irrigated agriculture in the Indus Basin. It will introduce topics that will be discussed in succeeding chapters in more detail.

Keywords Water security · Climatic variability · Water governance · Irrigated agriculture · Water policy in Pakistan · Indus River Basin · Water allocation

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3.1 The History of Water-Centric Policies and Strategies in Pakistan

As the water crisis worsens, the debate on policy over water resource development has become increasingly urgent. Pakistan's first water-centric policies were introduced in 1977, with a discussion focusing on formulating a strategy on water conservation and environmental protection. After that, in 1992, Pakistan's National Conservation Strategy (NCS) was established. The NCS covers a variety of environmental issues such as water and sanitation, soil, air, forestry, and climate change.

The Sanitation Policy of Pakistan was launched in 1993–1994. This was the result of several debates on shifting towards more participatory and localized approaches to water rights. This policy focused on providing water-related facilities since the water supply was lacking. Each of the provincial and regional governments developed a uniform policy under the Social Action Program, which called for the inclusion of consumer groups in the administration of rural water and sanitation facilities. Rural water supply and sanitation schemes were developed in collaboration with user groups, who were expected to take over the operation and maintenance (O&M) of the schemes after they were completed.

The National Environmental Policy (NEP) was launched in 2005. This policy aimed to provide a comprehensive framework to solve the environmental problems associated with freshwater and marine water contamination. The NEP focused on the country's climate through a cleaner energy program to enhance citizens' quality of life by resolving the environmental issues under changing climate. With recommendations for various sectors, the NEP established a legal and policy structure to enhance various water treatment facilities, provide clean drinking water, develop water quality monitoring and surveillance systems, and encourage water use metering to reduce indiscriminate water usage.

The National Drinking Water Policy was launched in 2009. The main objective of this policy was to eliminate gaps in access to clean drinking water and to reduce the number of people who died from waterborne diseases. It was authorized by the federal cabinet and created in collaboration with UNICEF by the Ministry of the Environment. It includes specific recommendations to increase access to safe drinking water, safeguarding and conserving surface and groundwater supplies, water treatment, community engagement, public awareness, capacity building, public-private partnerships, research and development, and emergency preparedness and response. The policy prioritizes the construction of new drinking water systems, the repair and upgrade of existing water supply systems, the long-term viability of water supply facilities, water storage, water quality enhancement, and water treatment. Finally, this policy also proposed water quality standards for drinking water.

The Pakistan National Wetlands Policy was launched in 2009. This policy ratified the Ramsar Convention in 1976, which emphasized the development of national wetlands policies as critical to achieving the Convention's "Wise Use" principle for wetlands. According to the Ramsar Convention on Wetlands, "Wise Use" of wetlands is the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the spirit of sustainable development. While this policy does make some progress on that front, it is ultimately insufficient. It addresses a number of issues, including the destruction and depletion of wetlands; the increased demand for water, soil, and natural resources; a lack of recognition, coordination, and power between institutions with wetland responsibilities; infrastructure; and a lack of policies, rules, and regulations. The policy tries to minimize harm to wetlands' ecological health while also preserving their usefulness. Thus, the policy focuses on enhancing wetland productivity for water supply and food processing, utilizing wetlands for water management, optimizing the different applications of man-made wetlands, utilizing wetlands as an educational resource, and utilizing wetlands for recreation and tourism.

The National Climate Change Policy (NCCP) was developed in 2013 and then revised in 2021. The NCCP aims to ensure that climate change is mainstreamed in the economy's economically and socially vulnerable sectors and steer Pakistan towards climate compatible development. The main objectives of the NCCP are:

- Sustained economic growth addressing climate change
- Integrating climate change policy with other inter-related national policies
- Focusing on pro-poor gender sensitive adaptation
- Climate-resilient infrastructure and agriculture
- Reducing the impact of climate change on water, food, and energy security
- Minimizing the risks arising from extreme weather events
- Cleaner, lower emissions and less carbon intensive development
- Achieving the United Nations' Sustainable Development Goals (SDGs) in the light of its Sustainable Development Report 2020
- Effective use of the opportunities—mainly financial, public, and private sector investment in adaptation and mitigation measures
- Enhancing the awareness and capacity of relevant stakeholders
- Promoting conservation of natural resources and nature-based solutions.

The policy measures of the NCCP suggest two principal strategies for developing climate resilience: mitigation, which concerns all policies and actions aimed at reducing the emissions of GHG such as CO2 or capturing them in forests, oceans, or underground reservoirs; and adaptation, which seeks adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects.

The National Forest Policy was launched in 2015. In accordance with national goals and international agreements, it calls for the extension, preservation, and sustainable use and conservation of national forests, watersheds, and natural ecosystems to reinstate ecological roles and improve livelihoods and human health. Its main priorities in terms of water conservation are wetlands, protected areas, and wildlife ecosystems to mitigate degradation and to promote the adoption of international treaties and agreements relating to forestry, wetlands, biodiversity, and climate change.

The National Water Policy of Pakistan was launched in 2018. Its goal is to recognize the looming water shortage and design a robust action plan. Pakistan is governed by a federal structure, with provinces enjoying significant autonomy due to the 18th Amendment to the constitution. As a result, this policy is a national framework for the provinces to develop their own action plans for water resource development and management. Provincial responsibilities include agriculture and irrigation, along with the environment, urban and rural water management, and other water-related subsectors.

3.2 The Stock of Available Water Resources and Their Sectoral Uses

3.2.1 Historical Trends in Withdrawals (Surface and Groundwater) in the Indus Basin

According to the FAO (2017), total water withdrawals (the sum of surface water withdrawal, which is extracted from rivers, lakes and reservoirs, and groundwater withdrawal, extracted from aquifers) from the Indus basin are around 200 billion cubic meters (BCM) (Fig. 3.1). It is predicted that by 2025, the Indus Basin's irrigation needs will be 250 BCM, with supply predicted to only be 185 BCM. If current storage capacities are further decreased because of siltation, this would result in a 32% deficit by 2025. If Pakistan proceeds with "business as usual" this will result in extreme food shortages in the years to come, wreaking havoc on the national economy and threatening the livelihoods of millions.

Pakistan's surface water—generated from glacier- and snowmelt, rainfall, and surface runoff—relies heavily on the Indus River and its tributaries, which include the eastern rivers of the Sutlej, Beas, and Ravi, and the western rivers Indus, Jhelum,

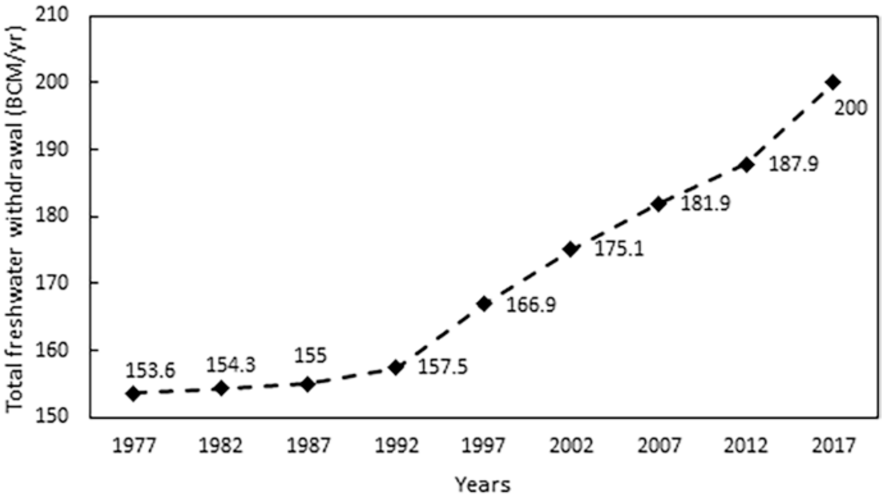

Fig. 3.1 Freshwater withdrawals from the Indus basin. FAO, 2017

Chenab, and Kabul (Nawaz et al., 2021). Annually, the Indus River and its tributaries contribute an average of 175 BCM of water, including 165 BCM from the three western rivers (Indus, Jhelum, and Chenab) and 10 BCM from the eastern rivers (Ravi, Sutlej and Beas). The majority of the water (approximately 128 BCM) is withdrawn for agricultural use; 35 BCM goes to the sea; and 12 BCM is lost due to system inefficiency (Zuberi, 1997; Ahmad, 2007; Briscoe et al., 2005; Ministry of Water and Power, 2002). The Indus River flows are quite variable, with minimum and maximum flows of 114.3 and 256.2 km^3, respectively, and an average flow of 182.3 km^3. Because of this variability, storage is necessary for regulated flows (Ahmad, 2016).

3.2.2 Historical Trends: Per Capita Water Availability

Pakistan's population is growing at a rate of 2.8% each year and is predicted to reach 250 million by 2025. During that time, the proportion of people living in cities will rise from 35% to 52%. Consequently, water demand for residential, commercial, and non-agricultural purposes is projected to rise 8% by 2025, accounting for 10% of total usable water supplies (Bhutta, 1999). Pakistan's water availability per capita has already declined from 5000 m^3 in 1951 to just 1100 m^3 in 2005, and is expected to drop to 800 m^3 by 2025—approximately the point at which there is not enough water to survive (Engelman & Leroy, 1993; FAO, 2017) (Fig. 3.2). The amount of agricultural land available to each person is also declining. Additionally, agricultural land has been damaged by salinity and waterlogging because of the

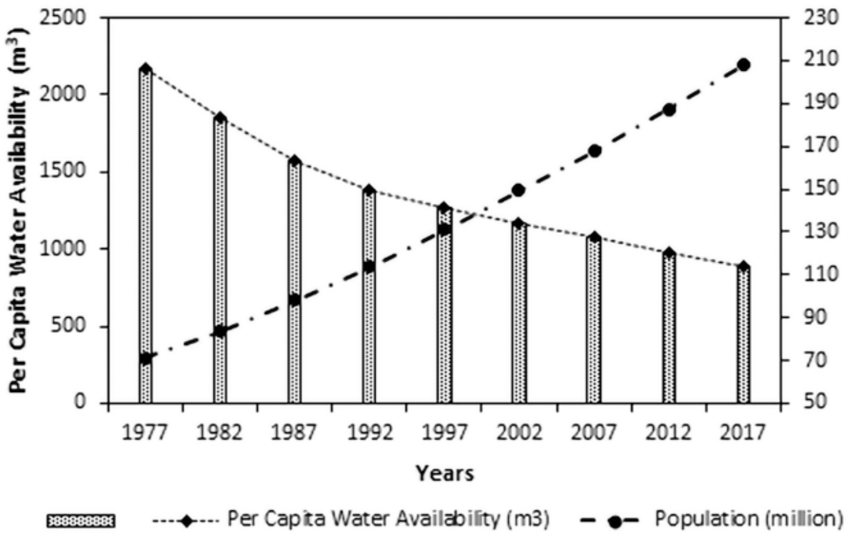

Fig. 3.2 Historical trends of per capita water availability in Pakistan. FAO, 2017

lack of high-quality irrigation water and drainage infrastructure. As a result, a multidimensional approach is necessary for the long-term development of land and water supplies.

3.2.3 Rainfall Stock in the Indus Basin

Pakistan's average annual precipitation varies from less than 100 mm in parts of Sindh and Balochistan to more than 1500 mm in the northern mountains. Pakistan's rainfall and precipitation show seasonal variation. Sixty percent of Pakistan's monsoon rains occur between July and September. During the *rabi* season (October to March), the average rainfall varies from less than 50 mm in some parts of Sindh to more than 500 mm in KPK. Meanwhile, the average rainfall in the *kharif* season (April to September) ranges from less than 50 mm in some areas of Balochistan to greater than 800 mm in northern Punjab and KPK (Ahmad, 2007). Surface runoff from rainfall contributes to river flows which vary seasonally.

The northern part of Pakistan contains a huge area (22,000 km^2) with permanent glaciers, with more than 100 of them longer than 10 km (Ahmad, 2007). The total ice reserves have been estimated to be around 2738 km^3, which is roughly 16 times the average levels of the annual river flows. The Shyok, Hunza, Shigar, Chitral, and Gilgit River basins are some of the major contributors to these immense ice reserves with respective contributions of 32, 30, 21, 9, and 3% (Campbell & Pradesh, 2005).

3.2.4 Water Allocation in Different Sectors of the Indus Basin

The agricultural, domestic, and industrial sectors are the major consumers of Pakistan's water. Since Pakistan's economy is heavily dependent on agriculture, it also uses the most water. However, domestic water usage is assigned a higher priority since Pakistan's Water Strategy of 2012 identifies drinking water as a basic right (Ahmad, 2016). From the total available freshwater resources, 94% is used for the agricultural sector, 5% for domestic use and 1%for industrial use (Fig. 3.3) (Blomquist & Ingram, 2003; Ahmad, 2011; FAO, 2019).

3.2.5 Water Allocation for the Agriculture Sector

As mentioned above, Pakistan is an agricultural economy. The agricultural sector accounts for 25% of the GDP and 75% of total export earnings, while two-thirds of the country's population lives in rural areas with agriculture as their main livelihood (Ahmad, 2011; Kamal, 2009; Briscoe et al., 2005). However, around 92% of the country's land is arid or semi-arid (Kamal, 2009). Therefore, agriculture in Pakistan must rely heavily on irrigation.

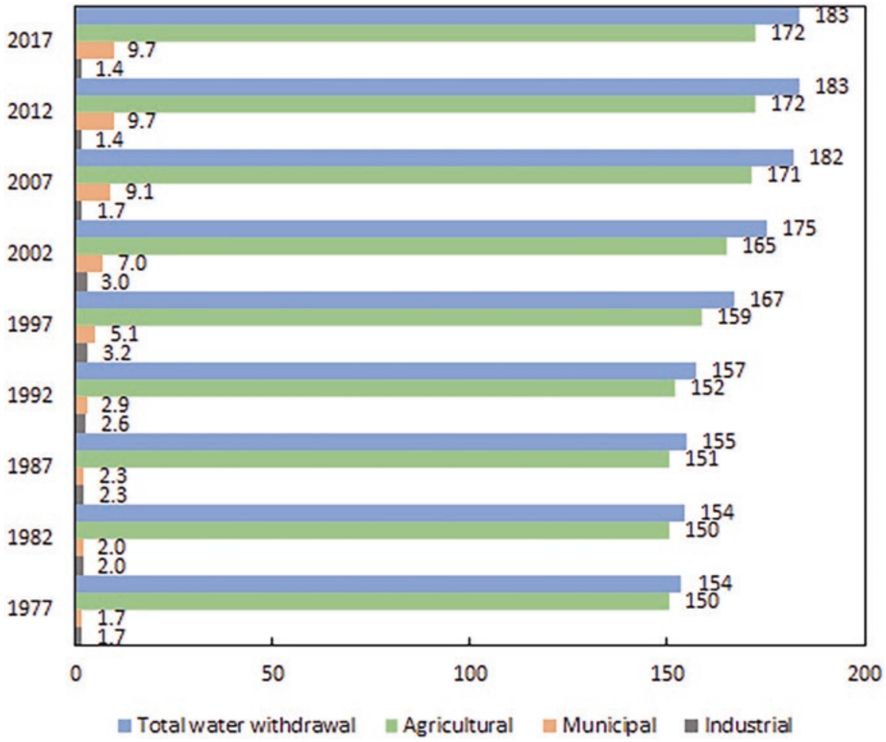

Fig. 3.3 Water use in different sectors of the Indus basin. (Data from Blomquist & Ingram, 2003; Ahmad, 2011; FAO, 2019)

The Indus Basin comprises around 25% of the total land area, which supports around 65% of the country's population. Most irrigated agriculture, which makes up around 80% of Pakistan's total cultivated area, is in the Indus Basin and satisfies 90% of its food and fiber requirements.

Cotton, rice, and sugarcane—Pakistan's main agricultural exports—are all water-intensive. Sugarcane consumes 60% more water than rice, 170% more water than cotton, and almost 580% more water than wheat (Tariq et al., 2020). Pakistan is the tenth largest producer of sugarcane, which accounts for 4.8% of the cropped area and 11% of the value added from all crops. Sugarcane produces around five million tons of sugar every year and contributes 3.6% to the GDP. However, the production of sugarcane and the extraction of sucrose is extremely inefficient. Pakistan's average sugarcane yield is 47.5 tons/ha, 24% lower than the world's average of 62.5 tons/ha (Tariq et al., 2020). Similarly Pakistan's sucrose recovery rate is 9% compared to 12–14% for other countries (Sharma, 2017).

The IBIS is designed as a supply-based irrigation system that cannot adequately address the change in the demand for water during the cropping season aside from the variability in the annual river flows resulting in extreme events of floods and droughts (Faruqui, 2004). Figure 3.4 illustrates the seasonal and annual canal

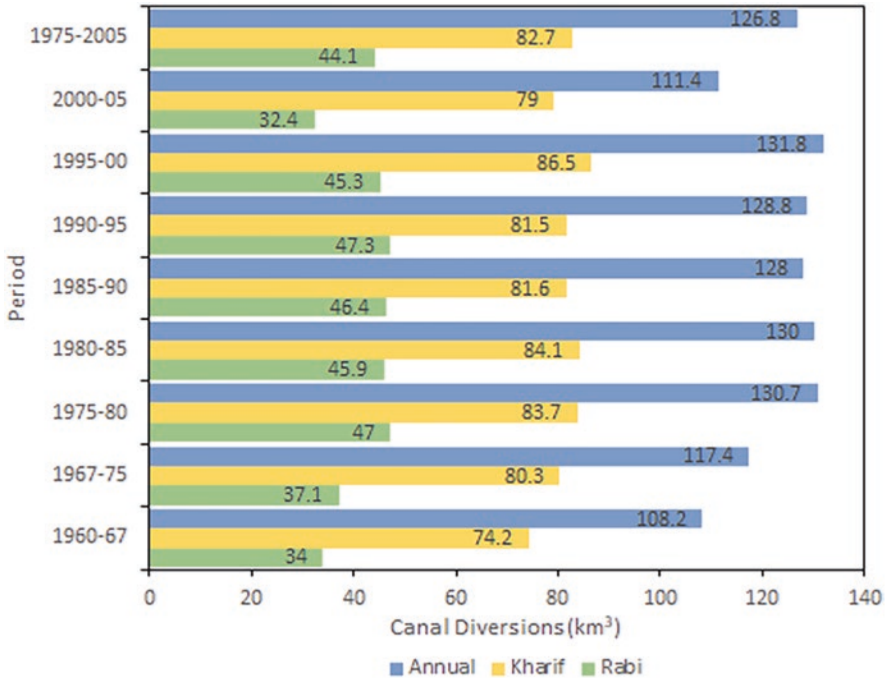

Fig. 3.4 Canal water supplies during different seasons in the Indus Basin. (Source: River flows. Water Resources Management Directorate, WAPDA, and IRSA)

diversions from 1960 to 2005, along with the averages of the post-Tarbela period (1975–2005). In the post-Tarbela period, the seasonal and annual flows show significant deviations from the average. In absolute terms, the deviations of flows during the *kharif* season vary from 1.0 to 3.8 km^3, 1.2 to 11.6 km^3 during the *rabi* season, and 1.2–15.4 km^3 annually. Additionally, both the total land under cultivation and the cropping intensity have increased, reducing canal water availability for each unit of irrigated land (Bhutta & Smedema, 2007). This, in turn, has led to higher demand for groundwater because of its availability, reliability, and high productivity (Tariq et al., 2020). This is reflected in the fact that farmers with access to groundwater can cultivate 90% of their total land compared to 63% of those who relied on canal water (Basharat, 2015). Moreover, farmers who have access to both groundwater and canal water earn five times more income than those who have access only to canal water (Faruqui, 2004).

3.2.6 Water Allocation for the Domestic Sector

Access to adequate drinking water is a basic human right, as has been identified in Pakistan's Water Strategy of 2012 (Ahmad, 2016) and the Pakistan National Water Policy of 2018. Domestic water use is not uniform and depends significantly on location, household characteristics, and socio-economic variables and increases corresponding to household size and income (Lyman, 1992; Renzetti, 2002; Bhatti & Nasu, 2010). Domestic water use in rural areas is 45 litres per capita per day but jumps to 120 litres in urban areas (Parry et al., 2017).

3.2.7 Water Allocation for the Industrial Sector

Very little reliable information is available on industrial water use. In Pakistan, urban and industrial water requirements are rarely calculated using real water consumption statistics. Generally, between 2% and 3% has been cited; these values come from a National Water Strategy document from the 1990s and two older WAPDA studies from 1976 and 1989.

3.2.8 Water Allocation for the Environmental Sector

The downstream effects of irrigation, such as sea intrusion and other environmental, ecological, and social consequences of reduced surplus flows, must be thoroughly investigated. "The need for some minimum escape to the sea below Kotri, to verify sea intrusion, was recognized," according to Paragraph 7 of the Water Apportionment Accord. Sindh's provincial government believed the optimal standard was 10 MAF (12.34 BCM), which was extensively debated, and other reports suggest lower or higher estimates. As a result, it was agreed to conduct further research to determine the minimum escape requirements downstream of the Kotri barrage. Unfortunately, no trials have been conducted so far, and there is no agreement on the escape requirements. Although there is still no agreement about the scope of these studies, we recommend that they be carried out as part of the National Drainage Program. To minimize perceived bias, these studies should be assigned to a foreign agency such as the World Bank, ADB, or FAO (Azad et al., 2003).

3.3 Best Water Use Options Under a Changing Climate

In the last few decades, water has connected various biophysical strategies and policies. To address the issues in these policies, the scientific options need to be linked to investments, institutions, water management, farming practices, and capacity development. These options should address the spatial scale (fields, farms, irrigation schemes, aquifers, transboundary river basins, and at the country level). These options can be included in adopting big data solutions by introducing machine learning and artificial intelligence to get information on water use across these spatial scales. GIS and remote sensing solve many challenges, especially at larger scales (from the irrigation system to the basin level).

3.3.1 More Storage to Improve Water Availability

Pakistan is very reliant on its water resources and has made significant investments in them. Most infrastructure has deteriorated because of age and negligence. There is no new maintenance plan to repair or renovate our irrigation facilities. Government funds are typically just 5–10% of what is needed to maintain this infrastructure. The cumulative impact on river barrages and headworks has made them extremely vulnerable to unanticipated harm, which could have disastrous consequences. Canal distribution capability is 30% less than designed because of delayed repairs and lack of reconstruction. As a result, urgent investments are needed to protect these strategic mechanisms to ensure the food security of Pakistan's 220 million citizens.

3.3.2 Improving Agricultural Water Productivity

Successful harnessing of Pakistan's freshwater resources would have a significant impact on its future development. If Pakistan is to achieve sustainable growth, it will have to change the way it uses water dramatically. At current yields, the area growing wheat would need to increase by 46% to satisfy the country's food needs. Similarly, other crop areas would need to be expanded. But given current water supplies, this is not realistic. As a result, the only way to fulfill this food target is to improve water quality in order to optimize land and water productivity. Water management measures such as precise field leveling, zero tillage (ZT), and bed and furrow planting can all contribute greatly to increasing water productivity. Farmers should be requested to employ high-efficiency irrigation technologies such as sprinkler and drip irrigation to reduce irrigation water demands.

According to studies undertaken by the International Water Management Institute (Ahmad et al., 2007), the use of ZT and laser-leveling technologies for wheat grew from 15% to 35% between 2000 and 2003 in the Rechna Doab subbasin. Between 2003 and 2004, the region using ZT expanded tremendously, with wheat planted on 400,000 acres. Farmers in Punjab already own approximately 5300 ZT drills, and 45 companies produce them. Farmers use Resource Conservation Technologies (RCTs) for a variety of reasons. Around 97% of farmers deployed new RCTs primarily to increase farm profitability, while 87% did so to harness scarce water resources.

Farmers in upper Rechna Doab, where rice-wheat farming was predominant, embraced ZT technology to the greatest extent (27%). Similarly, laser land leveling was more suitable in the middle and lower Rechna (with 4% and 12% adopting it, respectively), where wheat and sugar cane are the primary crops and irrigation water scarcity is a significant issue. Since using ZT and laser land leveling, farmers in these locations have seen fewer production costs, greater crop yields, and more net farm revenue.

3.3.3 Improve Groundwater Use by Rationalizing Cropping Patterns

Pakistan's water economy has largely survived over the last few decades due to millions of farmers, cities, villages, and factories exploiting unmanaged groundwater. This period of "productive anarchy" is now coming to an end, since freshwater in most areas has been depleted. As a result, strategies for balancing water withdrawal with recharge are urgently needed.

Improved irrigation has benefited rice and sugar cane, for example. Given that rice requires so much water, it is vital to examine if Pakistan can continue growing rice for export or whether it should divert this water to more competitive crops. Similarly, we should start developing low-water-use and high-market-value substitutes for sugar cane. Additionally, high-value grains such as sunflower, legumes, tomatoes, and orchards can considerably enhance agricultural incomes. Indeed, the world imports more than one billion dollars' worth of edible oils currently.

More than 70% of irrigation water in Pakistan's rice-growing regions is provided by tube wells (Awan et al., 2016). Thus, restricting rice production to meet domestic demand may alleviate groundwater stress. Groundwater can be conserved by using modern irrigation techniques such as alternate wet and dry rice irrigation. Similarly, direct-seeded rice requires 23% less water than transplanted rice.

Aquifer management is the most efficient method of achieving a balance between discharge and recharge. Widely used in developed countries such as Germany, Switzerland, the United States, the Netherlands, and Sweden, this has resulted in artificial recharge accounting for 15% to 25% of total groundwater utilization (Li, 2001). In 2021, India took substantial measures to use harvested rainwater to regenerate its aquifers, and the central government recently allocated significant funds to further promote this practice.

Because of Pakistan's groundwater socioecology, a multifaceted approach is required. For example, power subsidies need to be revisited in Balochistan Province. The current annual subsidy for agricultural tubewells is 8.5 billion Pakistani rupees (US$ 140 million), which encourages unsustainable groundwater mining. In addition, water availability should be used to calculate harvest regions for various crops. Finally, farmers in Pakistan's desert and rainfed regions have invested in rainwater harvesting systems to complement irrigation and recharge aquifers. The government should support these initiatives to ensure the impoverished have a means of subsistence.

3.3.4 Better Resources Utilization at the Field and Basin Scales

Pakistan does not have a well-developed drainage infrastructure, which is required to remove salt from the system. As a result, it is necessary to invest in rehabilitating current drainage channels and building new drainage systems to control salinity.

In the long term, transporting excess salts from irrigated areas to the sea is one possible solution. Construction of a main interprovincial drain to eliminate salt from the basin should begin immediately and needs the government's prompt attention. In Pakistan, technical solutions have gotten too much attention, and management solutions have not received enough. While technical solutions increase crop yields and intensities, they do not prevent the emergence of linked environmental concerns in neighboring areas.

The government should also promote replenishing salt-affected soils using gypsum, acids and other organic materials. The use of enhanced planting techniques and fertilizers and diverse salt-tolerant crops should be carefully considered as saline agriculture increases. Many varieties of crops have been adapted to Pakistani environments. For example, there has been considerable success growing seasonal fodder grasses, such as tall wheatgrass (*Elytrigia elongata*), Puccinellia (*Puccinellia ciliata*), and Rhodes grass (*Chloris gayana*). Incorporating salt-tolerant trees and bushes into agricultural systems on salt-affected soils has the potential to boost crop and animal yields while also minimizing soil depletion. Our current inefficient farming patterns can be reversed if land changes are accompanied by better agricultural techniques.

The biological approach prioritizes long-term stewardship of extremely saline water and soils, as well as enhanced farming practices, by maximizing the positive use of genetic capital in plants, livestock, birds, and insects. This technique supports reclamation through the use of salt-tolerant herbs, bushes, trees, and fodder grasses. Due to their vital role in any region's hydrological cycle, plants, particularly trees, are referred to as biological pumps. According to a Pakistani study, extremely saline streams can be used to cultivate salt-tolerant fodder grasses, hence increasing the quality and quantity of animal products (Hussain et al., 1990). Chemical additions, organic matter, and mineral fertilizers, in addition to selective harvesting of salt-tolerant forages and grasses, are used in these waterways. By acting as biological drainage agents, trees and plants lower water table depths simply and efficiently. This is essentially a "pro-poor" strategy that helps disadvantaged farmers, who would otherwise have to quit their farms, to increase their revenue.

In Pakistan, poplar, eucalyptus, tamarix, mesquite, and acacia can all be used for bio-drainage. Nonwoody plants, on the other hand, such as trees, sedges, grasses, and herbs, may have deep-rooted structures that touch groundwater. (Choudhary & Bhutta, 2000). Any major impact on the water table from such a plantation (woody and nonwoody) will be anticipated only if water consumption by plants is more than the water supplies. Planting trees to draw shallow groundwater is a useful tool to reduce water tables and salinity.

3.3.5 Strengthening Institutions

Agriculture in Pakistan is evolving rapidly through agricultural modernization implemented by the farmers and the substitution of high-value crops in place of traditional crops. Water demand is visibly changing as a result of agricultural diversification, urbanization, industrialization, environmental consciousness, climate change, and the evolution of the natural resource base. As a result, a modern water economy must be more adaptive, with water reallocated from those with the least need to those with the greatest need. Pakistan must invest in institutions that will enable it to address future water management concerns.

For example, groundwater is frequently blended with surface water so as to limit the amount of salt in the water to avoid soil salinization. Surface water and groundwater are also used concurrently at the canal system's head and tail ends in the majority of canal command areas. One of the biggest disadvantages of this is that upstream regions face rising water tables and flooding, while tail-end users' salinity issues are compounded by poor groundwater conditions.

In Pakistan, 32% more canal water is supplied to head-end farmers than to tail-end and middle-end farmers (Haider et al., 1999). As a result, upstream farmers should be permitted to use more groundwater (since it is fresh), while downstream users should be provided with additional surface water sources to lower their reliance on salty groundwater and prevent soil salinization and output loss. To accomplish this, the canal department must manage canal flows to suit the needs of tail-end farmers. While convincing farmers to adopt these techniques may be difficult, continuous and reasonable motivation may be beneficial. Farmers must also be instructed on the proper mixing ratios of surface and groundwater supplies to improve crop yield and prevent soil erosion. Additionally, farmers should diversify their revenue streams by cultivating high-value cash crops rather than conventional crops.

3.4 Water Governance

The water management is a joint responsibility of the federal and provincial governments. The Federal Ministry of Water Resources and the federal planning comission are responsible for policies and planning; the Water and Power Development Authority (WAPDA) is responsible for major interprovincial dams; the Provincial Irrigation Departments (PID) and Provincial Irrigation and Drainage Authorities are responsible for irrigation and drainage up to the field canal intake; the latter are also responsible for irrigation and drainage beyond the field canal intake. While numerous federal agencies are responsible for various parts of the water sector, there is no efficient interprovincial body to coordinate water sector planning, development, and management.

The Water Accord, governed by the Indus River Systems Authority (IRSA), allots the Indus River Basin's waters to the provinces. Disagreements about water allocation are widespread, especially when it comes to sharing water during dry years. This has resulted in a conflict between provinces, which has hindered water supply management in recent decades.

Numerous public sector operations, including water supply and sanitation, as well as on-farm activities, have been decentralized to the district level under the August 2001 Devolution Plan. Provincial Public Health and Engineering Departments and On-Farm Water Management Directorates have been downsized or eliminated. Some are skeptical that district governments possess the technological and administrative knowledge necessary to improve rural water supply and sanitation and expand water resources. These concerns are expected to be rectified as district administrators acclimate to their current responsibilities. The districts' progress in planning and building rural water supply, sanitation, and watercourse development should be monitored to ensure they remain on track and that assistance is supplied when possible. NGOs, Watercourse Associations (WCAs) at the watercourse level, Farmer Organizations (FOs) at the distributary/minor canal level, Drainage Beneficiary Groups (DBGs), Community Tube Well Organizations (CTWGs), and Rural Village Water and Sanitation Groups are all examples of existing consumer-level organizations (Azad et al., 2003).

A water control case study in Chitral District, Khyber Pakhtunkhwa (KPK), describes traditional water management techniques, primarily through the prism of irrigation, such as strategies for sharing water between households and societies, informal government arrangements known as "grammes," cooperative water storage, and irrigation channel maintenance schemes (Cooper, 2018).

3.4.1 Water Management and Governance Challenges

Several challenges exist across the provinces about water management and governance, including:

3.4.2 Fragmentation and Duplication of Roles and Responsibilities

This has resulted in a lack of consistent reporting lines, a lack of clarity regarding duties and tasks—which has caused uncertainty about who is responsible for what—a lack of communication, and the absence of formal coordination processes.

3.4.2.1 Technical Capacity and Human Resources

There is insufficient skilled staff to manage and administer the schemes adequately or to extend access to services (Cooper, 2018).

3.4.2.2 Inadequate Operation and Maintenance

Publicly maintained canal networks have deteriorated as a result of excessive use, interference with control mechanisms, damage to canal banks caused by human and cattle trespassing, and insufficient maintenance. Budgets for operations and maintenance (O&M) are far less than what is required. Salaries and electricity costs for tubewells and lift pumps consume the lion's share of the budget, leaving little room for maintenance. Apart from the deterioration of transportation networks, several significant structures, such as barrages and headworks, are exhibiting signs of aging and extended neglect, which, if left unaddressed, could compromise their structural integrity.

Additionally, the operation and maintenance plan neglected smaller drainage channels (distributaries and minors). Small channels frequently operate in the absence of control systems (gates, regulators). Significant investment has been made in the past to improve irrigation and wastewater systems. Between 1982 and 1994, two irrigation systems rehabilitation projects (ISRP) were launched to address the backlog of irrigation canal and surface drain repairs. While the project was successful in lowering the maintenance backlog, it did not include the structural modifications necessary to ensure the system's long-term viability (Azad et al., 2003).

3.4.2.3 Monitoring

There is no standard data collection process for water delivery schemes (WSS) (IUCN, 2014). Official reporting methods are either underutilized or ineffective. With UNICEF's support, a water knowledge management system is being set up in the Khyber Pakhtunkhwa province. This system aims to bring together data from all of the province's schemes, monitor needs in real-time, and make O&M easier.

3.4.2.4 Political Interference

Political interference happens often in the water industry, in the form of government recruiting, corruption, and biased project site collection.

3.4.2.5 Challenges Related to Financial Stability and Lack of Investment

Crops are heavily reliant on water, and the maintenance of existing infrastructure and new construction is unquestionably necessary for the growth and proper functioning of this vast system. In Pakistan, the buyer pays for the capital expense of developing irrigation structures. The part of the cost for operation and maintenance are dependent upon the water fees received by the provincial governments. However, the collected fee is insufficient to meet the operation and maintenance costs. It is estimated that every province has a shortfall of funds almost greater than 30%. Operation and management are the shared responsibility of provincial governments and federal agencies (Saleh, 2016).

3.4.2.6 Challenges Related to Mega-Trends

Rapid urbanization is the competition for water among various users and industries, leading to groundwater over extraction, declining water quality, and widespread groundwater table decline.

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Chapter 4
Water Supply and Demand: National and Regional Trends

Shahid Ahmad and Ghufran Ahmad

Abstract This chapter focuses on the supply and demand of water resources in Pakistan. Data on the availability and use of water in Pakistan will be used to develop a water balance for the IBIS. Because the per capita water availability is less than 1000 cubic meters (m^3), Pakistan is currently categorized as a water-scarce country. However, there is a silver lining in that productivity in the agricultural sector can be doubled by using better technology and reducing the amount of land that needs to be farmed, possibly reducing the gap between supply and demand. The Indus Water Treaty of 1960 has posed serious limitations for both countries in sharing the water supply during dry years. The provinces of Pakistan agreed on the Water Apportionment Accord in 1991 to resolve the water-sharing conflict. However, there are still issues between the provinces on sharing during dry years, resulting in reduced environmental flows to the ecosystems and reduced availability for the agricultural sector. Finally, water is discussed in the regional context of South Asia which will focus on Afghanistan, Bangladesh, India, and Pakistan. A brief overview of the current scenario along with historical trends will be provided for these countries. Then, we provide the successes and gaps related to water, specifically the measures taken to deal with issues related to climate change, in the four countries.

Keywords Water supply · Water demand · Per capita water availability · Water Apportionment Accord · Indus Water Treaty

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4.1 Introduction

This chapter focuses on the supply and demand of water resources in Pakistan. Precipitation and glaciated resources are the major sources of renewable water in the country. Rainfall, runoff, glacier- and snowmelt contribute to the main Indus river and to its western tributaries: the Indus, Jhelum, and Chenab rivers. In addition, the Kabul river, flowing from Afghanistan, also contributes to the Indus Basin Irrigation System (IBIS).

A major part of the IBIS was completed in 1880, with the second stage of the infrastructure developed during the 1960s–70s, after the signing of the Indus Water Treaty under the Indus Basin Development Programme (IBDP). In 1880, the water table in the Indus Basin ranged from 46 to 76 meters (m) (150 to 250 feet). Fast forward 100 years (in 1980), and it was less than 3 m (10 feet) in 42% of the Indus Basin area. The recharge to groundwater, by the IBIS, created a blanket of fresh groundwater of at least 2460 cubic kilometers (km^3) in the Indus Basin, which is almost equal to 14 years' worth of average annual flows to the IBIS.

This chapter uses data to provide the availability of water from all sources of water (surface and groundwater) and its probability based on the historical data. The IBIS provides water to 20% of the geographical area of Pakistan. Water scarcity is extremely severe in areas outside the Indus Basin due to a lack of perennial river flows. The domestic, agricultural, and manufacturing sectors are the major users of water. Agriculture consumes the most resources—93%—by far. Because of this, the demand for water in non-agricultural sectors, in the future, will need to be met by conserving water in agriculture, since non-agricultural sectors have a higher priority, especially domestic water use. Thus, the supply of water will increase only by reducing existing water use.

This data will be used to develop a water balance for the IBIS. The impacts of climate change on future water availability will also be discussed along with extreme weather events such as drought and floods, and future projections of water supply and demand.

Because the per capita water availability is less than 1000 cubic meters (m^3), Pakistan is currently categorized as a water-scarce country. However, there is a silver lining in that productivity in the agricultural sector can be doubled by using better technology and reducing the amount of land that needs to be farmed, possibly reducing the gap between supply and demand. Current weaknesses in water policies and water governance will also be covered in the chapter.

After establishing an understanding of water supply and demand in Pakistan, domestic and international water treaties and accords will be discussed. The Indus Water Treaty of 1960 was signed between India and Pakistan, in which the western rivers (Indus, Jhelum, and Chenab) were assigned to Pakistan and the eastern rivers (Beas, Sutlej, and Ravi) were assigned to India. This treaty has posed serious limitations for both countries in sharing the water supply during dry years. Similarly, the provinces of Pakistan agreed on the Water Apportionment Accord in 1991 to resolve the water-sharing conflict. However, there are still issues with sharing during dry years, resulting in reduced environmental flows to the ecosystems and reduced availability for the agricultural sector.

Finally, a brief overview of the current water situation in South Asia will be given, focusing on Afghanistan, Bangladesh, India, and Pakistan, particularly with regard to the measures taken to deal with climate change.

4.2 Pakistan's Water Resources

To understand water supply and demand, we need to first look at the historical trend of river flows in the IBIS along with the future probability of river flows to highlight the uncertainty involved. The distribution of water resources among the provinces is briefly discussed here. Further details are provided in Sect. 4.5.2 on the Water Apportionment Accord of 1991. Finally, some pertinent aspects of water resource management are also discussed.

4.2.1 Precipitation and Glacial Resources

The average annual precipitation in Pakistan is depicted in Fig. 4.1, which shows that it ranges from less than 100 mm in parts of Balochistan and Sindh to greater than 1500 mm in the northern mountains of the country.

The country's rainfall and precipitation show seasonal variation. Approximately 60% of Pakistan's monsoon rains take place from July to September. During the *rabi* season (October to March), average rainfall varies from less than 50 mm in parts of the Sindh province to more than 500 mm in the Khyber Pakhtunkhwa (KPK) province. Meanwhile, average rainfall in the *kharif* season (April to September) ranges from less than 50 mm in some areas of Balochistan to greater than 800 mm in northern Punjab and the KPK province (Ahmad, 2007). Surface runoff from rainfall contributes to the river flows which varies seasonally because of the seasonality of rainfall.

The northern part of Pakistan contains a huge area (22,000 km^2) of glaciers with more than 100 glaciers that exceed 10 km in length (Ahmad, 2007). The total ice reserves have been estimated to be around 2738 km^3, which is roughly 16 times the average levels of annual river flows. The Shyok, Hunza, Shigar, Chitral, and Gilgit river basins are some of the major contributors to these immense ice reserves with respective contributions of 32, 30, 21, 9, and 3% (Campbell & Pradesh, 2005).

4.2.2 Indus Basin Irrigation System

The surface water resources of Pakistan—generated from glacier- and snowmelt, rainfall, and surface runoff—rely heavily on the main Indus river and its tributaries, which include the Ravi, Sutlej, and Beas rivers in the east, and the Indus, Jhelum, Chenab, and Kabul Rivers in the west. The IBIS is the largest contiguous irrigation

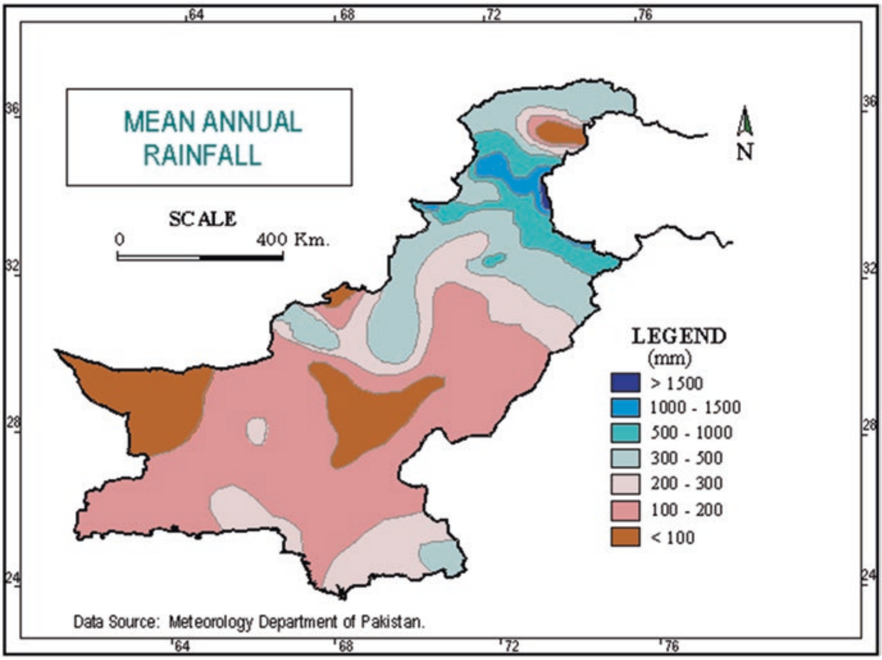

Fig. 4.1 Mean annual precipitation in Pakistan. (Source: Meteorology Department of Pakistan)

system in the world and commands an area of around 16.85 million hectares (mha) and provides water for 90% of Pakistan's food production (Ahmad, 2007; Briscoe et al., 2005; GoP Pakistan Water Sector Strategy, 2003; Qureshi, 2011).

4.2.3 Historical River Water Flow Trends

Table 4.1 presents the historical annual flows of the Indus river—covering the eastern and western tributaries from 1937–38 to 2012–13. The Indus River flows depict a high degree of variability with minimum and maximum flows of 114.3 and 256.2 km^3, respectively, and an average flow of 182.3 km^3. Due to the variability of river flows in the IBIS, storage is necessary for regulated flows (Ahmad, 1999).

4.2.4 Probability of River Water Availability

There is high variability in daily, seasonal, and annual river flows in the IBIS (Ahmad et al., 2003; Ahmad, 1993; Bhatti, 1999; Kijine et al., 1992; Mohtadullah et al., 1991; WCD, 2000; Warsi, 1991) which complicates the assessment of the

Table 4.1 Historical flows in the Indus River. Data source: Indus River System Authority (IRSA) 2015

Year	River flows (km^3)
1937–38	193.3
1940–41	161.0
1950–51	226.2
1960–61	219.8
1970–71	158.3
1980–81	166.2
1990–91	201.7
2000–01	120.4
2010–11	193.7
2012–13	149.9
Average flows	182.3
Minimum flows	114.3
Maximum flows	256.2

Table 4.2 Probability of rim station inflows to the IBIS for the pre-storage period (1937–1967). Data source: River flows. Water Resources Management Directorate, Water And Power Development Authority (WAPDA)

	Rim station inflows (km^3) for the pre-storage period (1937–1967)						
	Western rivers			Eastern rivers			
Probability (%)	*kharif*	*rabi*	Annual	*kharif*	*rabi*	Annual	Total
Minimum	111.0	19.1	134.5	9.6	1.7	11.3	145.8
10	123.9	22.8	143.9	15.6	1.9	17.5	161.4
25	136.2	24.2	163.1	17.9	2.9	22.3	185.4
50	144.5	26.3	173.0	22.1	3.3	26.2	199.2
75	155.3	30.5	184.9	27.4	4.9	35.2	220.1
90	166.8	32.6	198.2	32.2	8.6	38.1	236.3
Maximum	192.7	40.7	231.7	39.3	18.1	44.5	276.2

storage capacity to regulate river flows. This variability of river flows is better represented using the probabilities of the flows.

Table 4.2 shows the variability of rim station inflows to the IBIS during the pre-storage period (1937–1967), i.e., before completion of the Mangla Dam in 1967. The rim stations for the Chenab, Jhelum, Kabul, Ravi, Sutlej, and Indus rivers are located at Marala, Mangla, Attock, Balloki, Sulaimanki, and Tarbela, respectively. In the pre-storage period, the western rivers contributed 144.5 and 26.3 km^3 during the *kharif* and *rabi* seasons, respectively, in a normal year (50th percentile). Overall, the western rivers contributed 173.0 km^3 in a normal year, while the eastern rivers contributed 22.1 and 3.3 km^3 in the *kharif* and *rabi* seasons, respectively, for an overall contribution of 26.2 km^3.

River flows are relatively lower during the *rabi* season because of lower rainfall along with reduced glacier- and snowmelt. Moreover, eastern rivers have a higher variability in flow as shown by the fact that the once-in-ten-years high flows (90%) are 117.7% greater than the once-in-ten-years low flows (10%) compared to a 37.7% difference for the western rivers. This observation is true for the flows during both the *kharif* and *rabi* seasons.

The probability of rim station inflows to the IBIS during the post-storage period (1968–2007) is provided in Table 4.3. In a normal year, western rivers contributed 140.4 and 26.9 km^3 in the *kharif* and *rabi* seasons, respectively, making the annual contribution 167.3 km^3. For eastern rivers, the contribution during the *kharif* and *rabi* seasons was 6.9 and 1.4 km^3, respectively, while the annual contribution was 8.3 km^3 in a normal year. As in the pre-storage period, river flows are significantly lower during the *rabi* season. Moreover, the inflows from the eastern rivers continue to show higher variability in the post-storage period.

Table 4.4 shows the variability of Indus Basin river flows from 1975 to 2013. During this period, the normal annual flows were 166.2 km^3, whereas the one-in-ten low and high annual flows were 146.3 and 205.1 km^3, respectively. This indicates that variability in the Indus Basin river flows only differs marginally when comparing the periods 1968–2007 and 1975–2013. The variability in Indus River flows has resulted in extreme floods and droughts and driven interprovincial conflicts over water allocation.

Annual variability is also observed in river flows downstream from the Kotri barrage, which is located on the Indus River between Jamshoro and Hyderabad and feeds the Fulleli, Pinyari, and Kalri Baghar canals. Table 4.5 shows the probability of river flows downstream from the Kotri Barrage, showing that in a normal year, the river flows were measured at 33.2 km^3 for the 1975–2013 period.

Before the Kotri Barrage was constructed, there were downstream flows every single day. However, since the construction of the Kotri Barrage, the seasonal and annual downstream flows have decreased because of enhanced canal diversions. These flows decreased even more after the completion of the Mangla and Tarbela dams due to more canal diversions at the northern upstream commands (S. Ahmad, 2016). Figure 4.2 shows the number of zero-flow days downstream from Kotri during the 1975–2013 period.

Table 4.3 Probability of rim station inflows to the IBIS for the post-storage period (1968–2007). Data source: River flows. Water Resources Management Directorate, WAPDA, and IRSA

	Rim station inflows (km^3) for the post-storage period (1968–2007)						
	Western rivers			Eastern rivers			
Probability (%)	*kharif*	*rabi*	Annual	*kharif*	*rabi*	Annual	Total
Minimum	93.4	17.2	110.6	0.5	0.0	.5	113.5
10	111.6	20.9	135.5	1.1	0.2	1.4	136.9
25	125.7	23.9	153.5	3.2	0.6	3.7	157.0
50	140.4	26.9	167.3	6.9	1.4	8.3	175.6
75	157.2	30.5	180.8	12.6	2.3	15.4	196.2
90	159.7	34.3	194.6	18.5	4.3	20.1	214.7
Maximum	192.6	40.7	231.6	20.4	7.8	24.1	255.7

Table 4.4 Probability of Indus Basin river flows from 1975 to 2013. Data source: River flows. IRSA (2016)

Probability (%)	Indus Basin river flows (km^3)
Minimum	114.2
20	146.3
25	149.6
50	166.2
75	191.8
90	205.1
Maximum	209.8

Table 4.5 Variability of river flows downstream from the Kotri Barrage from 1975 to 2013. Data source: River flows. IRSA (2016)

Probability (%)	The downstream river flows from the Kotri Barrage (km^3)
Minimum	0.4
20	10.9
25	13.6
50	33.2
75	56.0
90	85.2
Maximum	113.2

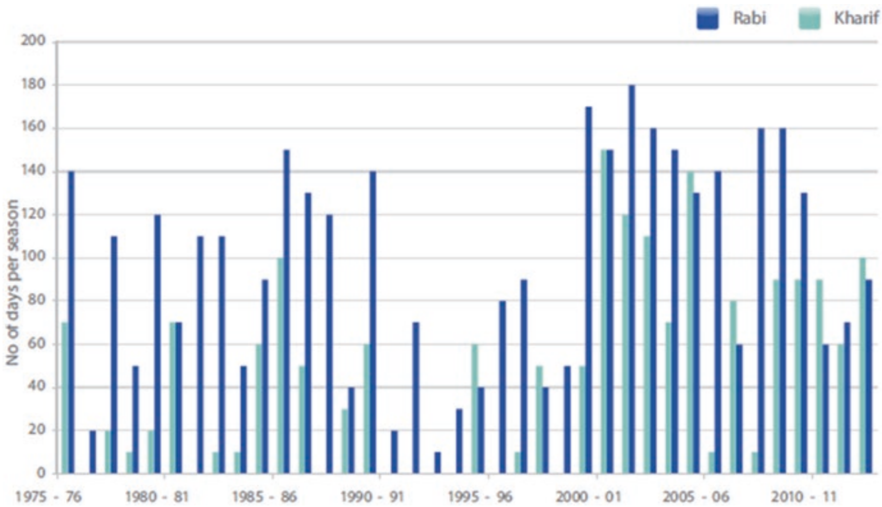

Fig. 4.2 Number of zero-flow days below the Kotri Barrage during the *rabi* and *kharif* seasons. Data source: River Flows. IRSA (2014)

4.2.5 Groundwater Resources

The Indus Basin is a groundwater aquifer that commands an area of 16.85 mha, of which 14 mha is culturable. Before the canal irrigation system was developed, the aquifer was in hydrological equilibrium, i.e., the inflow to the aquifer was balanced by the outflow and crop evapotranspiration. During the pre-storage period, the groundwater usage was around 11.3 km^3, which was 10% of the total water available for agriculture (Ahmad et al., 2001). The introduction of the canal irrigation system resulted in waterlogging and salinity because of increased percolation in the irrigated areas of the IBIS (Ahmad, 2007). Figure 4.3 shows the rise in the water table, measured in meters above sea level (masl), in the Punjab province during the first half of the twentieth century. However, the higher water table allowed tubewell irrigation in areas with fresh groundwater. The government of Pakistan also encouraged tubewell development by providing subsidies, free wells, and soft loans (Lytton & Ahmed, 2021; Johnson, 1989). This resulted in a significant increase in the number of tubewells in the Indus Basin, resulting in over 400,000 privately-owned tubewells in the early 1990s (van Steenbergen & Oliemans, 1997).

In the post-storage period, the estimated annual groundwater recharge in the Indus Basin is 67.9 km^3, with 44 km^3 of this recharge occurring in areas which have usable groundwater (Zuberi & Sufi, 1992). The development of the irrigation system increased the water table to less than 3 m, which is categorized as waterlogged. In June 2010, 34% of all canal command areas were waterlogged while roughly 13, 72, 41, and 48% of canal commands in Punjab, Sindh, Balochistan, and KPK, respectively, were waterlogged. During October 2010, 42% of the canal commands in the country were waterlogged and 22, 86, 46, and 25% of the canal commands in

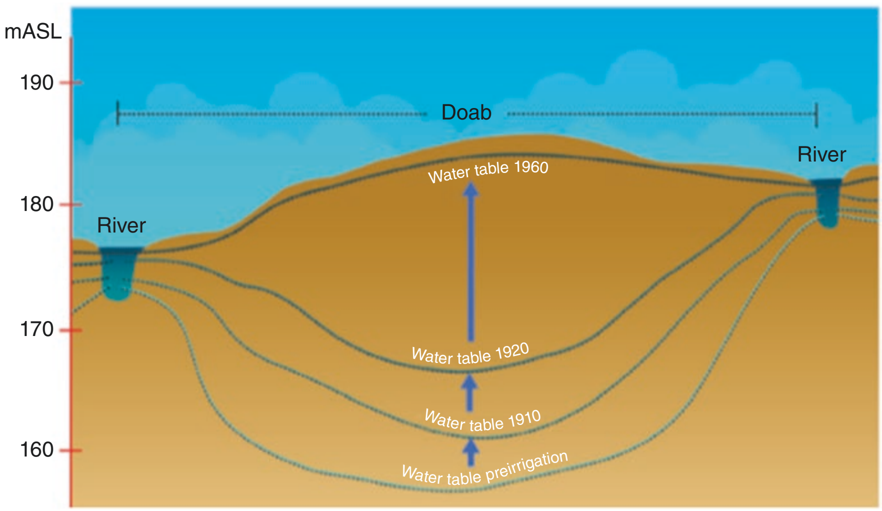

Fig. 4.3 Increase in the water table in a doab in the Punjab province in masl. (Source: Lytton & Ahmed, 2021)

Punjab, Sindh, Balochistan, and KPK, respectively, were waterlogged (Pakistan Bureau of Statistics, 2011).

4.2.6 Distribution of Water Resources

Ever since the completion of the canal irrigation system in the Indus Basin, the matter of water allocation has resulted in several conflicts between provinces (Shah et al., 2003) which were resolved through various commissions before partition in 1947 (Qureshi et al., 2008). Before partition, the water allocation from the eastern tributaries of the Indus River for Punjab and Sindh was 94 and 6%, respectively (Khalid & Begum, 2013).

After 1947, water allocation was initially carried out through informal arrangements. However, in 1991, the Water Apportionment Accord was mutually agreed upon by the four provinces. The Accord is based on historical water use by the provinces, i.e., 47, 42, 8, and 3% for Punjab, Sindh, KPK, and Balochistan, respectively. The Water Apportionment Accord is discussed in detail in Sect. 4.5.2.

4.2.7 Water Resource Management

Because of the growing population, food requirements are expected to increase significantly in the future, whereas expansion of irrigated areas is limited both because of lower investment in the water sector and environmental and ecological threats (Qureshi, 2011). Table 4.6 presents projected food requirements and production estimates for different crops for Pakistan in 2025. Based on these projections, Pakistan is expected to face shortfalls for all crops. Therefore, better management of water resources is required to meet the food requirements. Some potential solutions are provided here.

Pakistan's agriculture relies heavily on its water infrastructure, but that infrastructure is in decay due to age and neglect. The government allocates only 5–10%

Table 4.6 Projected food requirements and crop production (million tons) for 2025. Source: Asian Development Bank 2002

Crops	Requirement	Production	Shortfall
Grains	50.0	31.5	18.5
Sugarcane	82.0	46.4	35.6
Cotton	3.5	2.7	0.8
Pulses	1.9	1.4	0.5
Oilseed	3.3	1.5	1.8
Vegetables	14.3	9.0	5.3
Fruits	16.1	9.0	7.1

of the required amount for repair and maintenance. This has resulted in a 30% lower delivery capacity of the canals than designed (Qureshi, 2011). Therefore, immediate investment is required to restore the capacity of the water infrastructure and develop new storage to ensure future sustainability.

In the recent past, the agricultural sector in Pakistan survived by tapping into the groundwater. However, that groundwater use was unmanaged and unsustainable, and as a result, the water table has decreased significantly because of excessive groundwater abstraction. As such, the government should regulate and devise policies for bringing water withdrawals into balance with groundwater recharge. In this regard, electricity subsidies in Balochistan should be reviewed as they lead to excessive extraction of groundwater. Instead, farmers in the Kirthar Range, the riverine area, and the Tharparkar desert should all be encouraged to invest in water structures to harvest rainwater to both irrigate and recharge aquifers.

In addition, Pakistan exports rice and sugar, which are water-intensive crops. The government should assess whether the country should continue to produce these for export or instead produce enough for domestic consumption and use the remaining water for high-market-value crops, such as sunflower, pulses, and vegetables (Qureshi, 2011). This would reduce the pressure on the water resources of the country and increase production of high-market-value crops, leading to higher incomes for farmers and import substitution.

Aquifer management is another effective way of balancing discharge and recharge. This practice— in which interventions were used to artificially increase recharge to the aquifers—has been used in developed countries such as Germany, Switzerland, the United States of America (USA), the Netherlands, and Sweden. The proportion of artificial recharge to total groundwater use ranges from 15 to 25% in these countries (Li, 2001). Even India has taken steps to harvest rainwater to recharge its aquifers (Qureshi, 2011). Thus, the government should consider rainwater harvesting strategies to recharge depleted groundwater resources.

4.3 Demand for Water in Pakistan

This section assesses the allocation of water resources to different sectors in Pakistan. The focus will be on agricultural water demand as this sector consumes more than 90% of the available water in any year. In addition, temporal and sectoral water demand trends and approaches to demand management will also be discussed.

4.3.1 Water Allocation for Sectors of Water Use

As mentioned above, Pakistan's agricultural, domestic, and industrial sectors consume the majority of water. Since Pakistan's economy is heavily dependent on agriculture, this sector consumes the most water. However, domestic water usage needs to be assigned a higher priority because drinking water has been identified as a basic right according to Pakistan's Water Strategy of 2012 (Ahmad, 2016). From all available freshwater resources, 94% is used for the agricultural sector, with 5 and 1% for domestic and industrial use, respectively (Blomquist & Ingram, 2003; Ahmad, 2011; FAO, 2019).

4.3.2 Demand in Agriculture

Pakistan is an agricultural economy; the agricultural sector accounts for 25% of the Gross Domestic Product (GDP) and 75% of total export earnings, while two-thirds of the country's population lives in rural areas with agriculture as their main source of livelihood (Ahmad, 2011; Kamal, 2009; Briscoe et al., 2005). However, around 92% of the country's land is arid or semi-arid (Kamal, 2009), meaning that Pakistan relies heavily on irrigated agriculture.

The Indus Basin covers around 25% of the total land area which provides a livelihood for about 65% of the country's population. Most irrigated agriculture, which makes up around 80% of the total cultivated area, is in the Indus Basin and satisfies 90% of Pakistan's food and fiber requirements.

Again, as mentioned above, Pakistan's main agricultural exports consist of cotton, rice, and sugarcane, which are all water-intensive; sugarcane in particular consumes 60% more water than rice, 170% more water than cotton, and almost 580% more water than wheat (Tariq et al., 2020). Pakistan is the tenth-largest producer of sugarcane, which accounts for 4.8% of the cropped area and 11% of the value-added from all crops. Sugarcane is used to produce around five million tons of sugar every year and contributes 3.6% to the GDP. However, the production of sugarcane and the process of sucrose recovery from sugarcane is extremely inefficient. The average yield of sugarcane in Pakistan is 47.5 tons/hectares (tons/ha), 24% lower than the world's average yield of sugarcane which is 62.5 tons/ha (Tariq et al., 2020). Similarly, sucrose recovery from sugarcane is 9% in Pakistan compared to 12 to 14% recovery for many countries (Sharma, 2017).

The IBIS is designed as a supply-based irrigation system that cannot adequately address the change in demand for water during the cropping season aside from the variability in the annual river flows (Khan, 2017; Faruqui, 2004). Table 4.7 provides the seasonal and annual canal diversions from 1960 to 2005 along with the averages of the post-Tarbela period (1975–2005). In the post-Tarbela period, the seasonal and annual flows show significant deviations from the average. In absolute terms, the deviations of flows during the *kharif* season range from 1.0 to 3.8 km^3, 1.2 to 11.6 km^3 during the *rabi* season, and 1.2–15.4 km^3 annually. Additionally, there has been an increase both in the cultivated area and in the cropping intensity which has reduced canal water availability per unit of irrigated land (Bhutta & Smedema, 2007). These factors have led to the popularity of groundwater due to its on-demand availability, reliability, and high productivity (Tariq et al., 2020). This is reflected in the fact that farmers with access to groundwater can cultivate 90% of their total land

Table 4.7 Seasonal and annual canal diversions to the IBIS. Data source: River flows. Water Resources Management Directorate, WAPDA, and IRSA

		Canal Diversions (km^3)		
Key influences	Period	*Kharif*	*Rabi*	Annual
Pre-Mangla	1960–67	74.2	34.0	108.2
Post-Mangla	1967–75	80.3	37.1	117.4
Post-Tarbela	1975–80	83.7	47.0	130.7
Post-Tarbela	1980–85	84.1	45.9	130.0
Post-Tarbela	1985–90	81.6	46.4	128.0
Post-Tarbela	1990–95	81.5	47.3	128.8
Post-Tarbela	1995–00	86.5	45.3	131.8
Post-Tarbela	2000–05	79.0	32.4	111.4
Post-Tarbela	*1975–2005*	*82.7*	*44.1*	*126.8*

compared to 63% for farmers who only rely on canal water (Basharat et al., 2015). Moreover, farmers with access to both groundwater and canal water have five times more income than farmers with access to only canal water (Faruqui, 2004).

Pakistan has groundwater potential of 68 km^3 per annum and around 75% of this amount is being abstracted. From the groundwater abstracted annually, 82% is used in Punjab, 8% in Sindh, 5% in KPK, and 1% in Balochistan (Sarwar, 2000). The extensive groundwater abstraction has resulted in a continuous decline of groundwater tables (Tariq et al., 2020).

4.3.3 Demand for Non-agricultural Sectors

Access to adequate drinking water is a basic human right and has been identified as such according to Pakistan's Water Strategy of 2012 (Ahmad, 2016). Domestic water use is not uniform and depends significantly on location, characteristics of the household, and socio-economic variables, as it is positively correlated to the size and income of the household (Lyman, 1992; Renzetti, 2002; Bhatti & Nasu, 2010). Domestic water use in rural and urban areas is 45 and 120 liters per capita per day, respectively (Parry et al., 2017). Figure 4.4 shows the breakdown of daily household water use. The three household activities that consume the most water are bathing and showering, which comprise 29% of domestic water use; toilet use at 19%; and kitchen use at 16%. In contrast, drinking water makes up only 1% of daily water use.

Industrial water use is usually positively correlated with the growth rate of industrial GDP. However, the extent of that relationship is unclear in the context of Pakistan because of a lack of data (Parry et al., 2017). However, demand levels have been estimated using various rates of economic development using Thailand as a case study (Parry et al., 2017; Suttinon et al., 2009), presented below.

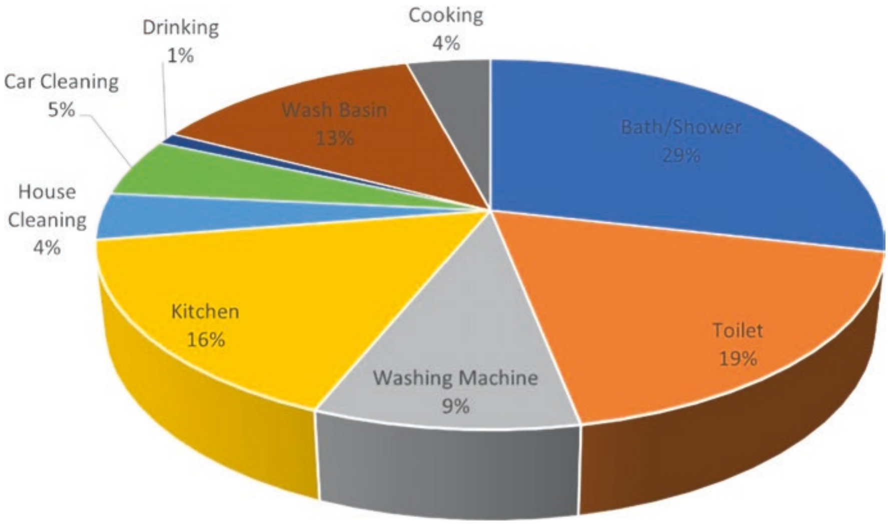

Fig. 4.4 Daily household water use (%). (Data source: Bhatti & Nasu, 2010)

4.3.4 Temporal and Sectoral Trends in Demand

The main determinant for the water demand of a country is its population. Pakistan is the sixth most populous country in the world and makes up roughly 2.8% of the world's total population. From 1960 to 2019, the average annual population growth rate has been 2.66%. Based simply on population growth, this suggests that, on average, water demand in Pakistan should have grown at least around 2.66% per year, absent any improvements in water use efficiency, from 1960 to 2019. Table 4.8 shows the historical water demand for the agricultural, industrial, and domestic sectors. The data shows that as a percentage of total water demand, agricultural usage made up 94–98%, industrial use comprised 0.8–2%, with domestic use making up 1–5.3%.

Using the data in Table 4.8, the average annual growth rates in water demand by sector since 1975 are provided in Table 4.9. Since 1975, the average annual growth in water demand ranged from 0.01 to 0.42% for the agricultural sector, −0.28 to 3.27% for industrial use, and 3.05 to 5.71% for domestic use. The average annual growth rate in total water demand since 1975 varied from 0.09 to 0.54%. The growth rate in domestic water demand reflects the impact of an increasing population. However, the growth rates for the agricultural sector remained low which indicates an increase in the efficiency of water usage.

Parry et al. (2017) use five different scenarios to make projections of water demand by sectors for 2030 and 2050 using 2015 as the baseline period. The five different scenarios are as follows:

Table 4.8 Historical water demands by sectors. Source: FAO (Parry et al., 2017)

Year	Agriculture (km^3/year)	Industry (km^3/year)	Domestic (km^3/year)	Total (km^3/year)
1975	150.3	1.534	1.534	153.4
1991	150.6	2.5	2.5	155.6
2000	162.7	3.47	6.39	172.6
2008	172.4	1.4	9.65	183.5

Table 4.9 Average annual growth rate of water demand by sectors since 1975

Year	Agriculture (%)	Industry (%)	Domestic (%)	Total (%)
1991	0.01	3.05	3.05	0.09
2000	0.32	3.27	5.71	0.47
2008	0.42	−0.28	5.57	0.54

Business-As-Usual This baseline scenario assumed that the United Nations' population projections (total and proportion living in urban areas) are realized, rates of rural and urban water use per capita per day remain unchanged, a medium level of economic growth occurs (leading to an industrial GDP growth rate of 6.9%), and irrigation efficiency remains at 30%. Any potential impacts of climate change were not considered.

Moderate Water Demand Management Scenario Under this scenario, all assumptions within the baseline scenario remained constant with the exception of an assumed increase in irrigation efficiency (the average delivery ratio) from 30% to 37%, which could be achieved by applying more sustainable irrigation methods such as sprinkler or drip irrigation.

Strong Water Demand Management Scenario In this scenario irrigation efficiency is increased from 30% to 45%, while all other factors remain constant.

Above Business-As-Usual Scenario with Exceeded Extrapolation of Current Water Demands This scenario projects water demand will be greater than the baseline, business-as-usual scenario due to a higher level of economic growth (leading to an industrial GDP growth rate of 9.7%) and an increase in population 15% greater than the United Nations' estimate. All other factors remained constant.

Climate Change Impact Scenario The scenario assumes that temperatures increase by 3°C, which would lead to an increase in agricultural water requirements of 6% by 2025 and 12 to 15% by 2050 according to research conducted by Amir and Habib (2015). All other factors remain the same (Parry et al., 2017).

Table 4.10 presents the projection results. The results highlight the importance of population growth, climate change, and water demand management in determining water demand in Pakistan in the future.

Table 4.10 Projections of water demand (km^3) by sectors in 2030 and 2050 using 2015 as the baseline period. Source: Parry et al. (2017)

Year	Scenario	Water demands in km^3			
		Agriculture	Domestic	Industry	Total
2015	Actual	173.0	5.1	2.3	180.4
2030	(1)	177.0	7.2	2.6	186.8
	(2)	166.0	7.2	2.6	175.8
	(3)	163.0	7.2	2.6	172.8
	(4)	177.0	8.2	4.7	189.9
	(5)	187.6	7.6	2.6	197.8
2050	(1)	182.0	10.0	2.7	194.7
	(2)	170.5	10.0	2.7	183.2
	(3)	166.0	10.0	2.7	178.7
	(4)	182.5	11.4	5.8	199.7
	(5)	206.2	10.7	2.7	219.6

4.3.5 Demand Management Approaches

Water use in the agricultural sector makes up 94–98% of total water use in Pakistan. Therefore, any attempt to manage water demand should focus on agricultural use. Water demand management is a policy that focuses on better using the existing supply instead of developing new resources (Winpenny, 1997). Therefore, water demand management aims to improve productivity in water use. In Pakistan, per unit productivity of agricultural water use is lower than in other countries in the world. For example, Pakistan grew 0.13 kilogram (kg) of cereal using 1 m^3 of water compared to 1.56 kg of cereal per m^3 in the US, 0.82 kg per m^3 in China, and 0.39 kg per m^3 in India. This indicates that the USA, China, and India are 12, 6.3, and 3 times more productive, respectively, compared to Pakistan.

Various water demand management practices can be used to increase water use productivity. Some of these approaches are described below:

Deficit irrigation is a strategy where a crop is irrigated during its drought-sensitive growth stages. Outside of these periods, irrigation is limited or unnecessary if there is some amount of rainfall. The main purpose of deficit irrigation is to maximize crop water productivity, instead of crop yields, by maximizing the productivity of irrigation water (English, 1990; Zhang & Oweis, 1999).

Technical and other interventions can be used to reduce irrigation losses. Alternatives to traditional irrigation methods, such as drip irrigation or sprinklers, can be used. In addition, precision land leveling (laser land leveling) can be used which can reduce water use by 25% while also increasing the crop yield by 23%.

Cultivation of drought-resistant crops can prove to be beneficial as these crops do not lose their biomass production in arid or drought conditions. These crops could be especially useful in avoiding production losses accompanied with deficit irrigation.

Pakistan currently produces several water-intensive crops: cotton, rice, and sugarcane (Tariq et al., 2020). Replacing these crops with less water-demanding crops will reduce the water requirements in the agricultural sector.

Soil mulching is a process of covering the soil with some material, such as plastic sheeting or organic material (leaves, wood chips, straw, etc.). This process can maintain soil moisture and thus reduce crop water requirements.

Conservation tillage is a tillage or tillage-and-planting combination used to retain at least 30% of the crop residue on the soil surface to enhance water use efficiency.

Economic measures such as establishing water markets or setting water prices. For example, during the 6 year drought in California, USA, a water market was set up where 1.048 km^3 water was sold by farmers to urban users and environmental resource agencies (Dziegielewski et al., 1993). The state government, acting as the water broker, purchased the water from the farmers at US $0.10 per m^3 and sold it at the rate of US $0.14 per m^3. Bringing market forces into action through such economic measures can lead to increased water productivity and even reallocation of water resources to more productive activities. Therefore, water markets can play an important role in managing water demand in the future. Similarly, water prices can be adjusted to manage water demand, especially as a rationing function during periods of shortages. For example, the price of water was raised 27 times over the normal price during the 1988 water shortages in Santa Barbara, California, USA, to deter uses other than the most essential ones (Ferguson & Whitney, 1996).

4.4 Water Balance

This section brings together the supply and demand for water to discuss the balance of water. Water balance will be explored in the context of climate change and the occurrence of extreme events (floods and droughts). Finally, a brief overview of the weaknesses in water governance and policies will also be identified.

4.4.1 Equating Demand and Supply

Since 1960, Pakistan's population growth rate has averaged at around 2.66%. The relatively high population growth rate and rapid urbanization have resulted in decreases in per capita water availability. Figure 4.5 shows the decreasing per capita water availability along with the increasing population. Water availability per capita was 5650 m^3 in 1951, which declined to around 1000 m^3 by 2010 and is projected to be 800 m^3 by 2025 (Yu et al., 2013). At the current level of per capita water availability, periodic water shortages are expected, whereas based on the 2025 projections, the country could soon face water scarcity (Larsen, 2011). So the gap between

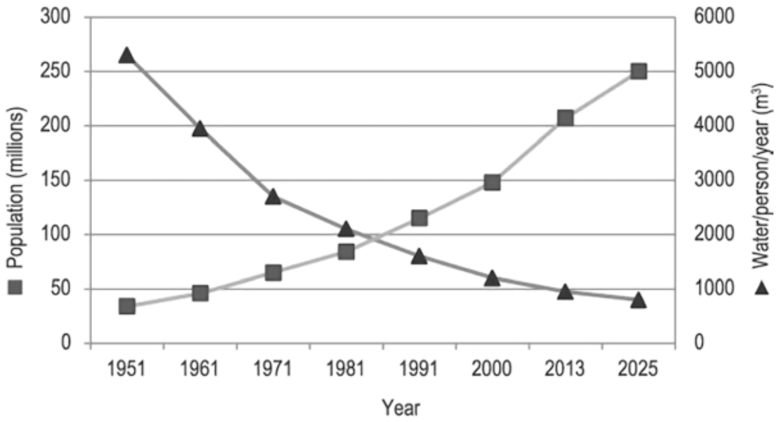

Fig. 4.5 Per capita water availability in Pakistan (m^3 per capita per year). (Source: WWF-Pakistan., 2007). Released as CC-BY

the demand and supply of water is expected to increase—a huge concern for the country.

4.4.2 Water Balance and Climate Change

Parry et al. (2017) consider the climate change scenario for the projected sectoral water demands in 2030 and 2050. In this scenario, Parry et al. (2017) assume an increase of 3 °C in the average temperature which increases agricultural water demand by 6% in 2025 and 12 to 15% in 2050. As shown in Table 4.10, in the presence of climate change, compared to actual water demand in 2015, agricultural water use will increase by 8.4 and 26.9% in 2030 and 2050, respectively, whereas domestic use will increase by 49.0 and 109.8%. Total water demand in 2030 will increase by 9.6% and by 21.7% in 2050 in the climate change scenario.

Yu et al. (2013) consider a broader range of climate change scenarios—inflows range from 10 to 90% exceedance probability and the crop water requirement corresponds to an increase in temperature ranging from 1° to 4.5 °C—to generate projections using computable general equilibrium and Indus Basin Model Revised. Figure 4.6 presents the estimated results and shows that, on average, GDP, agricultural GDP, and household income will annually decline by 1.1, 5.1, and 2.0%, respectively. In the most severe conditions—inflows at 90% exceedance probability and a 4.5 °C increase in temperature—the annual decrease in GDP, agricultural GDP, and household income is calculated to be 2.7, 12.0, and 5.5%, respectively.

These two projection results indicate the pressure climate change can pose on economic activity and future water demand, further worsening the gap in the demand and supply of water.

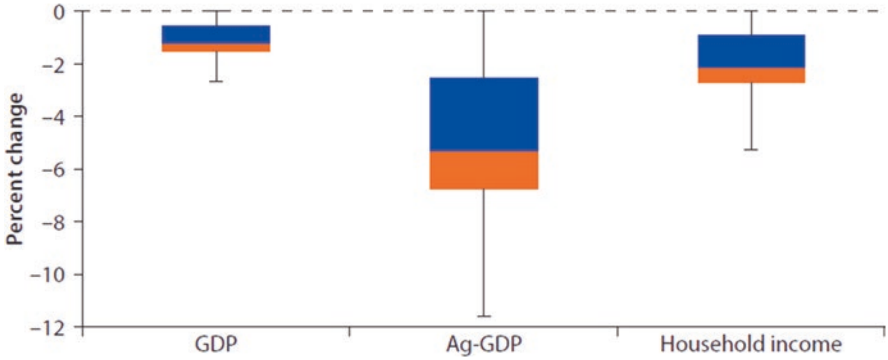

Fig. 4.6 Boxplots for impacts of climate change scenarios on GDP, agricultural GDP, and household income with second and third quantiles shown in orange and blue, respectively. CC-BY-3.0: (Source: Yu et al., 2013)

4.4.3 Role of Extreme Events: Floods and Droughts

In addition to the issues of a widening gap between demand and supply, and the effects of climate change, Pakistan also faces a declining per capita water storage. Figure 4.7 presents the projections of per capita water storage in Pakistan measured in m^3 per capita per year from 2020 to 2100. The per capita water storage decreases from around 140 m^3 per capita to roughly 70 m^3 per capita over 80 years, even when construction of additional storage is considered (Yu et al., 2013). This indicates that constructing additional infrastructure for water storage is not the solution for declining water storage.

Floods are particularly common in Pakistan because of the heavy monsoon rains over the Indus Basin. The flood of 2010 affected around 20 million people, with aftereffects lasting around 6 months (Ali et al., 2020). Since mid-June 2022, monsoon rains have caused urban and flash floods, landslides, and glacial lake outburst floods (GLOF) across Pakistan affecting more than 33 million people, with over 1.1 million houses damaged or destroyed, resulting in more than 1300 fatalities, and injuring more than 12,700 people by the beginning of September 2022, according to the National Disaster Management Authority of Pakistan. Droughts are also common, and they can affect agriculture, forestry, livestock, fisheries, banking, energy, transportation, inflation rate, and unemployment (Mazhar et al., 2015). The lower storage per capita worsens the impacts of floods and droughts. This concern may be more apparent by comparing Pakistan's storage capacity with that of other semi-arid countries as provided in Fig. 4.8. This figure shows that the USA has the highest per capita water storage among semi-arid countries, with around 40 times the per capita water storage in Pakistan.

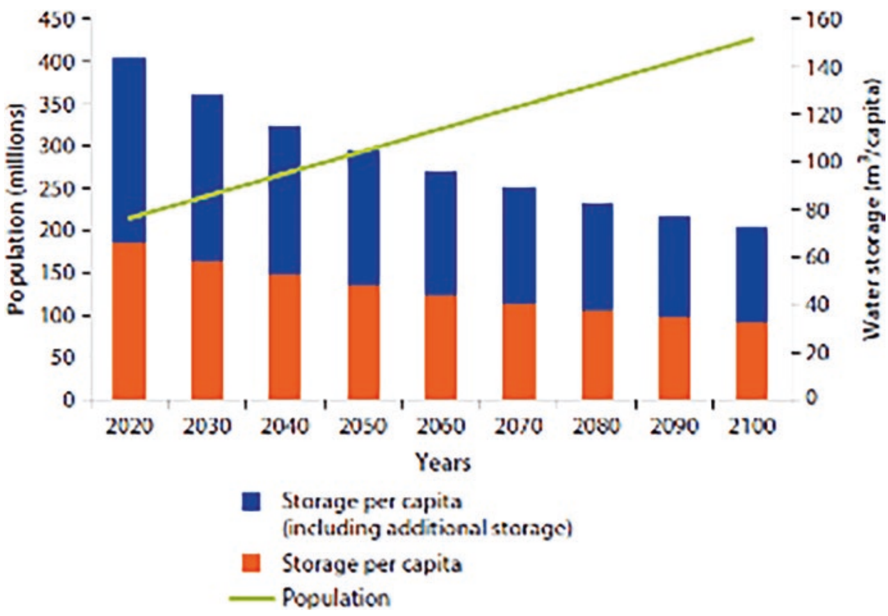

Fig. 4.7 Per capita water storage in Pakistan (m^3 per capita per year). CC-BY-3.0 (Source: Yu et al., 2013)

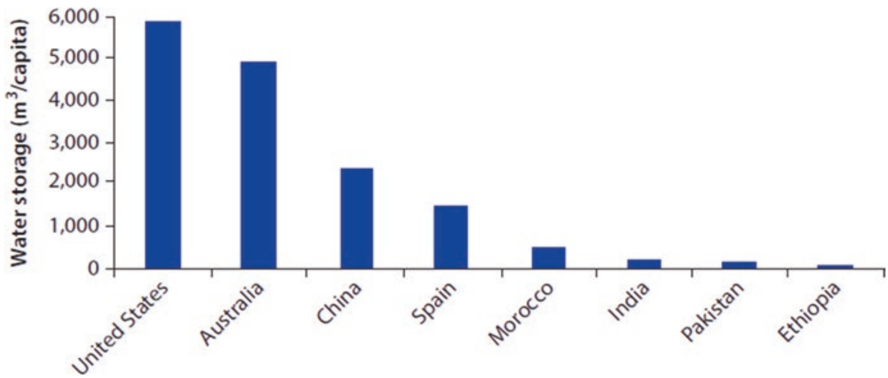

Fig. 4.8 Per capita water storage in semi-arid countries (m^3 per capita per year). CC-BY-3.0. (Source: Briscoe et al., 2005)

4.4.4 Weaknesses in Water Governance and Policies

In Pakistan, the water sector faces various institutional and policy challenges. These challenges include the need for sectoral integration (water, agriculture, environment, climate, etc.) across the country, national and provincial coordination, and resolution of interprovincial water conflicts.

The government has attempted to respond to these issues by establishing the Water And Power Development Authority (WAPDA) as a semi-autonomous agency and founding the Indus River System Authority (IRSA) for coordination between the provinces and the federal government and institutions. Moreover, the Planning Commission's Vision 2030 (GPPC, 2007) and reports of the task force on food security (GPPC, 2009) and climate change (GPPC, 2010) provide integrative analyses and recommendations.

Even with existing efforts, a lot more coordination and integration are needed across institutions along with the resolution of interprovincial conflicts to deal with the substantial issues of climate change and water, and their implications for the agricultural sector. The policy challenges are further complicated by various pressures and institutional shifts in the Indus Basin. The floods, droughts, and earthquakes have resulted in the establishment of national and provincial disaster management agencies which, however, are inadequate. Additionally, because of growing concerns regarding climate change, a national climate change policy was adopted in 2012 and, subsequently, the Ministry of Climate Change was created (Yu et al., 2013). These developments are promising but water and agricultural institutions still require additional capacity-building, integration, and coordination.

These changes occurred during the constitutional devolution from the national to the provincial level under the 18th amendment which was passed in 2010. This devolution requires stronger policy linkages and coordination between the federal water sector and the provincial agricultural and irrigation sectors. Moreover, adaptations to climate change should increasingly rely on provincial planning, management, and governance. Most of the development plans (national and provincial) continue to focus on the role of infrastructure to address such challenges even though recent studies have identified the increasing importance of improving irrigation efficiency, yields, and the irrigation revenue system especially since these relate to climate change adaptation. Water management plays an important role in agricultural productivity; however, this relationship is not comprehensively addressed in federal and provincial planning, which should be tackled in future policies related to irrigation, agricultural, and climate change policies.

4.5 Water Treaties and Accords

This section focuses on the Indus Water Treaty (IWT) of 1960 and the Water Apportionment Accord of 1991. The specifics of these are discussed briefly along with the current gaps that can be improved in the future.

4.5.1 Indus Water Treaty

After the independence of the subcontinent in 1947, east and west Punjab became part of India and Pakistan, respectively. Moreover, the states of Jammu and Kashmir, which cut across the head of the tributaries to the Indus, were placed in transitional status. This resulted in uncertainties for the development of both Pakistan's and India's irrigation systems. After intensive negotiations, with assistance from the World Bank, the countries agreed on the IWT in 1960 which led to a massive engineering and investment framework for the IBDP in Pakistan (Michel, 1967). Under the IWT, the eastern rivers of the Beas, Sutlej, and Ravi were allocated to India, and the western rivers of Chenab, Jhelum, and Indus were assigned to Pakistan. The treaty also provided specifications for any future upstream development of the Chenab, Jhelum, and Indus rivers (Yu et al., 2013).

The IWT and IBIS have reshaped the IBIS by enabling the construction of replacement works (which move water from the western rivers to the eastern rivers) in Pakistan, including the Mangla and Tarbela dams and link-canals to transfer inflows from the western half of the Indus Basin to canal commands that were formerly supplied by the eastern half (Wescoat et al., 2000).

4.5.2 Pakistan Water Apportionment Accord

The Water Apportionment Accord was agreed on by the provinces in 1991 to resolve interprovincial water conflicts. The Accord distributed the annual flows between the provinces based on a 5-year record of pre-Accord historical canal diversions. Assuming an average annual flow of 141.05 km^3 in the IBIS, the Accord allocated 69.0 km^3 to Punjab, 60.15 km^3 to Sindh, and the remaining 11.90 km^3 to be split between KPK and Balochistan (Mustafa & Wrathall, 2011). The seasonal distribution of the allocations to the provinces, based on the Accord, is provided in Table 4.11. Additionally, according to the Accord, Punjab, Sindh, Balochistan, and KPK will receive 37, 37, 12, and 14%, respectively, of the water exceeding 141.05 km^3 in any year. The Accord also set up IRSA, in 1992, to regulate and monitor the distribution of water resources to the provinces from the IBIS.

Table 4.11 Water allocation based on the Water Apportionment Accord (km^3). Source: Mustafa and Wrathall (2011)

Province	*Kharif*	*Rabi*	Total
Punjab	45.73	23.28	69.01
Sindh	41.86	18.28	60.14
KPK	4.29	2.84	7.13
Balochistan	3.52	1.26	4.78
Total	95.40	45.66	141.06

4.5.3 Gaps in the Water Treaties and Accords

Over time, the IWT has faced various challenges and pressures over the development of the upper basin to the eastern rivers (World Bank, 2012). For the case of the Baglihar Dam on the Chenab river, a neutral expert was appointed for resolution of the matter between the two countries in 2007. Similarly, the International Court of Arbitration was summoned to address Pakistan's concerns about the Kishanganga project in 2010. So far, the IWT seems to have worked reasonably even with the increase in the scale of hydropower generation in India and Pakistan. However, the IWT is expected to be tested again amid growing concerns of climate change resulting in issues related to food and water security across the two countries.

While the Water Apportionment Accord has provisions to allocate flows exceeding 141.05 km^3 between the provinces, it does not specify the mode of operation during periods of extremely low flow or the possibility of negotiated transfers among the provinces. This is concerning because, as shown in Table 4.3, in one-in-ten years the inflows to the IBIS will be lower than 141.05 km^3.

Another issue with the Water Apportionment Accord is that IRSA does not have effective methods and processes in place to regulate its political, technical, and administrative roles. This was observed in 2010 when IRSA was almost dissolved after rising tensions led to various resignations.

4.6 Water in the Regional Context

Water-related issues are discussed for the South Asian region with a focus on Afghanistan, Bangladesh, India, and Pakistan. Some data is provided to understand the current water scenario in these countries along with providing historical trends. Finally, regional successes are provided that can potentially be adopted in other countries of the region for an improved water outlook.

4.6.1 Water Resource Planning for Regional Sustainability

Water resource planning and management is a key developmental challenge in South Asia. The region is densely populated and extremely vulnerable to climate change. South Asia houses around 24% of the global population but contains only 4.6% of the world's renewable water resources (Hirji et al., 2017). The main challenge is a reliable supply of water for domestic, industrial, and agricultural use for sustaining economic growth, a growing population, urban areas, and rural livelihoods, especially in the presence of variable river flows. Due to water-related losses in agriculture, health, income, and damage to human settlements and infrastructure, the GDP growth in South Asia could decline by as much as 6% by 2050 (Hirji et al.,

Table 4.12 Ranking of climate change-related risks. Source: Hirji et al. (2017)

Country	High-risk level	Medium-risk level	Low-risk level
Afghanistan	Flash flood Landslide Riverine flood	Drought Erosion/siltation Groundwater depletion	Glacial Lake outburst flood Storm/inland storm
Bangladesh	Riverine flood Storm/cyclone Coastal floods Siltation	Erosion Drought Groundwater depletion Coastal aquifer salinization	Flash flood Landslide
Bhutan	Landslide Flash flood Glacial Lake outburst flood	Erosion/siltation Riverine flood Drought	Storm/inland storm Groundwater depletion
India	Drought Riverine flood Flash flood Groundwater depletion	Landslide Storm/cyclone Coastal aquifer salinization	Glacial Lake outburst flood Erosion/siltation
Nepal	Glacial Lake outburst flood Flash flood Landslide	Drought Erosion/siltation Groundwater depletion	Riverine flood Storm/inland storm
Pakistan	Drought Groundwater depletion Landslide	Riverine flood Glacial Lake outburst flood Flash flood Erosion/siltation Groundwater salinization	Coastal flood Storm/cyclone
Sri Lanka	Storm/cyclone Riverine flood Coastal flood	Flash flood Landslide Erosion/siltation Drought Coastal aquifer salinization	Groundwater depletion

2017). Moreover, climate change is a major concern in the region where each country faces a different climate change risk profile. Table 4.12 gives the rankings of the risks for these countries based on water-related extreme events in the past. However, it does not include the gradual changes that may arise due to climate change over time.

Improved water resources planning and management require that the region's existing water resources be used more efficiently. This may include improved water use efficiency, recycling and reuse, emphasis on demand management, and regulating the use of surface and groundwater. Moreover, a cost-effective adaptation opportunity exists in the South Asian region where the massive natural storage of the aquifers can be used effectively to deal with water shortages. However, this would require a proper understanding of the existing resources, managing and regulating the groundwater recharge, storage, and discharge, and protecting the groundwater quality.

4.6.2 Water Scenarios in Afghanistan, Bangladesh, and India

Compared to Pakistan, per capita water availability in Afghanistan, Bangladesh, and India is better. Based on the water availability per capita in 2015, provided in Table 4.13, India and Pakistan were water-stressed whereas Afghanistan and Bangladesh were not. The situation in India and Pakistan suggests the occurrence of periodic water shortages in the countries (Larsen, 2011).

The annual water usage in these countries, by sector and source, is provided in Table 4.14.

The data shows that agricultural use makes up most of the water consumption in Afghanistan, Bangladesh, India, and Pakistan; highest for Afghanistan at 98% and lowest for Bangladesh at 87.7%. Industrial water use is low in these countries with a maximum of 2.23% for both Bangladesh and India. In terms of water sources, Afghanistan, India, and Pakistan largely rely on surface water use which makes roughly 82, 70, and 66% of total water use, respectively, whereas surface water only makes around 21% of the total water use in Bangladesh. Even though Bangladesh relies heavily on groundwater, it only makes up around 2% of the total renewable water resources compared to 34, 53, and 24.8% for Afghanistan, India, and Pakistan, respectively.

Table 4.13 Per capita water availability (m^3 per capita per year) in Afghanistan, Bangladesh, Pakistan, and India in 2015. Source: World Bank (2016) Investment Reality Check, and FAO Aquastat

Country	Per capita water availability (m^3 per capita per year)
Afghanistan	2008
Bangladesh	7622
India	1458
Pakistan	1306

Table 4.14 Water usage in Afghanistan, Bangladesh, India, and Pakistan (km^3 per year). Source: World Bank (2017)

	Afghanistan	Bangladesh	India	Pakistan
Agricultural water use	20.0	31.5	688.0	172.4
Industrial water use	0.2	0.8	17.0	1.4
Domestic water use	0.2	3.6	56.0	9.7
Total water use	20.4	35.9	761.0	183.5
Surface water use	16.7	7.4	531	121.9
Groundwater use	3.7	28.5	230	61.6

4.6.3 Historical Trends of the Region

The available data on freshwater resources for Afghanistan, Bangladesh, India, and Pakistan was retrieved from Our World in Data. Figure 4.9 shows the available data on total water use in km^3 per year. It shows that total water use has increased marginally for Pakistan, has increased significantly for India, while the trend is inconclusive for Bangladesh and Afghanistan due to lack of data.

Figure 4.10 shows the trend of per capita water use in m^3 per capita per year. It shows that per capita water use has declined in Pakistan and decreases marginally for India. However, this figure does not highlight whether this decline in water use is due to lower demand or lower supply of water. Thus, it is important to observe the trend for renewable water resources in these countries.

Figure 4.11 shows the per capita renewable internal freshwater resources which refer to the renewable water resources from internal river flows and groundwater from rainfall. This shows a significant decline in the availability of internally generated water resources for the four countries since 1962. However, the figure excludes externally generated water resources, which can be misleading since internally generated water resources make roughly 72.3, 8.6, 75.7, and 22.3% of total renewable water resources for Afghanistan, Bangladesh, India, and Pakistan, respectively (FAO, 2019).

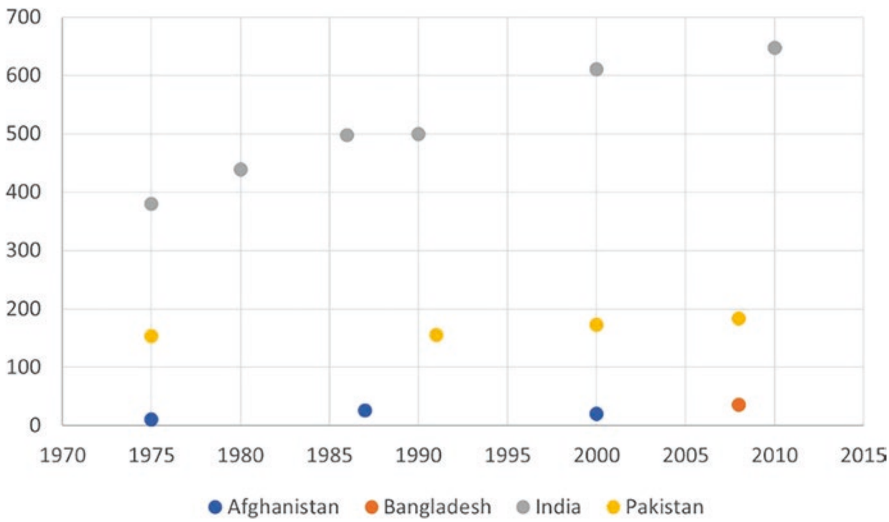

Fig. 4.9 Total water use (km^3 per year) for Afghanistan, Bangladesh, India, and Pakistan. (Source: Our World in Data-CC-BY-4.0)

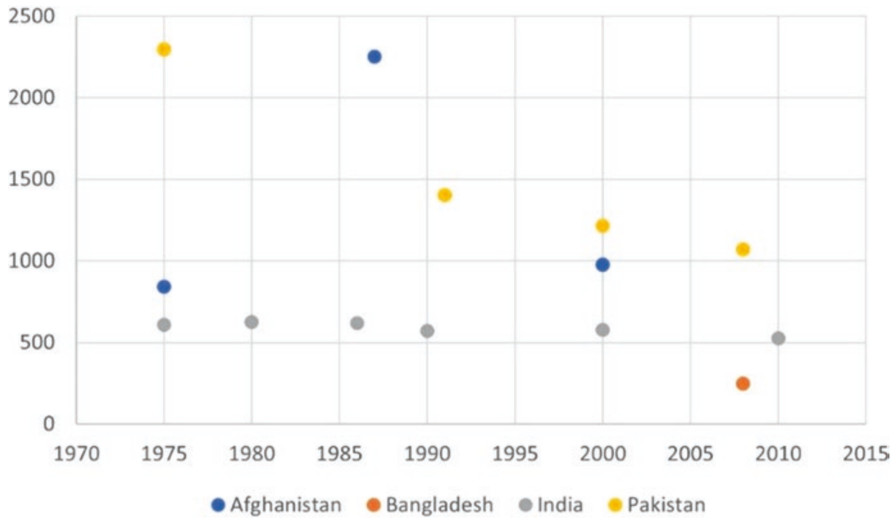

Fig. 4.10 Per capita water use (m^3 per capita per year) for Afghanistan, Bangladesh, India, and Pakistan. (Source: Our World in Data-CC-BY-4.0)

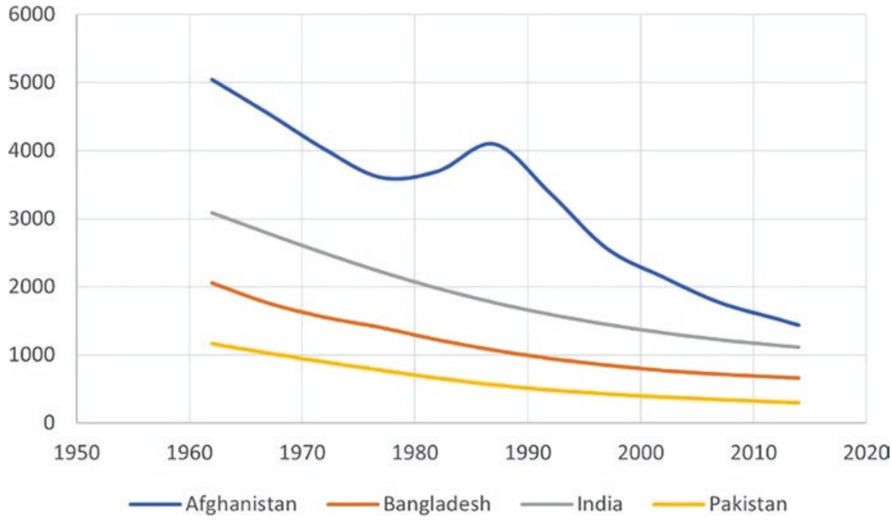

Fig. 4.11 Per capita renewable internal freshwater resources (m^3 per capita per year) in Afghanistan, Bangladesh, India, and Pakistan. (Source: Our World in Data-CC-BY-4.0)

4.6.4 Comparative Study of Regional Successes and Gaps

To combat issues related to climate change, Bangladesh, India, and Pakistan have adopted different varieties of crops. The salinity of soil is a growing concern for Bangladesh, especially in the coastal agricultural areas. To deal with this situation, Bangladesh has utilized high-yielding and salt-resistant rice varieties: CSR 26 and CSR 43 (Aryal et al., 2020). Similarly, India has introduced short-duration varieties of pigeon pea, soybean, wheat, and sorghum, which has increased the yield by 75, 15, 27, and 91%, respectively (Sonune & Mane, 2018). India has also relied on crop selection to deal with various climate change-related issues. For example, by growing sorghum in areas at a higher risk of droughts and leguminous crops in areas that are subject to erosion or excess flooding to supplement nitrogen in the soil (Satapathy et al., 2011). In Pakistan, several varieties of maize have shown reasonable tolerance to heat along with higher grain yield per unit area, compared to the regular variety of maize, under high-temperature conditions (Rahman et al., 2018). However, further improvements are still needed as other crop varieties can greatly benefit the region, especially with drought-resistant varieties of rice (Mottaleb et al., 2017; Reyes, 2009).

Rainwater harvesting is another farming practice that can help with irrigation in areas that have a water deficit. This is practiced in India (Satapathy et al., 2011) and almost 35% of the households in the coastal areas of Bangladesh rely on it (Ferdausi & Bolkland, 2000). Farmers in the riverine areas, Kirthar Range, and Tharparkar desert of Pakistan use spate irrigation, which relies on the seasonal floods to fill water storage canals, which are then used for irrigation purposes.

Aside from relying on different crop varieties, cropping patterns, or alternate methods of irrigation, some technical and agro-ecological adjustments have also been adopted. In Afghanistan, the Participatory Management for Irrigation System project has experimented since 2007 with the System of Rice Intensification (SRI) to replace the highly water-consumptive traditional method of rice cultivation. The SRI is a water-saving method which uses 25–47% less water (Barah, 2009; Wu et al., 2015; Reeves et al., 2016), which is used to enhance productivity of irrigated rice by changing the management of water, soil, and eliciting greater root growth. This can be adopted by upstream farmers to increase water availability for downstream farmers. Moreover, rice grown using the SRI matures quicker and is more resistant to heat, drought, and floods (Wu et al., 2015). In 2009, the farmers using the SRI method had an average yield of 9.3 tons per ha, which was substantially greater than the yield from traditional rice farmers (Thomas & Ramzi, 2011). Similarly, India has also relied on the SRI for rice farming (Barah, 2009). Aside from the SRI, in the Haryana and Punjab provinces of India, farmers have adopted laser land leveling to cope with the variability of rain and declining groundwater. Laser land leveling can substantially improve the efficiency of water use, by ensuring even coverage of water, which is why laser land leveling has become particularly popular in the irrigated systems of India that grow rice and wheat (Jat et al., 2015; Aryal et al., 2015).

A major water-related gap in the region is the absence of joint efforts to deal with climate change-related issues. These countries rely on the perennial rivers (Brahmaputra, Ganges, and Indus) emerging from the Himalayas. Therefore, regional cooperation and integration of climate change policies and adaptations can better resolve water scarcity issues. However, this would require a suitable and acceptable institutional framework to develop cooperation and policy linkages across the countries to manage and reduce the future impacts of climate change (Mirza et al., 2019).

4.7 Conclusion

For a comprehensive appreciation of water-related issues and the vulnerability of a country or region to climate change, it is imperative to understand the current situation of supply (based on the water resources) and demand (based on water use from different sectors) for water. This helps in identifying future issues and concerns especially related to climate change.

Identification of these issues is the first step in devising climate change adaptation to ensure sustainable economic growth, food security, and water security. In this context, the approach should be regional rather than country-specific due to the transboundary nature of the water resources. The next step is recognition of the successes and lessons learned in the region that can be utilized in improving the situation in other countries of the region.

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Chapter 5
Water Quality and Salinity

Muhammad Ashraf, Saiqa Imran, and Abdul Majeed

Abstract Water quality is one of the most important factors for any sector that uses water. However, despite its importance, it has been grossly neglected in Pakistan. This deterioration in water quality has caused human and animal health to suffer, land and water productivity to decline, and Pakistan's ability to support aquatic wildlife to decrease. The causes of this deterioration are easy to understand. They include the disposal of untreated wastewater into freshwater bodies and healthy ecosystems, a lack of understanding by both the general public and the institutions responsible on how to prevent and mitigate the effects of declining water quality, prolonged use of low-quality groundwater and, above all, poor water governance. Since the economy is largely dependent on agriculture, which consumes the most water, using poor-quality water for agriculture is a major threat to Pakistan's economy. Since approaches focused on engineering have not successfully or sustainably managed salinity—because of environmental issues and large O&M costs—it is time to learn to 'live with salinity'. This approach involves managing salinity below the root zone and using saline agriculture and saline aquaculture techniques in affected areas to improve productivity to support livelihoods.

Keywords Water quality · Untreated wastewater · Water governance · Managing salinity · Indus River Basin

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5.1 Introduction and Context

Pakistan has one of the largest contiguous irrigation systems in the world, irrigating about 17 Mha of land. This extensive network has helped develop one of the largest alluvial aquifers in the world after China, India, and the USA, and supplements irrigation supplies by over 60% and domestic water supplies by over 93%. Almost 100% of industrial water also comes from it. Groundwater has significantly contributed to increasing the overall cropping intensity in Pakistan from about 63% in 1947 to over 150% in 2015 (Khan et al., 2016).

The country is fast becoming water scarce, as annual per capita water availability has decreased from 5000 m^3 in 1947 to less than 1000 m^3 in 2005 (Ashraf, 2016). Water quantity and quality are closely linked and any reduction in water quantity has a direct bearing on overall water quality. Because of climate change, the increasing spatial, temporal and spatio-temporal variations in surface water supplies are stressing groundwater resources, leading to the salinization of irrigated areas (Ashraf, 2021). Disposal and use of untreated wastewater from municipal, industrial, and agricultural activities is one of the major sources of pollution. The twin menaces of waterlogging and salinity in the Indus Basin, which have prevented Pakistan from reaching optimal levels of land and water productivity, have already made millions of hectares of previously productive irrigated lands unproductive. The government has taken several measures—engineering-based, institutional, and legislative—to control the situation. This chapter describes the current status of surface and groundwater quality, the implications of deteriorating quality on ecosystems, the underlying issues—including the history and efforts to meet the challenges faced by the country—and suggestions for the way forward.

5.2 Situation Analysis

5.2.1 Groundwater Quality

The Indus Plain, covering about 20 million hectares (Mha), has one of the largest reservoirs of groundwater in the world. Yet it is being contaminated in many ways. Contaminated water is being disposed of in open areas, contaminants are seeping into groundwater through deep percolation, saline water and drainage effluents are being dumped into canals, and saline water is moving into freshwater zones.

In Pakistan, groundwater is contaminated from both point and non-point sources. One of the major point sources of contamination is disposal of untreated industrial and domestic waste in open ponds and water bodies. The major non-point pollution source comes from indiscriminate use of heavy amounts of fertilizers and pesticides/herbicides, which continuously adds heavy metals, trace elements, and organic contaminants to aquifers and surface water bodies. Solid municipal waste sites in all cities are a permanent source of organic and biological pollution. Liquid and solid domestic waste sites not only cause environmental hazards but also become hotspots for all kind of epidemics. The irony is that, in the absence of any safe disposal facilities, highly hazardous hospital waste also finds its way into open water bodies and groundwater.

Environmental protection departments have issued guidelines on how to manage hazardous and domestic waste. Similarly, industrial units are encouraged to install effluent treatment plants, so that these effluents do not contaminate water directly or indirectly. Unfortunately, these efforts have not been very successful, mainly because of ineffective regulations, poor implementation, and little information about the nature and extent of industrial effluents and illegally installed industrial units. There is no restriction on chemical factories that prevents them from discharging their effluents directly without treatment. However, recently in the Kasur district, the government of Punjab has commissioned a treatment plant to treat effluents from tanneries.

The native groundwater in the Indus Plain is saline because of its marine origins. Seepage from conveyance and irrigation networks has deposited freshwater layers of varying depth over the deeper saline groundwater. The depth of fresh groundwater increases when it is closer to the recharging sources and decreases the further it is from the recharging sources (Ashraf & Saeed, 2006; Ashraf et al., 2012; Iqbal et al., 2020). Pumping groundwater from such aquifers is a complex operation since excessive pumping leads to the mixing of the deeper saline water with the upper freshwater layers via up-coning. Using this saline-freshwater mix to irrigate is likely to have disastrous effects on the soil and make it less productive. Despite this issue, the growth of tubewells has mushroomed in the past few decades. While Pakistan had 20,000 tubewells in 1960, there are now over 1.2 million. This indiscriminate installation of tubewells, without any consideration of saline-freshwater interaction, has disturbed the hydro-salinity balance in the Indus Basin. Moreover, in some regions, groundwater abstraction has already surpassed safe annual yields, resulting in a decline of the water table. Because tubewells are improperly designed and installed, the cost to operate them increases and also leads to secondary salinization (Ashraf et al., 2012). Unfortunately, there is no framework in place to regulate how many tubewells are installed, their pumping capacity, or how many hours they pump. Wells are drilled based entirely on the advice of local drillers and the wishes of farmers. This has depleted groundwater and worsened water quality. Bhutta et al. (2000) have reported that the water table was declining in 26 out of 43 command areas because of excessive groundwater abstraction. Qureshi and Barrett-Lennard (1998) reported that over 70% of tubewells in the Indus Basin were pumping sodic water.

An estimated 28.2 tonnes of salts are annually brought to the surface through extensive tubewell pumping. Since most of this pumping is in Punjab, salt accumulation there is also higher (24.7 tonnes/year) than in Sindh (3.5 tonnes/year) (Qureshi et al., 2008). In Pakistan, about 6.3 Mha are impacted by salinity in some way or another, of which nearly half are irrigated agriculture. About 30% of this area is in Punjab (Qureshi et al., 2008).

Another one Mha are affected by waterlogging. Tarar (1995) reported that after a monsoon, about 4.7 Mha (30% of the irrigated area) have groundwater levels within the active root zone of 1.5 m. Punjab and Sindh have about 25% and 60%, respectively, of their irrigated areas severely waterlogged. This rising water table in turn may cause more waterlogging and soil salinity and increase drainage flow downstream. This drainage water usually transports a variety of chemicals (salts, pesticides, etc.) (Bos, 2004; Hussain et al., 2007).

Although salt accumulation in Sindh is much lower than in Punjab, there needs to be more of an effort to eliminate salts through drainage and reclaim salinized land. However, drainage water disposal is much more difficult in Punjab since the drainage effluent is reused and then disposed of in evaporation ponds usually located at the edge of irrigated lands. Moreover, drains can only handle a limited amount of water because of their location and capacity. Disposing saline effluents in rivers merely transports the salts further downstream where they can end up on irrigated land at the tail end of the system. However, this is not an environmentally friendly, long-term solution. On the other hand, since Sindh is close to the sea, this problem can be managed. In Sindh, saline effluents are discharged into the sea via the Left Bank Outfall Drain (LBOD) (Qureshi et al., 2008).

5.2.2 Surface Water Quality

River Water Quality Pakistan's water comes from a variety of sources, including rainfall, glacial melt, rivers, and groundwater. The upper reaches of the Indus River are highly turbid and torrential. The flow of water in the Jhelum and Chenab rivers decreases during the winter season with a corresponding increase in pollution. The water quality of surface water bodies in the upper Indus, the western rivers and most of the reservoirs, in spite of pollutants, was found to be acceptable both for drinking (after treatment of microbial contamination and turbidity) and for irrigation. However, in the eastern rivers water quality was not adequate because of the low flow and high pollution load from domestic and industrial wastes from surrounding cities, which increased the values of total dissolved solids (TDS), hardness, boron, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total coliforms, especially in the dry season. Similarly in low reaches of the Indus River (below Thatta and Manchar Lake), the quality of drinking and irrigation water was compromised because of pollution and higher salt content (Imran et al., 2022).

The Indus Waters Treaty of 1960 gave India full control of the eastern tributaries of the Indus River—the Ravi, Sutlej and Bias—which reduced the flow in these rivers and consequently increased pollution. In addition, the dumping of untreated municipal and industrial waste from the surrounding areas into these rivers, through 12 major drains in the Ravi river and three drains in the Sutlej river, increased the pollution load manyfold. The Hudiara Drain, originating from India, carries heavy loads of industrial and domestic effluents from India as well as from Lahore, where more than 450 industrial units are pumping untreated toxic industrial effluents into the drain at different points. This drain ultimately falls into the Ravi river at Manga Mandi (Imran et al., 2018).

This has an extreme impact on the levels of TDS, hardness, boron, COD, BOD and total coliforms in the rivers. The dissolved oxygen (DO) levels in the Ravi River drops to zero during the dry season, in which no aquatic life can survive. Very high concentrations of organochlorine pesticides (OCPs) were detected in the Ravi and Sutlej rivers at the point the river enters Pakistan, as well as at the confluence of the drain with the rivers, showing transboundry contamination (Imran et al., 2018). However, the SAR and the RSC values of the eastern rivers were within irrigation water quality standards in both seasons. The TDS level increased further downstream and from the wet to the dry season, possibly because of the increased mineral content downstream (Imran et al., 2022).

In Balochistan, no rivers have large perennial flows. In addition to the Indus Basin, Balochistan has the Coastal Basin and the Closed Basin of Kharan. The Coastal Basin is drained by the Hingol and Dasht rivers, while the Closed Basin is drained by the Pishin-Lora and other smaller rivers. After heavy rains, these rivers become raging torrents and so the quality of the surface water is still high. There are no seasonal changes in water quality in this region as are evident in the Indus System (Imran et al., 2022).

Water Quality of Reservoirs and Lakes Unlike flowing rivers, these water bodies have some contaminants, such as heavy metals and persistent organic pollutants (POPs), which settle with the suspended particles and are dissolved again whenever the volume of water changes. Pakistan has about 60 lakes and some of them are highly polluted. In Manchar Lake, many fish species have become extinct because of the pollution and especially high salinity. Manchar Lake is one of the largest living lakes in Asia. It is the floating village of Pakistan, and the only lake that is home to generations of fishermen who have been living on wooden boathouses for hundreds of years (Soomro et al., 2017). Other reservoirs and lakes are also facing the same situation. Figure 5.1 shows seasonal trends in DO levels in Pakistan's reservoirs. Restoring these lakes will improve biodiversity for lake-dependent species and promote ecotourism and agriculture.

Drinking Water Quality The Pakistan Council of Research in Water Resources (PCRWR) has been monitoring drinking water quality in major cities in Pakistan since 2002. Figure 5.2 shows the results for 29 of Pakistan's major cities. According to the survey, in 2002, more than 80% of samples were unsafe for human consumption; even with a slight improvement after 2014, more than 60% of the samples from major cities were not safe for human consumption (Fig. 5.2).

Bacteria, arsenic, nitrate, and fluoride were the major contaminants found. Another survey was conducted by the PCRWR in the rural areas of Pakistan from 2004 to 2011. Table 5.1 shows that out of 14,000 samples collected, only 2550 (18%) were found to be safe.

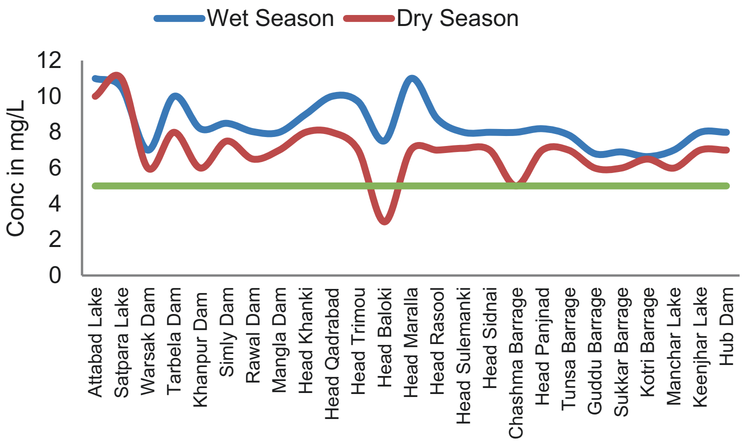

Fig. 5.1 Level of DO in major reservoirs in Pakistan. (Source: Imran et al., 2022)

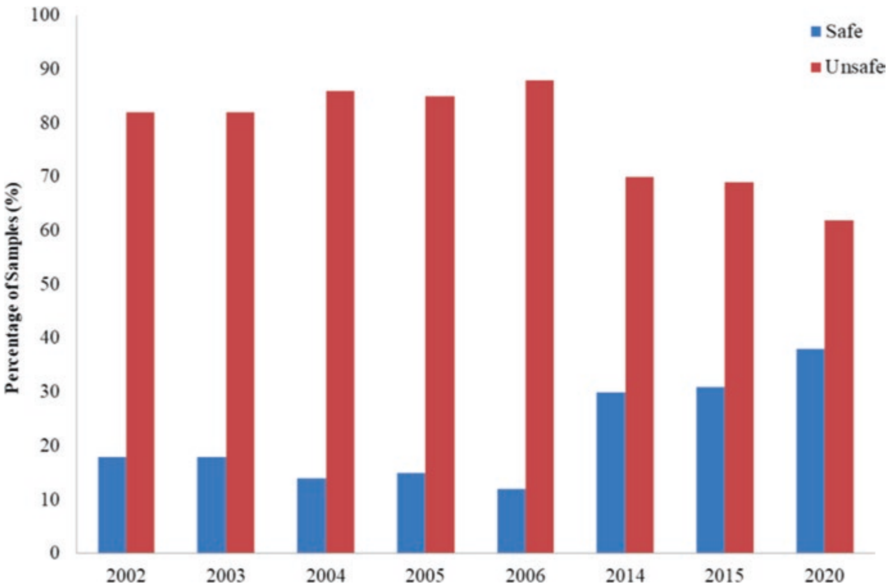

Fig. 5.2 Drinking water quality of major cities in the country. (Source: Rasheed et al., 2021)

The PCRWR also surveyed over 10,000 existing piped water supply schemes from 2006 to 2012 throughout the country. About 72% of water supply schemes were functional. Out of those 72%, only 23% in urban and 14% in rural areas were providing safe drinking water (Ashraf, 2016). The major contaminants found were microbiological with faecal coliform, arsenic, nitrate, and fluoride (Table 5.2).

Throughout Pakistan, about 57% of drinking water contamination is microbial (Imran et al., 2016). The main causes of microbial contamination are anthropogenic,

Table 5.1 Drinking water quality profile of rural areas (2004–2011). Source: Ashraf (2016)

Sr. No.	Province	Districts	Tehsils	Union councils	Villages	Samples collected	No. of water samples			
							Safe		Unsafe	
							No.	%	No.	%
1	Punjab	12	49	1227	2090	10,440	2183	21	8257	79
2	Sindh	3	12	54	149	745	212	28	533	72
3	KP	4	6	211	240	1200	89	7	1111	93
4	Balochistan	4	12	54	298	1465	05	0.3	1460	99
5	Federal Capital Area	1	1	21	30	150	61	41	89	59
Total		24	80	1567	2807	14,000	2550	18	11,450	82

Table 5.2 Water quality assessment of water supply schemes (2006–2012). Source: Ashraf (2016)

Province	Districts surveyed	Water supply schemes	Surveyed water supply schemes			Functional	Samples safe for drinking (%)	
			Total	Urban	Rural		Urban	Rural
Punjab	33	4100	3883	746	3137	2725	17	23
Sindh	22	1300	1247	123	1124	529	5	5
KP	16	3000	2203	474	1729	1710	63	26
Balochistan	14	1600	1034	480	554	968	20	13
GB/AJK/FATA	10	2000	1794	18	1776	1379	8	2
Total	95	12,000	10,161	1841	8320	7311	23	14

such as open defecation, untreated municipal wastewater, dumping high fecal loads in surface water bodies which cause contamination of groundwater sources through deep percolation. This problem is exacerbated by the lack of treatment facilities at water sources and distribution systems. High arsenic contamination was found in the groundwater along the Indus Basin, particularly in southern Punjab and upper and Central Sindh (Imran et al., 2016; Podgorski et al., 2017).

Other contaminants, such as nitrates and fluorides, in drinking water are also commonly found (Imran et al., 2016). High levels of nitrates were detected in groundwater sources near agricultural areas in the Khyber Pakhtunkhwa (KPK), Rawalpindi, and Islamabad districts, especially in rural areas. One possible reason for this is nitrates from fertilizers and animal manure leaching into the aquifer via heavy rains or flood irrigation. The groundwater of rural areas in the Lahore and Kasur districts, some areas of Balochistan, and the Thar and Cholistan deserts are contaminated with fluoride. In these areas the alkaline pH is accelerating the dissolution of fluoride in the groundwater.

Poor-quality drinking water is responsible for waterborne diseases, accounting for about 50% of diseases and 40% of deaths in Pakistan, according to community health studies (Daud et al., 2017). These diseases are particularly dangerous for children under the age of five. In 2017 alone, diarrheal diseases caused 74,647 deaths, almost half of which were children under the age of five (Ritchie et al., 2018). And this public health crisis is responsible for an economic loss of 25–28 billion PKR annually—approximately –1.44% of the country's GDP (Bashir et al., 2021).

5.2.3 Waterlogging and Salinity

Salinity and waterlogging are usually referred as irrigation-induced problems and generally occur together. However, they are actually two rather different processes that do not always happen simultaneously. For instance, irrigation during the rainy season may lead to waterlogging with no salinization, whereas salinization may occur with no waterlogging when there is insufficient fresh water to counteract leaching and/or there is no drainage. Both problems impact surface and groundwater quality.

Waterlogging and salinity are major bottlenecks to raising land and water productivity to optimal levels. Moreover, secondary salinization caused by shallow groundwater tables and the use of poor-quality groundwater for irrigation has further aggravated the problem of salinity. The problem was most serious in the 1970s–1980s, when 20–30% of irrigated land was at risk of lost productivity. (Bhutta & Smedema, 2007).

Waterlogging is more harmful to crop production when there is a shallow saline groundwater table because salts build up in the soil surface through capillarity. Over 1.30 Mha of the country's irrigated land is estimated to have severe surface salinity with 20% affecting lands in Sindh and less than 2% in Punjab. In 2010, between 20,000 ha and 40,000 ha of cultivated land was reported to have been lost (Anjum et al., 2010). Out of the 79.61 Mha of Pakistan's total area, 4.5 Mha are salt-affected (Aslam, 2016; Qureshi & Perry, 2021).

5.3 Infrastructure Development

In 1975, the Drainage and Reclamation Institute of Pakistan (DRIP) of the PCRWR was established with the mandate to conduct research on salinity control, land reclamation, irrigation, drainage, and seawater intrusion. DRIP played an important role in mitigating these twin issues (waterlogging and salinity) in the Lower Indus Plain (LIP) and worked extensively on horizontal (tile) drainage systems between 1985 and 2017. Apart from tile drainage, the Institute has conducted different research studies on the reclamation of salt-affected soils and conjunctive management of water (1989–2011).

The government enacted several laws including the WAPDA Act of 1958, the Provincial Irrigation and Drainage Authorities Act of 1997, and the Pakistan Environmental Protection Act of 1997 and initiated six salinity control and reclamation projects (SCARPs) and Left Bank Outfall Drain & Right Bank Outfall

Drain projects. The International Waterlogging and Salinity Research Institute (IWASRI) was created in 1986 under WAPDA primarily to conduct research and gather scientific information on waterlogging and salinity. This had been preceded by various other institutions/projects like the Mona Reclamation Experimental Project (MREP), SCARPs Monitoring Organization (SMO), and the Lower Indus Water Management and Reclamation Research Project (LIM).

The 18th Amendment to the Constitution of Pakistan turned water into a provincial matter. A variety of institutions—including tehsil municipal administrations (TMAs), water and sanitation agencies (WASAs), public health engineering departments (PHEDs), and provincial environment protection departments (PEPD)—are responsible for managing the water quality in their respective provinces, with the Capital Development Authority (CDA) managing water quality in the Islamabad Capital Territory (ICT). While provincial irrigation departments do handle salinity to a certain extent, there is no dedicated department at the provincial level that is responsible for managing it.

At the federal level, PCRWR and IWASRI are working on water quality and salinity research. While PCRWR maintains a database on drinking water, surface water, and groundwater quality (including salinity) at the national level, IWASRI and its subsidiary organizations maintain an extensive database on waterlogging and salinity.

Based on research conducted in the country in 1950s, tubewells and surface and subsurface drains were installed between the 1960s and 2000 to control waterlogging and salinity. The government has promoted using gypsum, acids, and organic matter to reclaim sodic soils. Over the last few decades, there has been research on saline agriculture such as how to profitably integrate the natural abilities of plants, animals, fish, and insects and how to improve agricultural practices. However, the fruits of this research have not been able to reach farmers because of poorly administered extension services. Therefore, farmers need to be properly trained and there should be mechanisms in place to effectively disseminate knowledge on how to reclaim sodic soils.

5.4 Projects to Control Waterlogging and Salinity

Various types of drainage projects from the 1960s onward were undertaken to control waterlogging and salinity. They are briefly described below:

5.4.1 SCARP Projects

SCARPs were introduced to reduce waterlogging and salinity by pumping groundwater to lower water tables (SCARP I to SCARP VI). In fresh groundwater (FGW) areas, tubewells were installed both as drainage and as additional irrigation.

However, in saline groundwater (SGW) areas, drainage tubewells were installed. On the left bank of the River Indus in Sindh, Scavenger Wells (SW) were installed, separately pumping freshwater for irrigation and saline water for drainage. In areas where tubewells were not feasible, sub-surface tile drainage systems were installed to control waterlogging and salinity (Table 5.3).

5.4.2 SCARP Transition Pilot Project

The 14.9 million dollar SCARP Transition Pilot Project (STPP) was implemented from 1987 to 1990 in the SCARP I area of Khanqah Dogran, Punjab. The objective was to reduce the financial burden of SCARP Projects on the government by transferring the responsibility for fresh groundwater pumping in the SCARP area from the public to the private sector. The SCARP tubewells were gradually replaced by private tubewells.

5.4.3 National Drainage Program

The National Drainage Program (NDP) was launched with the goal of minimizing drainage surplus and facilitating the eventual evacuation of the saline drainage effluent from the Indus Basin to the Arabian Sea. The program component included institutional reforms, sector planning, research, investment, coordination, and supervision (Table 5.4).

Table 5.3 Summary of SCARP Projects. Source: (Basharat & Rizvi, 2016)

Province	Gross area (Mha)	CCA (Mha)	Surface drains (km)	Subsurface drainage						
				Tubewells (Nos.)			ID (km)	Tile drainage		
				FGW	SGW	SW		Length (km)	Area (Ma)	
									GCA	CCA
Punjab	4.19	3.73	3402	8065	1985	–	6	2810	0.1	0.07
Sindh	2.72	2.31	9031	4190	1587	361	154	2046	0.04	0.04
KPK	0.36	0.36	971	491	–		–	7756	0.27	0.06
Balochistan	0.07	0.07	322	–	–		–	–	–	–
Total	7.35	6.39	13,726	12,746	3572	361	160	12,612	0.40	0.16

FGW Fresh Groundwater, *SGW* Saline Groundwater, *SW* Scavenger Wells, *ID* Interceptor Drains

Table 5.4 Major activities under NDP

Activities	Extent of work
Remodeling/Extension of existing surface drains	10,000 km
Number of saline groundwater wells rehabilitated/replaced	1150
Installation of pipe drains in new areas	100,000 ha
Number of watercourses lined in saline groundwater areas	1050
Construction of interceptor drains	400 km
Reclamation of waterlogged-areas through biological drainage	16,000 ha
Number of tubewells installed in fresh groundwater areas transferred to farmers	1500
Rehabilitation and modernization of canal command in pilot areas	One in each province
Mobile pump stations	3,10

5.4.4 Private Sector Groundwater Development

The private sector groundwater development project (PGWD) (1997–2001), worth 33.5 million USD, aimed to increase the scope and productivity of Punjab's irrigation and drainage subsector and increase farmers' incomes. Over 6700 community tubewells (CTWs) were set up and independent monitoring declared 85% of these to be "successful." Two thousand Water User Associations (WUAs) were established. Promising new agricultural technologies have been introduced to conserve resources, such as zero tillage for wheat on 60,000 ha (over 2800 sites), and laser-guided land levelling on 22,250 hectares.

5.4.5 Left Bank Outfall Drain Project (LBOD)

The Left Bank Outfall Drain (LBOD) provides drainage disposal for an area of 516,000 ha and subsurface drainage for about 392,000 ha on the left side (east bank) of the Indus river at the cost of US $150 million from 1986 to1997. The project comprised: (i) remodeling and completion of the main outfall drain to the sea; (b) construction of surface and subsurface drainage systems over about 970,000 ha; (iii) remodeling and rehabilitation of associated irrigation works; (iv) consulting services and training; and (v) a monitoring and impact evaluation. This project involved the construction of 1950 km-long surface drains, 2000 tubewells, 5000 structures, and 2000 km-long buried pipes for subsurface drainage and improvement in irrigation supplies (Qureshi et al., 2008). Under the LBOD project, 361 scavenger tubewells were installed in two districts (Nawabshah and Sanghar) in Sindh at a cost of US$12.75 million which was funded by the World Bank.

5.4.6 Right Bank Outfall Drain Project (RBOD)

The Right Bank Outfall Drain (RBOD) was a long-term project to drain out sewerage and water from towns and agricultural lands on the right bank of the River Indus. It was designed to dispose of saline water directly into the Sea. However, the project was never completed because of issues such as land acquisition, stakeholder conflicts, and price increases.

5.5 Outcome and Impacts of Drainage Projects

In addition to controlling waterlogging and salinity, the SCARP tubewells provided additional irrigation water. The additional water and the associated drainage increased cropping intensity from 84% to 115% in most SCARP areas. Qureshi et al. (2008) presented a detailed review on the causes, sources, and levels of waterlogging and salinity in the Indus Basin. While drainage systems were initially effective in lowering water tables, poor operation and maintenance and insufficient disposal facilities to drain saline effluent hindered its long-term success. Later on, there were more problems with sump pumps not working and the blockage of surface drains. However, the lack of farmers' participation, high operating costs, frequent energy failures, and repeated waterlogging resulted in the shutting down of these tubewells. The STPP, NDP, LBOD, and RBOD were only partially successful because of poor planning, a lack of coordination among the stakeholders, and the absence of participatory and integrated approaches. In a nutshell, while tubewells, tile drains, and surface drain systems solved many of the area's waterlogging problems, overall there have been various sustainability issues with these solutions. Most of these stem from poor operation and maintenance and lack of participation and ownership from farmers in these interventions.

5.6 Policies and Standards

Policies are the guiding principles when solving problems and Pakistan is very good at developing policies. However, the implementation of these policies leaves much to be desired. Following we give details of some policy documents and policy instruments which directly or indirectly relate to water quality and salinity.

5.6.1 Pakistan Water Vision 2025

Pakistan's Water Vision 2025 addresses issues of water security and aims to increase water storage capacity, improve agricultural efficiency by 20 percent, and ensure that all Pakistanis have clean drinking water by 2025.

5.6.2 National Water Policy, 2018

The National Water Policy, adopted in 2018, highlights the importance of monitoring water quality across the country through a well-established network, developing water quality zones, protecting water bodies, recycling and reusing wastewater, and applying the "polluter pays" principle. The policy places special emphasis on solving waterlogging and salinity concerns by using a holistic approach at the basin level, developing a national surface drainage system, and reusing drainage effluent.

5.6.3 National Drinking Water Policy, 2009

In September 2009, the government of Pakistan approved the National Drinking Water Policy, the goal of which is to provide safe drinking water to every Pakistani by 2025 affordably, efficiently, and sustainably. This will improve quality of life by reducing the incidence of death and illness caused by waterborne diseases.

5.6.4 National Environmental Policy, 2005

In 2001, the Pakistan Environment Protection Council approved the National Environmental Action Plan (NEAP), to address environmental problems including air pollution, water and sanitation, land, forestry and climate change. The National Environment Policy, prepared under NEAP and published by the Ministry of Environment in 2005, provides an overarching framework for addressing the pollution of freshwater bodies and coastal waters. It also aims to protect, conserve, and restore the country's environment in order to improve quality of life through sustainable development. In addition, it issues guidelines on how different sectors can take action.

5.6.5 Environmental and Water Quality Standards

National Environmental Quality Standards (NEQS) were established in 1993. They became effective in the year 2000 after being revised in 1999. In accordance with the Environmental Protection Act 1997, any entity that discharges contaminated effluents causing air or noise pollution that exceeds the limit set by NEQS is responsible for paying the government pollution reversal charges. However, government functionaries are hesitant to enforce these laws, either because of the difficulty in monitoring emissions or political pressure. Similarly, the National Standards for Drinking Water Quality (NSDWQ) were adopted in 2010 to improve the quality of drinking water. The process was completed in 3 years through intensive consultation, discussions, and the use of reading literature provided by the WHO and the Ministry of Health.

5.6.6 Provincial Water Policies

Some provincial governments also have policies that address water quality and salinity. Balochistan was the first province to have substantial water policies, such as the Ground Water Rights Ordinance in 1978, the Integrated Water Resources Management (IWRM) Policy in 2006, and the Balochistan Environmental Act in 2012. The government of Punjab has approved Drinking Water Policy 2011, Water Policy 2018, and Punjab Water Act 2019. Similarly, KPK has approved Drinking Water Policy 2016, IWRM Strategy 2019 and Water Act 2020. Sindh's drinking water and other water policies are currently undergoing the approval process. In addition, other policies that affect water quality and salinity have also been passed, such as local government, environment protection and irrigation and drainage laws. However, there have been some challenges to implementing these policies fully.

5.7 International Obligations—SDGs

In 2016, Pakistan's Parliament unanimously approved the adoption of Sustainable Development Goals (SDGs) as part of the national development agenda. SDG 6 seeks to ensure safe drinking water and sanitation for all, focusing on the sustainable management of water resources, wastewater and ecosystems, and acknowledging the importance of an enabling environment, which means the need for all stakeholders—governments, civil society and the private sector—to work together in true partnerships for the realization of the agenda.

To achieve these goals, the Ministry of Planning, Development & Special Initiatives (PD&SI), and the Planning & Development departments of provincial governments, with the support of UNDP, launched a 5-year joint project titled

"National Initiative for Sustainable Development Goals" to institutionalize the SDG 2030 Agenda. A federal SDG Support Unit was established at the PD&SI ministry with the mandate to ensure early institutionalization of SDGs and to provide coordination and advisory services to the provinces, respective ministries and line departments. However, even after 4 years, no baselines for any indicator except drinking water quality have been established. Without appropriate baselines, it is impossible to set realistic targets or allocate adequate resources to achieve the SDG 6. There is a fear that if Pakistan keeps on its current path, it will not be able to achieve the 2030 milestones set by the SDG.

5.8 Lessons Learnt

5.8.1 Management and Governance Issues

Most water quality issues are because of poor water governance. TMAs, WASAs and PHEDs suffer from a lack of capacity in terms of both human resources and management systems. Wastewater and waste management remain serious challenges while in major cities, service providers lack capacity, infrastructure, and working systems, including functioning water treatment plants (Cooper, 2018). In the absence of adequate capacity and authority, the responsible institutions cannot regulate and enforce the environmental regulations to protect water resources from deteriorating.

5.8.2 Financial Instability in Water Supply Infrastructure

It is unfortunate that most organizations operate on the principle of "build-neglect-rebuild", with the major focus on infrastructure development. Service delivery or maintenance is generally not on their agenda. Organisations that provide services are not financially viable because low revenues and tariffs cannot cover the O&M costs. Revenue collection is generally lower in rural areas than urban areas (Cooper, 2018). There are almost no laws punishing those who do not pay water bills or have illegal water connections, thus leading to deterioration in the quality of drinking water.

5.8.3 Over-Exploitation of Groundwater Sources

Increased population, urbanization, industrialization, and agricultural activities have put great pressure on groundwater resources. As a result, groundwater is being depleted in all canal command areas, particularly in the middle and tail reaches, and in almost all urban centers. With increased water table depths, installing and operating tubewells has become highly uneconomical (Ashraf, 2021). Moreover, this also causes the pumped water to deteriorate.

5.8.4 Control of Salinity and Waterlogging

There has been limited success in managing salinity because most efforts have focused almost exclusively on engineering solutions. Although these solutions help increase cropping intensities and yields, they fail to stop the emergence of similar environmental problems in adjacent areas. Thus, controlling salinity also requires selecting salt-tolerant crop varieties and using improved cultural practices (Ashraf & Saeed, 2006).

5.9 The Way Forward

More investment in Pakistan's water sector is the best way to advance sustainable social and economic development while ensuring that nobody is left behind. And for this, Pakistan needs a sound implementation framework of the National Water Policy in order to balance socio-economic development, management, and conservation of the country's water resources to address the challenges of climate change. Various action items are described in the following sections.

5.9.1 Control Wastewater Pollution

Disposal of untreated wastewater is one of the most important factors responsible for poor water quality and environmental degradation. Wastewater needs to be treated at the source, with polluters being held responsible for cleanup, adopting the "polluter pays" principle, since large centralized wastewater treatment plants have mostly failed because of poor operation and maintenance and a lack of capacity.

When water pollution originates from diffused sources, such as agricultural use of fertilizers and pesticides, best environmental practices should be used to minimize non-point source pollution. For example, giving farmers guidance on what fertilizer to apply, along with how much and when, can prevent or reduce pollution in water bodies.

5.9.2 Investment in Wastewater Infrastructure

Investing in wastewater treatment infrastructure is necessary to protect the water quality of available freshwater. It is especially important that the wastewater from municipalities, cities and industries should be treated before it is dumped into water bodies. At present, only Islamabad, Karachi, and Faisalabad have limited wastewater treatment facilities, and these are only partly functional because they do not have the financial resources to meet operation and maintenance costs and technical capacity. Therefore, massive investment is required to install and operate sustainable wastewater treatment facilities. Further, a mechanism needs to be developed to recover O&M cost from beneficiaries.

5.9.3 Rehabilitation of Existing Water Supply Infrastructure

Most water supply infrastructure is outdated. This is one of the major causes of drinking water quality deterioration. Therefore, the existing infrastructure for domestic water supply needs to be revamped with proper water treatment facilities. The domestic water supply should be metered and consumers should be charged based on the water they consume. This is a necessary improvement in the management of the water supply schemes that are required for financial sustainability.

5.9.4 Regular Monitoring of Drinking Water Sources

If you cannot monitor a thing, you cannot improve it. Therefore, regular monitoring of the water supply at the consumers' end is very important. It should be separate from the service providers, as a regulator cannot be a monitor. This would also help provide data to policy makers and planners to develop effective plans to maintain, manage, and restore drinking water quality as well as for SDG 6 reporting.

5.9.5 Enforcement of Water and Environmental Legislations

The Pakistan Environmental Protection Act 1997 is a regulatory framework for pollution control. But there are still significant administrative weaknesses, including unclearly defined roles for relevant institutions, work plans and targets, and ineffective coordination and communication between federal, provincial, and local administrative entities. The Federal Ministry of Climate Change and responsible provincial EPA departments need to enforce the legislative measures. The industrial sector should also be compelled to treat its wastes before discharging into water bodies.

5.9.6 Rain Water Harvesting and Artificial Ground Water Recharge

Increased urbanization is responsible for reduced recharge into the aquifers. In the absence of recharging, urban flooding becomes intense, as has recently been seen in Karachi and Lahore. It is important to make rainwater harvesting and groundwater recharge an integral part of any water development scheme intended for water supply. This would not only help recharge the aquifers but also help reduce the frequency of urban flooding. PCRWR has developed simple and smart technologies and practices for rainwater harvesting and groundwater recharge and demonstrated them throughout the country. Some organizations, such as the Capital Development Authority (CDA), have started taking up this concept. However, such interventions should be made part of groundwater regulations.

5.9.7 Control Waterlogging and Salinity

In order to achieve sustainable irrigated agriculture and improve farmers' livelihoods, it is necessary for more people to work together, at both the private and public levels, to manage salinity and waterlogging. Salinity is a dynamic rather than static phenomenon. It is difficult to remove it from the system. However, it can be managed by using salt tolerant crops and saline aquaculture. Going forward, we need focus on enhancing research capacity on certain aspects of engineering, reclamation, and biological approaches. In addition, we need to focus on the most seriously affected areas, building the capacity of farmers through efficient irrigation practices, introducing groundwater extraction regulations, and promoting saline agriculture.

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Chapter 6
Groundwater Governance in Pakistan: An Emerging Challenge

Ghulam Zakir-Hassan, Catherine Allan, Jehangir F. Punthakey, Lee Baumgartner, and Mahmood Ahmad

Abstract Water is an essential ingredient for life on this planet; major human civilizations settled along waterways. Control of water has remained central to all rulers. Water was under the jurisdiction of the national/federal government until the 18th amendment in the constitution of Pakistan in 2010. Groundwater has also become vitally important as demand for it has increased over the years in order to fill water supply-demand gaps and to safeguard against climate changes. Currently, surface water can irrigate only 27% of Pakistan's land, while the remaining 73% is irrigated directly or indirectly with groundwater. Punjab uses around 90% of the country's total extracted groundwater and is thus its food basket. Groundwater has become a source of drought mitigation and has thus helped in bringing a green revolution in the IRB. Uneven spatial and seasonal availability of surface water coupled with unplanned, unregulated, and poorly governed use of groundwater has resulted in multifarious and complicated water issues in the country, such as the over-mining of aquifers in freshwater areas, waterlogging and salinity, deterioration of quality, increasing energy use and overall extraction costs and interprovincial disputes. Climatic changes have aggravated the situation. After the 18th amendment, water policy was subject to the provinces and they have started to promulgate relevant

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policies and regulatory framework. Punjab has taken the lead in this area. This chapter encapsulates the recent policy paradigm shifts by the Punjab government to combat the challenges of water scarcity. Current initiatives by the Punjab government, including the Punjab Water Policy 2018, Punjab Water Act 2019, Punjab Local Govt Act 2019, The Punjab Khal Panchayat Act 2019, Punjab Local Govt Ordinance 2021, Punjab Water Resources Commission 2021, Punjab Water Services Regularity Authority 2021, have been discussed and evaluated as to how they can be helpful in mitigating the water crisis.

Keywords Groundwater extraction · Tail-end farmers · Open access regime · Water policy in Pakistan

6.1 Introduction

The use of groundwater in Pakistan—as in many other parts of the world—has risen rapidly over the past half century, bringing some prosperity but also new and now pressing problems of management and governance. In this chapter we consider the current situation with regards to groundwater governance by first situating Pakistan's groundwater use in the broader contexts of global water use and the country's total water use. The surface and groundwater challenges are then presented, with the contention that management and governance in Pakistan require an integrative approach. With these challenges in view, the policy, economic, and environmental perspectives of managing groundwater in Pakistan are considered, with Integrated Water Resource Management (IWRM) presented to integrate these issues in the context of rapidly changing policies.

6.2 Groundwater in the Global Context

Groundwater is a significant component of the hydrological cycle and is the largest source of fresh accessible water on the earth (Gleeson et al., 2020; Reinecke et al., 2020). Groundwater is the most important share of the water resources in many countries (Gorelick & Zheng, 2015). For example, in Tunisia 95% of water used is from groundwater sources, while in, Belgium it is 83%, and in the Netherlands, Germany and Morocco it is 75% (Gleeson et al., 2020). While groundwater is used in industrial and domestic sectors (Chesnaux, 2012), most of the 750–800 billion m^3/year of global groundwater withdrawals are used for agriculture (van Engelenburg et al., 2017; Shah, 2007). Groundwater is particularly important for countries with arid and semiarid climates, including southern and western areas of the United States of America, parts of Africa, Spain, Greece, Iran, India, and Pakistan (Shah et al., 2007; UNESCO, 2012). The unsustainable use of groundwater is a big threat for humanity (FAO, 2016), with overextraction essentially mining aquifers (Kahsay et al., 2018; Shrestha et al., 2020).

Groundwater pumping in the South Asian regions accounts for about one-third of global extraction (WB, 2020). The introduction of small pumps and drilling rigs in the 1970s brought a revolution in groundwater irrigation which the then-existing water administrations were unfamiliar with (Shah et al., 2006). For example, until the 1960s, India had been a minor user of groundwater, but the number of private tubewells increased from 150,000 in 1950 to 19 million in 2000; and by 2008 India was extracting 220–230 billion cubic meters per year (BCM/year) (Shah, 2009). This enabled India's groundwater-irrigated area to increase 178% between 1970 and 1999**.** Another example is Bangladesh, where groundwater contributes to 18.6% of GDP, and 80% of its population rely on groundwater for drinking and irrigation (Bhattacharjee et al., 2019).

Pakistan has been blessed with a large groundwater aquifer under a surface area of 16 million ha in the Indus Basin (Khan et al., 2017; LEAD, 2016). Groundwater in Pakistan has become source of livelihood and a safeguard against climate change, although it remains a poorly understood resource (Lytton et al., 2021; Mekonnen et al., 2016). Because of its ever-increasing use—indeed, mining—of aquifers, Pakistan has become the fourth largest user of groundwater after India, the United States, and China (Qureshi & Perry, 2021), with groundwater contributing about 45% of crop water requirements. It has thus attained a significant role in the national economy and in rural livelihoods (Hassan et al., 2019).

6.3 Groundwater in the IRB

Shah et al. (2007) points out that for millennia shallow wells and muscle-driven lifting devices have commonly been used in many parts of the world. In British India (which included current-day India, Pakistan, and Bangladesh), groundwater was used for over 30% of irrigated land even in 1903, when only 14% of the total cropped area was irrigated. During the 1970s, the introduction of pumping and drilling machinery, along with other factors (Fig. 6.1), gradually increased the amount of groundwater being pumped in the Indus Basin to the present alarming levels. Groundwater provides some resilience against climatic changes and their impacts like droughts and floods. It has helped in increasing the cropping intensity in the country from about 63% in 1947 to more than 120% in 2018 (Hassan et al., 2019; Qureshi & Ashraf, 2019). Groundwater is now being pumped by about 1.2 million (M) tubewells (Fig. 6.2) to meet 60% of irrigation water demand, over 90% of drinking water and almost 100% industrial water requirements (Qureshi & Ashraf, 2019).

While groundwater use can be beneficial, excessive extraction of groundwater impacts negatively on the social and economic development of the nation. These impacts include deterioration of groundwater dependent ecosystems and depletion of surface water resources. This depletion leads to increasing depth of wells, higher pumping costs, hence more energy consumption, higher costs of production and greenhouse gas release. The quality of groundwater is also impacted, including

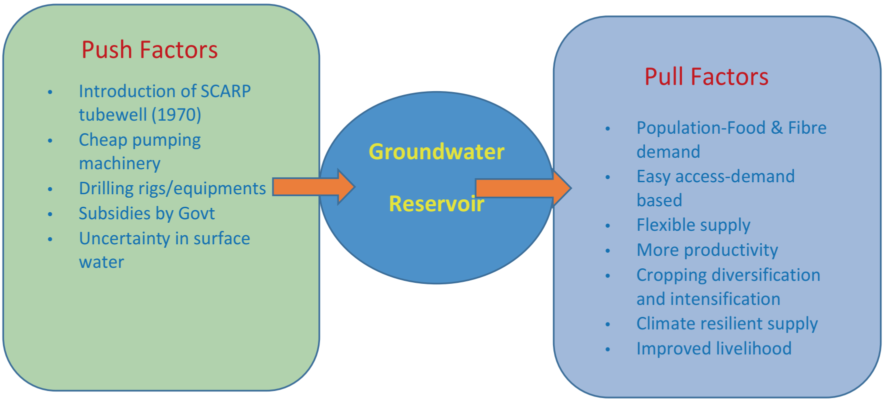

Fig. 6.1 Factors in the increasing use of groundwater in Pakistan. Source: modified from Shah et al. (2007)

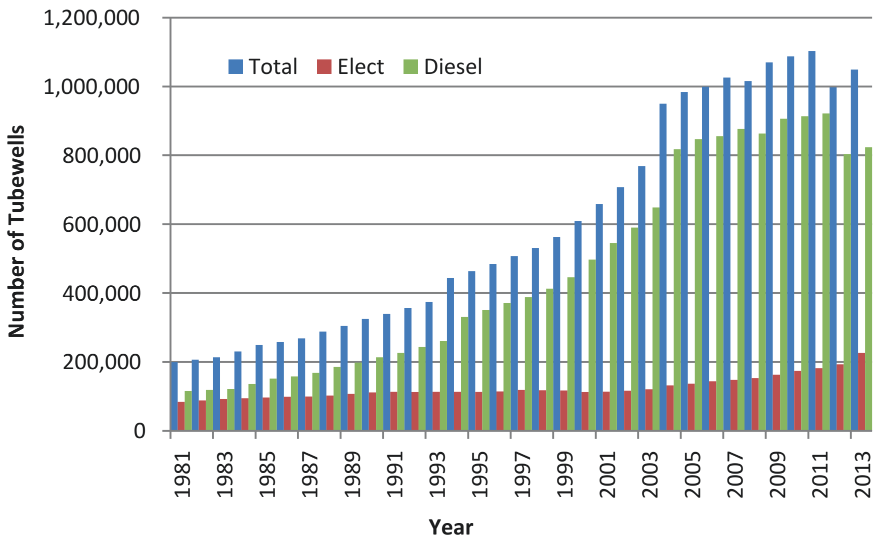

Fig. 6.2 Growth of private tubewells in Pakistan. (IRI, 2019b)

through saline intrusion from brackish groundwater areas, and sea water intrusion in coastal aquifers. Salinization and land subsidence reduces farm incomes. Additionally, competition among users and consumers results in social and political stresses and conflicts (Qureshi, 2018; Shah et al., 2007).

6.4 Poor Management of Infrastructure

Agriculture meets the growing demands for food and fiber for humans. The basic pre-requisites for successful agriculture include land, water, seeds, fertilizer, sunlight, and the labor or machinery. Irrigation is delivering water to where it is needed to support plant growth in agricultural fields. From an overall perspective, delivering water for irrigation entails the following components: (a) storage (dams/reservoirs); (b) diversion of water (barrages); (c) conveyance of water (canals); (c) distribution and application of water (water courses) to fields; and (d) drainage or removal of excess water from fields (drains) (PID_MIP, 2016). Successful irrigation systems require a network of infrastructure from the large, e.g., dams and barrages, right down to farm-scale watercourses, via canals and distributaries, minors, subminors, water courses, drains, escapes, flood-bunds (levees), small dams, and wetlands of various size. In Pakistan the infrastructure is centuries old and needs periodic maintenance. Although irrigators pay for their access to water, generally the fees coming into the system are much less than what is needed to cover the maintenance and operation costs; that is the government subsidizing Pakistan's surface irrigation system.

Groundwater infrastructure generally consists of different types of wells and pumps. Speaking historically, these include step-wells, Persian wheels, hand pumps, open/dug wells, and tube-wells. The type of structure varies from site to site, depending on the when it was built, what the underground water levels were, how much demand there was for groundwater, the type of aquifer and the quality of the groundwater, along with other factors such as the social, cultural and financial circumstances of the communities in which they were built.

Current groundwater pumping technology in Pakistan includes centrifugal pumps, submersible pumps, and deep vertical turbines. Groundwater energy sources include diesel (either by tractor or diesel/petrol engine) and electricity, with solar energy becoming more because of diesel costs and interruptions to the electricity supply. In contrast with the centralized surface water system, ownership in much of the groundwater infrastructure is dispersed. The number of tubewells is increasing, with current estimates suggesting that Punjab alone has 1.2 million private tubewells, mostly installed by farmers (Fig. 6.2). These extract about 50–62 BCM of groundwater annually.

Another, relatively new practice in the groundwater system is the monitoring of the network for levels and quality. Both WAPDA and the provincial irrigation departments are involved in this monitoring.

6.5 Public Perception and Cultural Aspects of Groundwater

While groundwater can be considered a public good, its hidden nature often leads it to be treated as private property. Countries approach ownership of groundwater through their own legal frameworks, with the result that it is often the case that the owner of the land has the right to extract it. In Islamic law groundwater is considered a public good, but the ownership of a well entails ownership of a certain amount of adjacent land called *harim,* or the forbidden area (Caponera & Alheritiere, 1978). As per Easement Act 1882 (Govt of India, 1882), groundwater under an aquifer belongs to the owner of land. It is not well understood that groundwater is a common pool resource (CPR) (Mbeyale et al., 2006). Because groundwater is mostly out of sight, the size of the resource and threats to it are often poorly understood—indeed to some it seems an infinite resource. This reduces the apparent urgency for action to manage groundwater better.

Many researchers like such as Agrawal (2001) and Ostrom (1990) have demonstrated that self-governance by communities—developing and enforcing their own rules and regulations for management of CPRs—can be more operative and effective on sustainable basis. They can decide as to who, when, where, and how a particular CPR can be used. (Meinzen-Dick et al., 2018) have described a pilot study in the Andhra Pradesh state of India in which groundwater was considered to as a CPR just like other natural resources, such as forests and fisheries.

6.6 Poor Economic Goals

The problems related to overuse of water, groundwater depletion, water logging and salinity highlighted in the above section are symptoms of much deeper problems embedded in policy and institutional failure both in the agriculture and water sectors (Ahmad et al., 2000). The "value" of groundwater currently reflects the cost of on-farm extraction, and this is complicated by the range of government subsidies and price distortions. For example, until 1991, Pakistan had metered electricity tariffs for irrigation tubewells, but in response to farmer complaints a flat tariff for the irrigation tubewells was introduced (Qureshi, 2018). Farmers in general supported this, since a flat tariff enabled higher pumping rates and longer hours. While this was to reduce pilfering and meter tampering, it also tends the water markets to seriously undervalue groundwater.

This policy failure is reflected in underpricing groundwater, as reflected in the investment and energy costs and the collection of only part of those costs (Kemper et al., 2004). Institutional failure is reflected in open access and a "race to the bottom" and market failure is embedded in rarely accounting for the external and opportunity costs.

Indian Punjab Guidelines for Groundwater Extraction and Conservation

The Punjab Water Regulation and Development Authority in Punjab India published the "Punjab Guidelines for Groundwater Extraction and Conservation" which shall apply to all commercial and industrial water users in the state of Punjab. Agriculture being the main user (95), the implementation mechanism is being proposed through any Water User or group or association of Water Users at their own level. Such Water Users shall earn appropriate Water Conservation Credits which shall effectively reduce their volumetric Groundwater Charges. The scheme incentivizes farmers through appropriate Water Conservation Schemes for water conservation in important sectors such as agriculture, groundwater recharge, urban rainwater harvesting, industrial wastewater treatment and reuse, and rural wastewater management. The tool proposed include conservation credits by water saving in existing crops; replacing paddy cultivation with other crops that consume less water.

A few examples are provided from the guidelines that identify feasible interventions (technologies or practices) that result in water saving, and thus cost-saving and also improve crop competiveness. For example, by delaying paddy transplanting to June 25th or later can result in water savings of 100–200 mm or 1000 to 2000 m^3 per hectare. Similarly, alternate wetting and drying, with a maximum water depth of 50 mm in the paddy field could result in saving 150–250 mm or 1500–2500 m^3 of water per hectare. Rice paddies can also be replaced with crops that consume less water in the *kharif* season. For example, planting maize could save a whopping 10,000 m^3 per hectare, while pulses pulses (moong bean) could save 11,000 m^3 per hectare.

For wheat and rice zones (also relevant with regards to Pakistan) the use of small irrigation plots (6–8 plots per acre) for wheat can save up to 35 mm or up to 350 m^3 of water per hectare. Sowing wheat directly in standing paddy stubble, using zero-till drills such as Happy Seeder or Super Seeder, have been documented to save up to 70 mm or up to 700 m^3 per hectare. And the most desirable intervention—furrow irrigation in bed-planted wheat—can be a major game changer by saving up to 75 mm or 750 m^3 of water per hectare.

This box also supports the case being made in Chap. 8 for a major paradigm shift in agriculture development—from traditional agricultural practices that waste water and degrade our soils to ones that look for nature-based or Regenerative Agriculture solutions. This can also, as discussed in Sect. 4.2, build on opportunities of the Punjab Local Govt Ordinance 2021 (GoPb_LG&CD, 2021).

Source: Adopted from Punjab Water Regulation and Development Authority 2020 "Punjab Guidelines for Groundwater Extraction and Conservation," Chandigarh.

6.6.1 Three Policy Responses to the Challenges with a Focus on Groundwater

Institutional reform requires a change in mindset; policy must move from business-as-usual to benefit-sharing mechanisms between provinces so that the needs and priorities of all provinces are met by the new water management legislative and institutional frameworks.

Policy is implemented partly through rules and regulations The existing regulatory framework in Pakistan deals mainly with the operation of the surface water/canal irrigation network. **We list** the policies and regulatory frameworks for water sector in Pakistan elsewhere in this chapter.

Prior to 2018, there was no comprehensive regulatory and policy framework to facilitate integration. However, current instruments such as the National Water Policy 2018 (GoP, 2018) and Punjab Water Policy 2018 (GoPb_PID, 2018) cover the development, exploitation and protection of groundwater resources thoroughly.

Punjab's government has enacted Punjab Water Act 2019, which deals with surface and groundwater in integrated mode under IWRM framework. This act envisiges the registration, licensing, permits, and pricing for groundwater.

Effective responses to the multiple challenges presented above require multiple and integrated approaches. Policy reform should seek to enable:

(i) improved coordination of surface and groundwater planning and management
(ii) better understanding of groundwater resources, including recharge management
(iii) increased awareness of groundwater issues in the general population
(iv) improved economic levers
(v) improved on-farm water use efficiency
(vi) integrated action (IWRM)

Major Water Laws and Policies in Pakistan

Federal/National Level

- The Easements Act of 1882
- Land Improvement Loans Act (1883)
- The Constitution of Pakistan 1973
- The Pakistan Water and Power Development Authority Act (1958)
- Indus Water Treaty (1960)
- Water Apportionment Accord (1991)
- Indus River System Authority (IRSA) Act (1992)
- Pakistan Environmental Protection Act (1997)
- Pakistan Water Vision 2025 (2001)
- Pakistan Water Resource Sector Strategy (2002)
- National Environment Policy (2005)

(continued)

National Sanitation Policy (2006)
National Drinking Water Policy (2009)
18th Amendment in the Constitution of Islamic Republic of Pakistan
Pakistan Water Vision/Framework for action 2025 (2010)
National Climate Change Policy (2012)
Pakistan Climate Change Act (2017)
National Water Policy (2018)
Provincial Level
The Canal & Drainage Act (1873)
Punjab Minor Canals Act (1905)
Soil Reclamation Act (1952)
On Form Water Management Ordinance (1981)
Punjab Water-User Association Ordinances (1981)
Water Apportionment Accord (1991)
The Punjab Irrigation and Drainage Authority Act (1997)
Punjab Government Rules of Business (2011)
Punjab Water Policy (2018)
Punjab Water Act (2019)
Local Level
Punjab Development of Cities Act 1976
Punjab Local Government Act (2019)
The Punjab Village Panchayats and Neighborhood Councils Act (2019)
The Punjab Local Govt Ordinance 2021
Punjab Khal Panchayat Act (2019)

While the new policies demonstrate a desire for more holistic and integrated management, implementation is still a work in progress. The actions taken by Punjab's government, discussed in Sect. 3.1, test ways to best implement new national and provincial policies.

6.7 Punjab Government – Some Recent Responses

6.7.1 Improving Coordination of Surface and Groundwater Planning and Management

Different steps have been and are being taken by the Punjab government to manage groundwater in conjunction with surface water, taking into account best practices around the world. A water resources zone has been created within the PID to monitor and help in regulating groundwater. The following steps have been taken:

(i) Monitoring of groundwater (level and quality) biannually and mapping throughout the Punjab province
(ii) Establishment of Punjab Water Resources Commission
(iii) Establishment of Punjab Water Services Regularity Authority
(iv) Establishment of Water Resources Zone in PID

6.7.2 A Better Understanding of Groundwater Resources and Recharge Management

6.7.2.1 Resource Assessment

To properly manage groundwater, it is imperative to properly assess the nature of the aquifer and its potential. The Punjab government is taking steps to monitor, manage, and regulate groundwater resources to use it sustainably. In Punjab about 3000 piezometers were installed in 2006 and onward to monitor groundwater levels in canal command areas, which is about 50% of the area of the province (IRI, 2019b; Zakir-Hassan et al., 2020). These steps include:

(i) Monitoring/ mapping/modelling
(ii) Geo-referencing of all tubewells in the Punjab
(iii) Strengthening of groundwater monitoring network (addition of 2000 observation points to cover the reaming areas and fill the gaps in existing network)
(iv) Introduction ICTs in monitoring loggers, sensors, and transmitters to improve the quality and frequency monitoring system in the province
(v) Demarcation of basin/subbasins (Fig. 6.3)
(vi) Development of hydrogeological zones

6.7.2.2 Resource Protection and Conservation

To sustainably use groundwater, it is of the utmost importance that it is assessed, protected, and regulated. In this respect, PID has executed some important research studies through thee Irrigation Research Institute (IRI). A few are mentioned in Table 6.1.

6.7.3 Increased Awareness of Groundwater Issues in General Population

Another step in raising awareness for stakeholders was a series of national seminars and six field workshops on groundwater governance and management that were held throughout Punjab. A few examples are given in Table 6.2.

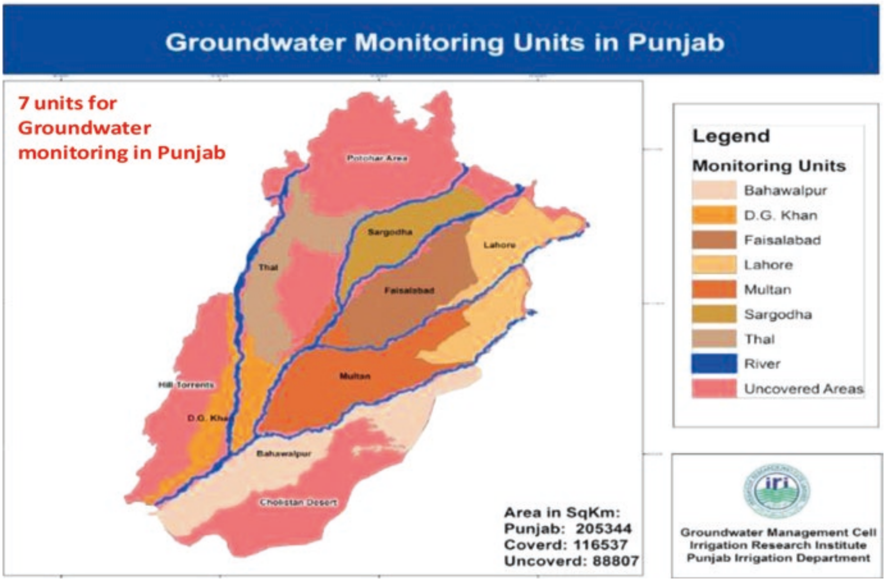

Fig. 6.3 Hydrological Zones in Punjab for groundwater management. (IRI, 2015)

6.7.4 *Integration*

The Punjab Water Act 2019 has been formulated and promulgated within an IWRM framework (GoPb-PID, 2019). All water resources are treated as one source and all demands/consumers have been assigned a priority for water, allocated according to the Punjab Water Policy (GoPb_PID, 2018). Dealing with each water resource (canals, rainfall, groundwater, rainfall, wastewater) in isolation leads to the uneven and unequitable distribution of water resources over time and space. The government is taking action to integrate functions: for example, management, regulation, and governance have all been entrusted to the department responsible for surface water resources. This means that all concerned stakeholders are working together under one umbrella—a body comprising of 22 departments headed by the Chief Executive of the Province i.e., the Punjab Water Resources Commission. This is the first time in Pakistan's history that a high-level body has been established in the province, which is evidence of ownership by the government and makes water a priority on its agenda.

6.8 Improved Economic Levers

Water discourse can be redefined in terms of unbundling land and water rights. Pricing policies could be developed to enable farmers to meet their crops' water needs while also restricting unnecessary exploitation of groundwater.

Table 6.1 Research studies from Irrigation Research Institute (IRI)

Sr#	Title of research study/report	References
i.	Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan:	Punthakey et al. (2021b)
ii.	Improving groundwater management to enhance agriculture and farming livelihoods: Integrating web and mobile based applications for groundwater management:	Khan et al. (2021)
iii.	Improving groundwater management to enhance agriculture and farming livelihoods: Groundwater model for the lower Bari Doab Canal, Punjab, Pakistan.	Anjum et al. (2021)
iv.	Recharge of aquifer for groundwater management in Punjab (old Mailsi Canal project)	IRI (2020b)
v.	Feasibility of rainfall harvesting for artificial recharge of groundwater	IRI (2019a)
vi.	Artificial aquifer recharge by rainwater harvesting at experimental Research Station Thokar Niaz Beg Lahore	IRI (2020a)
vii.	Historical sustainability of groundwater in Indus Basin of Pakistan:	Hassan et al. (2019)
viii.	Sustainable use of groundwater for irrigated agriculture: A case study of Punjab, Pakistan	Hassan and Hassan (2017)
ix.	Impact of drainage effluents on groundwater quality—a case study from Lahore Pakistan	Zakir-Hassan et al. (2017)
x.	Plastic pollution, canal irrigation and groundwater contamination in Punjab, Pakistan	Zakir-Hassan et al. (2021)
xi.	Environmental issues and concerns of groundwater in Lahore	Zakir-Hassan et al. (2016)
xii.	Research studies on artificial recharges of aquifer in Punjab.	IRI (2013)
xiii.	Groundwater investigations for water supply to FDA-city housing scheme Faisalabad	IRI (2012)
xiv.	Research studies on artificial recharge of aquifer in Punjab; preliminary activities for identification of potential sites for recharging of aquifer in Punjab	IRI (2009)
xv.	Seepage measurement and soil investigation from channels proposed for lining under PPSGDP: Punjab private sector groundwater development project (PPSGWDP	IRI (1998)
xvi.	Lining of distributaries and minors in Punjab; canal seepage and groundwater investigations: JICA-funded study	IRI (1996)
xvii.	Groundwater behaviour in Rechna Doab-Punjab- Pakistan	IRI (2015)
xviii.	Impacts of flood on groundwater – Example shown in Fig. 6.4	IRI (2016) and Zakir-Hassan et al. (2021)
xix.	Awareness raising and capacity building of FOs/farmers regarding “groundwater governance and management in Punjab”	IRI (2017)

Table 6.2 Workshops given to raise awareness among stakeholders

Seminars/Workshops	Location	Date
Seminar on the use of geosynthetics as canal lining material	IRI Lahore Auditorium	28-05-2013
Seminar on groundwater issues and way forward	IRI Lahore Auditorium	10-06-2013
Seminar on groundwater governance and Management in Punjab	IRI Lahore Auditorium	25-10-2017
Three Nos workshop on groundwater issues and Management in Punjab	Kamalia, District Toba Tak Singh	28-11-2015
	Pir Mahal, District Toba Tak Singh	20-02-2016
	Pabbarwala Disty, District Faisalabad	23-04-2016
Three Nos workshop on groundwater issues and Management in Punjab	Nai wala Bangla, District Sahiwal	25-11-2017
	Farooqabad, District Sheikhupura	9-12-2017
	Ada Musafir Khana, District Bahawalpur	21-12-2017

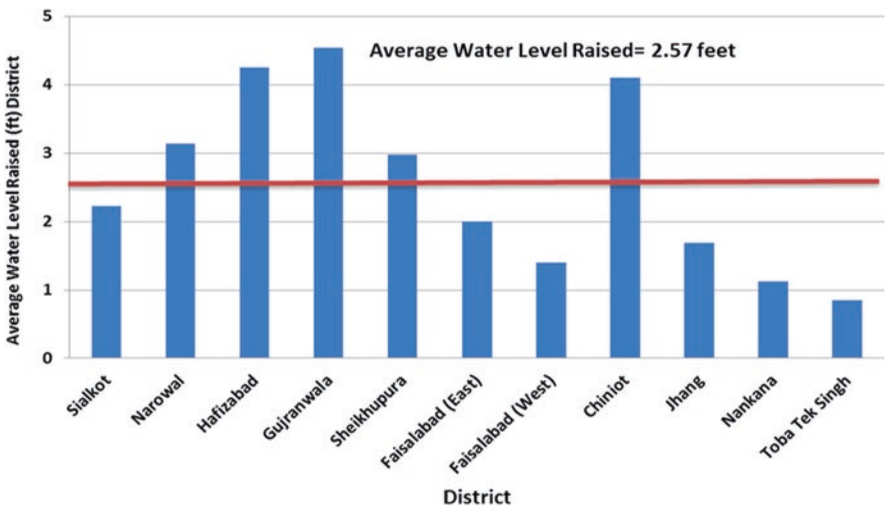

Fig. 6.4 Impact of flood 2014 in Rechna Doab area in Punjab, Pakistan

There is some movement towards clearer pricing signals. The flat tariff policy for tubewells was discontinued in 1999 and a flat-cum-metered tariff was introduced in 2000. The new incentive policy was designed to set a different tariff schedule, with fixed-cum-variable pricing—in addition to a cost per unit, consumers were charged a flat rate of approximately Rs. 400, Rs.700, or Rs.1050 per month for 5-, 7- and 10-horsepower motors, respectively. So the government is moving to a more rational pricing policy to cover not only the financial cost (fixed cost) but also the economic cost (the variable part), thus minimizing the risk of water overuse. The case study of Oman illustrates how it is moving towards monitoring,

Case Study: Smart Meters—The Case of Oman

In 1992, the government of Oman took an important step towards groundwater monitoring that included (1) performing a national inventory of installed tubewells, with GPS locations for each (2) considering the possibility of groundwater monitoring through individual quotas. The law or regulatory decree (MD 264/2000) stipulates that "The Ministry shall determine the quantity of water to be taken from each well," thus moving a step forward in their ability to monitor the wells and regulate how much water is extracted. The idea is that farmers use sanctioned water to grow more high value crops and use groundwater storage as a hedge against drought.

The feasibility of the above-mentioned policy was evaluated using the MODFLOW groundwater simulation model. The results revealed that the Net Present Value of measuring and monitoring groundwater extraction using climate smart water meters was $790 million (41,332/ha/year) with an internal rate of return of 93%—a very good return on the investment. Further, the research shows that the sustainable use of aquifers results in a 20% reduction in groundwater extractions, with a change in cropping pattern and 42% of the least efficient farmers exit farming when they have the option to convert the land for other uses. (Zekria et al., 2017).

Pricing irrigation groundwater is not politically feasible, nor is increasing electricity prices. A number of researchers argue that the best solution is to allocate groundwater shares to each farmer according to farm size and historical cropped area. Oman's case, in which 40 farms have benefitted from the installation of intelligent energy and water meters. The objectives are to reduce the cost of monitoring, to allow weekly/monthly observation of groundwater abstraction and send early alerts to those farmers who are in danger of exceeding their allocated water quota. India is a success story and an example for other regions/countries that are facing groundwater depletion. The successful farmer-managed groundwater systems initiative, Andhra Pradesh Farmer Managed Groundwater Systems (APFMGS), offers useful lessons on participatory groundwater management.[1] Collective action has resulted in sustainable ground water management, reductions in cost, and more growing of high value crops. While we in Pakistan continue to promote rice and sugarcane, we cannot justify growing either of them in conditions of water scarcity, unless we ration water use in agriculture, and more specifically for these two thirsty crops.

[1] Participatory Ground Water Management in AP; Draft Outline of the legal framework emerging following discussions with the Principal Secretary, RD, Govt of AP on 10th August.

It is often suggested that creating water rights and a water market would alleviate the problems of water allocation, availability, and accessibility, but the question is whether it would lead to water saving. This is true especially where water rights are not well defined or enacted. Pakistan provides an interesting case: while water markets are illegal, more than 70% of farmers trade water on the watercourses to meet scarcity and improve supply (World Bank, 1994). In Pakistan, given its social setup, the paramount concern is that legalizing water trading would add to the existing inequity between upstream and downstream users and so from that perspective, putting a value on water rights is not desirable. It is hard to stop illegal water markets for urban supply since there is much more willingness to pay in urban areas than in agriculture. Even if a regulatory structure was set up to manage the sale of water, underground markets will still exist. One must weigh these negative externalities against the expected benefits from this policy shift, keeping in view the facts on the ground. We should focus more on whether water rights should be tied to the land or whether they can be traded separately.

In summary, the energy pricing and load shedding policies have shown to play an important role in controlling overexploitation of groundwater; in addition, farmers who purchased water from tubewells with diesel pumps found them to be more reliable than tubewells powered by electricity. The introduction of water metering, though costly (though the cost is coming down) is a prudent policy option in order to ration water use in agriculture. In order to implement water metering, agencies must have the authority to enforce compliance on tubewell owners and formulate incentives to enforce metered tariffs.

6.9 Improved on Farm Water Use Efficiency

Inefficient use of water in agriculture is a big challenge for Punjab, since agriculture consumes more than 90% of total water resources while contributing only 22% to GDP.

Steps to Improve the Water Use Efficiency at Farm Level

(i) Groundwater Management to enhance agricultural farming community participation in water management
(ii) Reliability in water supplies
(iii) Water recycling/reuse at least in agriculture sector
(iv) Precision irrigation and precision agriculture
(v) Improved crop varieties and cropping pattern- climate smart agriculture
(vi) Improved cultural practices – shift from lower to higher value crops
(vii) Highly efficient irrigation techniques- shift from flood method
(viii) Rationalization of surface water allowances- in conjunction with groundwater

6.10 Integrated Water Resources Management (IWRM) Framework

6.10.1 Integrated Water Resource Management (IWRM) Policy Framework

Integrated Water Resources Management (IWRM) is "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (UN_Water, 2007). In its broadest sense, IWRM is a framework which mainstreams water for all needs of the society, involves stakeholders in decision making, integrates demand and supply management, invokes gender issues, accounts for the all water sources—waste, sewage, groundwater, rainfall, surface-water—faces the challenges of climate change that lead to floods and droughts, and to adaptive management. IWRM is understood to be crucial for water stressed areas to enable water management to integrate with the broader contexts of economic and social development and of environmental sensitivity (Chéné, 2009). Critics of IWRM have noted that it is vague in conceptualisation and difficult to find in practice. For example, (Biswas, 2008) attempts at IWRM in South Africa, (Colvin et al., 2008) in Nepal (Birendra et al., 2021), and Ghana (Frimpong et al., 2021) partly bely these claims, but also reveal just how difficult integration is. These and other works show that while specific tools are necessary, IWRM also requires an emphasis on governance (Katusiime & Schütt, 2020; Lankford & Hepworth, 2010). Food security and IWRM are strongly linked as IWRM can contribute significantly to meeting the increasing demands of food security. IWRM can allocate water for agro-ecosystems as well as for non-agricultural ecosystems (Boelee, 2011).

The Integrated Water Resource Management (IWRM) approach requires defining hydrological basins and sub-basins which are clearly represented/demarcated with boundaries and empowered basin/sub basin authorities, with sustainable financial resources and an IWRM framework. The challenge of implementing the IWRM approach is to bring about institutional and legal processes, decision-making, transparency, and a participatory approach to decision making as opposed to the traditional departmental hierarchical decision making process. Main components of IWRM framework are shown in Fig. 6.5.

6.11 Groundwater Governance Might Work Within an IWRM Framework: A Case Study in Punjab

6.11.1 Punjab Groundwater Management

With a large groundwater aquifer, Punjab is the most blessed province of Pakistan. Only 1.23 billion cubic meter (BCM) of groundwater was pumped in 1965, using the old Persian wheels. This has increased to 55 BCM at present, through 1.2

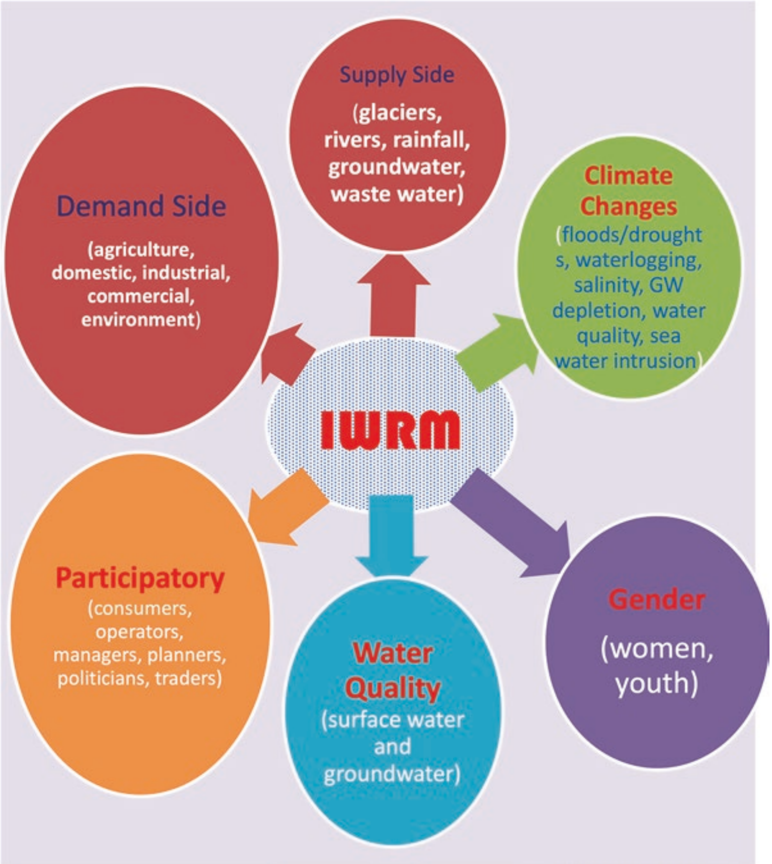

Fig. 6.5 Components of complex IWRM framework

million private sector tubewells (GoPb_PID, 2018). After the introduction of SCARP tubewells in the public sector during the 1960s, there were rapid advances in private groundwater development in Punjab (PID_MIP, 2017). To monitor rising groundwater tables, some 14 lines of open water table observation wells (called provincial well-lines) were installed across the doabs of Punjab by WAPDA. Some records of groundwater levels are available from 1882, but systematic observations started in 1886 (Bhutta & Smedema, 2007).

In 2006, the Punjab Irrigation Department also installed about 3000 observation wells (OWs) and started monitoring the depth to water table twice in a year: pre and post monsoon season. Locations of these observation wells are shown in Fig. 6.6.

Observation wells have been installed only in Punjab's canal command areas leaving large geographical areas of the province unmonitored, as shown in Fig. 6.7. These observation wells have also deteriorated over time. Some points have become dry because of falling water levels and presently only 50% of the wells are active. Because of this, human error, and the low frequency of sampling, the data from this monitoring is unlikely to represent the true impact on aquifers by recharge and discharge components.

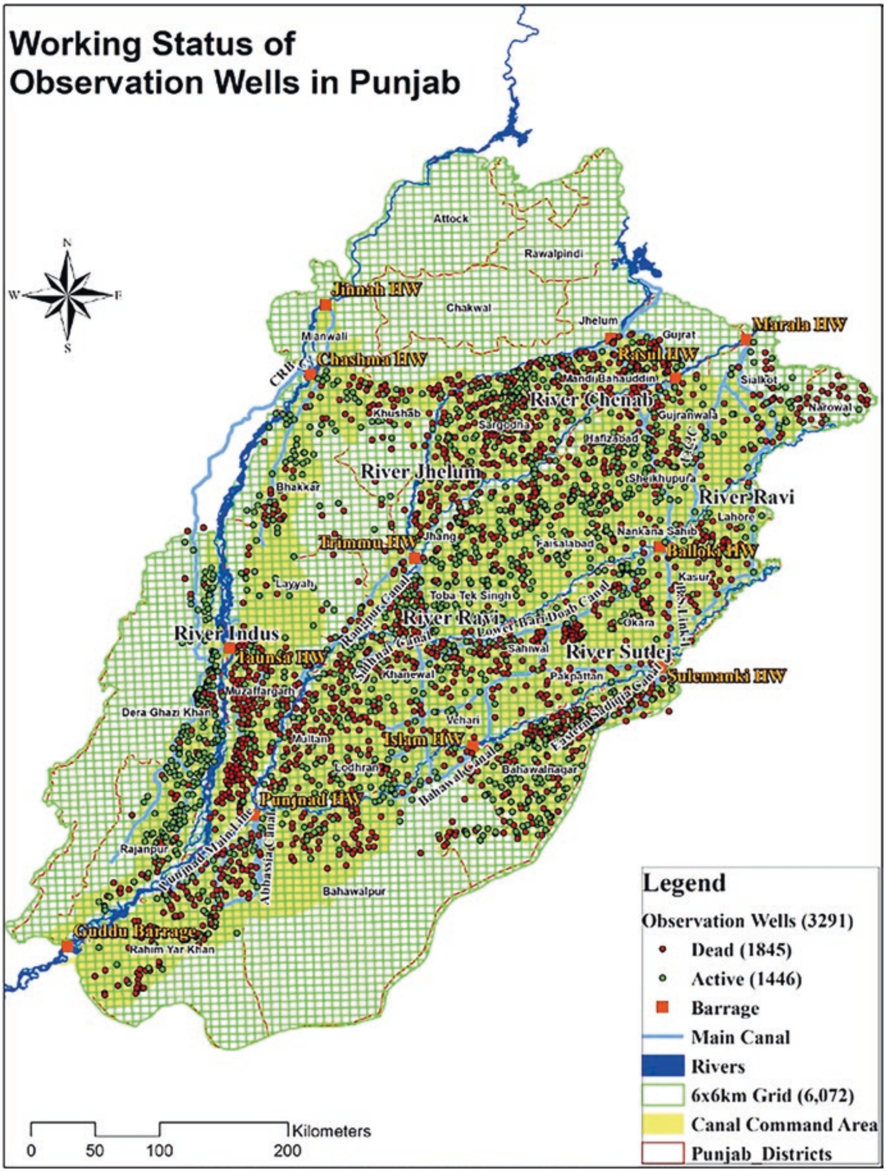

Fig. 6.6 Locations of observation wells in Punjab (Source: Punjab Irrigation Department)

Recently, with guidance from two projects—one funded by the World Bank, the other by ACIAR (Punthakey et al., 2021a, b), about 12 loggers have been installed to monitor the continuous fluctuations of groundwater table and transmit them directly to the main server at the Lahore head office.

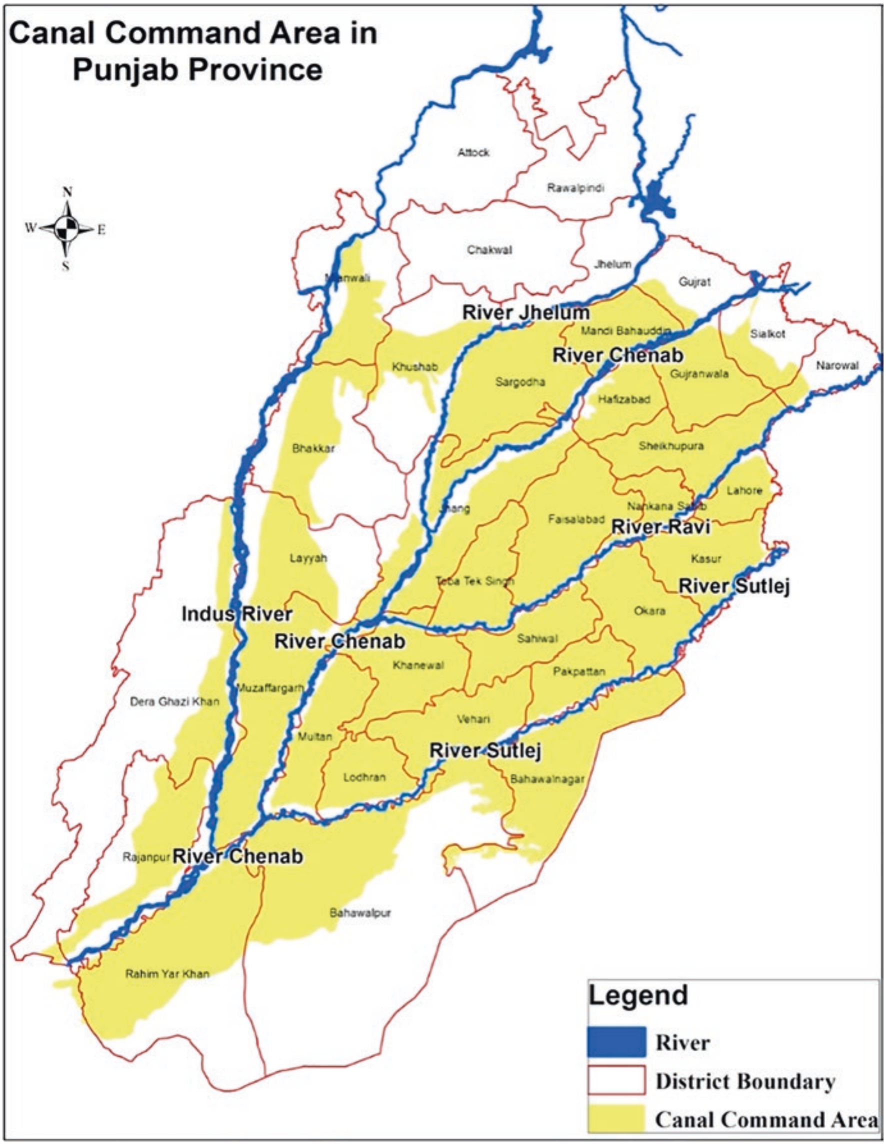

Fig. 6.7 Canal command areas in Punjab. (Punjab Irrigation Department)

In addition to depth, the quality of the water table quality is also being monitored for about more than 2500 farmers' tubewells in the canal command of the Punjab. Groundwater quality is mostly monitored and tested in labs for irrigation purposes. Groundwater quality status in Punjab for the year 2020 is shown in Fig. 6.8.

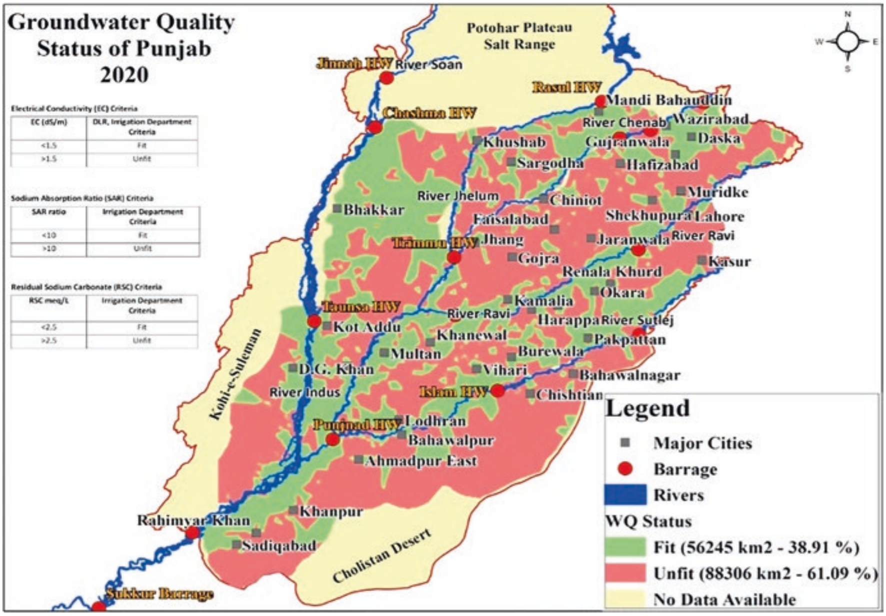

Fig. 6.8 Groundwater quality status of Punjab in 2020. (Punjab Irrigation Department)

Maps detailing depth to water table and groundwater quality are being prepared and placed on the website of the department. Different research studies and investigations are being carried out by Groundwater Management Cell established by PID in the Irrigation Research Institute (IRI). The Punjab province has been divided into different hydrogeological basins (doabs) for groundwater investigations and modelling studies. At present groundwater is contributing about 35–45% of Punjab's irrigation requirements (IRI, 2013). Extensive and unplanned pumping of groundwater has put the groundwater budget in the danger zone. The depth to water table map for the year 2020 is shown in Fig. 6.9, which indicates that southeastern areas of the province are badly depleted. The recharge to the aquifer has decreased while the pumping rate has increased. Punjab, as the largest food producer of Pakistan, is more stressed with respect to falling water levels—after Baluchistan—and deterioration of groundwater quality. At present, no comprehensive law or monitoring framework is in place for proper assessment of this natural resource, but the Punjab government is taking concrete steps to improve the system.

The quality of groundwater in the province is also deteriorating due to the intermixing of fresh and brackish ground waters which are further aggravated by the leaching contamination from domestic, industrial, and agricultural effluents (Zakir-Hassan et al., 2017). Groundwater quality in Punjab is shown in Fig. 6.10, which indicates that groundwater quality in many areas is not fit for irrigation purposes based on three criterions indicated in the figure.

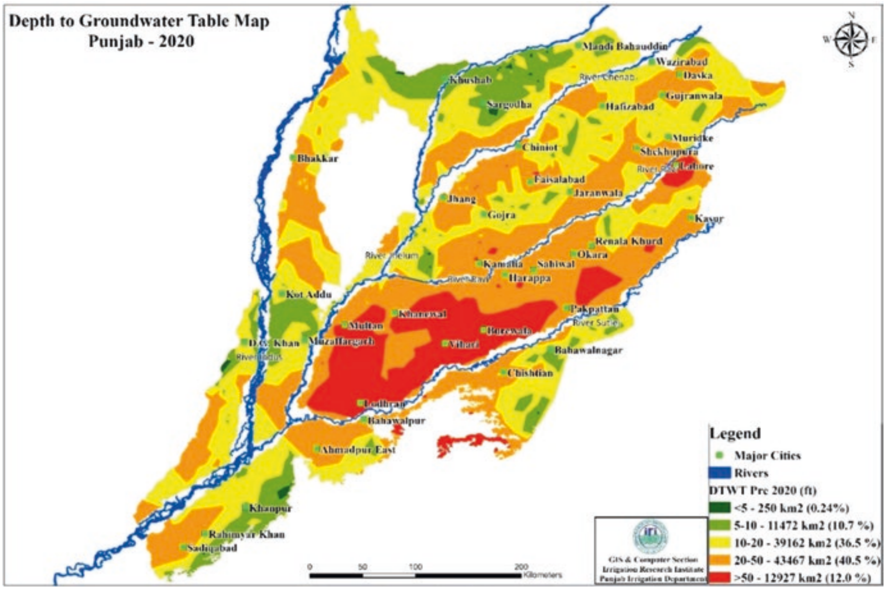

Fig. 6.9 Depth to groundwater table map (Punjab Irrigation Department)

Over time, many piezometers have become dead and dry and at present less than two thousand are functional as per 2018 records.

Keeping in view the importance of groundwater management and groundwater recharge under the National Climate Change Policy (GoP_MoCC, 2012) and National Water Policy (GoP, 2018), the Government of the Punjab under Punjab Water Policy (GoPb_PID, 2018) has clearly given the future line-of-action for beneficial use of floodwater. The policy outlines the guiding principles for implementation:

(i) Construction of flood channels to divert flood waters to desert areas like Cholistan, Thal and other similar areas.
(ii) Allow flood waters to spread overland through pre-planned breaches
(iii) Harness flood waters in Hill Torrent areas like DG Khan through construction of storage and delay action dams, dispersion, and diversion structures
(iv) Augment artificial recharge of aquifer from flood water

Globally, a lot of work is being done on managed aquifer recharge (MAR) using flood water (Rawluk et al., 2013).

As is the case anywhere, the use of groundwater in Punjab is a complex issue beset by numerous governance challenges. Governing and managing groundwater is difficult in conjunction with the planning and management of surface water, since the institutions that govern both are different (Fullagar et al., 2009).

Challenges for Groundwater Governance

- Groundwater use much beyond the sustainable limits
- Multiple groundwater uses.
- Complexities in defining groundwater entitlements and enforcement.
- General lack of awareness and capacity among the stakeholders.
- Slow implementation of regulatory framework
- Deterioration of groundwater quality
- Increasing cost of groundwater pumping with decline in water table.
- Poor and inadequate resource monitoring

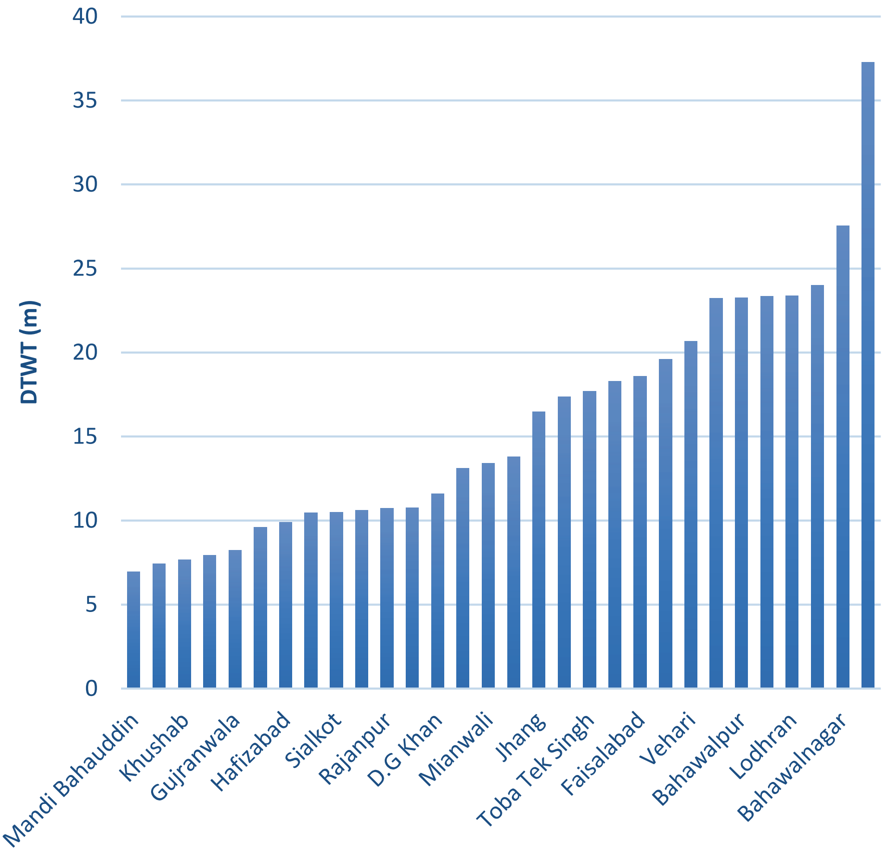

Fig. 6.10 Depth to water table below land surface in different district of Punjab (2016) (Punjab Irrigation Department)

6.11.2 Potential Integrated Approach for Groundwater

Groundwater is extracted mostly (90%) by farming communities for agricultural use. Participatory management of groundwater, through consultation, "bottom-up" planning and collaboration is most likely to result in positive on-farm groundwater management. One potential way to achieve this is to build on opportunities of the Punjab Local Govt Ordinance 2021 (GoPb_LG&CD, 2021). Village-scale Aquifer User Associations, (or Water User Associations, or Village Development Societies, or Village Councils) could be established and supported, initially by PID. The aim would be to strengthen and empower them to manage groundwater better through information sharing, training, and incentives. Resources for these associations may include extension services providers, agricultural machinery, community tubewells, village ponds, market access, surface water availability, rainfall harvesting infrastructure, soil and water testing facilities, high efficiency irrigation systems, updated information about subsidies from the government, flood and weather alerts. Other services which can be integrated at the grassroots level include measuring soil moisture and crop water needs, access to fertilizers and pesticides, value addition to agricultural products, storage facilities, guidance about latest tools and models such as tunnel farming, zero-tillage, hydroponics, land care services, protection of water quality, solid waste management, disposal of village effluents, cottage industry and handicrafts development centre, groundwater recharge facilities, on-farm storage options, smooth implementation of the *warabandi* system, mechanized farming, precision agriculture, use of ICTs, introduction of bio-fertilizers and pesticides, climate smart, energy auditing, taping the potential of solar energy, livestock and dairy development, aquaculture service, media and training centre. The village should be a strong institution that provides access to resources, information, and infrastructure, and focus on both sharing and maintenance (Fig. 6.11).

6.11.2.1 Vertical and Horizontal Linkages

Policies have been developed at the national, provincial, and local (grass root) levels to streamline water governance. This setup can support the groundwater governance if `implementation is carried out in both letter and spirit (Fig. 6.12).

The Punjab Khal Panchayat act 2019
– Establishment of Khal Panchayat.

(1) There shall be a Khal Panchayat for each water course.
(2) Every farmer entitled to obtain water for irrigation purposes under the Act shall be a member of the Khal Panchayat of a water course.
(3) Every Khal Panchayat shall have a President and a General Secretary to be elected through votes of all eligible members or the shareholders of a water course.

(continued)

(4) The term of President and General Secretary shall be 3 years.
(5) The elections of a Khal Panchayat shall be conducted by a person nominated by the Authority.
(6) No person, who is in arrears of payment of abiana, shall be eligible either to vote or contest for the election of President or General Secretary.

4) Functions and duties of Khal Panchayat.

(1) Every Khal Panchayat shall submit a warabandi to the Sub Divisional Canal Officer on the prescribed form.
(2) The Sub Divisional Canal Officer shall approve the warabandi after such modifications and changes as he deems necessary.
(3) Where a Warabandi is not submitted to the Sub Divisional Canal Officer by Khal Panchayat within 60 days, the Sub Divisional Canal Officer shall formulate a Warabandi and provide a copy of such warabandi to the Khal Panchayat for its implementation.
(4) A Khal Panchayat may lodge complaint to the Sub Divisional Canal Officer or the Deputy Collector Irrigation that a warabandi is being violated or water theft is being committed.
(5) Every such complaint shall be duly inquired into as soon as practicable, and the outcome thereof shall be communicated to the Khal Panchayat.
(6) The Sub Divisional Canal Officer shall inform the Khal Panchayat about rotational running of channels and the Khal Panchayat shall inform all members of the Khal Panchayat of such rotational running of channels.
(7) A Khal Panchayat shall mediate in disputes between farmers for equitable distribution of water.
(8) A Khal Panchayat shall check cattle trespassing on canal or drainage channels, right of way and report to the concerned Canal Officer for appropriate action.
(9) A Khal Panchayat shall help in preparation and distribution of abiana bill when so requested by the Sub Divisional Canal Officer.

Punjab Local Government Ordinance 2021
– Functions and powers of Neighborhood Council and Village Council.–

1. The functions and powers of Neighborhood Council and the Village Council shall be to:
   a) approve its budget;
   b) approve the levy of tax and fee etc.
   c) collect approved taxes, fees, rates, rents, tolls, charges, fines and penalties;

(continued)

d) enforce this Ordinance, rules and bye-laws regulating its functioning;
e) nominate members of the Community Councils in its respective urban area and monitor their performance;
f) nominate members of the Panchayats within its respective rural area and monitor their performance;
g) mobilize the community:
    i. for maintenance of public ways, public streets, streetlights, culverts, bridges, public buildings and local drains;
    ii. for plantation of trees, landscaping and beautification of public places;
    iii. for prevention and removal of encroachments on public ways, streets and places;
h) provide and maintain public sources of drinking water, such as wells, water pumps, tanks and ponds, and open drains;
i) coordinate with the community organizations for proper maintenance of water supply schemes and sewerage in the prescribed manner;
j) manage and maintain grazing areas, common meeting places and other common property
k) hold local fairs and recreational activities;
l) registration of births, deaths, marriages and divorces; (m) promote local, school and traditional sports;
m) promote local, school and traditional sports;
n) take other measures likely to promote the welfare, health, safety, comfort or convenience of the inhabitants of its local area;
o) identify deficiencies in delivery of services and make recommendations for improvement of services;
p) execute small scale development works relating to its functions;
q) report illegal excavation of earth, sand, stones or other material to the relevant authorities;
r) celebration of public festivals;
s) assist the relevant authorities in disaster management and relief activities;
t) manage properties, assets and funds vested in it; and
u) maintain such statistics and data as may be prescribed and disseminate information on matters of public interest; and

2. A Neighborhood Council and the Village Council may perform any other function entrusted to it by the Government or its respective upper level local government, in whose local area the Neighborhood Council or as the case may be the Village Council is situated.

Fig. 6.11 The village council as a central hub

6.12 Conclusions and Recommendations

6.12.1 Conclusions

To share a scarce resource while limiting environmental damage, it is imperative to limit future water use. Important ways to grow enough food with limited water are to increase the productivity of water in irrigated and rainfed areas, in animal husbandry and in aquaculture; improve water management in low-yielding rainfed areas; change food consumption patterns; and (possibly) by enabling trade between water rich and water scarce countries and areas. Increasing the water use efficiency of crop, livestock, and aquatic production, while preserving the functioning of water bodies in a context of increased demand for food and energy, is a real challenge. Consideration of the various ecosystem functions in irrigated and rainfed

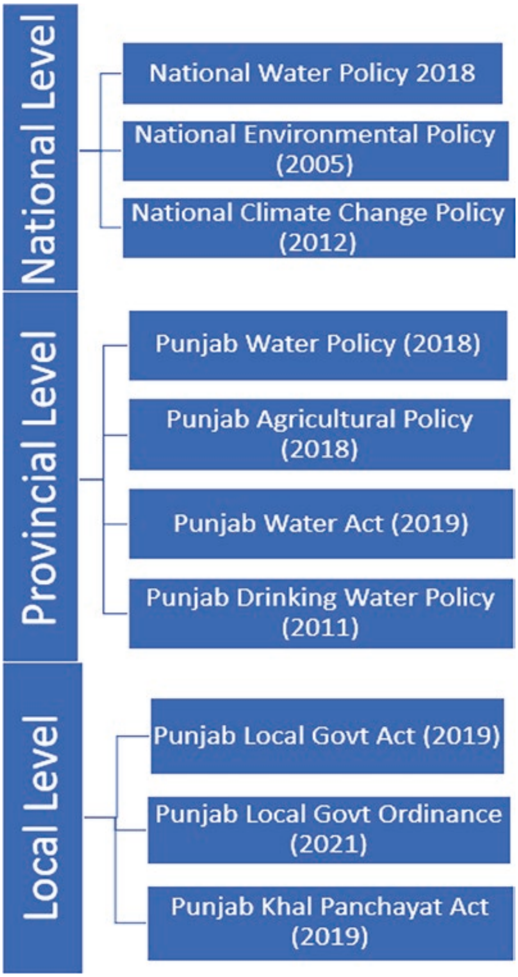

Fig. 6.12 Water sector policy and regulatory paradigm shift and linkages in Punjab

agroecosystems is crucial, as is effective water governance at different and appropriate scales to help ensure sustainable use of water resources. Water storage options along the continuum, from soil and groundwater to natural wetlands and dams, can make water more accessible at different spatial and temporal scales. This is especially important in rainfed agriculture, where other water management options and appropriate farming practices can help increase agricultural and water productivity through various water management options. Support should be given to systems and approaches that ensure high water productivity as well as gender and social equity and contribute to closing the water cycle to the benefit of many ecosystem functions. Sustainable livestock production systems should be encouraged in order to respond to changing diets and the increased demand for animal products while maintaining environmental flows and ecosystem services. The resulting improved livestock water productivity would allow more animal products and food to be produced without increasing the volume of water depleted. For aquaculture, various practical approaches and policies to enhance water use have been developed in different geographical settings all of which have potential to be useful elsewhere. Greater awareness of these amongst producers and policy-makers.

could encourage more cost effective water management strategies that would concomitantly reduce animal, environmental, and public health risks. Mass media campaigns are needed to raise awareness among the general public.

6.12.2 Recommendations

As mentioned earlier in the chapter, we need to manage groundwater on both sides i.e., demand (manage the people) and supply side (mange the resource/aquifer). Some recommendations for sustainable groundwater governance and management are tabulated in Table 6.3.

The monitoring of groundwater is a prerequisite for its proper management, governance, development and utilization. *"If we cannot monitor, we cannot manage*" (Zakir-Hassan et al., 2020). At present the state-of-the-art in monitoring groundwater is still not up to the mark. About 50% area of the province, including the Pothohar region (districts Chakwal, Jhelum, Rawalpindi, Attock), the Thal area, and the Cholistan area do not have monitoring network coverage. About half of the existing piezometers have become dead and dry and need replacement. Safety of observation points is another challenge in the field. Monitoring equipment needs to be upgraded and the capacities of human resources also need to be enhanced. For more frequent, consistent, reliable and more accurate data acquisition, some automatic loggers

Table 6.3 Options for the management of water resources

Supply side	Demand side
Improved O & M	Reduced pumping
Regulatory framework-policy/law	Efficient use of available surface water resources
Resource development	Improved land and water productivity—More crop per drop
Monitoring GW—Aquifers mapping	Enhancing capacity and awareness
Protection of GW quality	Reliability in water supplies-supply based
Rainwater harvesting	Precision irrigation/high efficiency systems
Groundwater recharge—Natural and managed	Institutional strengthening
Watershed management	Water & climate smart crop
Water education/professional capacity building	Irrigation scheduling (how much, when, and how to irrigate)
Storage capacity increase	Reallocation of water-higher values crops
Storage of flood water in aquifers	Cropping patterns/agro ecological zones
Construction of storage dams	Water recycling/waste water use for agriculture
	Conjunctive use/water quality management
	Awareness and capacity building
	Skimming well technology
	On-farm storages (supply based to demand based)

equipped with sensors and transmitters are required to be installed at some safe points. A framework for the monitoring grid for the Punjab province would look like this:

Proposed Framework for Installation of Groundwater Monitoring Network

- Division of the province into monitoring zones/basins and sub-basins.
- Coverage of non-canal commanded areas- whole geographical area.
- Monitoring may vary for basin to basin or sub-basin.
- Demarcation of critical zones.
- Intensive monitoring grid for critical areas/locations like steep slopes/hydraulic gradients; high depletion rates, extensive extraction like industries, water supply schemes; fresh-saline interface, potential sites for MAR and rainfall harvesting.
- Monitoring points may be installed away from water bodies to avoid misleading observations.
- Water quality shall also be part of monitoring framework.
- Different grids for rural and urban areas.
- Priority to be given to the restoration of dead points-data continuity.
- Build on existing network, instead of complete net network.
- Transboundary location (international, provincial, regional sub-basins).
- Overlapping with other agencies (SMO/WAPDA, PCRWR, and others) shall be checked.

Demarcation of basins and sub-basins is another important and complex challenge for the proper management, governance, and monitoring of groundwater resource. The nature of groundwater is more complex, since it is a hidden and invisible resource, and does not follow geographical or administrative boundaries. Therefore, its division into basins and sub-basins is very complex, and hydrogeological boundary conditions are imperative, which can help in studying the aquifer system and its modeling for future decision making. A proposed framework for demarcation of groundwater basins and sub-basins in Punjab is given in Sect. 6.12.2.1.

6.12.2.1 Proposed Parameters for Demarcation of Groundwater Basins and Sub-Basins in Punjab

- The size of the area- whole province
- Geological conditions/Hydrogeological boundaries
- Topography/Physiography
- Aquifer parameters with a relatively high permeability (aquifers), zones with limited permeability (aquitards) and zones with virtually no permeability (aquicludes)
- Sizes of the aquifer/depth
- Land use of the area (cropped, built up, rural, urban, desert, hilly, plain)
- Lithology, (lithological and geophysical)
- Groundwater system (groundwater levels, quality, critical zones, depleting areas),
- Surface water systems (canals, rivers, lakes, drains)

- Climatic parameters (rainfall, temperature, rainfall, evapotranspiration, droughts, floods)
- Cropping patterns, cropping zone, crop calendars
- Physiography, i.e., desert, hills, plains
- Aquifer recharge sources
- Climatic Conditions of the Area (rainfall, temperate, drought)
- Existing monitoring systems.
- Population of the area
- Aquifer hydraulic gradient
- Agro-ecological zones
- Current and future use of groundwater

6.12.2.2 Gaps Identification

Although many policies have been approved and implemented to tackle the looming water crisis in the country, to achieve the objective of bottom-up governance of groundwater, gaps have been identified for further improvement:

(i) As far as the institutional setup is concerned, there are very few human resources to manage groundwater as compared to surface water. Therefore, more dedicated staff with the appropriate capacity are needed.
(ii) Management of groundwater at the provincial level may entail transboundary issues among the provinces, which may require another look at the Water Apportionment Accord of 1991 (GoP-IRSA, 1991), as in its current iteration, does not take groundwater into account.
(iii) Interlinkages between different national and provincial policies and regulations are required to develop a sustainable management plan for groundwater use;
(iv) At the grassroots level, the Khal Panchayat Act, Punjab Local Government Ordinance 2021, Punjab Water Act 2019, and other relevant regulations and policy frameworks may be read together to strengthen the integrated groundwater governance model at the grassroots/village level;
(v) The Punjab Water Act may be a good initial step, but with the passage of time, it may not be able to cover the full governance and regulatory challenges of managing groundwater, since it is much more different and complex as compared with surface water management.
(vi) v) Implementation frameworks for the existing regulatory framework are not very clear, leading to very slow on-the-ground implementation.
(vii) Consultation with the community/stakeholders on developing IWRM frameworks is still lacking.
(viii) Proper monitoring and feedback mechanisms need to be embedded in the regulatory framework.

(ix) To implement policies, cooperative governance through top-bottom collaboration is imperative. Failure to recognize the role of local bodies/councils would be a departure from the stated objectives.
(x) Historically, the capacity of local councils at the grassroots level to handle water management issues has hindered groundwater governance. This aspect will need to be taken up in integrated mode. Providing training and institutional support at local level is a prerequisite to this.
(xi) The use of solar power in the private sector to pump groundwater is rapidly taking root in rural areas; proper policy and regulation in this regard is required. If there is a failure to do so, or if it delayed too long, we will repeat the history of using up groundwater (as we did in Balochistan) because of electricity subsidies given to pump groundwater (Khair et al., 2015).
(xii) All water sector challenges must be linked logically with relevant policy intervention.
(xiii) Generally, policies can not be successful due week and ambiguous, and non-practicable regulatory framework. Therefore, and well thought regulatory framework coupled with IWRM framework will warranty the success of policies.
(xiv) All policies and regulations must be published widely in local languages, so that these can get public acceptability.
(xv) Role of women and youth needs to be highlighted at policy and implementation level.

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Chapter 7
Storage and Hydropower

Muhammad Aslam Rasheed and Daud Ahmad

Abstract Pakistan's economy is heavily dependent on water for use in agriculture and hydropower generation. The country's water resources are shrinking, causing a big gap between allocations and the actual availability of water for irrigation, municipal, industrial and environmental uses. The storage capacity of existing dams is decreasing because of siltation. Additional storage is required to bridge this gap and increase water availability during periods of low supplies.

This chapter is an overview of the developments in water storage and hydropower production in Pakistan. It evaluates existing and under construction water storage capacity to enhance agricultural output and hydropower generation.

The energy sector faces serious supply shortages and financial losses. Initially Pakistan relied heavily on dams to produce electric power. Subsequently, the focus shifted to thermal power, which resulted in increased production costs because of imported fuels. Pakistan's energy mix became a major issue. Now the emphasis on hydel power production has again gained momentum, with several new hydel projects under construction or being planned. Future demand and supply situations have been analyzed.

Keywords Hydropower generation · Water storage · Supply shortages · Thermal power · Energy mix · Indus River Basin

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7.1 Land Resources

The total land area of Pakistan is 79.6 million hectares (mha), of which 70 mha is arid to semi-arid, or about 88% of its total geographical area (PADMU,[1] 1983). 41 mha of Pakistan's land is classified as arid, of which 11 mha include the main deserts (where climate is hyper arid) (Kahlown & Majeed, 2004). The total cultivated area is about 22.25 mha, with 8.29 mha classified as culturable waste (Pakistan Economic Survey 2020–21, 2021), which can be cultivated if irrigation water is available.

7.2 Rivers and the Irrigation System

Pakistan has six major rivers: the Indus, Jhelum, Chenab, Ravi, Sutlej, and Kabul. There are three major storage reservoirs —Tarbela and Chashma on the Indus and Mangla on the Jhelum River. 19 barrages, 12 inter-river link canals, 45 major canal commands, and over 120,000 watercourses which divert water for irrigation to one of the largest canal irrigation systems in the world. Pakistan's current river and irrigation system is shown in Fig. 7.1.

7.3 Population

Pakistan's estimated population was 215.25 million in 2020 (Pakistan Economic Survey 2020–21, 2021). The UN population projections for Pakistan are 309 million in 2050, which corresponds to a rate of 1.2% from 2021 to 2050 (UNO, 2015). The population growth rate in the 2017 census was 2.4 percent (Pakistan Economic Survey 2020–21, 2021). Therefore, the UN population projections seem unrealistically low. Assuming a rationalized growth rate of 2%, the population in 2050 is estimated to be 390 million. The substantial increase in population will increase the demand for both water and power as depicted in Fig. 7.2.

7.4 Water Demand

Water demand has been calculated as per Parry et al. (2016). Parry calculated water demand for five scenarios considering UN population projections and varying growth rates, demand management scenarios, and climate change impacts.

[1] Desertification Monitoring Unit of Pakistan Agriculture Research Council.

Fig. 7.1 Pakistan's rivers and irrigation networks. (Source: Authors' work)

As discussed, above, the UN population projections are on the lower side. The authors have accordingly adjusted Parry's 2016 scenario 4 demands for 2% population growth. The total water demand of 180.4 billion cubic meters (BCM) in 2015 is expected to increase to 210.4 BCM by 2050, which is about 3% lower than the demand of 219.6 BCM projected in Table 4.10 of Chap. 4: Water Supply and Demand: National and Regional Trends. The difference in the two estimates is negligible and can probably be attributed to a difference in assumptions, including the population growth rate.

7.5 Water Sector Dilemma

7.5.1 Coping with Growing Demand

Because of its rapidly increasing population, Pakistan faces a difficult situation in terms of water availability and the sustainability of irrigated agriculture—and hence food security—in the years to come. Chapter 4 of this book has evaluated the food

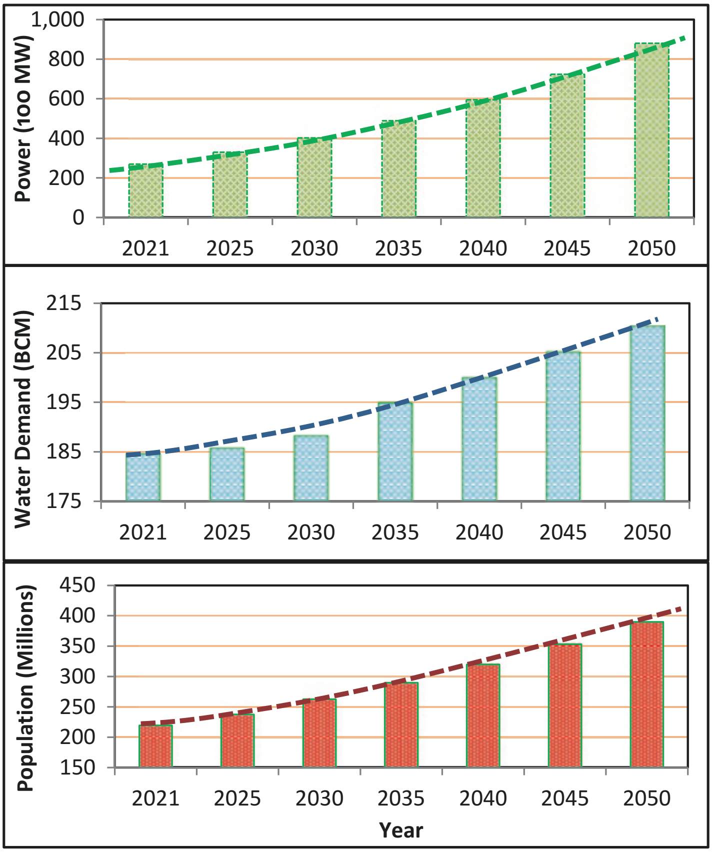

Fig. 7.2 Anticipated population growth, water demand, and power demand. (Source: Authors' work using data from Parry et al., 2016)

requirements for 2025, which are expected to increase significantly. Table 4.6 in Chap. 4 summarizes the projected requirements and production of different crops in 2025. It indicates that food grains will fall short by 37%; sugarcane by 43%; cotton by 23%; pulses by 26%; oilseeds by 55%; vegetables by 37%, and fruit by 44%.

Pakistan has already become a net importer of food items, including wheat, sugar, edible oils, and pulses, etc. Therefore, better management of water resources is needed to meet food requirements. While additional storage is required to provide water to extend agricultural areas, storage alone cannot solve all the problems since there are only limited unutilized water resources available to store. Additional measures are required to meet food and fiber requirements. Some of these include increasing crop yields, water conservation and management, rain water harvesting, high efficiency irrigation systems, and rationalization of cropping patterns, including substituting crops that need more water with those needing less water. Treatment and the reuse of sewage effluent also need to be considered. These measures have been discussed in Chap. 3 and are not repeated here.

With the rapid growth in population and urbanization, municipal and industrial water demands have also increased and compete with irrigation demand.

The availability of surface water flows varies significantly from year to year. Too little water is available when it is needed; too much when it is not. Water availability can be increased in three ways: the rational use of groundwater, conservation of seepage losses, or through the creation of carryover storage to store surplus water so it can be released, when needed most, during low flow periods.

Groundwater use in the Indus basin has more or less reached the upper limit and there is very little potential to increase it further (World Bank, 2004). The presence of saline water below the freshwater zone poses the risk of saltwater intrusion from over-pumping fresh groundwater and limits the possibility of any significant increase in groundwater use.

It is often argued that water conservation is a cheaper alternative to storage to make additional water available and that it is preferable. Water conservation measures can potentially save about 5.8 BCM of seepage losses (Rasheed & Ehsan, 2004). But it should be be noted that all of this water is not currently lost and some is later pumped back as groundwater. As such, water conservation should be approached with caution, as its effect on the availability of fresh groundwater has been established. Also, savings are linked to canal diversions and can be used at the same time, either for crop intensification or to irrigate additional areas in the same canal command. Another drawback to this approach is that the water can only be used when available and cannot be used in other seasons. Water conservation cannot solve the problem in periods of shortages or help extend irrigation into new areas.

Considering the limitations of both additional groundwater use and water conservation, the only viable option to increase water availability seems to be the construction of storage reservoirs. The downstream impacts of storing water, such as sea intrusion, along with other environmental, ecological, and social impacts from the reduction in surplus flows, need to be studied in detail. The Water Apportionment Accord (Sect. 7.8.3) mandated that further studies would be undertaken to establish the minimal escape needs downstream of Kotri Barrage. Both Sindh and Punjab have carried out separate studies to determine the escape needs downstream of Kotri, reportedly with different results. Still, as there is no consensus on the escape needs, the allocation of the balance river supplies (unused river supplies after diverting authorized shares to the provinces) which could be shared by the provinces, as per the provisions of the Water Apportionment Accord, remain undecided.

Storage reservoirs would also have the significant additional benefits of providing hydropower and flood control. In recent years, the development of large dams has been looked upon unfavorably because of the significant environmental, social, and cost implications. However, most of Pakistan's water needs will be within the Indus system and, given the size of the Indus, large storage is the only realistic option.

7.5.2 Coping with Floods

Pakistan is one of five South Asian countries that have the highest annual average number of people physically affected by floods (UNDP, 2001). The alluvial plains of the Indus river system formed as flood plains and remain vulnerable to recurrent flooding. Riverine floods occur during the summer monsoons. Flash floods and hazardous landslides occur frequently in the northern and western mountains. Districts along the Indus plain are particularly affected by riverine floods, while hill torrents tend to affect the hilly districts located in the northern and western parts of Pakistan.

The flood situation has worsened because of climate change. Pakistan is extremely vulnerable to the effects of climate change, including the rapid melting of glaciers that increase the base flow in rivers, and variability in rainfall patterns. In 2022 extremely heavy rains occurred in southwestern areas which normally received less rainfall.

The floods in 2010 and now in 2022 are often called super floods. These floods were mainly triggered due to unusually high rains. As per news reports, the 2022 floods in Sindh and Balochistan received almost more than six times the average rainfall of the last 30 years. Similarly, heavy rains occurred in Southern Punjab, Khyber Pakhtunkhwa and Gilgit Baltistan, and have caused extensive damage in these areas. About 1500 people have lost their lives and about 15,000 have been injured (as of September 2022) and 33 million people have been affected. About 7.6 million people were temporarily displaced and 575,000 people are still living in make shift camps. About 1.8 million houses have been either partially or fully destroyed. More than 936,000 livestock have been killed. About 800 health facilities have been damaged, of which 180 are completely damaged, leaving millions of people lacking access to health care and medical treatment. Over 18,000 schools were damaged or destroyed. At least 5000 km of roads and more than 150 bridges have been damaged or destroyed. Nearly 40 small dams have been overtopped and damaged. Crops over an area of nearly 1 million ha have been destroyed. The overall damage because of the floods has exceeded \$10 to \$12 billion so far (UNOCHA, 2022), which is likely to go up when the full damage assessment is available.

Three types of flooding occurred, including: (i) Urban flooding in several cities and urban centers. (ii) Flash floods from hill torrents which spread over vast areas (iii) River flooding.

7.5.2.1 Rainfall

Parts of Pakistan received excessively heavy rainfalls in July and August 2022, the most over a 62-year period. In July 2022, rainfall was 450% above average for Balochistan & 307% above average for Sindh, with both experiencing the wettest months ever during the past 62 years. (PMD, 2022).

The excessive rainfall continued in August 2022, with it being 590% above average in Balochistan, 726% above average in Sindh, 233% above average in Gilgit Baltistan, 58% above average in Punjab and 52% above average in Khyber Pakhtunkhwa; meanwhile, rainfall in Azad Jammu & Kashmir was 3% below average. (PMD, 2022).

On the flip side, despite unusually heavy rains in the southern and western areas of Pakistan, there was insufficient rain in the catchment of the Jhelum river. As a result, the Mangla dam reservoir was only half full and was unlikely to be filled in 2022.

The torrential rains caused massive floods in Balochistan, Sindh, and southwest Punjab, as discussed in the following sections.

7.5.2.2 Urban Flooding

Urban flooding occurred because of excessive rainfall and a lack of outfall capacity to drain the accumulated water. Extensive urban flooding occurred in Karachi, Hyderabad, Quetta, Khairpur, Larkana, Nowshera, and several other urban centers. Over time, the carrying capacity of the cities' drainage channels has decreased, resulting in the rise of water levels in the streets and roads practically being turned into rivers. Water entered houses and damaged appliances and furniture. This type of flooding can be controlled or minimized by improving the flood carrying capacity of various carrier channels through the removal of encroachments, the construction of flood containment dykes along the carrier channels, and by ensuring proper outfall capacity and maintenance of unhindered water ways.

7.5.2.3 Flash Floods

High-speed flash floods flowed from hill torrents in Balochistan, Sindh, Southern Punjab, and DI Khan, which, on reaching the plains, covered vast areas, resulting in the loss of human lives and livestock, and damaging houses, agriculture, and infrastructure. These flash floods most likely caused maximum damage, including the failure of more than 40 dams.

Management of flash floods calls for a comprehensive approach, including building properly designed and maintained dams where feasible, constructing delay action dams, improving the flood carrying capacity of various carrier channels through the removal of encroachments, constructing flood containment dykes along the carrier channels, and ensuring proper outfall capacity and maintenance of unhindered water ways. Because of the steep slopes in these areas, high dams would need to be built to store even small quantities of water, which would then be more expensive. And because of the variability in rainfall, the dams might not be filled every year and so there would be a low cost-benefit ratio. It may be pointed out that

Drawat Dam in Sindh, completed in 2014, was only filled for the first time in 2022. The 41 m high dam has a live storage of 110 million cubic meters and a command area of 10.117 ha. As such, the construction of dams in hill torrent areas can only be justified for flood control benefits, with limited irrigation benefits.

7.5.2.4 River Flooding

River flooding occurred due to a combination of various factors, including the early melting of glaciers, bursting of glacier lakes, and excessive rainfall in part of the catchment. The Swat River was badly affected as roads, bridges, and more than 50 hotels and restaurants built on the edge of the river were washed away. The Munda Headworks was also damaged. The cofferdam of the Mohmand Dam, currently under construction, was breached and water entered the under construction diversion tunnel.

The upper reaches of the Indus river were also flooded, resulting in damages to bridges and washing out the employees' camp of the Dasu Dam, also currently under construction. As of September 6, 2022, the flood wave was passing through the lower reaches of the Indus and about 17,108 m^3/s was approaching Kotri Barrage.

Flood-protection infrastructure in Pakistan comprises about 6800 km of flood protection embankments and 1410 spurs, which protected most vulnerable reaches. More embankments and spurs are needed to protect the presently unprotected areas. In Sindh, as the river flows over relatively higher ground and the overflow water does not return to the river, two lines of flood protection embankments have been provided. Provincial Irrigation Departments maintain this flood infrastructure. During the current floods the flood protection infrastructure worked reasonably well except at a few locations. Because the water level in Manchar Lake rose alarmingly high, the protection bund was purposely breached at three places in order to prevent uncontrolled breaches and save those nearby. Still, the water level could not be controlled and ultimately breached the main embankment, flooding large areas. Evaluation of the flood protection infrastructure may reveal that some additional embankments and spurs might be needed.

Building storage on the Indus and its tributaries could mitigate flood magnitude and resulting damage. While there is the common perception that if Kalabagh dam had been built, the damage could have been avoided, Kalabagh alone could not have absorbed all the flood peaks. Kalabagh would not have relieved any of the urban flooding or flash flooding from hill torrents. To minimize flash flooding several storage dams as well as delay action dams are required on the hill torrents. Kalabagh would have reduced flooding on the Indus river downstream of Kalabagh, but more dams are also needed in addition to Kalabagh Dam. A dam on the Swat River near Kalam would reduce flooding in the upper reaches of the Swat River, where significant damage occurred this year. The under construction Mohmand Dam will reduce flood magnitude and resulting damages in Nowshera.

7.6 The Challenges of Hydropower in Pakistan

At the time of independence in 1947, Pakistan had an installed power generating capacity of only 60 MW, which increased to 119 MW by the late 1950s. In 1959, the Water and Power Development Authority (WAPDA) was established to develop and manage Pakistan's water and power resources, except for the Karachi area, which was being served by the Karachi Electric Supply Company (KESC). During the 1960s and 1970s, WAPDA undertook development of major hydropower and irrigation projects under the Indus Basin Program, through which large dams such as the Mangla and Tarbela and an integrated network of barrages and link canals were constructed. Power generation capacity reached about 3000 MW towards the end of the 1970s. The hydropower development program hit a major snag in the 1980s when the proposed Kalabagh Dam, which was deemed to be the next logical project, faced major political opposition and could not be implemented.

Electric power demand has been higher than the population growth rate because of increased agricultural and industrial demands, higher living standards and the extension of the power distribution network to new areas. During the past three decades, power demand has been increasing around 8% per year. The average annual growth in power generation has lagged behind demand between 2 to 8% during this same time period. Pakistan started to face serious power shortages in the late 1980s, when demand exceeded supply by 2000 MW. Since then, power shortages have become a serious and chronic problem hampering Pakistan's social and economic growth.

Unable to pursue the hydropower route, different political governments opted for alternative power generation sources—thermal and renewable energy—mainly through private sector investments. A large number of natural gas plants were installed in the late 1990s and early 2000s. Subsequent shortages in natural gas supply affected this mode of production. Pakistan then started to look to imported fuels for energy generation. Earlier administrations generally favored importing coal and liquid natural gas (LNG), while later administrations favored importing fuel oil. They also tried rental power plants, which did not work. Starting in 1995, there was a major shift in the energy generation mix towards thermal plants, resulting in much higher production costs, and imported fossil fuel bills resulting in huge government subsides. An over-reliance on imported fuels, which are subject to price fluctuations, for thermal generation is at the core of Pakistan's energy crisis. Hydropower, which once underpinned the country's power sector, accounting for nearly 50% of power generation in 1991, now only comprises 28%.

The growth in population, together with an improved standard of living, will also give rise to a significant increase in power demand. Currently, about 61.4% of power is generated through thermal power plants, which mostly depend on costly imported fuel such as RLNG, furnace oil, and coal, etc. Diesel-operated plants are being

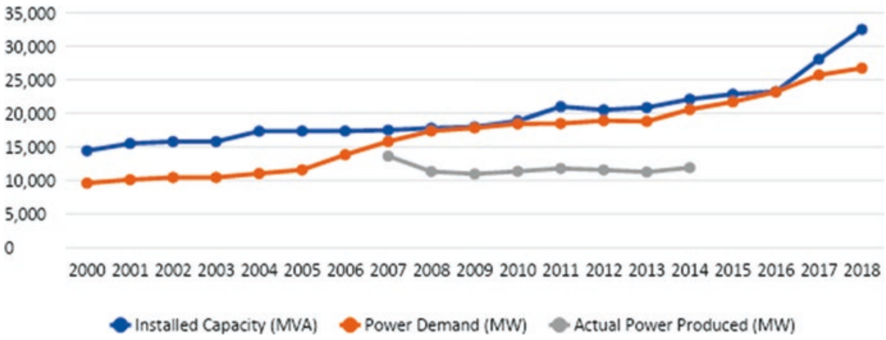

Fig. 7.3 Power demand, production capacity, and supply trends. (Sourced from: http://www.ntdc.com.pk/Files/PSS%2043rd%20Edition.pdf. Public domain)

phased out. Nuclear generation accounts for 6.7%, whereas renewable energy resources, such as wind, solar, and bagasse make up a meagre 5.4%. Hydropower can be generated both from storage reservoirs and runoff river projects. The government has planned to increase the share of hydel generation to 40% by 2030 (NTDC, 2021).

Figure 7.3 shows the supply and demand curve for power in Pakistan along with its production capacity. Pakistan's average annual power demand growth is around 8%, and the average supply growth rate since 1990 has been around 4.6%. Population growth alone adds about 1000 MW of power demand every year. According to the World Bank, taking into account expected economic growth, Pakistan's energy demand over the next 15 years is expected to grow at a rate of between 4.4 to 6.1% per annum. A striking feature of Pakistan's power situation is a mismatch between production capacity, demand and actual supply. Currently Pakistan has nearly 150 operational power plants, with a potential to produce 37,000 MW, but actual production has only averaged about 15,000 MW in the last decade.

Despite significant increases in production capacity in the last 5 years, mainly through China Pakistan Economic Corridor (CPEC) projects, Pakistan is still facing power shortages because of various technical, financial, and management factors that will be discussed later. This electricity crisis is estimated to have cost the economy at least 2% of GDP ($5 to 6 billion) annually in terms of lost output—and a further 1.2% of GDP each year, on average, in terms of fiscal costs to the budget between FY2007 to FY2019. From an economic perspective, it is distressing to see that the circular debt that stood at Rs.1.2 trillion in 2018 was reported to be Rs.2.3 trillion in December 2020. The government subsidies to the power sector during FY 2011–14 averaged 91% of total government subsidies (Asian Development Bank, 2014).

Salient Features of Pakistan Water Policy (2018) regarding Storage and Hydropower

1. The "Indus Basin Replacement works" (dams in particular) are approaching the end of their designated life span because of siltation, requiring replacement storage.
2. Storage is the most important instrument of mitigation against the impact of climate change.
3. The impact of climate change shall be minimized by storing water in carry over surface storage.
4. Water availability can be enhanced through reduction in water loss, additional water storage through large, medium and small dams, recycling used water, desalinization of sea water, and more efficient water use.
5. The existing water storage capacity of 17.3 BCM shall be increased by immediately starting construction of the Diamer-Bhasha Dam Project with 7.9 BCM live storage.
6. The accelerated development of hydropower shall be treated as a high-priority objective. Water projects with power generation potential shall be given preference.
7. The government shall encourage private power producers to develop hydropower.

Source: (Pakistan Water Policy, 2018)

7.7 Policy Perspective on Storage and Hydropower Generation

The Pakistan Water Policy (2018) recognizes the importance of storage and hydropower generation in Pakistan and sets out targets for the future development of storage and hydropower generation. It provides a set of agreed-upon national targets for water conservation, water storage, water treatment, and clean drinking water, and envisages hydropower development in order to increase the share of renewable energy. Relevant abridged extracts from the Water Policy relating to storage and hydropower have also been given in the sidebar.

7.8 The Need for Storage in the Indus Basin

The need for storage in the Indus Basin is dictated by climatic and hydrologic factors to provide the required amount of water in different seasons.[2] Only 9% of Pakistan receives more than 50 cm of rain per year. A further 22% receives between

[2] A typical water year in Pakistan commences from April. Period from April to September is known as *kharif* season while period from October to March is called *rabi* season

20 to 50 cm and the remaining 69% receives less than 25 cm. 70 to 80% of the total annual rainfall of Pakistan occurs in the monsoon months of July, August, and September (UNO, 2000). Scarcity and uneven rainfall give rise to the need for irrigated agriculture which in turn depends on water released from storage.

About 79% of the flow of the Indus River and its tributaries occurs during the summer season (*kharif* season) while the remaining 21% occurs during the winter season (*rabi* season). Even within the *kharif*, most of the flow occurs during the 90-day period from mid-June to mid-September. As such there is a need to store water during the flood season in order to meet the irrigation demands of low flow periods. Besides hydrological factors, there are several other factors which dictate the need for storage in The Indus Basin System (IBS). These include:

- The Indus Waters Treaty between India and Pakistan (1960), which has created the need for storage to transfer the water from the western rivers to the eastern rivers allocated to India.
- To meet the shortfall in water allocation under the Water Apportionment Accord, 1991
- To replace the capacity of existing storage lost due to sediment deposits in the reservoirs.
- To generate hydropower

The IBS not only has to meet the irrigation requirements as agreed under the 1991 Water Accord, but also provide enough water supplies to increase the irrigated area, and to meet the demands of a growing population. This can only be done by storing surplus flood flows during the summer and releasing them during the winters when river inflows are low.

Existing large storage facilities as well as future large storage sites all lie in the Indus Basin (IBS) on the river Indus and its tributaries. Accordingly, all analyses of water resources, water use, and storage potential are restricted to the Indus Basin System (IBS). Small storage reservoirs constructed for local use, both in the Indus Basin and in other smaller basins, have small storage capacities and do not have any noticeable hydropower potential. As such, small dams have not been covered.

7.8.1 Contribution of Existing Storage Reservoirs to Increased Water Availability

The Tarbela and Mangla reservoirs, constructed as replacement works under the Indus Water Treaty, have substantially contributed to water availability in the IBS as shown in Table 7.1.

The average canal diversions before the completion of the Mangla Dam stood at 104.64 BCM which increased to 116.95 BCM after its completion. Similarly, average canal diversions in the 1977–82 period increased to 124.33 BCM after the completion of the Tarbela Dam. The overall average annual canal diversions for

Table 7.1 Historic canal water diversions

Year	Canal head diversions BCM	Remarks
1949–50	82.48	Just After Independence
1959–60	104.64	Before Indus Basin Treaty
1967–68	116.95	Post Mangla
1975–76	124.33	After Tarbela Commissioning
1977–82	128.59	Post Tarbela (average)
1991–92	128.19	After Water Accord
1977–2019	125.09	Post Tarbela Average

Source: Based on data from Water Resources Management Directorate, WAPDA

irrigation in the Indus Basin for the post-Tarbela period (1977–2019) have now been reduced to 125.09 BCM due to the combined effects of sediment deposits reducing the reservoir storage capacity and the drought of 1998–2002.

7.8.2 Indus Waters Treaty

When Pakistan and India achieved independence in 1947, the borders of the two countries divided the Indus River Basin, leaving India the upper and Pakistan the lower riparian state. In 1960, Pakistan and India concluded the Indus Water Treaty mediated by the World Bank. Under the treaty, Pakistan was allocated unrestricted use of the western rivers (the Indus, Chenab. and Jhelum) and India was given unrestricted use of the eastern rivers (the Ravi and Sutlej) (Birch et al., 2006).

In order to supply water to the irrigation systems that used the eastern rivers' water prior to the treaty, two large storage dams (the Mangla and Tarbela), six barrages, and eight inter-river link canals were constructed. The Chashma Barrage also has a small storage reservoir.

Under the Indus Water Treaty, a permanent Indus Water Commission, comprising one commissioner each from India and Pakistan, monitors the implementation of the treaty. The two countries are required to share data on common rivers. The commission holds regular meetings and any points of disagreement are discussed.

7.8.3 Water Apportionment Accord

The Water Apportionment Accord on the distribution of water in the Indus River System was reached between the provinces in 1991. The actual average system uses for the period 1977–82 were utilized as guidelines for developing future regulation patterns. Actual water use during the 1977–82 period was 128.59 BCM. However, after adjusting for the provinces' future planned projects, 140.89 BCM (95.36 BCM in *kharif* and 45.63 BCM in *rabi*) was distributed among the provinces.[3] An additional 3.7 BCM were allocated for civil canals in NWFP (now Khyber Pakhtunkhwa, or KPK). The shortfall in actual water use prior to the accord and accord allocations can only be met by building additional storage and diversion capacity in the system.

The water distribution in the light of the accord is managed by the Indus River System Authority (IRSA). IRSA has five members; one from each province and one from the federal government. Chairmanship of IRSA rotates among the members. IRSA adopts a probabilistic approach to assess available water at rim stations, and keeping in view the available storage in the reservoirs, allocates 10-daily[4] irrigation indents for a season with the consent of the provinces.

The major storage reservoirs are maintained and operated by WAPDA. The operation of the reservoirs and releases follow the indents prescribed by IRSA.

7.8.4 Replacement of Lost Storage Capacity

The existing reservoirs of the Mangla, Tarbela and Chashma, built as part of the Indus Water Treaty, are losing their storage capacity due to sediment accumulation as shown in Table 7.2.

Tarbela has lost almost 38% of its capacity whereas the raised Mangla has also lost 11.8% capacity and Chashma has lost 62.3% of its capacity. The overall loss in capacity of the three reservoirs is about 27.6%, which continues to increase with time. Additional storage is needed to replace this lost storage capacity in the IBS.

Table 7.2 Loss of storage capacity of existing reservoirs in the IBS

	Live storage capacity			
Reservoir	Original	Existing	Loss of storage	% loss
Tarbela	11.95	7.34	4.61	38
Raised Mangla	10.16	8.965	1.195	11.8
Chashma	0.88	0.332	0.548	62.3
Total[a]	22.99	16.637	6.354	27.6%

Source: Authors' estimate based on WAPDA data
Note: All capacities in BCM
[a]Total live capacity of Tarbela, Raised Mangla and Chashma

[3] For inter provincial distribution see Chap. 3 of this book.

[4] Water accounting in Pakistan is done on a 10-daily basis. The first and second periods in a month are each 10 days' long whereas the last "10-day" period includes all the remaining days of the month. The 10-daily refers to the average flows for each 10-day period.

7.9 Surface Water Availability in the Indus Basin

In order to estimate the IBS' storage potential, its water balance has been estimated. The essential components of the water balance include: surface water availability, water use for irrigation, municipal and industrial supplies, system losses, escape to sea, and environmental flows.

7.9.1 Inflows

The Indus River and its tributaries, the Chenab, Jhelum, and Kabul rivers, are the main source of surface water. The Indus river rises in the Tibetan region of China and flows across Kashmir and through Pakistan to the Arabian Sea. Pakistan is fully dependent on the water of the Indus and its tributaries to support both its agriculture and its level of population. Without the water of these rivers, much of the region would be desert.

Surface water availability in Pakistan is dictated by the Indus Water Treaty between India and Pakistan. The average river inflow for the period 1977 to 2019 amounts to 188.84 BCM (149.20 BCM in *kharif* and 39.64 BCM in *rabi*) as shown in Table 7.3.

The average inflow (1977 to 2019)[5] at rim stations from the western rivers amounted to 181.02 BCM while during the same period an average of about 7.82 BCM flowed through the two eastern rivers, mainly during the summer.

Figure 7.4 shows the annual distribution of inflows at rim stations. Figure 7.5a shows the distribution of inflows contributed by the Indus and its major tributaries. Figure 7.5b shows that about 79% of the total flow occurs in the *kharif* whereas the remaining 21% flows in the *rabi*.

Table 7.3 Average water availability (1977 —2019) of the Indus Basin at Rim Stations

Location	Season		
	Kharif	*Rabi*	Annual
Indus at Kalabagh	96.03	25.80	121.83
Jhelum at Mangla	21.25	6.37	27.62
Chenab at Marala	25.83	5.74	31.57
Sub-Total (Western rivers)	**143.11**	**37.91**	**181.02**
Ravi at Balloki	3.75	1.16	4.91
Sutlej at Suleimanki	2.34	0.57	2.91
Sub-Total (Eastern rivers)	**6.09**	**1.73**	**7.82**
Total	**149.20**	**39.64**	**188.84**

Source: Estimates based on inflow data from IRSA. All values in BCM

[5] While inflow data on the Indus is available from 1929 onwards, the analyses use data from 1976, after the completion of the Tarbela dam.

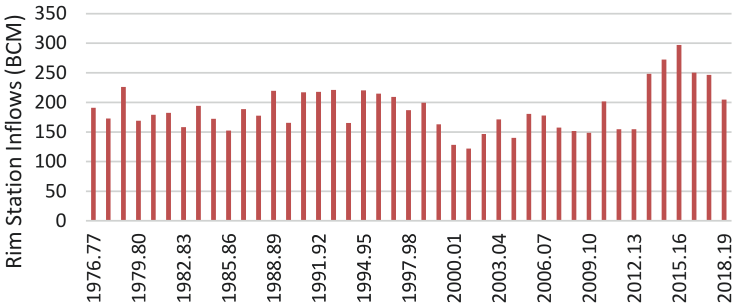

Fig. 7.4 Rim station inflows —1977 to 2019. (Authors' work, using inflow data from IRSA)

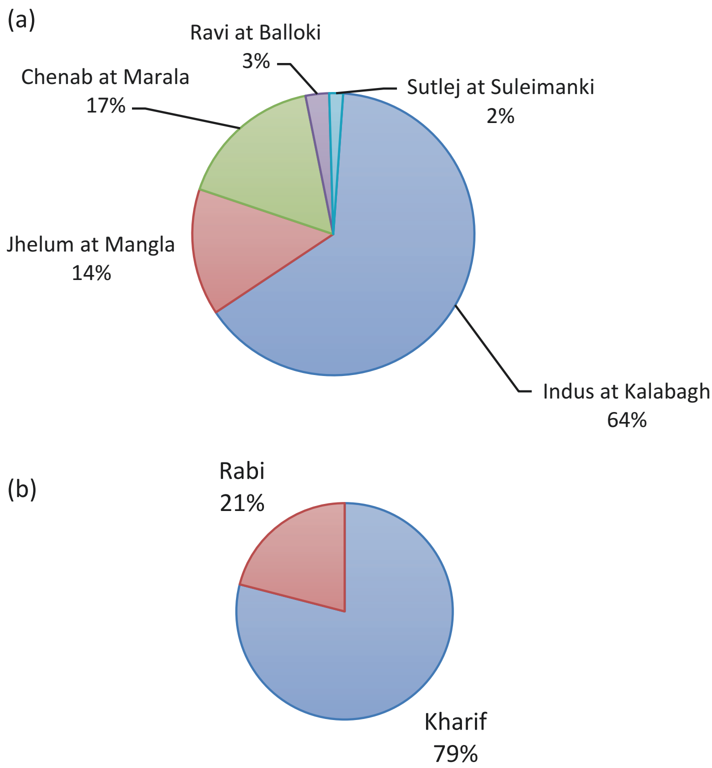

Fig. 7.5 Distribution of rim station inflows. (**a**) Flow distribution w.r.t to rim station. (**b**) Flow distribution w.r.t season. (Source: Authors' work, using inflow data from IRSA)

7.9.2 Canal Withdrawals in the Indus Basin

Since 1992, canal withdrawals in the Indus Basin have been governed by the 1991 Accord signed by the provinces. Average canal withdrawals from the Indus Basin during 1977 to 2019 varied between 91 BCM and and 148.8 BCM with an average of 125.1 BCM as shown in Table 7.4. Figure 7.6 shows the percentages of canal diversion to the provinces.

It may be noted that the Accord allocation of 140.89 BCM (excluding the allocation for KPK (NWFP) Civil Canals) is about 9–10% higher than the average historic uses in the Indus Basin prior to the Accord, which were of the order of 127–128 BCM. Presumably, the allocations were fixed at this higher level because there was an assumption that further storage would be built—an assumption that turned out to be incorrect. As a result, since 1991, the annual canal diversions have varied between 91.0 and 148.8 BCM. The present system is not capable of supplying the allocated amount because of shortages in available river supplies in the early *kharif* season and higher-than-needed runoff in July through September, which cannot be stored for subsequent use because storage capacity is lacking. The availability of surface water from the Indus and its tributaries can best be improved by constructing carry over storage reservoirs.

7.9.3 Outflow to the Sea

The annual outflows to the sea from 1977 to 2019 are shown in Fig. 7.7. The average outflow to the sea during 1977 to 2019 amounted to 34.5 BCM, with a maximum of 113.3 BCM and a minimum of 0.4 BCM as shown in Table 7.5. The decline in the outflow to the sea, is the result of increased withdrawals upstream combined with several relatively dry years since the year 2000, as shown previously in Fig. 7.4.

Table 7.4 Canal withdrawals: 1977 to 2019

Seasonal/ Annual	Punjab	Sindh	Baluchistan	Khyber Pakhtunkhwa	Total
Kharif	41.4	35.4	1.7	4.4	**82.9**
Rabi	21.9	16.7	1.0	2.6	**42.2**
Annual Average	**63.3**	**52.1**	**2.7**	**7.0**	**125.1**
Max (1977–2019)	71.8	63.8	3.9	9.2	**148.7**
Min (1977–2019)	45.7	38.9	1.6	4.7	**90.9**

All values in BCM. IRSA

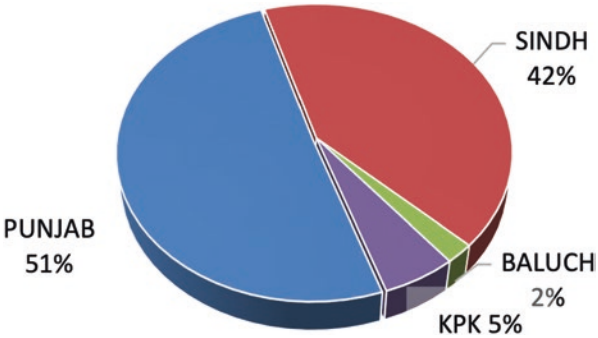

Fig. 7.6 Canal withdrawals: 1977 to 2019. (Authors' work using data from IRSA)

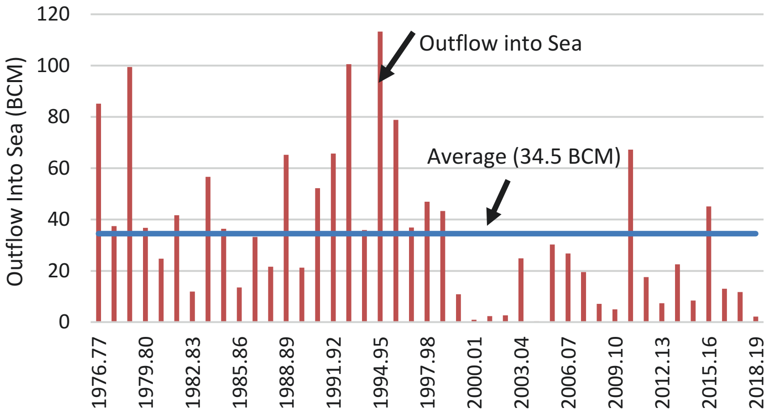

Fig. 7.7 Outflow into the sea. (Source: Authors' work using data from IRSA)

Table 7.5 Outflows to sea (BCM): 1977 to 2019 (IRSA)

Season	*Kharif*	*Rabi*	Total
Average	**32.4**	**2.1**	**34.5**
Maximum	**108.8** (1994.95)	**15.2** (1992.93)	**113.3** (1994.95)
Minimum	**0.3** (2004.05)	**0.0** (2001.02)	**0.4** (2004.05)

Note: Values in bracket denote years of corresponding maximum/minimum flows

7.9.4 Water Losses from Rim Stations to the Sea

Water losses through the river system have been estimated as the difference between inflows and the sum of canal withdrawals and outflows to the sea in Table 7.6. Accounting for canal withdrawals of 125.09 BCM during this period (1977 to 2019), on average 29.21 BCM (23.7 MAF) of water is lost from rim stations to the

Table 7.6 Estimated gains and losses (1977 to 2019)

Season	Average inflow	Average canal withdrawal	Outflow into sea	Gain / loss
Kharif	149.20	82.85	32.46	−33.89
Rabi	39.64	42.24	2.08	4.68
Annual	**188.84**	**125.09**	**34.54**	**−29.21**

Note: Negative values mean loss from rim station to the sea and positive value means gain /increase in flow from rim station to sea

Table 7.7 Surface water balance of the Western Rivers of Indus System (1977 to 2019)

Description	Discharge (BCM)
Inflow	
Western Rivers Inflow	181.02
Eastern Rivers Inflow	Not considered
System Losses	−29.21
Net Inflow	151.81
Outflow	
Average Canal Diversions	125.09
Available Surplus	
Surplus with Actual Diversions (Net Inflow —Actual Diversion)	26.72

sea because of seepage or unaccounted-for water and unauthorized uses within the system.

7.9.5 Surface Water Balance of Indus System

The water balance of the Indus system under average inflow conditions is shown in Table 7.7. The water balance considers the current level of average canal diversions and considers inflow from the western rivers only. Eastern river flows have been neglected due to their unreliability with the assumption that not including these will compensate for any future water use by India on these rivers in line with the Indus Water Treaty.

Under average inflow conditions (1977 to 2019), 26.72 BCM of surplus flow is available to meet the shortfalls in average canal diversions and has the potential to augment supply while still meeting the likely environmental needs below the Kotri Barrage. On average 34.54 BCM flow to the sea annually.

Over the last 44 years, a total of 1485 BCM have flowed into the sea, equivalent to more than 12 years of average canal withdrawals during the same period. Once environmental needs are assessed and agreed upon, the remainder of the water could be effectively utilized to supplement irrigation and hydropower generation, but only with additional storage.

7.9.6 Environmental Flows

Environmental flows are those required to maintain the aquatic ecology of natural waterways. In the case of the Indus Basin, these include:

i. Maintaining the minimum flows in eastern rivers
ii. Maintaining outflows to the sea to an acceptable level

The environmental flows required to maintain an ecological balance in the rivers downstream of the reservoirs have received little attention in the past. The Indus Water Treaty did not consider the environmental flows needed for the Ravi and Sutlej rivers, which dried up after all of the water in these rivers was allocated to be used by India. As a result, groundwater recharge has decreased and available fresh groundwater has also decreased. Pakistan is currently studying the adverse environmental impacts of allocating the waters of the eastern rivers to India.

The environmental flows required in the Indus below the last control structure—Kotri Barrage—to prevent sea water intrusion in the Indus delta and maintain an ecological balance have been recognized under the Water Accord. Despite several studies, no consensus has been reached on what the actual requirements may be. Both Sindh and Punjab have carried out independent studies but their conclusions have not been made public.

WAPDA is conducting a feasibility study of the proposed Sindh Barrage, to be constructed on the Indus below the Kotri Barrage to minimize the environmental problems downstream. The proposed Indus barrage is to be located about 30 km upstream the Indus River outfall from the sea. Project objectives include water storage of about 2.5 to 3.7 BCM in order to utilize about 5 BCM of fresh water, reduce sea water intrusion, and improve the growth of mangroves/marine life, increase irrigation water supply to the surrounding areas, improve the ecology of the Indus river downstream of Kotri, help flood mitigation for the surrounding 30,400 ha of land and supplement the domestic water supply to Karachi and other towns. Two canals, one on each side, have been proposed for irrigation and drinking water in the coastal area up to Dhabeji and Tharparkar, which will irrigate about 22,300 ha of land that has been lost due to desertification and high soil salinity.

7.9.7 Existing Storage Projects in the Indus Basin

Pakistan's current storage capacity in the Indus Basin is about 9% of the average annual inflow. This is much lower than the estimated world average storage capacity of 40%. In comparison, the storage capacity of the Colorado river is 497% and 281% on the Nile. The current carryover capacity in Pakistan is only about 30 days, whereas the carryover capacity in the U.S. is 900 days, 700 days in Egypt, 600 in Australia, and 500 in South Africa (WAPDA, 2021) Fig. 7.8 shows a sattelite image of Tarbela Dam.

Fig. 7.8 Satellite image of the Tarbela Dam Project. (Source: Google, Maxar Technologies, 2021. Used with permission according to Google Terms of Use)

Table 7.8 Existing storage projects in the IBS

Reservoir	Present live storage capacity (BCM)
Mangla (after raising)	8.97
Tarbela Dam	7.34
Chashma	0.33
Total	**16.64**

There are one minor and two major storage reservoirs in the Indus Basin: the Mangla, Tarbela and Chashma, which have a combined storage capacity of 16.64 BCM (Table 7.8).

7.9.8 Storage Projects Under Construction

At present two major reservoirs are under construction in the Indus Basin: the Diamer Bhasha on the Indus and Mohmand Dam on the Swat river, a tributary of the Kabul River. These projects will have a live storage capacity of 8.72 BCM (7.89 BCM for Diamer Bhasha and 0.83 BCM for Mohmand). The Dasu Dam, also currently under construction, will have a nominal storage capacity and will operate as a run-of-river hydropower project.

7.9.9 Planned Storage Projects

There are five storage projects planned on the Indus River with an estimated combined storage capacity of 28.36 BCM (Table. 7.9).

Table 7.9 Planned storage projects in IBS

Project	Gross storage
Shyok	6.78
Skardu	3.7
Akhori	7.40
Kalabagh	7.40
Indus Barrage	3.08
Total	**28.36**

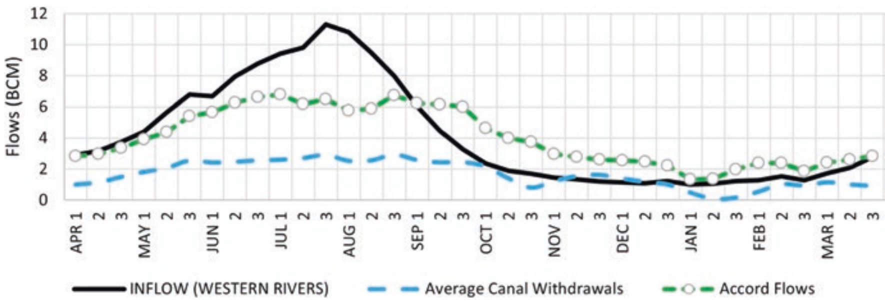

Fig. 7.9 Average inflows (western rivers) and canal diversions (1999 to 2018). (Authors' work using data from IRSA)

7.10 Storage Potential of the Indus Basin

The Water Apportionment Accord allocated 144.5 BCM of water to provinces. The main source of inflow is the western rivers, as the inflow of the eastern rivers is not-reliable. A plot of the average 10-daily inflow of the western rivers, average canal diversions and accord allocations for the period 1999 to 2018 is shown in Fig. 7.9. It can be seen that surplus water is available from April to the start of September, after which allocated withdrawals exceed available inflows. Thus, water has to be stored in the summer season to meet canal water requirements in the winter season.

A diagram showing the cumulative inflows from the Western rivers and the canal withdrawals for the post-Tarbela period is presented in Fig. 7.10. It indicates the gap between availability and the use of surface water and shows a possible potential draft (withdrawal) on the order of 165 BCM, still leaving enough surplus to meet the environmental requirements below Kotri. This draft will only be possible if enough storage capacity (about 37.5 BCM) is provided in the system to capture large flows through a cascade of reservoirs so that the stored water can be used in dry seasons/years.

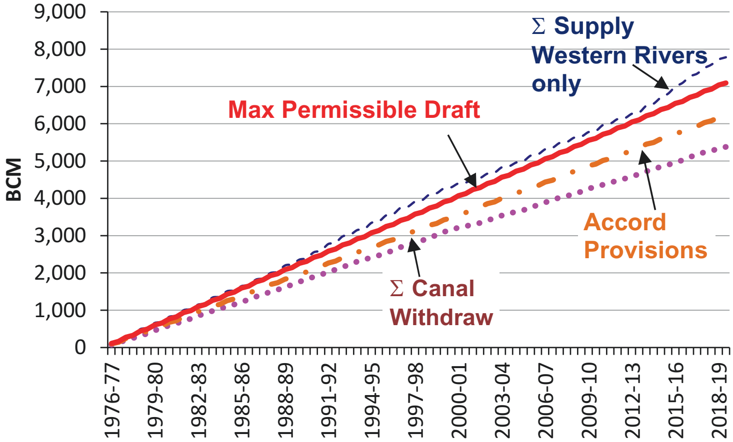

Fig. 7.10 Mass diagram of western rivers of Indus Basin Flows. (Authors' work using data from IRSA)

7.11 Small Dams

7.11.1 Definition and Purpose

As per the International Commission of Large Dams' (ICOLD) criteria, small dams are those with a height of less than 15 meters from the foundation or with a height between 5 to 15 meters and a reservoir capacity of less than 3 million cubic meters. However, in Pakistan the restriction on the height of small dams is generally not observed, and dams with heights exceeding 40 m but with less than 3 million cubic meters' storage have been designed and constructed and classified as small dams.

Thus, Pakistan has more than 100 dams on smaller streams which are classified as small dams, but most of these fit the category of large dams due to their height as per ICOLD criteria. These dams have significantly small storage volumes and only irrigate relatively small command areas. These dams do not have the potential to mitigate shortages on a system-wide basis; rather, they are useful only to the command areas covered by such dams.

The basic purpose of these dams is to conserve available flood and rain water for agriculture and minimize the adverse effects of drought and water scarcity in arid/rainfed areas. Besides providing much-needed irrigation water, these dams also provide drinking water to the local population in their vicinity. The construction of small dams is often done without command area development. The absence of these command area works results in delayed benefits.

7.11.2 Performance of Small Dams

Where the command areas have been developed, these dams have been successful in improving the socioeconomic conditions of their respective areas. After construction, land use, crop intensities, and crop yields have all improved.

A study by National Engineering Services (Pakistan) Ltd. (NESPAK) (1991) evaluated 31 small dams both in Punjab and NWFP (now Khyber Pakhtunkhwa) and concluded that only 32% of the anticipated command areas were developed, and that average cropping intensity was only 35% as opposed to the target of 96%. On average, 69% of anticipated water was being released from the reservoirs.

The situation has now improved. A recent study (NDC-EGC, 2015) on “small dams” in Punjab covered 53 dams: The study concluded that the dams have comparatively fewer problems and that the shortcomings can be fixed easily, except for a fewdams which have spillway problems. Problems in the irrigation canals can still be noticed as some of the canals have either not been built or have not yet become functional, and some outlets are not appropriate,[6] resulting in inequitable distribution. The positive outcome is that wheat yields have increased from 1107Kg/ha to 2490 Kg/ha and yields of maize have increased from 1015 Kg/ha to 2859 kg/ha but they still have not reached their full potential. An analysis of cropping intensity for the period 2010 to 2014 indicated that mean *kharif* cropping intensity varied from 0 to 103%, while mean *rabi* cropping intensity varied from 0 to 105%. Out of 53 dams, there are six dams (11%) that do not irrigate any land because the command areas have not been developed.

The Irrigation Department’s rationale for not developing the command areas is that the dams are always capital-intensive. It is difficult to get an Economic Internal Rate of Return (EIRR) of more than 12% if the cost of developing the command areas, including lining water courses, levelling the land, and installing high efficiency irrigation systems is also included in the construction costs. Therefore, almost all the projects are designed and implemented without including command area development, which is considered a secondary effort to be implemented in later years, after the projects are completed. But the absence of command area works results in delayed benefits.

All small dam projects should include command area development, including the construction of watercourses, so as to ensure that the benefits of the project are realized soon after its completion.

[6] Some outlets draw more whereas some outlets draw less than their authorized share.

7.11.3 Small Dams vs Large Dams

Small dams, as some people argue, are not an alternative to big dams/reservoirs; similarly, large dams are no alternative to small dams. Small dams are more useful in promoting local development whereas large dams are more helpful in the development of large areas and often in producing large amounts of environment friendly renewable energy. Both types of dams are equally important and need to be built.

Large dams have a bigger footprint and often result in the resettlement of large number of people who would likely be submerged in the reservoir. These dams also affect the ecology of the area and need much more detailed investigations and design studies compared to the small dams. Small dams also have the problem of resettlement and ecological changes, but over a smaller area, and while they too need more investigation and design studies, it is at a smaller scale..

7.12 Mini Dams

The agency for Barani Areas Development (ABAD) in the Punjab and other similar agencies and departments in other provinces are promoting the construction of mini dams to harvest rainwater. Mini dams have a pond capacity of 50,000 m^3 to 125, 000 m^3 and a command area of at least 6 ha. The height of existing mini dams constructed in Pakistan ranges from 6 m to 15 m. Mini dams are often owned by individual farmers or a group of farmers. These structures usually last 20–30 years. Thousands of such dams have been constructed which, in addition to supplementing available water supplies also recharge the groundwater aquifer.

7.13 Power Demand

Current power demand (in July 2021) is estimated to be about 27,000 MW. Current generation capacity is about 34,501 MW. Power demand is estimated to rise to 38,797 MW in 2030 (NTDC, 2021). Figure 7.11 shows the supply and demand projections for the period 2021–2030, which substantiates that Pakistan's installed power generation capacity will continue to exceed demand. Its main challenge will be managing this capacity cost effectively.

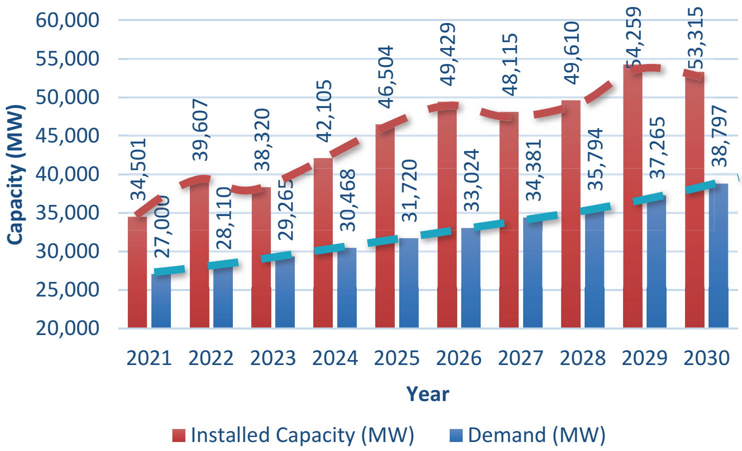

Fig. 7.11 Installed capacity vs power demand (2021–30). (Data source: Installed Capacity obtained from Table 6–7 of NTDC publication, *Indicative Generation Capacity Expansion Plan,* National Transmission and Dispatch Company (NTDC, May 2021). Public domain)

7.14 Current Production Modes and Fuel Costs of Generation

7.14.1 Production Mode

As per Wikipedia,[7] as of July 21st, Pakistan's total installed power generating capacity increased almost six-fold since 1990, from 7000 MW to the current 41,700 MW. Projects for nearly 44,000 MW of additional power generation are under construction or active planning.

Table 7.10 gives a summary of both existing and proposed power generation capacity by different modes. This table suggests that power generation capacity is not a problem for Pakistan. In fact, if all the currently proposed schemes are actually implemented, Pakistan would have the serious problem of having surplus power which it cannot distribute or use.

In 2015, Pakistan and China entered into the China-Pakistan Economic Corridor (CPEC) agreement, which would help Pakistan lower the costs of electricity generation and alleviate electricity shortages by 2020. The agreement included an investment of $34 billion from China to develop energy and other infrastructure projects, including more than 10,400 MW of power plant capacity from coal and renewable energy. To date, {fourteen} energy projects (seven coal, 1 hydel, five

[7] While Wikipedia may be a questionable source in academia, it does provide the most up-to-date and comprehensive information about Pakistan's power plants. For different production modes, it lists all power plants in operation, under construction and planning. It is suggested as a good indicative data source.

Table 7.10 Overview of power capacity by different modes

Power source		Capacity (MW)			
		In Production	Under construction	Under planning/ consideration	Total potential capacity
Hydel	*Large*	7488	10,230	14,624	32,342
	Medium	2004	2537	5007	9548
	Small	640	433	903	1976
Thermal	*Coal*	4868	1950	300	7118
	Multi-Fuels	4263			4263
	Nat. gas	10,322	2163		12,485
	Furn. Oil	7836			7836
Renewable	*Solar*	540	42	2002	2584
	Wind	1240	610	1988	3838
Nuclear		2510	1100		3610
Total		**41,711**	**19,065**	**24,824**	**85,600**

Source: Wikipedia Data, July 2021 Large: > 1000 MW; Medium: 100 —999 MW; Small; < 100 MW. Under Planning are those for which Letter of Intent or MoU is signed

solar/wind plants and one transmission line project) have been completed, with a total generating capacity of 7,620 MW and a reported cost of $12.6 billion. Another two energy projects (one coal, one hydel, are under implementation for an estimated cost of $2,2 billion. {source: www.cpec.gov.pk} These projects are to generate an additional 1,170 MW. Another 13 or so energy projects are being planned, with the aim of producing another 8000 MW. Table 7.11 shows installed capacity categorized with respect to power generation source in May 2021 and planned capacity in 2030.

The full expected benefits from CPEC energy projects have yet to be realized despite large investments. The power outages continue; the circular debt situation has not improved. The debt burden from new power plants is hurting the country; the government is seeking to arrange some debt relief from China. It seems the situation has not changed. This experience needs to be reviewed and analyzed. Perhaps one reason for these deficiencies is that dominant commercial interests in these investments have compromised due diligence in project selection and design.

Figure 7.12 compares the energy mix from different fuel sources in 2021 and 2030. The share of hydel power generation is planned to increase to 23,035 MW (40%) as compared to 9874 MW (26.6%) in 2021. Similarly generation from other renewable resources (wind, solar, baggase) are planned to increase whereas use of expansive RFO is planned to decrease.

Table 7.11 Fuel-wise installed capacity breakup (MW). Source: NTDC May 2021

	May 2021		2030	
Sources	Installed (MW)	Percentage share	Installed (MW)	Percentage share
Hydel	9874	26.61%	23,035	40.08%
RLNG	7325	19.74%	6786	11.81%
HSD	–	–	–	–
RFO	6274	16.91%	1220	2.12%
Coal (Local)	660	1.78%	3630	6.32%
Coal (Imported)	3960	10.67%	4920	8.56%
Gas	4529	12.20%	2582	4.49%
Nuclear	2490	6.71%	3635	6.32%
Wind	1235	3.33%	4964	8.64%
Solar	400	1.08%	4954	8.62%
Baggasse	364	0.98%	749	1.30%
Cross Border	–	0.00%	1000	1.74%
Total	37,111	100.00%	57,475	100.00%

7.14.2 Fuel Cost for Different Power Generation Sources

Increasing the share of hydel generation will help reduce the overall cost of generating energy, since there are no fuel charges for hydropower, which in turn will reduce dependence on more costly fuels. The cost for some of the expensive fuels were: US ¢ 11.77/Kwh for HSD, US ¢ 7.67 for RFO, ¢ 6.11 for cross border purchases of electricity, ¢ 5.18 for LNG, ¢ 4.75 from gas and ¢ 4.03 from coal (NEPRA, 2021) as shown in Fig. 7.13 based on NEPRA's determination of fuel adjustment charges for January 2021.[8]

Electricity production capacity is not a problem for Pakistan. The system, however, is unable to produce the available power due to following reasons:

- Hydel plants are underproducing because of reduced inflows, storage shortages, and reduced irrigation demands.
- Establishment of a significant domestic gas-based production capacity which could not be utilized due to subsequent gas shortages and is now being run on imported LNG.
- Most private thermal power plants are performing under par due to a lack of maintenance, equipment fatigue, and poor technical and managerial skills.
- An intermittent and unreliable fuel supply chain resulting from the circular debt issue.

[8] Average exchange rate for January 2021 used is US$ 1 = PKR 160.47.

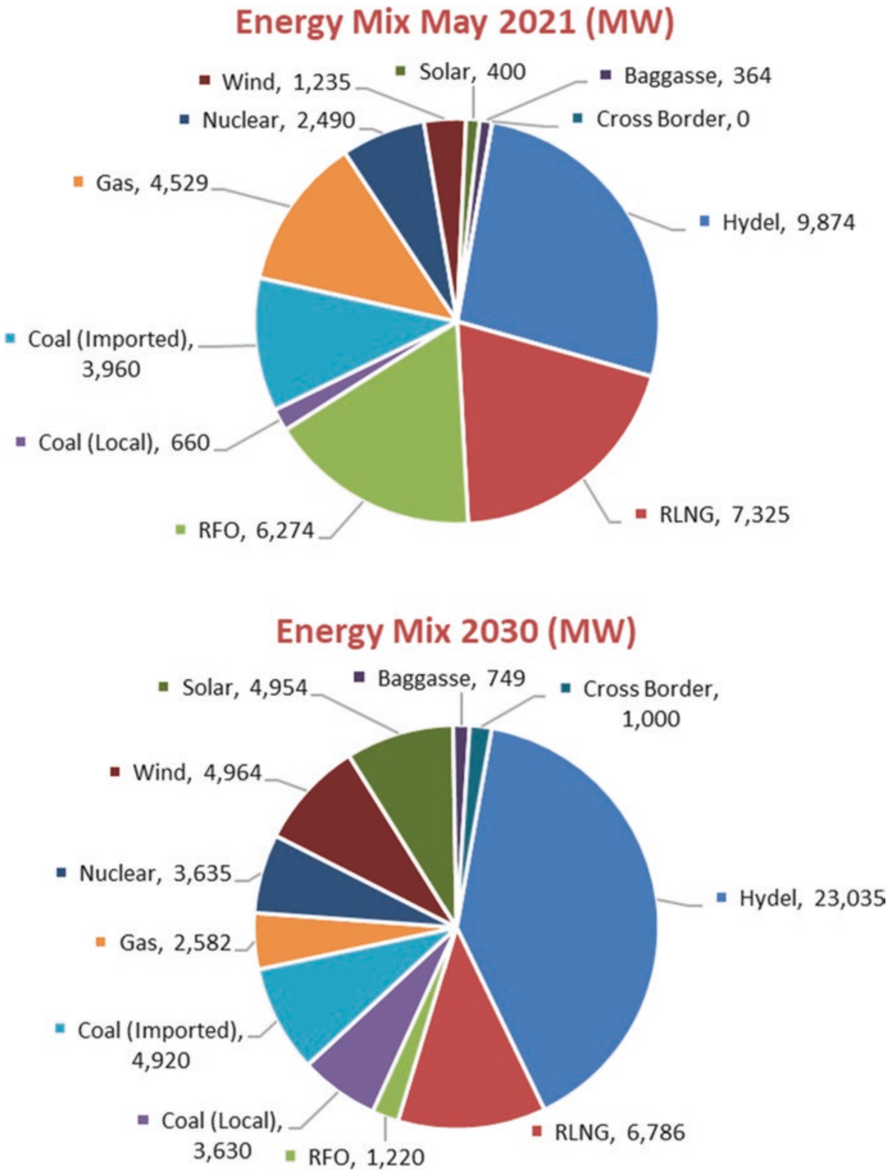

Fig. 7.12 Comparison of energy mix for year 2021 and 2030. (Source: NTDC, 2021. Public domain)

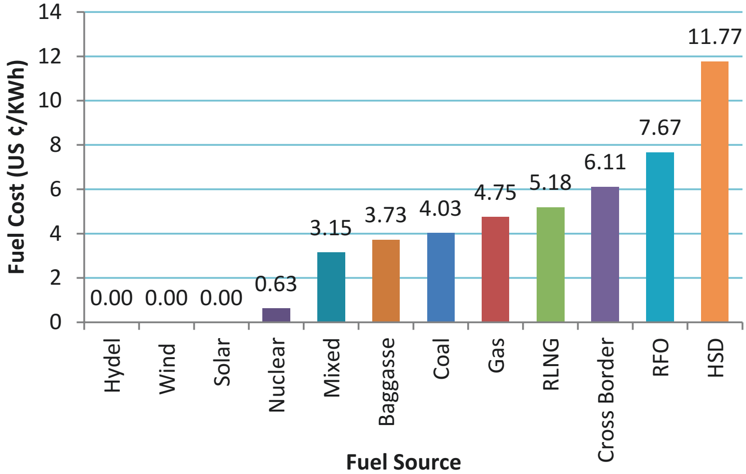

Fig. 7.13 Source wise fuel cost/energy price. (Source: NEPRA March 2021 notification for Fuel Charges Adjustment (SRO 723(I)/2021). Public domain)

- High cost of production relating to use of expensive imported fossil fuels.
- Weak management of IPPs and poor government oversight.

One reason for poor performance of IPP power project is that for each undertaking a new dedicated power entity is established, perhaps to isolate its legal and financial liabilities.

7.15 Energy Sector Policy and Institutional Framework

Over the years, various governments have issued policy documents to resolve energy issues. Yet, one cannot say that Pakistan today has a clear and comprehensive national energy policy in place. Power Policy 1994, Hydel Power Policy 1995, Power Policy 1998, Power Policy 2002, Power Policy 2013, Power Policy 2015, National Power Policy 2020 (draft) are some of the attempts at formulating a comprehensive power policy. The 2013 Energy Policy was a comprehensive document that had two major goals: (i)reducing Pakistan's power shortfall from about 5.000 MW to zero by 2017 and (ii) enhancing the energy mix by incorporating renewable energy sources. This document articulated a vision for the power sector, highlighting its key challenges, setting major goals, summarizing policy principles, and highlighting the strategies for supply, demand, generation, transmission, distribution, and sector financing. The energy sector received prominence during 2013–18 and a substantial investment boost through the CPEC program, resulting in enhanced new generation capacity. Yet there was only marginal progress in resolving the fundamental energy issues, mainly because the government was focusing on short term capacity enhancement. At presnt, Pakistan faces an enormous challenge to ensure the production of inexpensive and affordable electricity for domestic, commercial, and industrial uses and improvement in transmission and distribution and minimization of pilferage, etc. A comprehensive policy document is still awaited.

A major institutional restructuring of Pakistan's power sector, commonly called "WAPDA unbundling", was initiated in the 1990s. Then, WAPDA (handling all aspects of water and power development) was perceived to have grown into a too-large and unsustainable entity. The World Bank (WB) and the Asian Development Bank (ADB) supported a major initiative to restructure Pakistan's power sector with the goal of privatization. WAPDA's Strategic Plan (WAPDA, 1992), approved in 1992, had the following key objectives: (i) Reorganization/corporatization of WAPDA into a holding company with decentralized power generation, transmission, and distribution subsidiaries operating as discrete profit centers; (ii) Establishment of a national regulatory authority to set standards and regulate a gradually privately-operated power sector; (iii) Adoption of pricing policy to support the restructuring and privatization objectives; (iv) Development of a supporting manpower plan, and (v) Initial offering for sale of parts of WAPDA's assets to the private sector. The plan was to be implemented in phases during fiscal years 1995–1998.

To date, this scheme has only been partially implemented. WAPDA's thermal generation, transmission, and distribution functions were reorganized into 12 companies—three generation companies, eight distribution companies, and one national transmission company. WAPDA's non-hydro generation portfolio was transferred to a "holding company" for privatization, on which progress has been limited. Subsequent new power production was mostly financed by the private sector. The transmission and distribution parts have been "corporatized" with substantial government control. These companies now operate under the umbrella of the Pakistan Electric Power Company (PEPCO). The National Electric Power Regulatory Authority (NEPRA) was established in 1997 as the sector regulator. The main outcome of this program was the mushrooming of Independent Power Plants (IPPs) (now nearly 50) and the addition of nearly 14,000 MW of generation capacity through private investments. The operational efficiency and cost effectiveness of these undertakings is questionable.

The power sector restructuring program did not achieve the broader objectives of a rational energy sector meeting power demands with reliability and affordable prices. The outcome of this program was rated as less than satisfactory in ADB's own evaluation (ADB, 2004). A key lesson from this is that un-bundling alone is not sufficient; privatization must lead to improvements in operational efficiencies, which has not been the case in Pakistan. This reflects a failure on the part of the oversight and regulatory entities, which failed to ensure that additions to power capacity were rational and cost-effective. The stalled WAPDA corporatization plan has resulted in a situation where new power generation is mostly in the private sector, with high production costs and low operational efficiencies; the rest of the power sector—regulation, transmission, distribution, etc.—is in pseudo "corporate mode", with the agencies still mostly under government control. This has resulted in both weak governance and a weak financial situation.

7.16 Hydropower in Pakistan

Pakistan is endowed with considerable hydropower potential. According to WAPDA, there is potentially 60,000 MW of untapped hydropower in Pakistan. This potential lies largely in the mountainous north along the Indus River in Gilgit Baltistan and the KPK, as well as the Jhelum River in Punjab and Azad Jammu and Kashmir.

The story of hydropower production in Pakistan can be described as boom, bust, and restart. During the1960s and 70 s, the country's focus was on multi-purpose dam construction for electricity generation and the release of irrigation water from storage reservoirs.[9] Mangla and Tarbela, the two mega dam projects constructed under the Indus Basin Treaty, have created over 5000 MW of generation capacity. As mentioned earlier, further hydropower production stalled due to political controversies surrounding the proposed Kalabagh Dam. Thus, in the last four decades, Pakistan has been unable to add any significant water storage capacity. It has had to resort to a few run of the river projects and the raising of the Mangla dam reservoir. Table 7.12 lists existing hydropower projects in Pakistan. There are only three dams with reservoir storage; others are run of the river projects. The total live storage capacity of these three reservoirs currently is 16.6 BCM, while the total installed hydropower generation capacity is 9012.4 MW.

Table 7.12 Existing storage/hydropower projects

Reservoir	Year Completed	Present live Storage Capacity (BCM)	Installed Generation Capacity MW
Mangla (after raising)	1967	8.965	1115
Tarbela Dam	1974	7.340	3478-
Chashma	2001	0.332	184
Ghazi Barotha	2002	–	1450
Neelum Jhelum	2018	–	969
Warsak	1960	–	243
Jinnah	2013	–	96
Karot Hydropower Project	2017	–	720
Several Run of River Projects			757.4
Total		**16.637**	**9012.4**

[9] It must be recognized that in terms of managing the water released from the reservoirs, these two objectives are often conflicting.

Starting in the mid-2010s, Pakistan's policy makers have begun to realize that continued reliance on thermal modes of production is not viable; emphasis needs to shift toward renewable energy sources. In 2014, the WB approved a loan and arranged a financing package for the Dasu Dam on the Indus River. It was a major undertaking after a prolonged hiatus in dam construction in Pakistan. The implementation of this project, to date, has been slow and problematic.

The CPEC Phase I program included four run of the river power plants, all commercially financed. These projects are currently being built. In the beginning of 2019, dam construction became an emotional national issue. With a lot of fanfare, a "National Dam Fund" was created to finance new dam projects; this initiative fizzled out soon. Nevertheless, the government has committed to two new dam projects—the Mohmand and Diamer Bhasha (DB). Construction of the Mohmand dam is underway. Initial work has also started on the DB Dam, which will take at least 10 years to complete with all its technical and financial challenges. Table 7.13 lists the dams/hydropower projects currently under construction. These eight projects will have a live storage capacity of 8.72 BCM and total power generation capacity of 12,260 MW. With the completion of these projects, hydropower output should double, resulting in an improved energy mix.

Various hydropower projects in the planning stages are listed in Table 7.14. The locations of all completed, ongoing and planned power plants in Pakistan that have an installed capacity above 80 MW is shown in Fig. 7.14.

Globally, there is an ongoing controversy about large dam projects because of their environment and socioeconomic impact. The obvious alternative source—thermal power—has proven to be more damaging to the environment as well as having economic and fiscal implications. For countries that rely on imported fossil fuels, thermal power plants have proven to be very expensive and problematic in terms of managing foreign exchange accounts. Pakistan is a glaring example in this regard. As a result, its policy makers started to shift their emphasis, in the mid-2010s, towards renewable energy sources—hydel, solar, and wind energy. Pakistan has already made serious efforts to exploit the run of the river potential to generate

Table 7.13 Storage/hydropower projects under construction

Project	Live storage (BCM)	Installed generation capacity (MW)	Estimated cost US $ Billion	Estimated completion
Diamer Bhasha	7.89	4500	10 ~ 14	2030
Mohmand	0.83	800	0.8	2026
Dasu Phase 1	–	2160	4.2 (2014)	December 2026
Tarbela 5th Extension		1,410	0.807	2025
Suki Kinari[a]	–	870	1.70	December 2022
Kohala[a]	–	1100	2.35	December 2026
Azad Pattan[a]	–	700	1.65	2023
Karot[a]	–	720	1.70	December 2021
Total	**8.72**	**12,260**		

[a] CPEC financed

Table 7.14 Planned storage/hydropower projects

Proposed Project	Gross storage (BCM)	Installed generation capacity (MW)
Shyok	6.78	640
Skardu	3.7	1200
Tungus	–	2200
Yulbo	–	2800
Bunji	–	7100
Dasu (Stage II)	–	2160
Pattan	–	2400
Thakot	–	4927
Akhori	7.40	600
Kalabagh	7.40	3600
Indus Barrage	3.08	–
Total	**28.36**	**27,373**

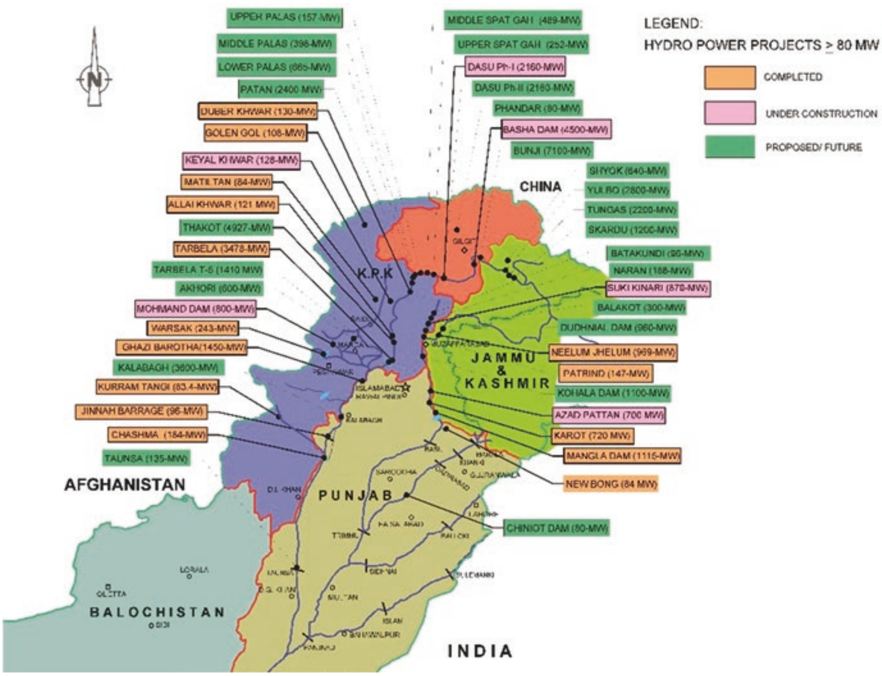

Fig. 7.14 Location of existing and potential hydropower projects. (Authors' own work)

power, as can be seen in the tables above. In addition, approximately 67 small (< 100 MW) hydel power plants are in operation with an installed capacity of 640 MW (Table 7.10).

The CPEC program mentioned above has made a significant start in exploiting solar and wind energy sources, but with limited results. The large 100 MW

Quaid-e-Azam solar power plant near Bahawalpur was completed in 2016 with much publicity. However, the power output from this plant is reported to be less than 25% of its installed capacity for various reasons, including a lack of water to clean the solar panels. The levelized tariff of US14.15 cents/kWh is also on the higher side. Currently with a total installed capacity of 1780 MW, the solar and wind plants account for less than 5% of total energy production capacity. The next phase of the CPEC program has modest investments of a second phase 600 MW solar plant and two small wind plants (100 MW) under consideration. The potential for hydropower in Pakistan is quite significant compared to other renewable sources. The focus has thus lately shifted back to hydropower development.

7.17 Hydropower Outlook and Challenges

Hydropower is going to be an important source of energy in Pakistan along with other sources. The choice is not between one or the other; it is a matter of having an optimal mix among various sources considering the country's particular situation. For Pakistan, it is now well recognized that the current energy mix is distorted in favor of thermal sources and there is a need to enhance renewable energy production. Hydropower is the leading source in this regard. It is a renewable source which has high initial installation costs but very low recurring operational costs. In terms of building storage reservoirs, the main issues are relocating the existing population in the area to be flooded and the impact on ecosystems because of a changed river flow regime. However, it is still largely a cheap and reliable source of electricity that does not require imported fossil fuels. WAPDA's goal at this time is to achieve a 40% hydropower share by 2030 and 50% by 2050. These reasonable goals would require a sustained and balanced program of hydropower development comprising large dams as well as run of the river projects.

Pakistan is seemingly on a path to increase its use of hydropower for its energy needs. Eight hydropower projects are under construction with a total output capacity of 12,380 MW (Table 7.13). This includes three large dams: Dasu, Diamer Bhasha and Mohmand. While the Dasu and Mohmand dams could be completed in the next 3–4 years, the Diamer Bhasha dam is likely to take 10 or more years to complete. At this stage, undertaking yet another large dam project would not be realistic or desired. However, the emphasis should remain on exploiting additional hydel sources from run of the river projects.

As mentioned above, the energy sector of Pakistan is facing serious technical, managerial, and financial challenges which need to be addressed. Some challenges specific to the hydropower sector are described below:

- Since the mid-70s, dam planning and selection has become overly politicized. This has created a damaging hiatus in the construction of much required additional water storage and power production. While in the last few years, things have improved, the hydel projects selection process needs to be depoliticized and professionalized.

- Pakistan is faced with two sets of interprovincial disputes hampering effective utilization of water resources. The first one is the water allocation and release of water from reservoirs for competing irrigation and power generation needs. The second relates to the allocation of hydropower profits based on the physical location of the project. The definition of "net hydel profits" has been controversial, causing perpetual disputes between provinces and the federal government. Pakistan needs to address this controversial issue. The country would have been better off if all the hydel profits had been put into a dedicated "national energy fund" to be used to finance power investments based on national needs.
- The three large dam projects, Dasu, Mohmand, and Diamer Basha, have been under "implementation" for a rather long time. Dasu was started in 2015 and was scheduled to be completed by 2020. The Dasu project financing was approved and arranged by the World Bank in 2014. It has faced long delays due to the land acquisition required for the project. The DB dam had a number of inaugurations before its current one in 2019. Reportedly, the DB dam is also facing initial delays in acquiring land. It is likely to face technical and financial challenges in the coming years. Pakistan needs to address the startup delays relating to land acquisition if these projects are to be implemented efficiently. This requires administrative and political solutions.
- Pakistan also needs to address the weak links of transmission/distribution systems and tariff distortions to fully benefit from large planned hydropower undertakings.

7.18 Concluding Remarks

7.18.1 Storage

- The total water demand of 180.4 BCM in 2015 is expected to increase to 210.4 BCM by 2050 due to the increased requirements of agriculture, industry, and municipal water. Storage alone cannot meet these water requirements as the water required for this level of demand is not available.
- Additional measures are required to meet food and fiber requirements and corresponding water requirements. Some of these include increasing crop yields, water conservation and management, rain water harvesting and high efficiency irrigation systems, and the rationalization of cropping patterns, including substitution of high-water consuming crops with those needing less water.
- Analysis of data on availability and use of surface water shows a possible potential draft (withdrawal) of the order of 165 BCM, still leaving enough surplus to meet the environmental requirements below Kotri. This draft will only be possi-

ble if enough storage capacity (about 37.5 BCM) is provided in the system to capture large flows through a cascade of reservoirs to use the stored water in dry seasons/years.

- Consensus is required on the amount of environmental flows required in the Indus below the Kotri Barrage to prevent sea water intrusion in the Indus delta and maintaining ecological balance. The release of agreed environmental flows needs to be ensured.
- Small dams conserve available floods and rain water for agriculture and minimize the adverse effects of drought and water scarcity locally in arid/rain-fed areas.
- Small dams, as some people argue, are not an alternative to big dams/reservoirs; similarly large dams are no alternative to small dams. Small dams are more useful in promoting local development whereas large dams are more needed in the development of large areas and in the production of large amounts of environment friendly renewable power/energy. Both types of dams are equally important and need to be constructed.
- All small dam projects should include command area development including construction of watercourses so as to ensure that benefits of the projects are realized soon after their completion.

7.18.2 Hydropower

- A striking feature of Pakistan's power situation is a mismatch between production capacity, demand, and actual supply. The present power demand (in July 2021) is estimated at about 27,000 MW, whereas Pakistan has nearly 150 operational power plants with a potential capacity of 37,000 MW for electricity production, but actual production has averaged about 15,000 MW in the last decade.
- Pakistan is still facing power shortages due to various technical, financial, and management factors. This electricity crisis is estimated to have cost the economy at least 2% of GDP ($5 to 6 billion) annually in terms of lost output —and a further 1.2% of GDP each year, on average, economically.
- Globally there is an ongoing controversy on large dam projects for their environment and socio-economic impact. The obvious alternative source —thermal power —has proven to be more damaging to the environment as well as having economic and fiscal implications. As a result, Pakistan's policy makers started to shift emphasis, in mid-2010s towards renewable energy sources — hydel, solar and wind energy. Pakistan has already made serious efforts to exploit run of the river potential to generate power and install small power plants where feasible. Approximately 67 small (< 100 MW) hydel power plants are in operation, with an installed capacity of 640 MW.
- It is well recognized that Pakistan's current energy mix is distorted in favor of thermal sources and there is a need to enhance renewable energy production.

Hydropower is the leading source in this regard. It is a renewable source which has high initial installation cost but very low recurring operational costs.

- Increasing the share of hydel generation will help reduce the overall cost of energy generation as there are no fuel charges for hydropower. The fuel cost for some of the expensive fuels were: US ¢ 11.77/Kwh for HSD, US ¢ 7.67 for RFO, ¢ 6.11 for cross border purchase, ¢ 5.18 for LNG, ¢ 4.75 for gas and ¢ 4.03 for coal.
- Electricity production capacity is not a problem for Pakistan at this time. The system, however, is unable to produce the available power due to various reasons: under production from hydel plants during periods of low flow, under production from gas plants due to gas shortages, inefficiency of thermal power plants due to a lack of maintenance, equipment fatigue, poor technical and managerial skills, unreliable fuel supply resulting from the circular debt issue, the high cost of production relating to use of expensive imported fossil fuels and weak management of Independent Power Producers (IPPS) and poor government oversight.
- Pakistan also needs to address the weak links of transmission/distribution systems and tariffs distortions to fully benefit from large planned hydropower undertakings.

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Part III
A Transformative Agenda and Its Drivers

The world has to learn to live with less water because climate change is affecting our water resources. Advances in water science and technology will show us how this can be done through research, teaching, training, and dissemination to each sector of the society as needed—whether it be adopting regenerative agriculture, recycling, micro-irrigation, changing the crop mix in different water regimes, rationing water use in agriculture or reworking the right per capita allowance in times of water stress and water scarcity.

Pakistan has underinvested in water demand management, a term often used that refers to managing people rather than the resource itself. Demand management practices are a set of interventions and organizational systems intended to increase technical, social, economic, environmental, and institutional efficiencies for competing use of water. Pakistan needs a new water strategy to address the fact that agriculture uses a whopping 96% of available water. If just 5–10% of the water used in agriculture was saved, it would be enough to meet the growing needs in other competing sectors while also resolving challenges caused by climate change.

The government's priority is to enhance water productivity in order to help farmers. The government should consider a broader framework focusing on these three aspects: (1) enhancing the marketable yield of crops for each unit of crop transpiration; (2) reducing non-beneficial atmospheric depletions and the outflows that cannot be recovered and; (3) enhancing the effective use of rainfall, marginal-quality water and stored water.

Agriculture and the water sector are faced with many challenges, including a diminishing natural resources base, with changing climatic conditions further exacerbating the situation. Climate change affects agricultural productivity and agricultural production generates greenhouse gases (GHG) emissions that drive climate change. In addition, for decades input-intensive farming has deteriorated soil systems in Pakistan and in many other developing countries because of high salinity from the overuse of fertilizer and irrigation water. All these factors are putting agriculture production and food security at risk. The key to a sustainable future is to move towards more ecologically friendly farming systems that use less water in harnessing nature to sustain higher levels of productivity.

The transformative agenda can broadly put as:

- Moving from supply side focus to demand management with tradeoffs documented.
- Moving from canal based water development focus to integrated groundwater management approach.
- Rehabilitating watersheds, flood control diversions, wetlands and coastal estuaries through low cost nature-based solutions including climate-smart options.
- Bringing about further efficiency gains by harnessing the food, water and energy management nexus.
- Finding a new policy tools such as adaptation, mitigation and productivity enhancement as the main drivers in achieving sustainable goals including estimating carbon footprints and balance.

The Drivers

Water Sector

Demand Management provides possible tradeoffs which have not been studied deeply:

- Productive versus allocative efficiency—do we need to invest in technology that might improve efficiency at the farm levels but decrease basin-wide water use efficiency which is quite high?
- Ration water use in agriculture through using fewer water intensive crops.
- Use innovative and low cost supply enhancement options such as promoting run-off river water storage, water harvesting, low cost water storage at the farm or community levels and supplementary irrigation.

Groundwater Management must be focused storage alternatives and adaptation possibilities to address climate change issues. It still remains a classic case of policy, institutional and market failure:

- Policy failure—large divergence between private and social price of resource use. It is necessary to to rationalize inputs and outputs of direct and indirect subsidies.
- Institutional failure continues be a concern because without enforcement of rules and regulations, over time proposed policies will not be effective. A mix of regulatory framework and incentive policies is highlighted in two chapters.
- Market Failure—we need to assess the unaccounted cost paid by tax payers and internalize these costs.

Reinvest in *Ecosystem-based Adaptation (EbA)* measures that often manage increasingly erratic precipitation, resulting in consequent flooding or drought impacts, and also the expected increases in temperatures that will exacerbate water security concerns. The possible interventions may include:

- Planting trees in order to provide eco service, water shed management, landscape improvements and improve habitat and biodiversity that can be beneficial for farmers and society at large. Forest and planted trees on the farm are renewable by nature and enjoy a carbon neutral footprint.
- Enabling a paradigm shift towards EbA for selected prioritized sites.
- Promoting decentralized wastewater management, preferably with community ownership.
- Site specific restoration techniques including: de-silting and excavation, reconnecting wetlands to river channels and afforestation initiatives, degraded wetlands (especially those with natural blocked flow paths to river channels), enhanced flood-water storage and groundwater recharge, only divert water to wetlands for excess flood water storage.

Agricultural Sector

To build climate resilience and ensure food and water security in this context, the agricultural sector needs to undergo a transformation of crop production and water management practices, supported by an enabling policy and institutional environment. The proposed transformative process can reposition the sector to be profitable, competitive, sustainable and inclusive. Removing or reducing the water constraint can be achieved in a cost effective way. The identified drivers include:

- Transform agriculture from industrial agriculture to nature-based agriculture or regenerative agriculture. The focus in particular on conservation and regenerative agricultural practices, which are a promising means to enhance the resilience of agricultural systems to climate change, improve food and water security and restore the soil carbon sink.
- Assessment of current farmer experience with shifting to Regenerative Agricultural Practices (RAP) practices in Pakistan. This will include an identification of the constraints to adoption as well as the policy environment needed to scale up such practices.
- Methods for reliably measuring carbon sequestration in soil are also relatively recent—but they are increasingly being tested at scale. This will soon allow smallholder farmers in developing countries including Pakistan to benefit from eco-system payment services, including potential transfers to support transition costs.

Chapter 8
The Impact of Climate Change on the Indus Basin: Challenges and Constraints

Asif Khan and Muhammad Hamza Idrees

Abstract The Indus River Basin is a significant transboundary river system that is one of the largest in Asia in terms of volumetric flow and which feeds irrigation and hydropower systems in Afghanistan, India, and Pakistan. This also makes the Indus River Basin politically significant. The physiography, river networks, and climate of the Indus River Basin area are explored in detail. The twin challenges of population growth and climate change are outlined. Population growth will drive demand for more hydropower; climate change will lead to more intense and more frequent flood events, including riverine and urban flooding, GLOFs, and hill torrents. The impact of climate change on precipitation and flows, together with the rise in temperature, could adversely affect agriculture, human health, ecosystem, soil erosion, energy consumption, water use, infrastructure, and agriculture. A comprehensive list of these major threats from climate change are given, followed by a thorough discussion of adaptation measures and policy options to mitigate these effects.

Keywords Indus River Basin · Riverine floods · Urban floods · GLOFs · Flood adaptation and mitigation

8.1 Introduction to the Indus River Basin

The Indus River basin, with a drainage area of 833,759 km^2, is one of the major river basins of the world. The Indus is a noteworthy river for various reasons. It is a tranboundary river (Fig. 8.1). Its drainage basin is distributed in China (7.2%), Afghanistan (8.6%), India (9.4%), Pakistan (52%), and an area with unsettled sovereignty (22.8%). It is one of the mightiest rivers in Asia in terms of its annual volumetric flow and sediment load. It originates at and passes through a high-altitude

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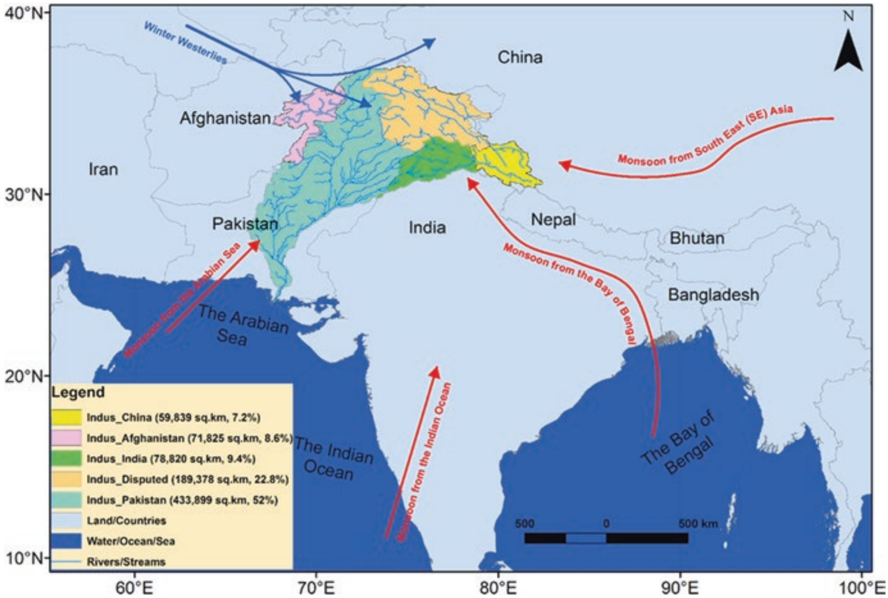

Fig. 8.1 Geographic location of the Indus Basin. Blue lines with arrows indicate westerlies towards the Hindukush, Karakoram, central Pakistan and central Asia, while red lines with arrows are monsoon depressions. The direction of the monsoons from the Arabian Sea, from the Indian Ocean, from the Bay of Bengal and from southeast Asia are duly shown. Source: Both monsoon and westerly directions have been adapted and redrawn by the authors from Hodges (2006), Hussain and Lee (2009), Yao et al. (2012) and Bolch et al. (2012)

terrain spanning the Greater Himalayas, Hindukush, and Karakoram Mountain ranges where the glaciers and snow packs, which are the main sources of river flows, are vulnerable to climate change. Numerous tributaries, some of which are themselves major rivers of the basin, join the Indus throughout its course. The river network of this basin has been extensively engineered to create extremely important irrigation systems for vital agriculture and hydroelectricity in Afghanistan, India, and Pakistan. With these systems, it carries significant hydro-politics as well.

8.2 Physiography of the Indus River Basin

The Indus (~ 3200 km), called *Sindhu* in Sanskrit, originates from a spring that is known locally as Singi Kahad (mouth of a lion) in remote western Tibet at an elevation of about 5166 m on the northwestern slopes of the Kailash approaching Lima la Pass. In its mountainous course, the Indus flows northwest between the Ladakh Range and the Karakoram Mountains to the north and the Zanskar Range and the Greater Himalayan Range to the south until it reaches the foothills of the Hindu Kush Mountains. There it bends sharply to continue its southward journey, cutting through the foothills of the Lesser Himalayas and Siwalik Ranges, and then descends to the plains. From there it flows over the fertile plains of the Punjab and Sindh provinces of Pakistan and ultimately discharges into the Arabian Sea after forming a large delta flat at its mouth. After descending from the mountains, the river flows over an expansive tract of the plains where the Indus Valley (Harappa-Mohenjo-Daro) civilization flourished in about 2500 BC.

Several major rivers originating from Tibet and the Greater Himalayas flow from northeast to southwest and form an extensive tributary system to the east of the main stem of the Indus. A few major rivers originating from the Hindu Kush form a relatively smaller tributary system to the northwest of the main stem.

8.3 River Network and Principal Hydrological Units of the Indus River Basin

Broadly, the Indus Basin can be subdivided into 10 major sub-basins drained by 27 major tributaries and their numerous lower-order tributaries (Fig. 8.2).

The area that is drained by the Indus and its tributaries from their headwaters in the Karakoram and the northern slopes of the Zanskar and the Greater Himalayas up to the Tarbela impoundment reservoir in Pakistan forms a natural drainage boundary that is known as the Upper Indus Sub-basin with an area of 172,173 km^2 (Khan et al., 2014). The sub-basin straddles two great mountain ranges and home to some of the most remarkable glaciers of the world, such as the Hispar, Batura, Chogo Lungma, Biafo, Baltoro, Siachen, and Masherbrum glaciers, and hosts snow-covered mountain slopes and mountain peaks such as Godwin Austen or K2 (8611 m), Nanga Parbat (8126 m), and Rakaposhi (7788 m). According to Bajracharya and Shrestha (2011), there are 11,413 glaciers covering an area of 15,062 km^2 in the Upper Indus Sub-Basin, which is one of the most meltwater-dependent river basins in the world.

One of the major tributaries of the Upper Indus is the Shyok River which originates from the eastern Karakoram Range. Two other major rivers, namely the Nubra originating from the Siachen glacier and the Hushe which flows from the Masherbrum glacier in the Karakoram, feed the Shyok with meltwater. The Zanskar and Shingo Rivers, both of which originate from the western ranges of the Greater Himalayas, feed the main stem of the Indus before its confluence with the Shyok. Downstream of this confluence, the major rivers that contribute to Indus flows are the Shigar, carrying meltwater from the central Karakoram; the Hunza, carrying meltwater from the western Karakoram; the Gilgit, originating from the Hindu Kush; and the Astore, originating from the Burzil Pass (4100 m) of the western Greater Himalayas. Nine major watersheds constitute the Upper Indus Sub-Basin (Mukhopadhyay & Khan, 2014).

Downstream of the Tarbela Dam, near Attock, the first major western tributary joining the Lower Indus is the Kabul River, originating from the southeastern slopes of the Hindu Kush mountains. The Kabul River has two major tributaries, namely the Chitral River and the Swat River. The drainage area of the Kabul River sub-basin

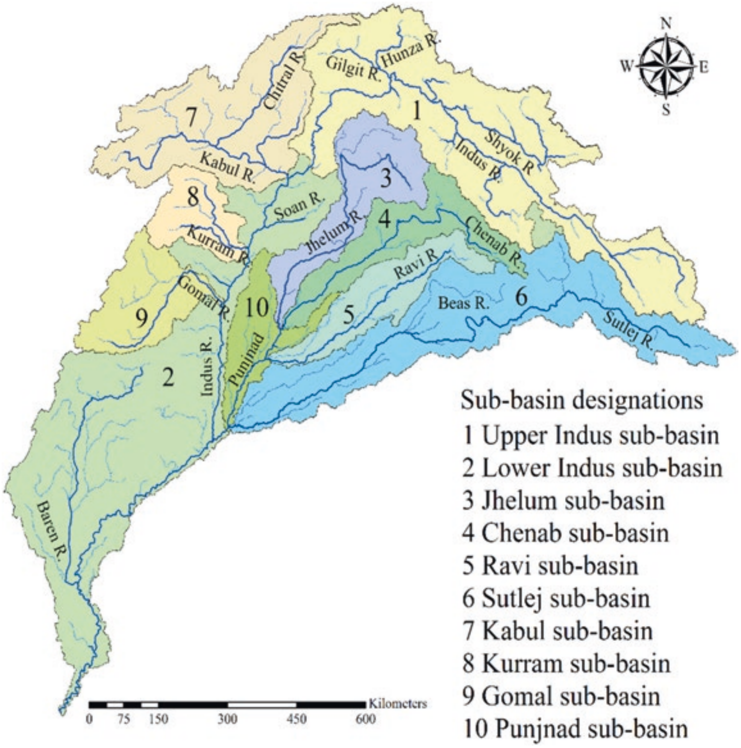

Fig. 8.2 The major rivers and the major drainage units (sub-basins) of the Indus Basin. (Source: Stream and drainage area delineations are the authors' work based on the data and methods described in Khan et al. (2014))

is 92,829 km^2. Below Attock, the Haro and Soan Rivers join the Lower Indus on its eastern flank. Further downstream, two major western tributaries are the Kurram and Gomal Rivers, with sub-basin areas of 25, 911 and 39, 755 km^2 respectively.

The major eastern tributary, joining the Lower Indus above Guddu Barrage in Pakistan is Punjnad, meaning five rivers. The Punjnad is the flow resulting from five main rivers: the Jhelum, the Chenab, the Ravi, the Beas, and the Sutlej. These five rivers form an extensive drainage system spanning the southern slopes of the Greater Himalayas in Tibet and India to the plains of Punjab in Pakistan. The Jhelum River originates from the eastern mountain belts of Kashmir Valley in India, about 54 km east of Anant Nag, flows in a general northwest direction along a valley (2000–3000 m) formed between the Greater Himalayas to the northeast and Pir Panjal Range to the southwest, up to Muzaffarabad, where it turns sharply southward to complete its 816 km journey to converge with the Chenab River near Athara Hazari in Pakistan. The Jhelum Sub-Basin has a drainage area of 49, 838 km^2. The major tributaries of the Jhelum are the Neelum/Kishan Ganga, Kunhar, Poonch, and Kanshi.

Two rivers, the Chandra and Bhaga, originate from the southern sides of Baralacha La Pass (5030 m) in the Greater Himalayas in the Himachal Pradesh state of India and then join together near Tandi to form *Chandrabhaga,* or the Chenab

River. It traverses through the mountainous tracts of the greater, middle, and outer Himalayan and Pir Panjal ranges and then descends to the plains. Further to the southwest of Akhnoor in Jammu, it enters Pakistan and flows through the plains of Pakistan's Punjab to ultimately become the Punjnad before its confluence with the Lower Indus. The total drainage area of the 1232 km-long Chenab River is estimated as 45,389 km^2. The major tributaries of the Chenab are the Throt, Shedi, Lidar, Marusudar, Neeru, Pugal, Bagi, Bachieri, Ana, Dowara, Halsi, Bhimber, Palku Nullah, and Budhi.

The Ravi River originates in the lesser Himalayan range in India,flows along the southern slopes of the Dhauladhar range and enters the plains at Madhopur in Indian Punjab, and then nearly following the India-Pakistan border for some distance flows westward to enter Pakistan and finally converges with the Chenab River near the township of Sarai Sidhu. The Ravi, with a length of 880 km and several major tributaries such as the Ujh, Bein, Basantar, Degh Nullah, and Hudiara, drains an area of approximately 38,210 km^2.

The 464 km long Beas River, *Bipasha* in Sanskrit, meets the Sutlej River at Harika in Indian Punjab as its most important tributary, after draining an area of 9, 920 km^2 with a few tributaries.

The Sutlej River, *Shatadru* in Sanskrit, originates from the northwest of Mount Kailash in Tibet and enters India north of Shipki La Pass (5, 670 m) in Himachal Pradesh. It flows through the mountainous tracts of the Himalayas and descends to the plains of Indian Punjab near Rup Nagar. Further downstream it flows westward to enter Pakistan north of Ferozpur, India, to continue its course to Alipur-Uch Sharif Road where it unites with the Chenab. The Sutlej, 1536 km in length, has a drainage area of 125,437 km^2. The area drained by the Punjnad is 28,054 km^2. The rest of the basin is called the Lower Indus Sub-Basin with an area of 216,193 km^2. In the various literature, the total area of the Indus Basin has been said to range from 1.2 to 1.6 million square kilometers. This difference is due mainly to the inclusion of an area to the east of the confluence of the Punjnad and the Lower Indus. However, this part is mainly desert (Cholistan and Thar). These areas drain internally and therefore are excluded from the Indus Basin in the current delineation (Fig. 8.1). There are gravity canals from both the Guddu and Sukkar Barrages which irrigate downstream areas, previously included as part of the Indus catchment. The downstream slopes also suggest that these areas do not drain into the Indus Basin, but are either interior drainage or drain to the Arabian Sea directly.

8.4 Climate of the Indus River Basin

Due to the marked physiographic variation in the basin, precipitation and temperature show remarkable spatial variation and seasonal fluctuations throughout the basin. In general, the basin covers arid to semi-arid climatic zones where average annual rainfall varies from 200–400 to 2000–2500 mm. The northern parts of the basin experience harsh winters when the temperatures dip down to well below freezing with significant snowfall, whereas in the middle and southern parts winters are mild but summers are very hot when temperatures rise above 35 °C. Largely due to variations in altitude, the climatic conditions range from tropical, hot, and moist in the lower valleys to cool temperatures at 1500–2000 m; above this, the climate becomes progressively colder until it reaches polar temperatures at the highest altitudes.

The basin experiences two major climatic systems: the mid-latitude westerly or western disturbances from December to March, and the South Asian monsoon from June to September (see Fig. 8.1 for westerlies and monsoons). The Karakoram and Western Himalayas receive heavy snowfalls during the winter from incursions of the moisture-laden winter westerly circulation and cyclonic storms from the Mediterranean, Black, and Caspian Seas. Two-thirds of high altitude snow accrual in the Karakoram occurs in winter. Even though the monsoon is more focused on the outer or lesser Himalayas, high altitude summer monsoonal snowfall accounts for the other one-third of snow accumulation in the Karakoram (Hewitt, 2011).

A well-known fact of geography is that the towering ranges of the Himalayas interpose an insurmountable orographic barrier that halts the masses of monsoon clouds from the south and thus have created rain shadows in the landscape to the north. Naturally, rainfall in the Upper Indus Sub-Basin is scarce. Basin-wide average annual rainfall is approximately 300 mm. However, this aridity of the basin is mostly at elevations in the range of 1000–2500 m. Since the Karakoram is located a considerable distance away from the seas and ocean, the bulk of the moisture to this mountain range is transported from the west and southwest in the middle troposphere by winter westerlies. As a result, the bulk of precipitation in the Karakoram falls at elevations higher than 4000–5000 m during the winter. Furthermore, there is orographic enhancement of precipitation. Although the valley floors are quite arid, precipitation amounts increase substantially with increasing altitude. At 4000 m, annual snowfall of greater than 600 mm can be expected, whereas snow accumulation of 1500 mm to over 2000 mm occurs at elevations of 5500 m and above (Mukhopadhyay & Khan, 2014).

In the Himalayan parts of the basin, seasonal as well as annual precipitation increases from the Greater Himalayas to the Middle Himalayas and reaches maximum levels in the outer Himalayas and the foothills (Singh & Kumar, 1995). From the Himalayan foothills to the plains, rainfall decreases from northeast to southwest. Average annual rainfall in the Jhelum Sub-Basin is 1052 mm; in the Beas watershed it is 1146 mm; in the upper parts of the Chenab, Ravi, and Sutlej sub-basins precipitation totals are 1334 mm, 1215 mm, and 1157 mm respectively, as determined from 34 years' (1971–2004) of station records. In the middle parts of the basin, average annual rainfall is around 500 mm (e.g. 516 mm in the middle Chenab and 555 mm in the middle-lower Sutlej), also based on 34 years' (1971–2004) of station records (CWC – NRSC, 2014). In the plains of the Lower Indus Sub-Basin, mean annual rainfall varies between 90 mm in the downstream segment to 500 mm in the midstream segment (Ali, 2013).

8.5 Significance of the Indus River Basin

8.5.1 Contributions in Irrigation

The Indus basin's river flows play a vital role in the irrigation of India and Pakistan. The Indus Basin Project (IBP) in Pakistan was developed in pursuance of the IWT and received.

US $150 million as a loan from the World Bank, US $ 541 million in grants, and US $ 315 million in foreign exchange from a consortium of countries (U.S.A, Canada, U.K., Federal Republic of Germany, Australia, and New Zealand), and US $174 Million from India (Biswas, 1992). Subsequently, extensive water resource development projects started in Pakistan and as a result, the IBIS is the world's largest contiguous irrigation system. Broadly speaking, the system schematically represented in Fig. 8.3 contains three large reservoirs associated with the Tarbela and Mangla Dams, and the Chashma Barrage; 23 barrages/headworks/siphons; 12 inter-river link canals and 45 canal commands extending for 60,800 km, with communal watercourses, farm channels, and field ditches covering another 1.6 million km to serve the watercourses used by over 90, 000 farmers (FAO, 2011).

In Pakistan, almost all agricultural land is dependent on irrigation, and irrigated agriculture yields about 90% of agricultural production per annum (Afzal, 1996), which is about 24% of the total gross domestic product (GDP) (Muneer & Asif, 2007; Piracha & Majeed, 2011). Some 70% of this irrigation is provided by the Indus Basin Irrigation Network, which is one of the world's largest irrigation networks, irrigating 17 million hectares (MHa) in a total 24 MHa cultivable command area (Wescoat, 1991; Wescoat et al., 2000; Kahlown et al., 2007; Akhtar et al., 2008).

On March 31, 1970, after a 10-year moratorium, India secured full rights for the use of the three eastern rivers allocated to her under the IWT. India developed and subsequently implemented a master plan to utilize the water resources of the Sutlej, the Beas, and the Ravi. The result was the Bhakra— Nangal— Ranjit Sagar System (Fig. 8.4). This system alone has significantly increased India's agricultural output, created a rich granary, and thereby has been a great source of food security for the country. In addition, the system has increased water availability in both urban and rural areas and has helped in poverty reduction in the states of Punjab, Haryana, and Rajasthan.

8.5.2 Contributions in Hydro-Power

There are 13 hydropower stations in Pakistan, generating more than 30% of total power production (OSEC, 2011). In India the hydro-power generation in the western Himalayas is ~15,000 MW, part in the Indus Basin. Similarly, in Afghanistan overall hydro-power production is ~300 MW, partly generated in the Indus Basin. For details, see Table 8.1.

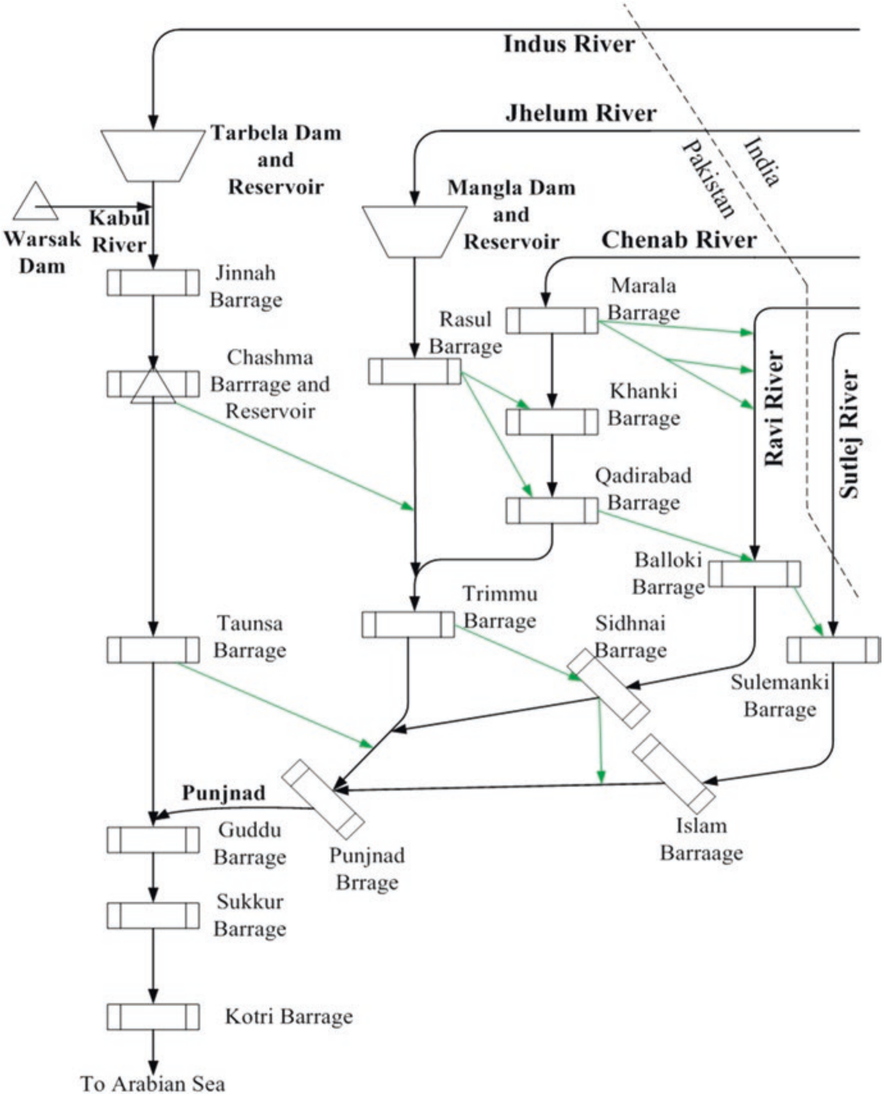

Fig. 8.3 Schematic representation of the Indus Basin Irrigation System in Pakistan. The major structures and link canals are shown. Other canals taking off from the barrages are not shown for sake of simplicity. (Authors' work using data from FAO, 2011)

8.6 Challenges

There are two main challenges in the Indus Basin (and at the global scale) for future sustainable agriculture, energy, and water resources. These are: (1) Population growth, and (2) Climate Change. These are explained below.

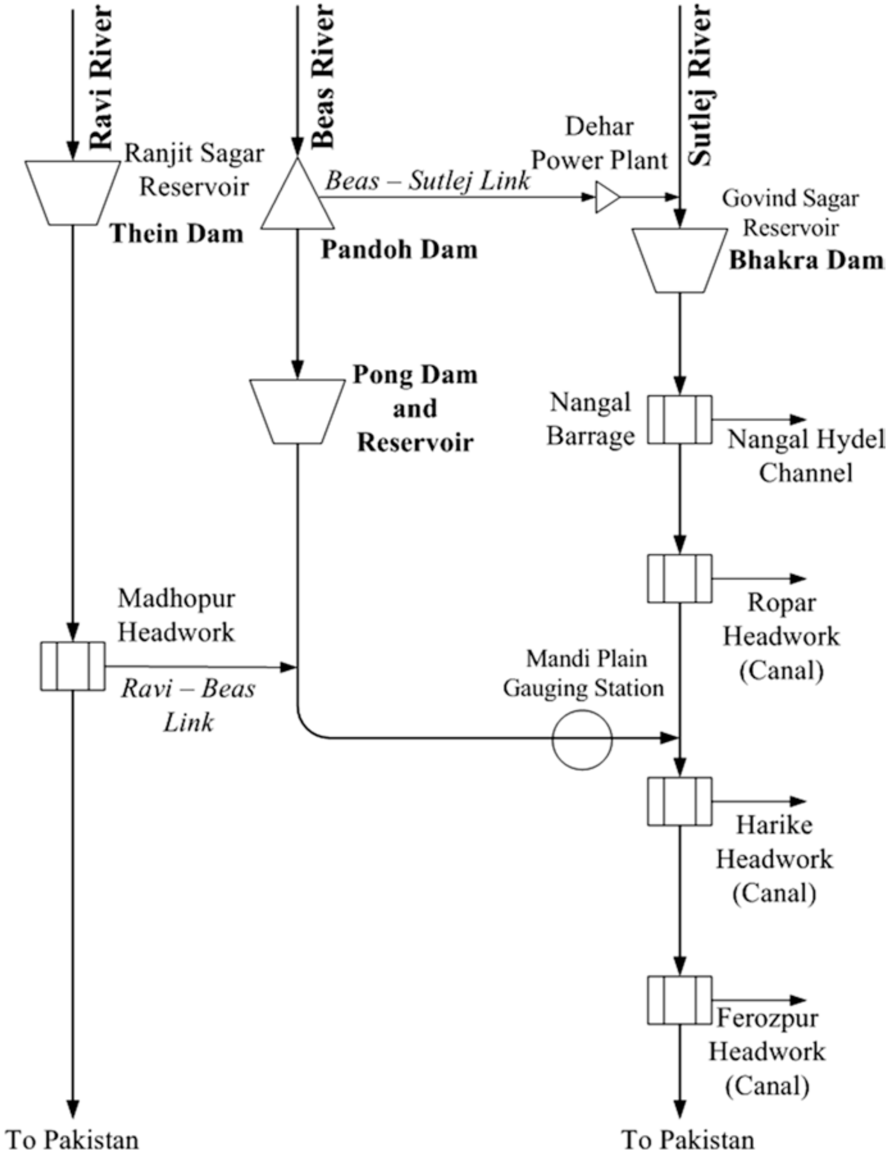

Fig. 8.4 Schematic representation of the Sutlej-Beas-Ravi water resource projects in India. (Source: Authors' work)

8.6.1 Population Growth

The overall global population is increasing at various growth rates. The population in the Indus Basin (Afghanistan, China, Pakistan, and India) is also rapidly increasing. An increase in population demands more urbanization, food, and energy. The

Table 8.1 Installed hydro-power capacities in Afghanistan, Pakistan, and India. (OSEC, 2011)

S.No	Country	No of schemes	Already installed hydro-power (MW)	Reference
1	Afghanistan	–	300 MW[a]	Doran et al. (2014)
2	Pakistan	13	6720 MW	PPIB (2011), OSEC (2011)
3	India	74	15,208 MW[a]	IR (2008)

[a]Only part of the above mentioned hydro-power is in the Indus Basin

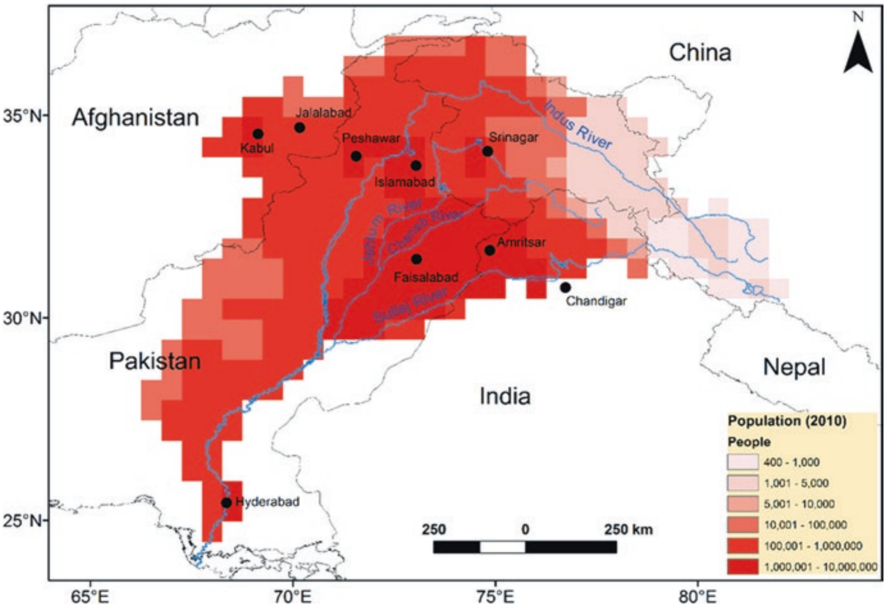

Fig. 8.5 Population distribution in the Indus Basin based on 2010 data. Well known rivers and major cities are also shown. Source: Authors' work based on Jones and O'Neill 2013

population of the Indus Basin was estimated to be ~186 million during 2010, and will range between 255 and 366 million by the end of 2050 (per SSP1–5 scenarios of Jones & O'Neill, 2013), although the average expected will be ~308 million at the end of 2050. The water, food, energy, and urbanization demands will depend on population densities in various parts of the Indus Basin (see Fig. 8.5). Therefore, the expected population at the end of 2050 and 2100 and respective population densities are provided in Table 8.2. It is also noteworthy that the population of the Indus Basin directly benefits from the basin's natural resources, while those outside of the Indus Basin are also dependent on its resources.

For example, with a current growth rate of 2.62%, Pakistan's population will reach 267 million (about 1.5 times the present population) by the year 2025 (Muneer & Asif, 2007). According to a United Nations population study, using three different (lower than present) growth rates, by 2025 the expected population will reach about

Table 8.2 Indus Basin areas in Afghanistan, China, Pakistan, India, and the disputed area, together with population and population densities during 2010, 2050, and 2100 in the same countries

S.No	Description	Year	Units	Afghanistan	China	India	Disputed Area	Pakistan	Total
1	Area	–	km^2	71824.9	59838.8	78819.5	189377.5	433898.5	833759.2
			%	8.6	7.2	9.4	22.8	52	100
2	Population	2010	Million	11.69	0.02	22.4	12.5	139.3	185.91
		2050	Million	24.7	0.09	32.6	15.1	235.1	307.59
		2100	Million	34.8	0.12	30.7	17.1	259.3	342.02
3	Population Density	2010	people/km^2	162.8	0.3	284.2	66	321	223
		2050	people/km^2	343.9	1.5	413.6	79.7	541.8	368.9
		2100	people/km^2	484.5	2	389.5	90.3	597.6	410.2

Note: Areas are as per delineation procedure explained in Khan et al. (2014). Population data is as per Jones and O'Neill (2013) SSP2 scenario. Population increase till 2050 based on scenarios SSP1-SSP5 is ranging between 255.3 million people to 366.6 million people

Table 8.3 Water availability and shortfall during 2000–2025. (Afzal, 1996)

Description	Units	2000	2013	2025
Population	million	148	207	267*
Water requirement				
Irrigation	1000 m^3	176.5	254.6	
Non-irrigation	1000 m^3	7.3	10.7	
Total requirement	1000 m^3	183.8	265.3	342.2*
Water availability**				
Total surface and ground water	1000 m^3	134.1	132.3	156.2
Shortfall	1000 m^3	49.7	133	186

*Projected estimates, ** Available at watercourse head

240 to 250 million (Yu et al., 2013). During the same period, the shortfall of freshwater resources for irrigation and non-irrigation requirements will become even more critical: from $49.7 \times 10^3 m^3$ to $186 \times 10^3 m^3$ as tabulated in Table 8.3. Thus, by the end of 2050 or 2100, there will be more food demand (not only in Pakistan but in other countries as well) and hence even more water shortages if new reservoirs are not constructed.

Similarly, Pakistan's average per capita consumption of electricity is 3894 kWh compared to the world's average per capita consumption of 17,620 kWh (Muneer & Asif, 2007). Despite the low per capita consumption, there is a current shortfall of 3000–4000 MW of power production (Javaid et al., 2011). The reasons for this shortfall are the growth in population and a shortage of water for power generation over the last two decades (Muneer & Asif, 2007). It is estimated that, between 2009 and 2030, because of the increase in population, demand will rise from 20,594 to 113,695 MW, as shown in Fig. 8.6.

This challenge is not limited just to Pakistan; India and Afghanistan also need more energy to cater for their needs. Currently, hydropower contributes about 33%, 16%, and 39% of total energy production in Pakistan, India and Afghanistan. Contributions from other renewable sources, such as solar, wind, and biofuel, are significant in India (~13%) but negligible in Pakistan and Afghanistan. However, all of the above countries are planning to increase development of their renewable energy resources on long term basis.

Therefore, a large number of new irrigation and hydro-power dams are under construction and planned in Afghanistan, Pakistan, and India. A total of 13 dams are planned in the Kabul river basin (the western part of the Indus Basin), with a capacity of about 2200 MW (see Table 8.4). Pakistan is constructing 57 new irrigation cum hydro-power dams in the Indus Basin. These dams will provide an additional energy of ~42,500 MW, bringing overall hydropower energy production to about 50,000 MW. India is also constructing and planning to build more than 350 dams in the western Himalayas (Table 8.4), with a total capacity of ~111,380 MW. New dams in Afghanistan and Pakistan, along with exiting dams and barrages in all three countries are shown in Fig. 8.7.

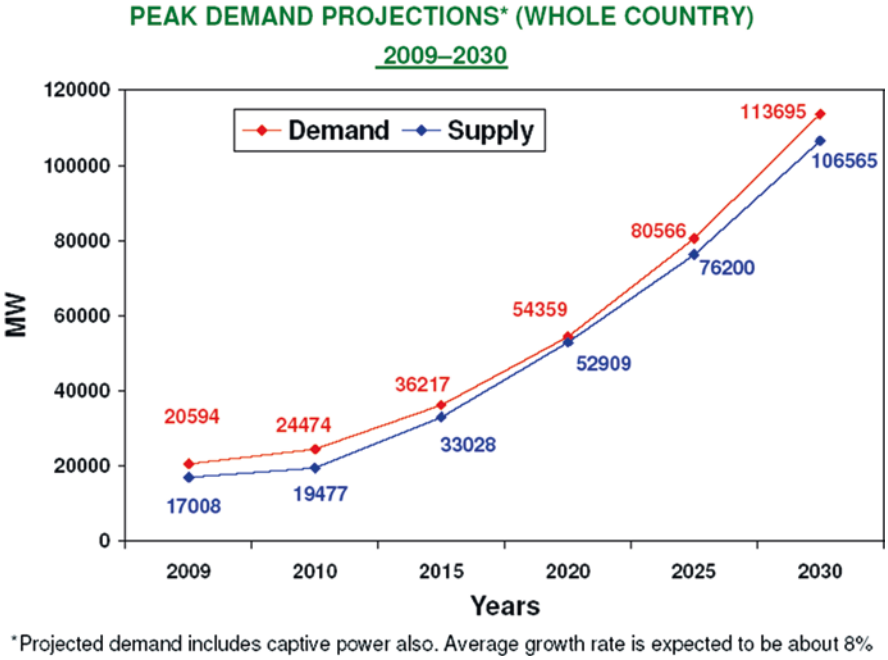

Fig. 8.6 Pakistan Power Production and demand from 2009 to 2030. (Source: Authors' work using data from Hussain et al., 2011)

Table 8.4 Dams, both planned and under construction, in Afghanistan, Pakistan, and India

S.No	Country	No of Dams	Hydro-power potential (MW)	References
1	Afghanistan	13	~2200	FAO Aquastat (2011)
2	Pakistan	57	~42,500	PPIB (2011)
3	India	355[a]	~111,380	IR (2008)

[a]Total dams in the Himalayas (dams in the Indus Basin boundary to be identified). Dam sites that are planned or under construction in the Basin (within Pakistan and Afghanistan) are shown in Fig. 8.7. While the total available natural potential is greater than the above-mentioned hydro-power potential, the above-mentioned is either under construction or planned

However, existing and planned water resource schemes, together with agriculture, energy, and biodiversity, are likely to be affected by global warming and climatic pattern changes. For details see the next section.

8.6.2 Climate Change

The Hindukush-Karakoram-Himalaya (HKH) mountain and Tibetan Plateau (TP) highland regions supply freshwater to more than 1.4 billion people (1/5th of the world's population in the Indus, Ganges, Brahmaputra, Yangtze, and Yellow River

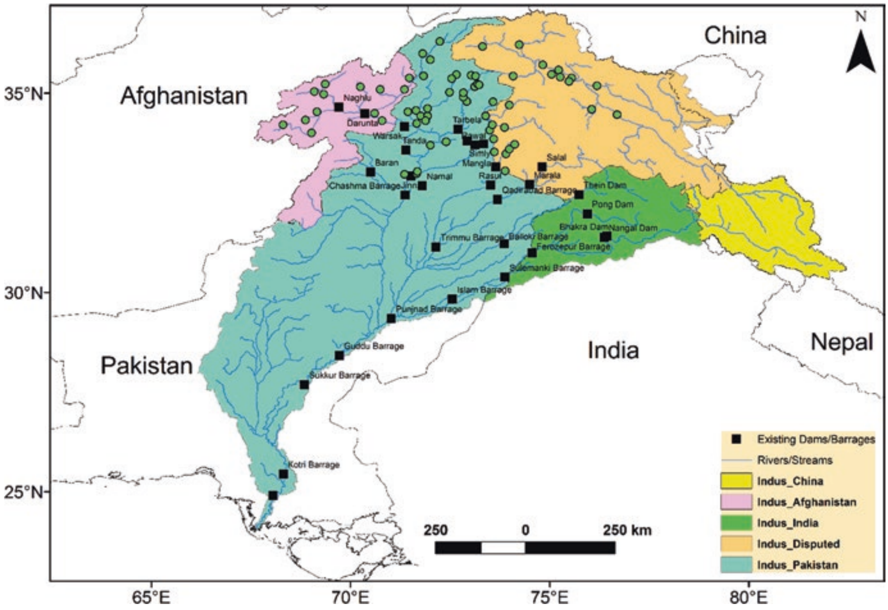

Fig. 8.7 Existing dams and barrages (black squares) in Afghanistan, Pakistan, India, and in disputed area, and new dams (green circles) in Afghanistan, Pakistan, and in disputed areas. Source: Authors' own work

basins (Immerzeel et al., 2013). The HKH-TP region has a glacier area of about 33,000 km^2 (ICIMOD, 2009) and contains about 12,000 km^3 of freshwater (IPCC, 2007).

About 2 billion people in river basins (including the Indus river basin) of Asia rely on the HKH region for their freshwater. The HKH region has approximately 33,000 km2 of glaciers (ICIMOD, 2009) and 12,000 km3 of freshwater (IPCC, 2007). In the HKH-TP region, glaciers have generally experienced terminal retreat and a real shrinkage over the past 50 years.

The Himalayan glaciers have generated many Glacial Lake Outburst Floods (GLOFs) in the past 50 years, and more than 33 glacial lakes have been recognized as potential future flooding causes (Qiu, 2008). Campbell (2005) found 165 glacier lakes that might cause catastrophic floods throughout the whole HKH region. Additionally, the Karakoram glaciers have experienced over 34 surges since the 1860s, which have increased in frequency since 1985 (Hewitt, 1998, 2007).

The future climate change projections predicts hot and wet climate in the HKH region and throughout Pakistan. Therefore, riverine, urban, and GLO floods and hill torrents are likely to become more intense and frequent. The projected floods will result in loss of lives, infrastructure, and property.

In the last five decades, terminus retreat and areal shrinkage of glaciers have been noticed in the HKH-TP region. Table 8.5 shows that glacier tongue retreat rates have been higher in the Himalayas and TP compared to the Karakoram mountain range.

Table 8.5 Details of glacier areas, and termini retreat, stability, and advancement in the HKH-TP region

S. No	Location	Glacier/Basin Name	Period	Avg. mass balance	Unit	Method/Data	References
1	Western Himalayas	Naimona'yi	2002–2010	−0.556	mwe/yr	MSS, TM, ETM, ASTER	1
2	Nepal Himalayas	Yala	2012	−0.89	mwe/y	Insitu	2
3	Western Himalayas	Indian Himalayas	2000–2010	−20 ± 4	Gt/yr	Insitu, AAR, ELA	3
4	Western Himalayas	Chotta Shigri	1988–2010	−0.09	mwe/y	Insitu	4
5	Nepal Himalayas	Mera	2007–2012	−0.08 ± 0.51	mwe/y	Insitu	5
6	Nepal Himalayas	Pokarlde	2007–2012	−0.72 ± 0.54	mwe/y	Insitu	5
16	Eastern Himalayas	–	2000–2011	−0.22 ± 0.12	mwe/y	SRTM and SPOT	6
17	Western Himalayas	Mount Everest region	1999–2010	−0.45 ± 0.13	mwe/y	SRTM and SPOT	6
9	Western Himalayas	Zanskar	2003–2009	−0.5 ± 0.1	mwe/y	ICESat and SRTM	7,8
10	Western Himalayas	Astore	2003–2009	−0.55 ± 0.1	mwe/y	ICESat and SRTM	7,8
7	Eastern Korakoram	Siachin	1990–1991	−1.08	mwe/y	Insitu	9
8	Eastern Korakoram	Siachin	1988–1989	0.358	mwe/y	Insitu	9
13	Eastern Korakoram	Shyok	2003–2009	−0.25 ± 0.1	mwe/y	ICESat and SRTM	7,8
14	Eastern Korakoram	Siachin	1999–2010	0.14 ± 0.14	mwe/y	SRTM and SPOT	6
18	Eastern Korakoram	Part of the Shyok basin	1999–2010	0.11 ± 0.14	mwe/y	SRTM and SPOT	6
12	Western Korakoram	Hunza	2003–2009	−0.03 ± 0.1	mwe/y	ICESat and SRTM	7,8
15	Karakoram	Part of Hunza and Shigar	1999–2008	0.11 ± 0.22	we/y	GRACE Data	10
19	Karakoram	Western Korakoram	1999–2008	0.09 ± 0.18	mwe/y	SRTM and SPOT	6
11	Hindukush	Gilgit	2003–2009	−0.2 ± 0.1	mwe/y	ICESat and SRTM	7,8
20	Hindukush	Part of the Gilgit basin	1999–2008	−0.12 ± 0.16	mwe/y	SRTM and SPOT	6
21	Pamir	Wstern Pamir	2000–2011	0.14 ± 0.08	mwe/y	SRTM and SPOT	6

References are: 1. Yao et al. (2012), 2. Baral et al. (2014), 3. Kulkarni and Karyakarte (2014), 4. Vincent et al. (2013), 5. Wagnon et al. (2013), 6. Gardelle et al. (2013), 7. Kääb et al. (2012), 8. Kääb et al. (2015), 9. Bhutiyani (1999), 10. Gardelle et al. (2012), mwe/y is meter water equivalent per year, MSS stands for Multispectral Scanner System, TM stands for Thematic Mapper, ETM stands for Enhanced Thematic Mapper, ASTER stands for Advanced Space-borne Thermal Emission and Reflection, AAR stands for Accumulation Area Ratio, ELA stands for Equilibrium Line Altitude, SRTM stands for Shuttle Radar Topography Mission, ICESat stands for Ice, Cloud and land Elevation Satellite, while GRACE stands for Gravity Recovery and Climate Experiment. For locations of various basins and mountain ranges see Fig. 8.2

Similarly, areal shrinkage of glaciers has also been reported at a higher rate in the Himalayas and TP compared to the Karakoram (see, for example, Scherler et al., 2011; Bhambri et al., 2011; Sarikaya et al., 2011, 2013; Rankl et al., 2014).

The warm climate followed by intense rainfall events triggers GLOF events. May–August remained significantly high temperature months during 2022. Extremely intense and frequent rainfall events have also happened during July and August 2022. The high temperatures and intense rainfall generated more than 5 GLOF events in Chitral and GB.

In addition, the recent monsoon-2022 generated all other types of floods in Pakistan. Hill torrents have been reported in various districts of KP, Punjab and Balochistan. Riverine floods triggered throughout Pakistan, particularly in the Swat, Kabul, and Upper Indus river basins. Urban floods have also been observed and reported throughout Pakistan.

However, areal shrinkage could be due to temporal differences in the remote sensing data selected and to variations in seasonal snow. Many researchers (such as Kääb et al., 2012, 2015; Gardelle et al., 2013) have also noticed significant glacier mass loss in the Himalayas, whereas the Karakoram range has had a slight mass loss to neutral mass balance in the last decade. Details of these differences are provided in Table 8.6, which also shows good agreement in glacier mass balance estimates (within their accuracy limits) for various studies in the different regions and sub-basins.

However, there is one controversial result for the eastern Karakoram (the Shyok basin), which could be due to differences in methods, study time periods, glacier inventories used, snow and ice densities used, and extents studied (only the western part of the Shyok basin is covered in the study of Gardelle et al. (2013)).There is accordingly a need for further investigation.

The estimated increase in temperature in the Himalayan region over the last 100 years has been reported as being well above that of the increase in global mean surface temperature, and this may be the cause of the high negative glacier mass balance (IPCC, 2007; Tahir et al., 2011; Kääb et al., 2012, 2015). The Asian mean surface temperature increase during 1990–2100 is also expected to remain higher than the global mean surface temperature increase (IPCC, 2007, 2013; Immerzeel et al., 2013). The latest IPCC (2013) assessment report (the 5th) provided four

Table 8.6 Details of glacial and potentially dangerous lakes in sub-basins of the UIB

Watershed	No of glacial lakes	Area (km^2)	Specific Area (km^2)	No of Potentially dangerous lakes
Gilgit	614	39.17	0.064	8
Hunza	110	3.21	0.029	1
Shigar	54	1.09	0.02	0
Shyok	66	2.68	0.041	6
Kharmong	812	37.65	0.046	20
Astore	126	5.52	0.044	9
UIB at Tarbela	1782	89.32	0.05	44

Source: Campbell (2005). Specific Area is total Area divided by number of lakes

Representative Concentration Pathways (RCPs) based on increases in greenhouse gas concentration. These are RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5, which are based on increased radiative forcing values in 2100 relative to base pre-industrial values of 2.6, 4.5, 6 and 8.5 W/m^2 (IPCC, 2013, Immerzeel et al., 2013). There is significant variability among various climate model output results. However, for the Coupled Model Intercomparison Project (CMIP) 5, under the RCP 4.5 scenario, the expected regional temperature is expected to rise by about 2 °C (relative to 1961–1990) in the whole HKH during 2021–2050, together with an annual precipitation change of −8 to 12% during the same period.

On a longer term basis (to 2100) the warming climate may further enhance temperature in the region (Immerzeel et al., 2013, Lutz et al., 2014a, b). According to Ridley et al. (2013) and Wiltshire (2013) it is thought that western disturbances will bring more and more frequent precipitation in winter to the Karakoram mountain range, so that it may maintain a positive glacier mass balance. It is further argued that precipitation will also increase in the Himalayas, but in the form of rainfall, which will further enhance glacier melt, floods and degradation.

Over the last 50 years, Himalayan glaciers have generated 20 Glacial Lake Outburst Floods (GLOFs) and more than 33 glacial lakes have been identified as possible causes of future flooding (Qiu, 2008). In fact, Campbell (2005) has identified 165 potentially dangerous glacier lakes across the whole HKH region which could generate devastating floods (details of a few are provided in Table 8.6). Therefore, if glaciers continue to recede as reported in Kääb et al. (2015), and precipitation becomes more intense and frequent (as argued in Wiltshire, 2013; Ridley et al., 2013), the likelihood of GLOFs will also increase. GLOFs not only produce devastating floods but also damage hydropower schemes and adversely affect biodiversity (Rasul et al., 2011).

In addition, wetlands, deserts, birds, coral reef, fisheries, snow leopards, numerous mammals, and ethno-botanical plants are expected to be affected by climate change, retreating glaciers, and deforestation (Rasul et al., 2011; Afzal et al., 2009; IUCN, 2000; Foley/World Bank, 2009). Some of the main aspects of ecosystems which are likely to be affected by climate change are provided in Table 8.7.

Effective climate change adaptation cannot be undertaken without careful consideration of the crosscutting nature of risks and synergies between adaptation activities. The impact of climate change on precipitation and flows, together with the rise in temperature, could adversely affect agriculture, human health, ecosystem, soil erosion, energy consumption, water use, infrastructure, and agriculture. The major threats are summarized below:

1. A rise in temperature may result in rapid melting of snowfall. Rainfall, along with hastened snowmelt, may increase river flows and flash floods on a short-term basis and decline on a long-term basis;
2. A rise in temperature may result in triggering Glacier Lakes Outburst Floods (GLOFs) in the northern parts of the study area, and may damage hydro-power infrastructure;
3. A rise in early snowmelt may result in changes to river flow patterns and peak flow occurrence, and may affect water availability of perennial streams;

Table 8.7 Climate change impact on ecosystems in various countries (Foley/World Bank, 2009)

Ecosystems	Threats	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Coastal (mangroves, mudflats, estuaries)	Inundation, salination, storms, species loss		■		■	■			
Coral reefs	Bleaching, acidification, loss of ecological and protective services, reduction in species diversity				■	■			■
Inland wetlands	Desiccation, drainage and diversion, degradation and service loss	■			■			■	■
Forests	Loss of forest cover and species, altered composition and structure, enhanced evapotranspiration			■	■		■		■
Mountain (subtemperate, temperate)	Altitudinal shifts in vegetation disrupting species types			■			■		
Mountain (subalpine, alpine)	Loss of vegetation cover	■		■	■		■	■	
Glaciers	Loss of coverage	■		■	■		■	■	
Desert	Expansion	■			■			■	
Rangelands & Grasslands	Regime shift, degradation due to overgrazing and increased incidence of fire	■			■			■	
Freshwater (rivers, lakes)	Desiccation, increased salinity at coast, degradation due to increased demand	■	■		■	■	■	■	
Species diversity (floral & faunal)	Loss of diversity and habitat, changes in species composition and food web		■		■		■		■
Key: ■	Locations particularly vulnerable to impacts of climate change.								

4. A rise in snow and glacier-melt may increase sediment transport in river flows;
5. A rise in temperature may result in a decline in snowfall and an increase in rainfall, which may result in rainfall-runoff increase;
6. An increase in temperature may result more water loss, particularly evapotranspiration;
7. An increase in evapotranspiration losses could increase stress on crop water demand;
8. An increase in temperature may result in changes to cropping patterns;
9. Variability in precipitation may result in changes to cropping patterns;

10. Effects related to climate change may affect crops' health;
11. Changes in climate may adversely affect irrigation practices and the working environment in the fields;
12. A rise temperature is likely to affect human health and ecosystems;
13. A rise temperature will increase energy consumption;
14. A rise temperature will increase water consumption and groundwater depletion;
15. A rise temperature will increase the risks of viral diseases;
16. A rise temperature will have adverse impacts on bridge expansion joints;
17. The expected change in climate is likely to affect eco-system and erosion/land-degradation adversely.

Thus, the water resources, agriculture, energy generation, ecosystem and biodiversity in basins draining from the HKH-TP could be adversely affected by warming climate and climatic pattern changes, and this is likely to affect the food and energy supply to millions of people, which together with the population at risk of potential glacier lake outburst floods, intensifies the need for detailed assessment of present and future nexus studies in the HKH region.

8.6.3 Potential Adaptation and Mitigation Measures

Keeping in view the above risks, the climate change assessment component provides guidelines to adapt and mitigate adverse effects of climate change as follows:

Climate Change Policies and Action Plans

1. Revision and updating of NDCs-2021;
2. Downscaling of NDCs at provincial and local scales;
3. Development and implementation of provincial climate change action plans;
4. Prioritizing climate financing based on GHG emissions and adverse climate change impacts and risks;
5. Development and enforcing climate change assessment and check-list in project planning and PC-Is approvals;
6. Update the implementation strategies and frameworks at national and provincial levels.
7. Update and revision of climate change act-2017, particularly coordination and cooperation mechanism
8. Public and key stakeholders awareness campaigns (together with religious Khutbas), and capacity building of line departments' staff to educate people about climate change risks and adaptation measures;
9. Afforestation to control temperature and to reduce water losses together with adverse climate change impacts;
10. Enforcement of climate inclusive infrastructure planning, design and implementation.

Water Resources Policies, Strategies and Action Plans

1. Implementation of national water policy-2018;
2. Development of provincial water policies, wherever not available;
3. Development of provincial water acts, wherever not available;
4. Preparation of climate change inclusive water resources investment plans;
5. Construction of water storages; reservoirs and ponds;
6. Rainwater harvesting in hill-torrents, urban flooding, and flood affected areas;
7. Well managed operation and maintenance of irrigation systems to avoid water losses;
8. Recycling and res-using water from mosques, kitchens, and car-wash centers;
9. Revision of infrastructure designs (such as bridge piers, buildings plinth levels, buildings HVAC, roads) based on climate change assessment and climate change inclusive hydrological modeling;
10. Water conservation through awareness, water-pricing, and house-hold based rainwater harvesting;
11. Planning and implementation of water conservation activities and infrastructure development;
12. Use of future projected datasets in hydrological modelling as well as considering latest CMIP scenarios data together with socio-economic scenarios;
13. Use of sunken fields, wherever floods threats exist;
14. Adaptation of best water management practice, such as lining of watercourses and land leveling together with demand-based supplies using soil moisture sensors;
15. Improvement of groundwater recharge and discouraging groundwater abstractions;
16. Installation of flow and climate stations to monitor climate change impacts and frame adaptation strategies.

Climate Inclusive Agricultural Policies and Actions

1. Implementation of Agriculture Policies and Climate Green Plan: Federal and Provincial agriculture policies and climate smart green plans, which provide guidelines related to an increase in agriculture production as well as the use of different cropping patterns in various parts of the country and province. Also, selection and use of climate resilient crops/agriculture and cropping patterns together with water-efficient irrigation systems are need of the time.
2. Promote adequate farmers' health facilities provision;
3. Promoting watershed management to reduce land-degradation, sediment transport, and increase carbon capture;
4. Encouraging urban agriculture and forestation;
5. Adequate control and measures against crops and livestock viral diseases;
6. Adaptation of best agriculture practices and use of climate resilient crops;
7. Use of least water-intensive crops and water efficient irrigation systems such as RDI, sprinkler and drip irrigation, particularly where rice and sugarcane are grown;

8. Promoting research and development in bio-technology and seed for climate resilient, low-delta crops and agriculture;
9. Launching of farmers' awareness campaigns to educate them about climate change risks, efficient irrigation systems, use of best available seeds variety, changes in cropping patterns;
10. Changes in cropping patterns to increase food production and to cope up with the rise in food demand and water losses;
11. Parthenium and other such types of weeds should be treated through biological treatment and Integrated Pest Management (IPM),

Energy, Transport, Waste and Industries

1. Use of green energy at household, agriculture, industries and transport sectors;
2. Replacement of diesel pumps with solar and ram-pumps, which are more climate-friendly;
3. Plan and develop green energy, transport and industries;
4. Promoting solar drying systems for fruits and crops;
5. Promoting solar RO and water purification plants;
6. Promoting bio-gas plants;
7. Plan and implement integrated waste management systems;
8. Promote adequate water availability and cooling facilities;
9. Improve quality of roads and traffic awareness;
10. Encourage kinetic hydro-power energy generation;
11. Promoting future water-energy-food-land nexus studies under changing climate.

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Chapter 9
Managing Pakistan's Groundwater

Sanval Nasim

Abstract To ensure water security and sustainability, Pakistan's policymakers must keep groundwater extractions and stock at reasonable levels. How do policymakers currently manage groundwater? Why have they struggled so far? What are some of the tools that they can harness to improve groundwater allocation? By surveying existing data and literature on Pakistan's groundwater, I address these questions, identifying the challenges that the country faces in managing groundwater and explaining policy instruments that could tackle these challenges. The chapter serves as a guide for scholars, practitioners, and policymakers interested in contextualizing Pakistan's groundwater issues and understanding policy prescriptions that incentivize welfare-enhancing extractions.

Keywords Groundwater · Open Access · Tradable Permits · Water policy in Pakistan

9.1 Introduction

Pakistan relies heavily on groundwater to sustain its farmers, industries, and households. Agriculture uses over 90% of the country's total annual groundwater supply while industries and households consume the remaining share. The country's population has soared from 132 million in 1998 to 208 million in 2017—an annual growth rate of 2.4% and a 57% increase in population between the two censuses (Pakistan Bureau of Statistics, 2021a, b). A surging population requires more food and access to water and sanitation, increasing the stress on existing water resources.

Given the rising demand for water, Pakistan's groundwater extractions have increased considerably in the last two decades. But with withdrawals exceeding recharge on average, the groundwater stock has started dwindling. Figure 9.1 shows

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the water table depth across space in Punjab—Pakistan's most populated province, which extracts considerably more groundwater compared to the other three provinces (Sindh, Khyber-Pakhtunkhwa, and Balochistan), one federally-administered area (Islamabad), and two autonomous territories (Azad Jammu and Kashmir and Gilgit-Baltistan). In some parts of Punjab, the water table lies more than 50 feet beneath the surface. A deeper water table raises future extraction costs, potentially reducing subsequent extractions and thus incomes and welfare.

Though groundwater pumping in Pakistan took off in the 1960s, the history of how the groundwater stock grew dates to the late 1800s, when the British colonists in the subcontinent created the canal colonies—settling communities in the land encompassed by the Indus Basin (Bhutta & Smedema, 2007). The colonists heavily invested in large-scale irrigation infrastructure, leading them to construct a network of canals and barrages for flood irrigation, which transformed the barren landscape into the region's breadbasket. As Fig. 9.2—a cross-section of the Basin's doabs (land between two rivers)—shows, the colonial irrigation project led to a 10-meter average rise in the water table level.

Building on its inherited colonial legacy, Pakistan added more irrigation infrastructure after its independence in 1947. The Indus Waters Treaty with India in 1960 laid the groundwork for new investments. The treaty allocated the three eastern rivers (Ravi, Sutlej, and Beas) to India while Pakistan retained control over the three western rivers (Indus, Jhelum, and Chenab). To maintain adequate flows in its eastern territories, Pakistan diverted water from the western to the eastern rivers through

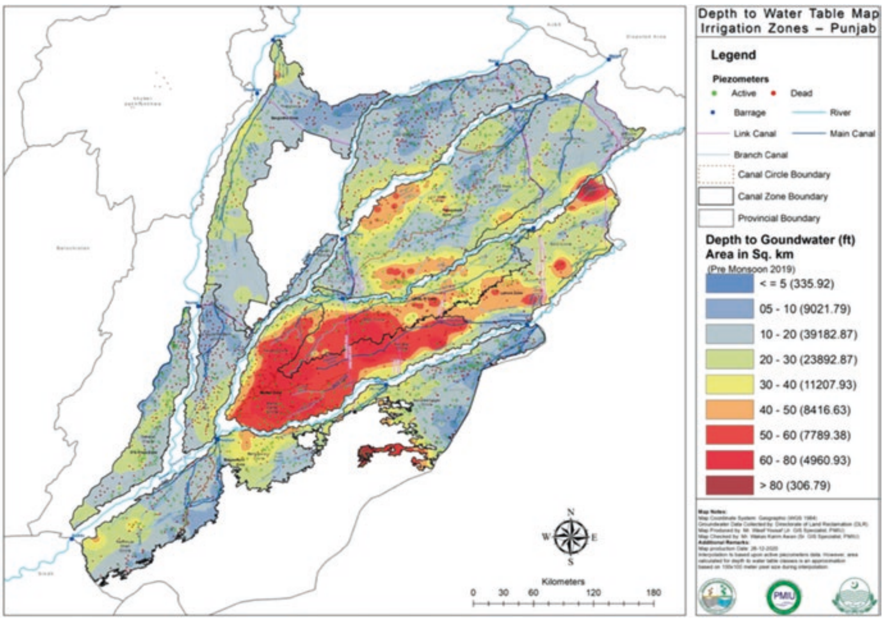

Fig. 9.1 Punjab's water table depth. (Government of Punjab, 2020)

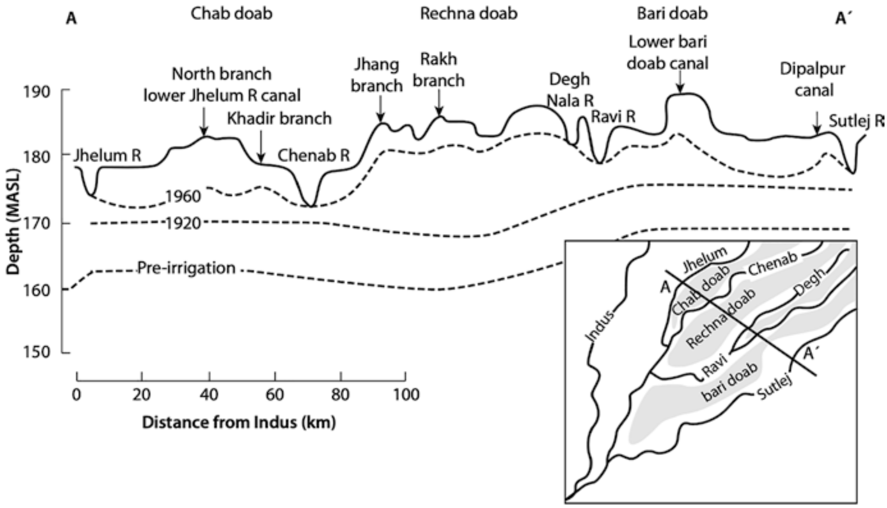

Fig. 9.2 Historical trend of Punjab's water table (Bhutta and Smedema, 2007)

a series of new link canals. It also revamped the existing canal network and barrages and constructed two large dams (Mangla and Tarbela), which provided storage and generated electricity.

Expanding the irrigation system and bringing new areas under its fold considerably increased the water flow in the Basin. This increased flow led to more water seepage into the aquifer, raising the water table level over a short period of time. The rising water table level eventually waterlogged several areas and brought salts to the surface. The resulting waterlogging and salinity rendered growing and harvesting crops on these lands impossible.

To control waterlogging and salinity and reclaim the affected area, the government introduced the Salinity Control and Reclamation Programme (SCARP). Under this project, the government invested in thousands of public tubewells to extract groundwater to drawdown the water table level, reduce salinity, and increase agricultural productivity. The government further encouraged farmers to install private tubewells to irrigate their lands and subsidized electricity for electric tubewells.

As a result of this additional source of irrigation, groundwater extractions swelled. Figure 9.3 shows the trend of the number of tubewells in the country, which rose from roughly 30,000 in 1960 to over 1.2 million in 2018, with over 90% lying in Punjab (Qureshi, 2020). This drastic increase in the number of tubewells turned groundwater into an integral irrigation source—and not just a means to supplement surface water. Groundwater extractions allowed farmers to bring more land under cultivation. Figure 9.4 reveals that between 1960 and 2018, total irrigated area increased by almost 75% (11 million hectares to 19 million hectares). While area under only surface water fell nearly 45% (9 million hectares to 5 million hectares), area under only groundwater and conjunctive use (groundwater and surface water) rose almost 400% (3 million hectares to 14 million hectares).

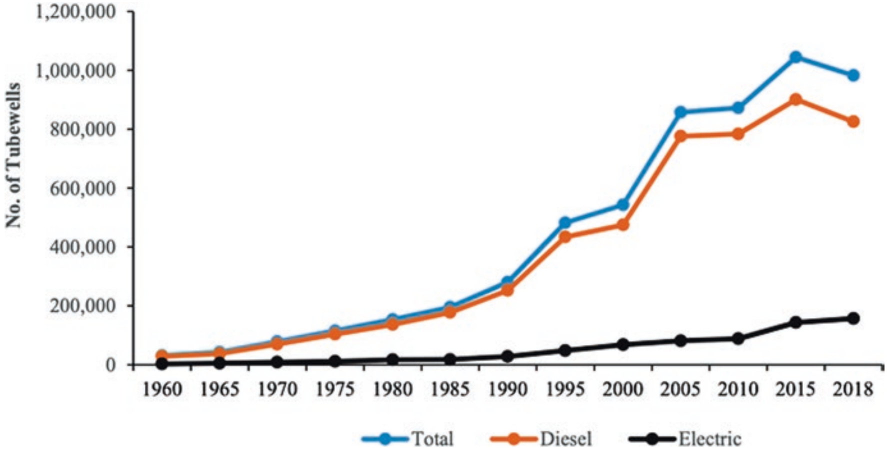

Fig. 9.3 Tubewells trend. (Qureshi, 2020)

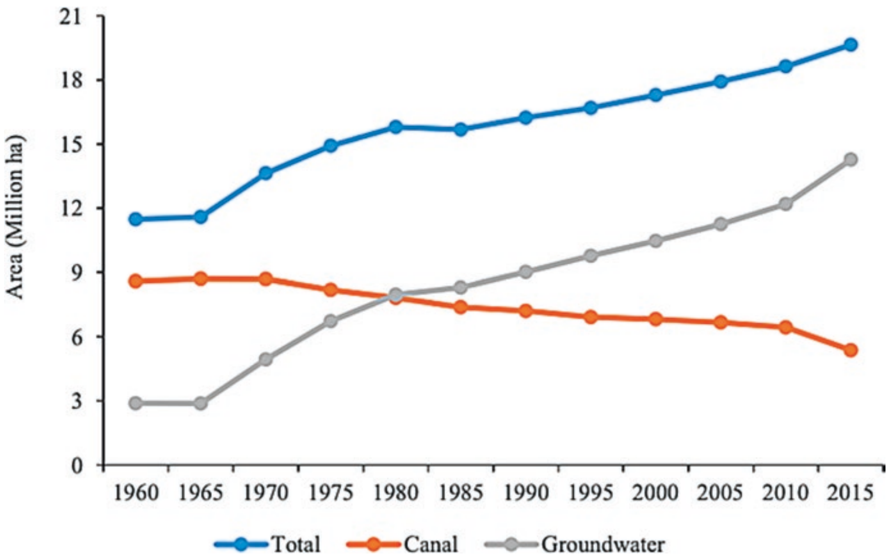

Fig. 9.4 Area under surface water and groundwater irrigation. (Qureshi, 2020)

Surface water supplies became more variable over time owing to greater irrigation needs—as farmers brought more land under cultivation and cultivated land more intensely—and, more recently, climate change. Changing climatic conditions affect glacial melt—the main source of the Indus Basin's water—and precipitation patterns, forcing surface water supplies to become increasingly stochastic. When farmers face uncertainty regarding their irrigation supplies, they underinvest on their farms. This is particularly apparent on tail-end farms in the Basin where surface water supplies dwindle after flowing through a watercourse's length, allowing head-end farmers to access the water before those further down the watercourse. The uncertainty and inequitable access leads to potentially lower crop yields and disincentivizes farmers from investing in productivity-enhancing capital and practices.

Groundwater allowed farmers to mitigate the risk of uncertain surface water supplies. As an easily accessible source of irrigation, farmers could extract groundwater to meet their needs at critical stages of cultivation when faced with inadequate surface water supplies, enabling them to reduce the uncertainty around their irrigation needs, lower the risk of crop failure, and increase yields. Moreover, buffering the risk of variable surface water allowed them to invest on their farms with the intent to increase their productivity and realize stable yields over the long run. Groundwater came as a boon to tail-end farmers who often did not receive the same volume of surface water as head-end users.

The colonists established a rights-based system for allocating surface water across farms. The system—known as *warabandi* in the local parlance—allocated shares of total water in the system according to farm size and time. A farmer with an acre of land could access the system's water—through tertiary canals—for a fixed number of hours a week under either a predetermined schedule or a schedule negotiated with neighboring farmers. Pakistan inherited and continued to apply *warabandi* to allocate surface water to farms across the Basin.

Warabandi worked well in the initial decades as it ensured fair access to surface water. The system had enough water to more than compensate for losses through seepage and evaporation. Farmers across watercourses—from the head-end to the tail-end—received roughly equal amounts of water, more than enough to adequately irrigate their crops. However, as the population rose and agriculture expanded, the demand for irrigation significantly increased. This implied that most farmers along the entire length of a watercourse needed to irrigate more. Given their position on a watercourse, head-end farmers accessed the water first and received enough to either fully irrigate their crops or enough to get by. By the time the water reached the tail-end, it became barely a trickle. This forced tail-end farmers to overwhelmingly rely on groundwater to irrigate their crops. The original spirit of *warabandi*—to ensure equitable access to surface water—faltered as head-end farmers benefited considerably more relative to tail-end farmers.

The immediately apparent flaw in the *warabandi* is that it ties surface water allocation to land rather than volume of water. As the water flows through the system, it either seeps into the aquifer or naturally evaporates. Thus, the volume of water diminishes as it passes through the system. Farmers at the head-end of a water course access water before those located further down its length. Since the volume of water at the head-end of a watercourse is larger than the volume of water at the tail-end, head-end farmers receive a greater quantity of water than tail-end farmers. Therefore, the system—originally designed as an equitable means to allocate water under abundance—ends up becoming inequitable when one considers the actual volume received under scarcity.

Owing to the inequitable access to surface water, groundwater created new opportunities for farmers. First, it narrowed the gap in access to irrigation. Farmers who once relied solely on surface water to irrigate crops and struggled to receive adequate surface water supplies now had a readily accessible alternative. Second, groundwater allowed tail-end farmers to meet their irrigation requirements and reduce the risk of crop failure, thereby helping them sustain their livelihoods. Without it, tail-end farmers would have struggled to compete, rendering large swathes of land uncultivable.

However, the opportunities created by groundwater have steadily diminished. The inequitable access to surface water has inadvertently led to unequal access to groundwater. Most head-end farmers receive enough surface water to irrigate crops, which precludes them from relying on groundwater to meet irrigation deficits. Also, enough surface water flows through these areas to compensate for—through seepage—any excessive extractions.

On the other hand, tail-end farmers rely overwhelmingly on groundwater to irrigate crops. Without an adequate alternative source, these farmers compete to extract groundwater to meet their irrigation requirements. At the tail-end of a watercourse, not enough surface water flows through the irrigation infrastructure, leading to low natural recharge of the aquifer. High extraction and low recharge—with extraction well exceeding the recharge—implies that the water table level at the tail-end has gradually fallen, increasing extraction costs over time. As Fig. 9.1 reveals, the water table level in the lower reaches of Punjab is considerably lower than the water table level higher up the basin.

Farmers competing to extract groundwater in the tail-ends of watercourses cause the stock of groundwater that they can access to fall. Not only do tail-end farmers end up with lower amounts of surface water compared to head-end farmers but they also extract groundwater from greater depths, thus bearing higher extraction costs. Higher irrigation costs constrain tail-end farmers' choices and can lower their crop yields and incomes. In a bid to meet their irrigation requirements and maintain yields, tail-end farmers end up depleting the groundwater stock and raising irrigation costs in future periods.

Another cost that farmers bear relates to groundwater salinity—I want to clarify to the reader that though important, I will not focus on groundwater salinity beyond the next few paragraphs. In many parts of Pakistan's Indus Basin—especially in Sindh—one finds marginal to poor quality groundwater. In areas with considerable groundwater extractions, groundwater quality can deteriorate over time. Groundwater naturally contains more salts compared to surface water. Also, groundwater return-flows—share of water used for irrigation which seeps back into the aquifer—can carry salts accumulated in the soil into the aquifer, increasing the salinity of groundwater.

In areas with higher surface water flows and precipitation, aquifer recharge from these sources can dilute the existing groundwater stock, thus lowering its salinity. However, in tail-end areas, where surface water flows are low, not enough water seeps into the aquifer to dilute the groundwater stock, and groundwater salinity tends to significantly deteriorate. As farmers irrigate with this marginal-quality and poor-quality groundwater, their crop yields fall. Excessive irrigation with saline groundwater also causes salts to accumulate in the rootzone, affecting soil health and further lowering yields.

Besides salinity, several other contaminants affect the Indus Basin's groundwater quality. Fertilizer use leads to leaching of nitrate and chloride in the aquifer. Other chemical contaminants include arsenic, fluoride, and trace metals, some of which exist naturally in the aquifer. Poor solid waste management, wastewater disposal, and sewerage conditions foster the growth of dangerous bacteria in water bodies. Groundwater contaminated with these chemicals and microbes can seriously harm health when consumed—many towns and communities rely on such groundwater for drinking and sanitation.

To ensure water security and sustainability, Pakistan's policymakers must keep groundwater extractions and stock at reasonable levels. How do policymakers currently manage groundwater? Why have they struggled so far? What are some of the tools that they can harness to improve groundwater allocation? By surveying existing data and literature on Pakistan's groundwater, I address these questions in this chapter, identifying the challenges that the country faces in managing groundwater and explaining policy instruments that could tackle these challenges. The chapter serves as a guide for scholars, practitioners, and policymakers interested in contextualizing Pakistan's groundwater issues and understanding policy prescriptions that incentivize welfare-enhancing extractions.

9.2 The Problem

9.2.1 Open Access Regime

The fundamental issue with groundwater in Pakistan's Indus Basin is that the country manages it as an open access resource. One classifies groundwater as an open access resource because of two unique properties: (1) rivalry; and (2) non-excludability. Rivalry indicates that the consumption of the resource by any one user reduces the quantity of the resource available for competing users to consume. Non-excludability indicates that any one user or a third party—such as a regulator—cannot prevent other users from consuming the resource. In contrast, pure market goods share the rivalry property but are excludable—which means that one can exclude competing users from consuming the good, mostly through prices in the market for those goods.

Often when conversing about resources, researchers and practitioners erroneously use the term "common property" to describe an open access resource. Bromley (1989, 1991, 1992) has drawn attention to this persistent confusion and demonstrated that this oversight results from a lack of clarity on the meaning of property rights. He describes a common property resource as one which has well-defined co-owners who manage the resource by setting collectively-determined use rates. In an open access regime, the resource does not have a defined group of users and the benefit stream from using the resource is available to anyone.

Our current understanding of common property stems from the study of collective action in Elinor Ostrom's and related scholars' extensive body of work. Ostrom and others have shown how in the absence of a formal regulatory system or markets, resource users can create local institutions to manage and govern resources (Ostrom, 2008; Libecap, 2008). In this bottom-up governance approach, resource users acknowledge the costs that they impose on each other owing to unmanaged resource consumption and collectively engage in establishing use rights, which can lead to effective resource management. Collective action scholars have studied the circumstances in which effective cooperative behavior can arise, describing how coordination and reciprocity can foster trust between individuals over time and enable mutually beneficial management.

However, collective action can often fail when a resource has a considerably large number of users. Getting many competing users on the negotiating table to devise and enforce commitments can get prohibitively costly. Even when some users agree to limit their resource consumption, others could still free ride on their efforts and either refuse to lower their existing consumption or consume beyond the negotiated levels. In these circumstances, ensuring consensus and compliance among competing users can become impossible, leading to a breakdown of agreements and a likely collapse of local institutions.

Pakistan's groundwater environment makes collective action in managing groundwater as a common property resource impossible. The Indus Basin lies over an extensive unconfined and shallow aquifer. Over a million Pakistani farmers—mostly across Punjab and Sindh—rely on groundwater from this common aquifer to irrigate their crops. These farmers vary ethnically, speak different languages, and have vastly different levels of wealth and incomes. Given the sheer number of farmers and their diverse characteristics, the space for consensus on creating an indigenous institution to manage groundwater does not exist. Pakistani farmers cannot conceivably manage groundwater as a common property resource.

9.2.2 Myopic Behavior

Without collective action, property rights, and a central regulator and markets, Pakistan's groundwater management falls squarely under an open access regime. This signifies the following: (1) when a farmer extracts groundwater, they leave less of the resource for other farmers to extract (rivalry); and (2) given the absence of clearly defined property rights for the resource—the status quo in Pakistan—anyone with a tubewell can extract groundwater without restrictions (non-excludability). The open access nature of groundwater pits farmers against one another, with each rushing to extract before others get to it. The water left unpumped becomes available to competing users without any incentives to conserve it for future use.

In slightly more technical terms, the open access nature of groundwater implies that in each cropping period farmers keep extracting groundwater until the benefit they receive from the last unit of groundwater just equals the cost of extracting that last unit. This response translates into two negative consequences for all farmers (or externalities, the term economists prefer): (1) potential groundwater depletion; and (2) increased extraction costs. When extraction exceeds recharge, the stock of groundwater in the aquifer starts falling, leading to potentially permanent depletion. As the groundwater stock fall, the water table level falls too, raising the depth from which farmers can extract groundwater. Consequently, their extraction costs increase.

Under an open access regime, farmers behave myopically, focusing on short run gains rather than long-run security. When competing with other farmers for groundwater access, each farmer bears the cost of running their tubewell but not the long-term cost of depleting the resource. This cost reveals itself as higher extraction costs in each successive cropping period as the water table level drops. In each period, farmers look at the current water table level to decide how much groundwater to extract. If recharge does not equal extractions, the water table level falls in the next period making it more costly to extract groundwater. Each farmer's net returns fall subsequently, holding other parameters constant.

This myopic environment leaves little scope for farmers to conserve groundwater. No farmer has an incentive to limit pumping in the current period so that they can access the conserved water in future periods. Since the resource is open access, and no one farmer has absolute rights over the resource, leaving the groundwater in the aquifer means a competing farmer will end up extracting it instead. In this competitive, high-stakes environment, leaving groundwater in the aquifer as "potential savings" does not yield a return on investment. Farmers have no choice but to forgo the possible opportunities from conserving groundwater.

9.2.3 Regulatory Failures

Even though Pakistan's groundwater stock has steadily diminished since the 1980s and the water table level has considerably dropped in several areas, policymakers have failed to establish a comprehensive groundwater policy. The closest the country has come to developing a groundwater governance framework was when the federal government introduced the National Water Policy in 2018. The National Water Policy attempts to spell out a national-level policy for managing all water resources in the country. Since Pakistan's constitution devolved management of water resources to the provinces in 2012, the Punjab government released its own water policy in 2018.

However, both policies devote barely a page to groundwater—see Figs. 9.5 and 9.6. The documents recognize that groundwater constitutes a major irrigation source and that users must sustainably extract it, but they fail to provide a rigorous action plan on how to limit extractions. Given that groundwater is as important as surface water—or perhaps more important—for irrigation, the federal and

16. GROUNDWATER

16.1 The Indus aquifer, underlying the vast Indus plains, and other aquifers in valleys and in the hard rock formation are recognized as important national resources and deserve protection from pollution and unsustainable abstractions.

16.2 Monitoring efforts shall be strengthened to determine sustainable groundwater potential and prepare groundwater budgets for sub-basins and canal commands. All measures to prevent lateral/vertical movement of saline water interface shall be introduced. Provincial governments shall be persuaded to enforce legislation and take regulatory measures.

16.3 Various technologies used for sustainable extraction and skimming of fresh groundwater layers overlying saline water shall be evaluated and development of improved techniques initiated.

16.4 The transition of SCARP tubewells in the public sector to the private sector shall be expedited leaving development of fresh groundwater entirely to the private sector, as a local resource.

16.5 All sources of recharge/discharge and their interaction on groundwater reservoir shall be evaluated. Groundwater recharge including artificial recharge shall be promoted wherever technically and economically feasible. Abstractions from the aquifer shall be managed to the sustainable level that balances the recharge and boundary flows.

16.6 The Provinces shall be encouraged to prepare a Groundwater Atlas for each Canal Command and sub-basin delineating:

- Groundwater development potential;
- Water quality zones;
- Water table depth zones;
- Recommendations for installation of different types of tubewells.

16.7 Investment in groundwater recharge schemes shall be given due priority.

16.8 Secondary salinization due to indiscriminate groundwater abstraction shall be avoided by controlling or restricting pumping through enforcement of a strict regulatory framework.

Fig. 9.5 Groundwater section in the National Water Policy 2018. (Government of Pakistan, 2018)

provincial governments must establish their respective standalone groundwater policies. These policies must precisely delineate and describe instruments to curb extractions besides identifying the institutions as well as the agents required to deploy the instruments.

The two existing documents' brief sections on groundwater come across as a vacuous laundry list. They fail to undergird their assertions with any established theory, data, and analyses. Beyond the jargon, one struggles to detect the details and substance. For example, the National Water Policy states "abstractions from the

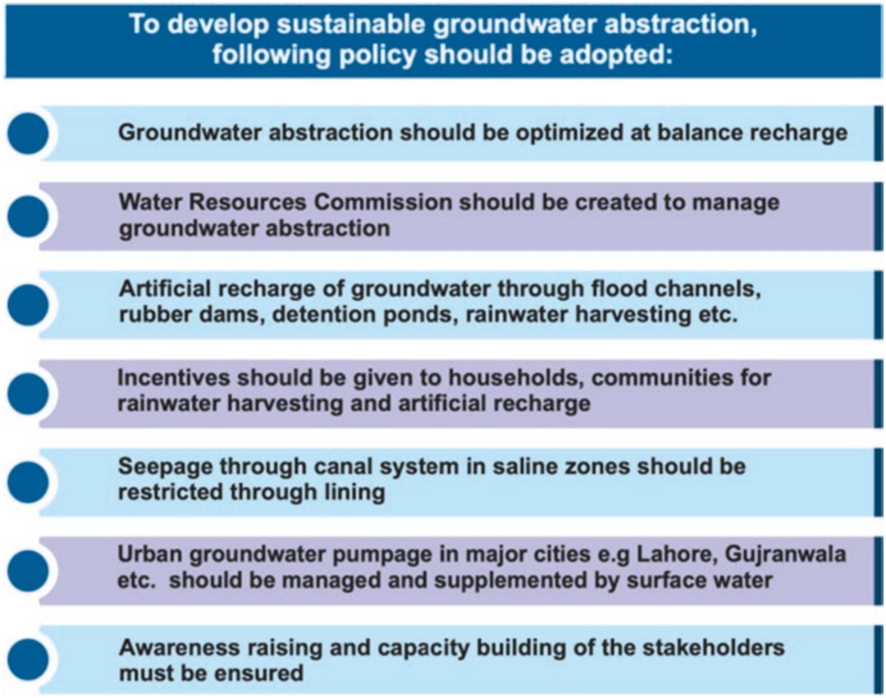

Fig. 9.6 Groundwater section in the Punjab Water Policy 2018. (Government of Punjab, 2018)

aquifer shall be managed to the sustainable level that balances recharge and boundary flows" while Punjab's policy declares "groundwater abstraction should be optimized at balance recharge." These statements might sound like noble aspirations but are quite abstract from a policy perspective.

First, the documents do not provide a rationale for *why* we should manage the aquifer to balance extractions and recharge. Balancing extractions and recharge is one type of sustainability goal; several other sustainability goals exist too—more on this in the next section. Why pick one and not the others? Second, even if we pick a particular sustainability goal, how do we ensure extractions meet that goal? Which actions and incentives will lead users to limit extractions? A viable groundwater policy must address these questions. The existing documents come nowhere close to providing concrete actions and incentives for meeting their sustainability goals.

Moreover, the two documents do not acknowledge the open access nature of groundwater. Any effective policy must first consider the source of the underlying externality—open access resource. Without recognizing that users unsustainably extract groundwater because of its open access nature, a groundwater policy cannot offer informed and precise prescriptions to manage the resource. Policy drafters must link measures to limit extractions with the externality. If they continue to delink measures from the problem's source, the externality will persist, and the proposed measures may fail to achieve their desired results.

Across the border in Indian Punjab, policymakers have drafted a comprehensive document that addresses industrial and commercial groundwater extractions, listing guidelines on how to manage and conserve the groundwater. The guidelines institute a tiered pricing system for groundwater based on volumetric consumption—measured through water meters—along with a credit system to incentivize conservation. The document also delineates the roles and responsibilities of public agencies and water user groups in implementing the guidelines. Offering considerable insights on how to draft meaningful groundwater guidelines, the document serves as a template which Pakistani policymakers could learn from and adapt.

9.3 Policy Instruments

9.3.1 Sustainability Criteria

Given the unviability of collective action in managing groundwater in Pakistan, a regulatory approach offers a solution to fix the market failure that results from the open access regime. These top-down approaches use incentives as the primary mechanism to induce changes in groundwater extractions—economists often label these policy tools "incentive-based mechanisms." The two most common incentive-based mechanisms include *water charges* and *tradable water permits*—I will focus on these mechanisms in this chapter to illustrate the options that Pakistani policymakers can exercise to better govern groundwater. Incentive-based mechanisms, if suitably designed, can lead to more sustainable groundwater extractions relative to an open access regime.

But before detailing incentive-based mechanisms, we need to define the term "sustainability" as conceptually reflected in their design. Sustainability can take on a variety of meanings depending on which discipline or framework one applies. For example, economists often adopt a broader definition of sustainability, emphasizing substitutability between physical and natural resources. Ecologists, on the other hand, stress the symbiotic relationship between nature and the environment, asserting the non-substitutability of natural capital. Scholars generally use two criteria for assessing sustainability: (1) the strong sustainability criterion; and (2) the weak sustainability criterion.

The strong sustainability criterion posits that society cannot substitute natural capital with physical and human capital. For intergenerational equity, society must leave enough natural capital to ensure that future generations receive the same services from natural capital as received by any previous generation. When considering groundwater, the strong sustainability criterion implies that society ensures balance between groundwater extractions and recharge—society extracts only as much as nature allows. The criterion is restrictive in the sense that it limits the consumption and production possibilities that could potentially replace natural capital.

On the other hand, the weak sustainability criterion states that society can substitute natural capital with physical and human capital. Technological innovation and higher standards of living can compensate for the loss of natural assets. Intergenerational equity depends on ensuring equal or greater access to consumption and production opportunities across successive opportunities. For groundwater, the weak sustainability criterion implies that society maximizes the discounted net returns from groundwater extractions over a long-term horizon. This allows extractions to exceed recharge—the groundwater stock depletes—if society realizes greater opportunities from consuming groundwater in the present. Pursuing this objective is called *optimal management*.

9.3.2 Optimal Management

Under optimal management, farmers internalize the scarcity value of the resource. This means that farmers account for not only the cost of extracting the resource at the margins but also the opportunity cost of extracting the resource in the present—versus leaving it in the aquifer for future use. Compared to farmers under an open access regime, farmers under optimal management face higher costs of using groundwater at the margins, thus they extract less. This reduces the difference between extractions and recharge, leading to a larger groundwater stock and greater annualized net benefits than under an open access regime.

Figures 9.7 and 9.8—taken from Nasim et al. (2020)—show the dynamics of groundwater extractions, the water table level, and annual net returns for farmers in Sindh under an open access regime (the status quo) and under optimal management. Moving from open access to optimal management leads to undiscounted welfare gains of roughly 5% in the long run. However, when one considers the present value of future net returns, the welfare gains of moving from open access to optimal management drop to roughly 1.5%. This modest gain in welfare when considering discounted net benefits over a long-term horizon is consistent with results from other aquifers—the literature coins it the *Gisser-Sanchez Effect*, recognizing the researchers who first discovered the effect.

Even though optimal management might lead to modest welfare gains, it leads to a better outcome than an open access regime. But optimal extractions are a normative goal. How do policymakers ensure optimal extractions? The three instruments that could accomplish this goal are: (1) quotas; (2) water charges; and (3) tradable water permits. Extraction quotas—a command-and-control approach—rely on state machinery to enforce compliance. Water charges and tradable water permits, on the other hand, leverage prices to incentivize farmers to extract less—therefore, some refer to these instruments as *incentive-based strategies*.

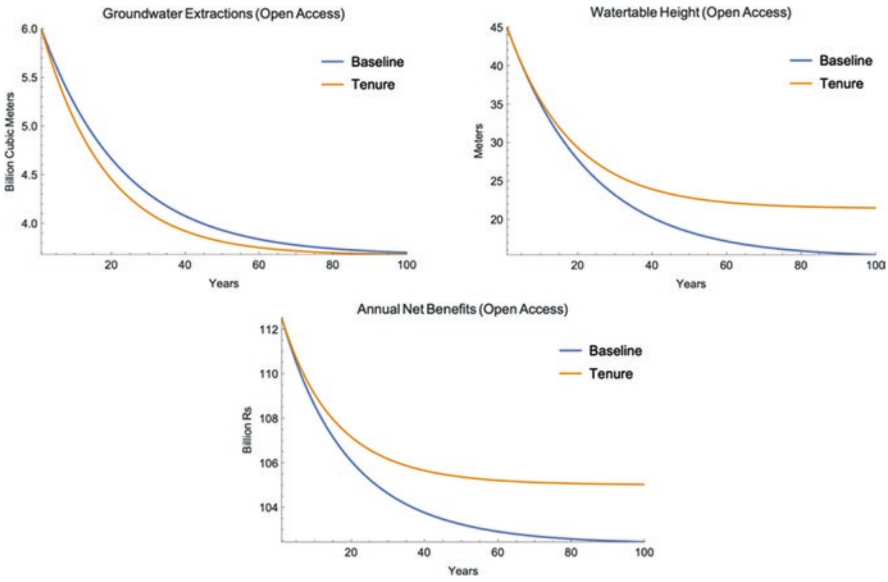

Fig. 9.7 Dynamics of extractions, aquifer state, and net benefits under open access in Sindh. (Nasim et al., 2020)
Note: the "Baseline" model assumes that all farmers are owner cultivators while the "Tenure" model assumes that farmers are a mix of owner cultivators and sharecroppers

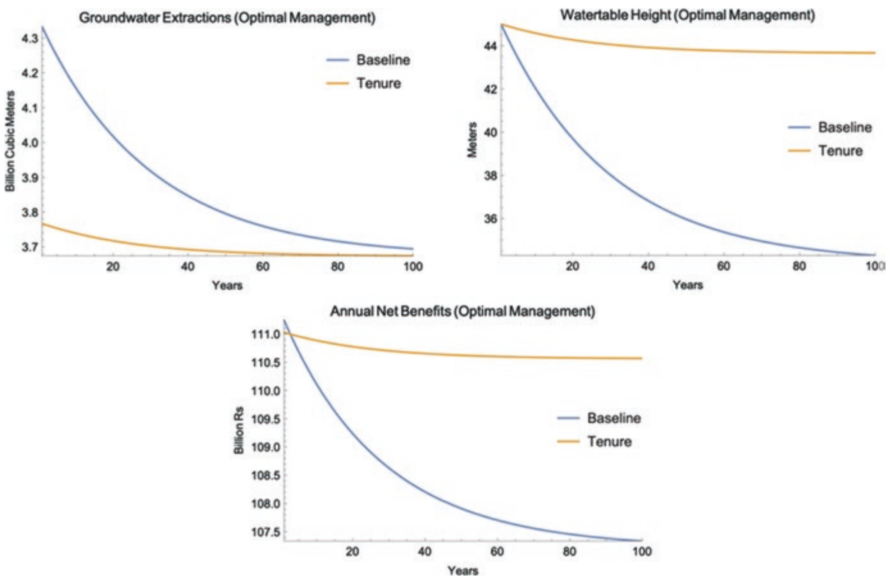

Fig. 9.8 Dynamics of extractions, aquifer state, and net benefits under optimal management in Sindh. (Nasim et al., 2020)
Note: the "Baseline" model assumes that all farmers are owner cultivators while the "Tenure" model assumes that farmers are a mix of owner cultivators and sharecroppers

9.3.3 Groundwater Quotas

Groundwater quotas work by restricting extractions through official mandates. For optimal management, the public agency would cap extractions at the optimal level and then allot quotas—allowances to extract—to farmers, ensuring that the sum of all the allowances under the quotas does not exceed the cap. For example, to optimally manage groundwater in Sindh, the agency could restrict extractions each year to the levels depicted in Fig. 9.8, annually distributing quotas equal to these levels across farmers.

How the agency allocates the quotas is a matter of contention. To ensure that extractions maximize welfare, the agency would have to figure out user-specific optimal extractions since welfare differs considerably across farmers. A uniform quota across farmers would yield maximum returns only if all farmers were identical. This is rarely the case anywhere, and each unit of groundwater generates varying benefits across farmers. However, setting user-specific optimal quotas requires the agency to know in detail how each farmer utilizes groundwater, particularly their extraction costs and net returns. Collecting this information across millions of farmers is prohibitively costly.

Given the difficulty of setting user-specific extraction quotas, agencies find it easier to tie quotas to factors such as land area and historic use. For example, the agency could decide to allocate higher groundwater quotas to large farmers than small famers. Or it could allocate higher quotas to farmers who demonstrate that they historically extracted more groundwater. As already stated, these quotas do not lead to optimal extractions since each farmer does not receive their optimal quota. Some farmers might end up with higher quotas than they require while others might not receive enough. Therefore, quotas do not necessarily improve groundwater stock or farmers' net returns even though public agencies might find them convenient to implement.

9.3.4 Groundwater Charges

Groundwater charges allow each farmer to adjust extractions in response to a per unit (volumetric) price on the right to extract the resource. Under open access, farmers' extractions in the present create a temporal externality—a unit of groundwater extracted today means one less unit of groundwater tomorrow. In other words, farmers are not paying for the cost of depleting the resource, thus making it scarcer for future users. A straightforward way to make farmers internalize this social cost is to charge them for extractions.

The price that leads farmers to extract the optimal level of groundwater constitutes the optimal price. Keep in mind that this charge is in addition to what it costs them to extract the water—extraction costs and scarcity are two separate constructs. Figure 9.9—taken from Nasim et al., 2020—shows the annual optimal groundwater

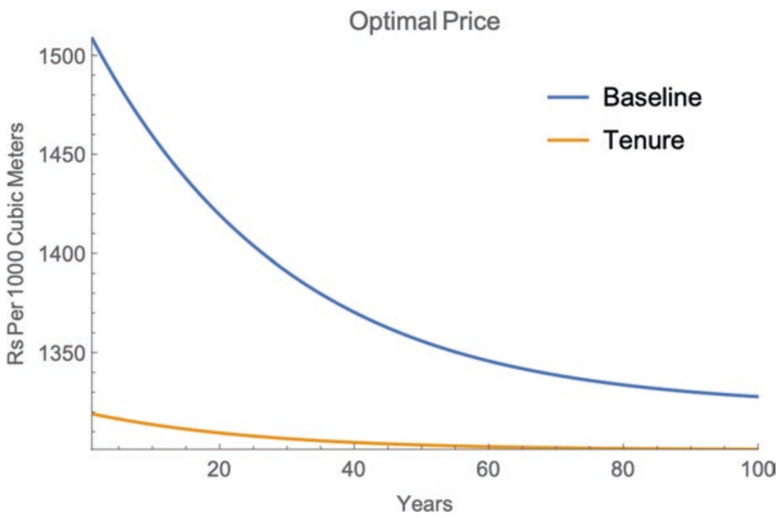

Fig. 9.9 Optimal groundwater extraction price in Sindh (Nasim et al., 2020)
Note: the "Baseline" model assumes that all farmers are owner cultivators while the "Tenure" model assumes that farmers are a mix of owner cultivators and sharecroppers.

price for Sindh. Setting groundwater charges equal to these prices each year would lead to optimal extractions. Charge collection critically depends on requiring farmers to install meters and on regularly collecting readings.

Charging farmers for groundwater incentivizes them to reduce their extractions and conserve the resource. Farmers can either substitute towards other inputs, adopt new farm practices and water-conservation technologies, or recycle on-farm water. The charge leaves it to the farmers to decide how best to limit extractions by relying on their own private information on the costs of using alternative practices and technologies. This grants farmers more flexibility to adjust extractions than command-and-control policies such as quotas which mandate standardized behavior.

The total water charge collected from farmers constitutes a transfer payment to the public sector and eventually to society—in effect, a revenue stream for the government. Ideally, the government should reinvest the payment back into the agricultural sector as a benefit to farmers. This could include enhanced extension services, promotion of sustainable and climate-smart agricultural practices and technologies, and frictionless access to low-cost loans. The reinvestment should never incentivize groundwater extractions as that negates the primary objective of the charge scheme—limiting extractions. To create buy-in for the groundwater charge scheme, the public agency should disclose from the outset that it would return to farmers the revenue collected from the groundwater charge in the form of productivity-enhancing services.

A flat volumetric charge on extractions may financially burden poor farmers. In such cases, a two-part (or tiered) charge system might alleviate some of the burden.

Under a two-part groundwater charge system, the public agency charges for extractions above a threshold—extractions below the threshold do not carry a charge. This favors small and poor farmers who might pump low amounts of groundwater yet struggle to pay their groundwater bills. However, without the charge, the incentives to use less groundwater to produce a fixed level of output disappear.

What if the public agency lacks information on farmers' production technologies, inputs, and extraction costs to set the correct groundwater charge? In this case, the public agency can use the information it already has to set an initial charge and then wait to see its effect on extractions, allowing farmers sufficient time to respond to the charge. The agency can then adjust the charge depending on whether extractions are too high or low.

However, successive changes in the groundwater charge may adversely affect farmer behavior. In response to an initial charge, farmers might invest in new practices and technologies to reduce their extractions—investments which often carry high sunk costs. Changing the charge soon after could render these investments pointless, forcing farmers to bear avoidable risks. To preclude this possibility, the public agency should determine the correct charge from the beginning. This underscores how important it is to conduct comprehensive empirical research on the value (benefits and costs) of groundwater.

9.3.5 Tradable Groundwater Permits

A tradable groundwater permit system relies on the interaction of farmers in permit markets, using the incentives inherent in the market-system to efficiently allocate groundwater permits across farmers. Under this system, the public agency caps the total allowable aggregate extractions each period. It then generates permits (or allowances) equivalent to this quantity of aggregate extractions and distributes them to farmers according to a predetermined criterion. After farmers receive their permits, they can trade them in specially established markets or exchanges.

Permit trading occurs because of the variation in the per unit benefit of using groundwater across farmers. Differences in production techniques, practices, and technologies may lead to different benefits per unit of groundwater. The bargaining for permits between a substantial number of farmers establishes a competitive price in the permit market. Permits will flow from farmers who need them the least to those who need them the most, exhausting the gains from trade. Trading does not affect the total level of extractions, which remain fixed because of the cap set by the public agency.

If the public agency caps extractions at their optimal levels each year, the allowances will trade at the optimal prices—equal to the optimal groundwater charges—in a permit market. Figure 9.9 shows the price for groundwater permits that would prevail each year in Sindh under a tradable permit system capped at the optimal level of extractions.

A tradable permit system essentially distributes valuable rights to farmers. If permits are fixed, they inherit a scarcity value, allowing farmers to benefit from trading them in the market. For the tradable permit system to work, the public agency must ensure that the market remains thick—lots of permit buyers and sellers—and it functions smoothly. Farmers should have access to information regarding permit prices while bearing minimal transaction costs of entering and participating in the market. If transaction costs are high, farmers will lack an incentive to participate, reducing market competitiveness and distorting permit prices. This will dimmish the gains from trade along with the agency's overall goal of limiting extractions.

The initial allocation of permits is a crucial step for ensuring equity. The public agency must ensure an initial permit distribution that seems fair and equitable to all parties involved. An equal distribution of permits would allow small farmers to earn additional returns by selling their excess allowances to large farmers. However, large farmers might consider this allocation discriminatory since it restricts their endowment relative to their historical extractions. The agency could make the initial permit allocation proportionate to farm size for a more equitable distribution. It could also distribute permits according to each farmer's existing extractions—each farmer receives a certain percentage of their current extractions. To reduce disputes and legal challenges, the agency must carefully plan the initial allocation rule, considering input from all stakeholders.

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Chapter 10
Agriculture and Water

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Abstract Water plays a significant role in Pakistan's agriculture sector, which is backbone of the country's economy. Presently, agriculture consumes a heavy amount (96%) of available resource base but most of it is wasted due to poor management practices. Over the years, the water supply to agriculture has moved from canal to groundwater, leading to over extraction. Water use (or misuse) has demonstrated consequences in the form of low water productivity, groundwater depletion and poor governance. There is a pressing need for a new mindset and necessary actions in the agriculture sector, to gain higher productivity with less water usage. This may be possible through the adoption of Regenerative Agriculture (RA) or Nature-based Agriculture (NbA). Both RA and NbA focus on restoring soil health that allows microorganisms to flourish and conserve the water that is already in the soil thus reducing significantly the need for artificial fertilizers, tillage, and watering. In Pakistan, private advisory groups, such as PEDAVER/PQNK, are showcasing the benefits of NbS and RA, which not only produce healthy and cost-effective food to meet domestic and export needs but also reduce the use of water.

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RA practices and technologies for conserving water are highlighted in the chapter. It is important to implement such policies and programs at the national level, which promote RA and eliminate obstacles in its adoption.

Keywords Groundwater depletion · Water productivity · Regenerative agriculture · Nature-based agriculture · Laser land leveling · Zero-tillage · Raised bed

10.1 Introduction

Pakistan's economy depends heavily on the productivity of its natural resources, particularly water, which plays a significant role in agricultural development and food security. Agriculture in Pakistan is predominantly irrigated, using probably one of the oldest and largest gravity flow irrigation systems in the world – the Indus Basin. Currently, the agriculture sector provides 19.2% of the country's Gross Domestic Product (GDP), employs more than 38.5% of the labor force and contributes more than 55% of exports (GoP 2020–21). Pakistan's total land area is 79.61 million hectares, of which about 20.60 million hectares is cultivated with 64% average land-use intensity. The total cropped area is around 22.6 million hectares, with cropping intensity of 97%. About 17.57 million hectares of the cultivated area are irrigated, that is, 12.24 million hectares from the Indus canal and 5.33 million hectares from other sources. The importance of water has been growing because of rising competition from certain actors other than traditional users. Over time, agricultural water supply has shifted from canal water to groundwater, even though the groundwater was already the primary source for domestic and industrial use. The country is moving towards a critical demand-supply gap due to over extraction of groundwater, disturbing the water balance (Habib, 2021).

As of 2022, the agricultural sector consumes a gigantic 96% of the available water resource base, less than half of which is used for irrigating crops. According to Shah (2016), if every drop of water was used rationally, one million acre-feet of water could generate up to one billion USD, implying the agriculture sector has the potential to generate USD 200 billion instead of the current USD 50 billion, which reflects very low water productivity in terms of value. Furthermore, a large part of this water is wasted because canal water is almost free and that is why there is no incentive for users to conserve the water. Another noteworthy trend is that farming is now becoming increasingly dependent on groundwater. It is costly because the water now has to be pumped up from deeper wells due to growing depletion of water levels from the shallow surfaces. Further, the extracted water from such depth is of poor quality due to presence of agro-chemicals thus underlining yet another issue of quantity and quality of the available water.

At the global level, the following assessment by the Food and Agriculture Orgaization of the United Nations (FAO) best summarizes the present situation of world food systems and natural resources:

> Food system demands have increased exponentially in recent decades and are estimated to continue growing due to increase in global population and expansion of economic affluence. However, the very foundation of a productive system—healthy soils and clean water supply—is already under immense pressure. In fact, by the most credible estimates, up to 52% of global agricultural lands are now moderately to severely degraded, with millions of hectares per year degrading to the point of abandonment of lands by the land managers. The loss of productive land, coupled with increased food demand, pushes agriculture to be the primary driver in 80% of native habitat loss. Agricultural irrigation is driving the majority of water scarcity issues in high-risk basins, threatening food systems, community water supplies, and ecosystem health. These pressures have resulted in the global agriculture sector causing more biodiversity loss, destruction of natural habitat, soil degradation and depletion of natural resources around the world more than any other industry (Miralles-Wilhelm & Iseman, 2021).

It is true that irrigation water enabled a quantum leap in farm productivity during the Green Revolution. Nonetheless, water use (or misuse) is now starting to show consequences in terms of low water productivity, groundwater depletion, and declining quality. Therefore, an important question is: can the agricultural sector continue to produce enough food for a growing population with the currently available water resources? It is significant to tackle this question in light of an ever-growing demand for water from communities, industries, and most importantly, the growing environment concerns (preserving the ecology) worldwide. Moreover, as climate change causes fluctuations in water supply, more climate-resilient agriculture is needed, first, to meet future food security needs and, second, to develop a competitive and reliable agriculture sector.

The key challenge for the agriculture sector is to improve food production so that it can provide high-quality food that meets health standards, but at the same time uses less water by improving water productivity both in actual and value terms. Water savings from improving allocative efficiency will be of significant importance especially in rice-based cropping systems. The sooner the policy of rationing water use in rice and sugarcane cultivation is adopted, the better it will be. Regulating the price of water is another policy instrument that needs to be considered for adoption.

Presently, Pakistan is not making optimum use of its water endowment mainly due to wasteful agricultural practices, use of large volumes of water to produce low-value crops under the false notion of food security, and failure to generate potential value-addition to its crops and other agricultural produce. There is an indeed pressing need for a new mindset and innovative solutions that can help build sustainable production and consumption patterns. In this chapter, we will make the case that Climate Smart Agriculture (CSA) or Regenerative Agriculture (RA) or Nature-based Agriculture (NbA) are feasible solutions that can help Pakistan move towards sustainable, low-cost, nature-based agricultural solutions and enhanced water productivity.

10.2 Water, Agriculture and Climate Change

10.2.1 Water and the Green Revolution

As in other relevant countries, the Green Revolution of the 1960s and 1970s in Pakistan was largely driven by heavy applications of chemical fertilizers, pesticides, and irrigation. Following this approach, high-yielding modern varieties performed far better than old varieties, leading to significant productivity increases in wheat and rice—so much so that surplus rice, and sometimes surplus wheat, could be exported. This enhanced farmers' incomes and achieved the government's self-sufficiency and food security goals. This was a quantum jump in food production. But at the same time, experts and policymakers also learned valuable lessons for the future.

By the middle of the 1980s, agricultural yield gains had started stagnating (PEDAVER, 2016). After decades of input-intensive farming, soil systems in the flood-irrigated areas of Pakistan, particularly in Punjab, have been deteriorating due to high salinity, caused by the overuse of chemical fertilizers, chemical pesticides and irrigation water. Ostensible food security and some progress made in achieving food security and export objectives has relied increasingly on tubewells, powered by electric and diesel pumps. Extraction of groundwater for irrigation purposes is rapidly increasing in many areas even though only up to 40% of this water is utilized for crops. Poorly managed irrigation systems cause waterlogging and salinity, changing previously fertile lands into barren fields. Salinity affects approximately 21% of the irrigated land in Pakistan (Qureshi, 2020). Overtime, many small farmers may not be able to benefit from the Green Revolution because of their custom of purchasing seeds (rather than saving them from year to year), and lesser use of expensive inputs. As the adoption of a few selected high-yielding varieties of wheat and rice is spreading, it might result in the loss of traditional varieties and also make crops more prone to pests and diseases. Despite such negative factors, the potential to increase irrigated farming cannot be overlooked since Pakistan has large, untapped endowments of rainfall that can be harnessed through conservation farming and supplementary irrigation (Kay, 2011).

The water dimension of the Green Revolution is explained by farmers' increased access to groundwater through the installation of tube wells. More than 50% of irrigation needs are met from groundwater in the Punjab and up to 20% in Sindh (Lytton et al., 2021). In the 1970s, the Green Revolution transformed the country's ability to feed itself and allowed it to export the surplus grain. But it has also turned Pakistan into one of the world's largest extractors of groundwater, second only to India, with both countries' water extraction practices becoming increasingly unsustainable owing to the depletion of groundwater levels.

In short, farming as presently practiced, is not sustainable in the long run, neither from an environmental perspective nor an economic one. However, as in many other developing countries, the Pakistani government and the relevant international community continue to promote the use of polluting inputs such as fertilizers and pesticides. This largely overlooked policy is significantly damaging the fragile layer of topsoil, which is critical to the future supply of the country's growing food needs.

From an economic perspective, it is mainly the agricultural sector that will have to adjust to the growing scarcity of water resources since it consumes most of the water even though the economic value of water is much lower for this sector compared to domestic or industrial use. However, politically, bringing such a change is exceedingly difficult. Government programs to redistribute land and enhance domestic food production in the past have led to the creation of strong interest groups who are resistant to any change that takes away their share of water supplies. The fact that the agriculture sector must use less water to produce more food brings a policy conflict to the forefront: meeting food security needs vis-a-vis achieving the objective of export-led growth despite growing water constraints. Yet resolution of this conflict is possible as subsequent sections will show, through the adoption of CSA/RA that could transform agriculture from a water-intensive system to one that is efficient and sustainable.

10.3 The Need for a New Approach and Mindset

Most researchers argue that the Green Revolution led to short-term gains at the cost of developing long-term, sustainable agriculture. Climate change, the current COVID-19 pandemic, and other health crises have made this argument even more convincing. This is further highlighted by the inclusion of agriculture on the climate and sustainable development agenda (Fischer et al., 2007; Beddington et al., 2012). An appropriate response to this unsustainable and chemical-intensive agricultural growth should be an assessment of the increasingly negative externalities associated with past policies. At the global food level, a revolution, based on a new paradigm for agricultural development, is urgently needed (Rockström et al., 2017).

Agriculture has a crucial role to play in achieving the UN Sustainable Development Goals (SDGs) of eradicating hunger and ensuring food security for a world population, expected to reach 9 to 10 billion by 2050. According to FAO estimates, 60% more food production is needed by 2050 to feed the growing population (Da Silva, 2012). This is in the context of increasing environmental risks around the globe. As a result, there is now greater emphasis on the need to reduce or completely eliminate the use of chemical-intensive farming. Instead, organic or near-organic agriculture (nature based) must be developed, as advocated a long time ago by Sir Albert Howard (d. 1947), who invented organic farming and pioneered composting techniques while residing in India. In addition, there is a large set of academic papers and reports from international organizations that support this methodology as the future for agricultural development. Some current works are presented in the FAO's publications (1) *Save and Grow: A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production* (2011) as detailed in Sect. 6.3.1.1, and (2) *Nature-based Solutions in Agriculture: The Case and Pathways for Adoptions (2021).*

India's Zero Budget Natural Farming (ZBNF), a set of farming methods, supported by a farmers' movement, is gaining recognition through its practice of incrementally moving farms towards zero dependence on purchased inputs. According to the FAO (2006), ZBNF focuses on practices that improve soil health, provide nutrients, and most importantly, act as catalytic agents that promote the activity of microorganisms in the soil, as well as increase earthworm activity. It also keeps seeds, seedlings or any planting material healthy. This practice is effective in protecting young roots from fungus as well as from soil-borne and seed-borne diseases that commonly affect plants after the monsoon period. It further promotes three types of mulching to save moisture or water and regulates better soil temperature.

The most promising results of ZBNF come from the southern Indian state of Andhra Pradesh, where a successful pilot was started in 2015 with a comprehensive action on inputs supply, production, and marketing. According to a 2022 media report, half a million farmers have already converted to ZBNF and Andhra Pradesh is showcasing the benefits of adopting ZBNF practices to other states.

While at the national level, ZBNF leaders claim that numbers could run into the millions (FAO), it is important to note that this movement has gained steam without any formal organization, paid staff, or official bank accounts. In Pakistan, the grassroots organization PEDAVER is most similar to this ZBNF movement in India, as will be discussed later in this chapter. ZBNF inspires a spirit of volunteerism among member farmers, who are the champions of the movement. At the local level, the movement is self-organized and self-motivated, with farmers learning from other experienced farmers. It is also quite decentralized as each district has its own organizational structure and designs to implement policies at the local level.

This section highlights how we can move from traditional agriculture to RA. Examples of global initiatives and local Pakistani best practices have been given. We can learn from them to determine our priorities in the area of agriculture and water.

10.3.1 Moving Towards Nature-Based Climate-Smart or Regenerative Agriculture

The concept of nature-based agriculture (NbA) is not new to the world. Globally, there is substantial evidence of chemical-based agriculture being replaced by new farming techniques such as natural biology-based agriculture. Many such farming systems, have already been followed by quite a number of farmers under different names. The examples include conservation agriculture, organic farming, mulching, zero tillage agriculture, minimum tillage farming, biological control of pests, biofertilization, and more recently, climate-smart agriculture, nature-based agriculture, and paradoxical agriculture. With changing climate patterns and emerging human diseases, particularly due to unsafe levels of carcinogens in food, the demand for organic food grown without the use of chemical inputs has risen globally. Consumers are willing to pay even a premium price for such produce.

Nature-based agriculture is a production system that takes nutrients from the soil without disrupting its organic matter. The soil is made of seven layers, each with a different chemistry and role. The top layer, or the topsoil, is composed of humus, roots, and living organisms. This layer has the maximum number of nutrients, including oxygen and nitrogen, that are essential for agriculture. Topsoil takes nutrients created by decomposing leaves, insects and other organisms, and provides ideal conditions for seeds to germinate. The second layer, called the subsoil, consists of less organic matter, fewer nutrients, and more clay. This layer is, however, rich in phosphorus and moisture, providing a different set of nutrition to the roots of plants.

In traditional agriculture, the top layers of soil are mixed together through deep ploughing or tillage. This process disrupts the natural working of the soil, hence changing the soil chemistry. The pH, moisture, oxygen (for aerobic bacteria), phosphorus, and carbon (for anaerobic bacteria) required for natural organisms to flourish is disturbed, creating the need for artificial or chemical fertilizers. Mixing of these layers also causes the soil to lose moisture. When the subsoil, which conserves moisture and prevents evaporation, is mixed with the topsoil, the soil's inherent moisture is released into the air. This, in turn, creates a different need, that is, for external and excessive watering of plants. Every type of soil has an abundance of the minerals needed for vigorous growth. The plants draw these minerals from the soil with the help of biota present in the natural ecosystem. In traditional agriculture, the use of agrochemical fertilizers kills this biota, hence altering this natural system of drawing nutrients from the soil, and increasing the need for agrochemicals and fertilizers.

Nature-based agriculture focuses on the restoration of soil composition for maintaining its health to produce food naturally. By leaving soil layers unmixed, allowing microorganisms to flourish and conserving the water already in the soil, this system significantly reduces the need for artificial fertilizers, extra watering or tillage. Therefore, in addition to being environment friendly, it reduces the cost of production for farmers.

10.3.1.1 Global Initiative—FAO's "Grow and Save Approach"

The FAO's "Save and Grow" model of sustainable intensification of crop production aims to look at ecosystem and its potential to add growth on sustainable basis. In a global context, it calls for "greening" the Green Revolution by adopting an ecosystem approach that is based on nature's contributions to crop growth, such as soil organic matter, water flow regulation, pollination, and bio-control of insect pests and diseases (FAO, 2011). The transformation process requires the following steps as outlined in the FAO publication "Sustainable Food Production and Climate Change":

Identifying Climatic Risk Factors that Influence the Adoption of Sustainable and Climate-Smart Practices

To begin with, climatic profiles need to be prepared for ecological regions. The profiles should include information on average temperature, duration of temperatures, total seasonal rainfall, and the frequency and duration of dry spells, and then linking the information to optimum stages of crop growth. Defining locational attributes based on climactic conditions allow for improved planning and cropping design processes.

Prioritizing Farmers' Needs

By undertaking "constraints analysis," we can address the factors that limit sustainable and climate-smart intensification and diversification of smallholder crop production systems. Irrespective of the analysis results, one major factor is bound to be farmers' lack of access to new technology practices, skills, knowledge, credit and markets. The technologies and practices that farmers need to adopt can be prioritized, such as introducing High Irrigation Efficiency System (HIES) or moving cultivation to raised beds. A matrix may be developed to identify the trade-offs. For example, in the case of RA, appropriate farm machinery is key to adopting nature-based systems (see Fig. 10.1).

A participatory approach involving stakeholders including farmers is necessary to identify the most relevant technologies and ways to scale up sustainable practices at the national, regional or farm level. To build climate resilience and ensure food and water security, the agricultural sector needs to transform its crop production and water management practices, supported by an enabling policy and institutional environment that is responsive to local needs and conditions. Indeed, it should be an in-depth analysis to identify barriers to mainstreaming best practices in crop management, and also to identify knowledge, information, policy and institutional gaps that will need to be addressed. In addition, necessary technology and climate-smart innovations along value chains (e.g., improved cold storage and logistics) should be implemented at scale.

Fig. 10.1 Seed planter being designed for local use. (Source: Photograph by Authors)

Scaling Up Validated Methodologies from National to the Regional Level
This is the most difficult step. Currently, three actions are being rolled out nationwide in Pakistan. First, a farmers advisory group led by PEDAVER is demonstrating how to promote and enable the transition to more sustainable and climate-smart production systems at the grassroots level. It is claimed that adoption is already taking place at scale not only in Pakistan, but also in India and Afghanistan. Second, the National Planning Commission, supported by credible institutions, is trying to address critical issues such as the machinery needed for this transformation. Third, several donors including the World Bank are of the view that while there is significant global research demonstrating the potential in general, these techniques have a lot more potential in Pakistan than currently realized. Therefore, local research is required for foolproof evidence before investments are made to scale up these techniques.

10.3.1.2 Nature-Based Agriculture in Pakistan— Leading Initiative by PEDAVER

In Pakistan, PEDAVER, under the banner of "*Pedaver Qudarti Nizam Kashtkari*" (PQNK) is taking the lead in promoting sustainable nature-based agriculture system (SNAS) or regenerative agriculture (RA). The objective is to produce green and healthy food, following centuries-old techniques and using nature-based nutrients (microbes) for plant growth rather than applying purchased environment-polluting inputs. The value chain of this approach also benefits all stakeholders. Figure 10.2 provides a summarized version of moving from traditional or unsustainable farming to sustainable nature-based agriculture.

The case of PEDAVER is an interesting learning experience. In 1972, Asif Sharif, one of the co-authors of this chapter, coined the term PEDAVER. He used to grow crops in a traditional manner on his farm, located in Punjab. Since the farm relied on canal water for irrigation, it only grew *kharif* (summer) crops because water

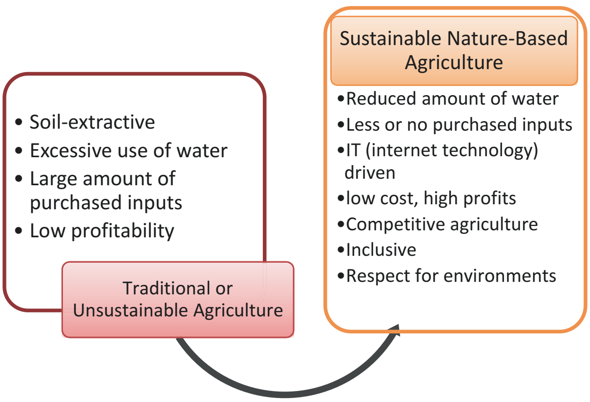

Fig. 10.2 Moving from unsustainable to sustainable agriculture. (Source: Elaborated by Authors)

channels would dry up in the winter. Realizing that growing crops in only one cropping season was not an optimal use of the land, he installed a tubewell on the farm to pump groundwater to irrigate the crops. A technology to cultivate long fields using furrow irrigation enabled him to grow cotton, wheat, sugarcane, and later, potato and corn. Furrow irrigation on the farm involves creating ridges or parallel sets of grooves allowing more efficient flow of water. Using the potato cultivation as an example, after marking the soil in the traditional manner and preparing the seedbed, potato seeds are placed by hand and manually covered with soil. This method gave up to five tons of potatoes per acre. Later, PEDAVER experimented with changing the ridge size, which allowed mechanical ridges to plant all crops on the ridges. These simple changes, as explained in Fig. 10.3, increased the yield threefold (from 5 to 15 tons per acre). Figure 10.3 also shows higher yields in response to various farm practices, with an amazing jump from 5 tons to over 24 tons. This was considered as the beginning of the experimentation, adoption, and promotion of nature-based agriculture in Pakistan.

In order to replicate nature-based agriculture, PEDAVER's approach focused on limiting the inundation of fields in order to avoid soil disturbance. For this purpose, PEDAVER team decided to keep higher-elevation land for vegetation and lower land for water channels. Raised beds were established, with furrows on each side for water supply and drainage, with the water-intensive crop of rice on 44 acres of land where four acres were used as a control group and 40 acres for the experimental group. The team while researching new rice production methods came across the System of Rice Intensification (SRI) method being followed at Cornell University in the U.S. The SRI improves rice productivity, using environment-friendly and

Fig. 10.3 Yield Responses to Various Farm Practices (PEDAVER). From left to right: 40 bags' yield to 5 tons per acre; 120 bags' yield to 15 tons per acre; 200 bags' yield to 24 tons per acre; no till, no irrigation, no input, more yield. (Source: Photographs by Authors)

climate resilient agricultural practices that preserve the natural resource base (SRI-RICE, n.d.). PEDAVER combined nature-based agriculture with the SRI system, conservation agriculture and organic farming. Plant spacing, soil aeration, water management, and raised-bed application were some of the practices adopted for the trial.

As PEDAVER team realized the value of these modifications in the process, it was motivated to experiment further. The team continued to make improvements to get closer to precision agriculture, using syphon tubes for furrow irrigation to manage the water, promoting a practice of side dressing fertilizers instead of broadcasting them, and more advanced fertigation and foliar techniques. It introduced pneumatic precision planters to establish an accurate seed-to-seed distance that not only increased the plant population but also saved seed. The team also brought in improved seed varieties such as crossbreeds, hybrids, and Genetically Modified Organism (GMO) seeds. While all these efforts increased yields to a certain extent, the yields somehow started to decline and then stagnate. Learning from Brazil where vegetation thrived without the depletion of resources or the use of agrochemicals, the team was motivated to try the approach in Pakistan under the banner of the PQNK. The next section presents a small sample of the vast work done during the last decade under this program.

In central Punjab, farmers usually grow rice and wheat throughout the year, so the next experiment was done on the wheat crop. Wheat, a staple food in the Pakistani diet, is the main crop cultivated in the province in terms of area planted. Conventionally, wheat is planted with random seeders, using 40 to 60 kilograms of seed per acre. Using the SRI technique of providing optimum space to each plant, above and below ground, as with rice, the PQNK team experimented with planting 62,000 seeds to get 58,000 plants per acre. A nine-by-nine-inch row-to-row and plant-to-plant distance was maintained. No purchased input was used. The results were exceptional with an average of 37 tillers per plant, whereas some plants even reached 86 tillers at a significant cost reduction (from PKR 1160 per acre to less than PKR 100 per 40 kilograms' yield), not to mention significant reduction in irrigation costs (Fig. 10.4).

Similar experiments were conducted for corn, potato, cotton, and sugarcane, and all of them showed promising results. Later on, the same procedure was applied to a troubled citrus grove, where plants had been dying despite excessive use of fertilizers, nutrients, and pest and disease management. When the orchards were

Fig. 10.4 PEDAVER's wheat crop experiment. (Source: Photographs by Authors)

Fig. 10.5 PEDAVER's citrus grove experiment. (Source: Photographs by Authors)

transferred to raised beds, covered by live alfalfa mulch, the plants recovered and produced substantially more and better-quality fruit.

After years of further trials conducted in different areas of Punjab, PEDAVER's PQNK agriculture today is based mainly on no-tillage, raised beds with organic mulch and changed irrigation practices.

Once the raised bed is prepared, seeds are planted without soil tillage. This method protects the mycorrhizal fungi network and prevents tillage costs while improving water absorption, infiltration, and retention. A tractor, with an implement mounted on it for specific operations, facilitates the process. The raised beds are prepared with a width of the distance between two tires of the tractor. The tires compact soil on both sides, creating furrows without affecting the raised-bed soil. These furrows work as an optimum channel for water because furrow irrigation does not inundate the raised beds. With this technique, the plants only absorb the required water thus reducing water usage and wastage by 75%. During heavy rains, excess water also drains through the furrows.

PQNK nature-based agriculture promotes the application of organic mulch on top of the raised bed after the seed is planted. Organic mulch is any natural material that decomposes easily. This process enables biota to flourish in the beds, which helps convert mulch and plant residue into minerals and elements required for optimal plant growth. Organic mulch cover also moderates soil temperature and prevents possible soil moisture loss that could occur through evaporation by direct sunlight exposure. This also prevents salinization on the soil's surface hence maintaining a healthy balance of nutrients. This allows the roots to grow longer thereby anchoring the plants deeply and strengthening them to protect from dislodging in stormy weather. Additionally, the use of organic mulch reduces the cost of fertilizer application by 90%.

10.3.1.3 Technologies and Practices for Water Conservation

Presently, agricultural water usage in Pakistan is not sustainable because of its poor management at the farm level—a running theme in a number of chapters in this book. In addition, climate change has a profound effect on the water system in the country as it is getting more complicated to allocate the erratic supply of one of the most important sources of water – the Indus Basin. We, therefore, need to change our water consumption practices, especially in the agriculture sector. All the techniques and practices detailed below promote sustainable crop production without exploiting the natural ecosystem and, more important, they reduce water demand.

Laser Land Leveling Laser land leveling is an effective technology that enhances water productivity at the farm level. When land is even, water is applied to the entire field in an even manner, minimizing runoff and water logging. It is also more suitable than traditional land leveling methods because it reduces operational costs, requires less time, and is more precise. Monitoring and evaluation consultants from the Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) assessed the impacts of laser land levelers. Results showed 20–30% savings in irrigation time, reduction in energy use, 9–11% enhancement in crop yields, 11% increase in fertilizer-use efficiency, and 18% reduction in labor costs.

Laser technology in Punjab that was introduced in 1985 under the On-Farm Water Management (OFWM) program, is now being promoted by the government among farmers and service providers. Farmers are currently using the technology in all districts of the province, and in order to further promote it, the government is providing 50% subsidy on the technology to the farmers. There are more than 25,000 laser land levelers in Pakistan, and Punjab has the highest number of units, i.e., 20,000 (OFWM, 2016).

The importance of laser land leveling is highlighted during discussions between farmers and experts. Although the availability of localized technology has reduced imports yet smallholder farmers in most rural areas cannot financially afford to buy the required equipment. Presently, most of the equipment is owned by progressive farmers or co-operatives and provided to small farmers on rental basis.

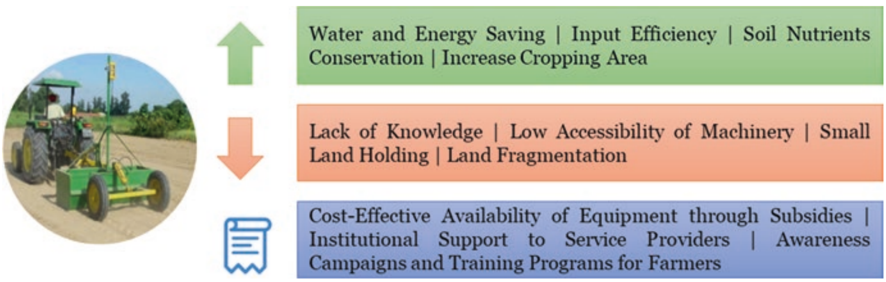

Fig. 10.6 Laser land leveling—Analyzing benefits, constraints, and policy options. (Source: Authors' work elaborating OFWM, 2016)

While many districts have machinery, it is still not enough to meet the demand. The adoption rate for the technology is increasing with more awareness among farmers, but further adoption depends on the convenient availability of the machinery. Effective government support and prioritization is needed to overcome the hurdles (Fig. 10.6).

Regenerative Agriculture (Zero-Tillage, Raised-Bed Planting)
Raised-bed planting is an effective method to save water and input. It has many advantages such as increased yields, improved irrigation, more efficient fertilizer use, prevention of weed infestation, reduced lodging, and reduction in greenhouse gas (GHG) emissions due to lower input use. Natural resources are used efficiently in contrast to conventional farming practices in which about 40–50% of irrigation water is wasted in the fields. Research shows that cultivation on raised beds requires 30% less water than that on flat surfaces (Fahong et al., 2004). In irrigated areas of Punjab, crops are cultivated on flat fields and irrigated via flooding. Quite a bit of valuable water is lost when passing through unlined courses from the main source to the fields. Raised beds are low-cost and save substantial amount of water. These benefits make them a top priority for adoption by farmers.

No tillage means the cultivation of land with little to nil soil manipulation. This practice has the potential to decrease greenhouse gas (GHG) emissions, use of farm machinery and production costs as well. In addition, soil health is improved. The retention of crop residues maintains the soil cover due to decreased mechanical soil disturbance. The retained crop residues also provide protection from raindrops and sunlight's direct impact on the soil. Soil, air, and water movements are enhanced because of minimum soil disturbance. The Water Management Department has shown that zero tillage helps in water saving, cost reduction and yield enhancement in rice-wheat cropping systems in the Punjab (Kahlown et al., 2002). Growing rice on ridges/beds can save up to 50% water, raise yield up to 20% and reduce methane emission from the rice fields (Qureshi & Ashraf, 2019).

Field research was conducted to evaluate the performance of conservation tillage system for rainfed wheat production in the uplands of Pakistan. The results confirmed that crop yields are enhanced by minimum tillage with retention of crop residues whereas input cost is increased by conventional tillage with no retention of crop residues. In conclusion, conservation tillage practices, especially the reduced tillage residues, have potential to boost soil quality and crop yield (Sharif et al., 2018).

Redesigning Farm Machinery to Transform Agriculture
The availability of appropriate farm machinery is critical for the proposed transformative process. The National Planning Commission initiated a cooperative process to design the Punjab Resilient and Inclusive Agriculture Transformation (PRIAT) Project. The key components of this project are transformation of farming from flatbed to raised bed, introduction of appropriate farm machinery through a participatory approach, and exploration of low-cost options such as the use of multipurpose precision planters. Specific machinery is being developed and procured from the private sector. Once success of the project interventions is clearly demonstrated, the project can possibly be scaled up with donors' support.

An engineering dealer from Lahore manufactured precision planters but they did not perform as well in the trial runs as was expected by the Pakistan Agricultural Research Council (PARC). The planters recorded a precision level of less than 50%, with the machines breaking down frequently. Learning from this unsatisfactory case, the government continued to invest in the design process, importing gear boxes from China and adjusting them to local conditions. As a result, precision level increased by 80%. Later, it was found that the best precision planters, called Volterra,[1] were manufactured in France by Monosem Company. A new consultation process was initiated through a consortium of the National Agricultural Research Centre (NARC), National Rural Support Program (NRSP), Tefta, and the University of Engineering and Technology (UET), Peshawar to redevelop the technology. Finally, a customized multipurpose machine has been prepared, which is far better than those available in the market.

Most of the precision planters used worldwide are crop-specific (Fig. 10.7). However, the machine developed through the consortium can be used for several crops including wheat, maize, cotton, vegetables and some other commodities commonly cultivated in Pakistan. This machine is also equipped with a mulcher that can prepare the bed before planting the seed, making it truly multipurpose. In addition, it has an impressive 96% precision level.

The estimated cost is now budgeted at Rs 1.2 million with little concerns for pay back as it can be used year-round. The government-run Heavy Mechanical Complex at Taxila has been approached by the consortium to manufacture these machines on a large scale, expecting the cost to be as low as Rs 0.6 million per unit.

Mulching

Mulching is a technique to minimize water loss through evaporation by covering the soil surface with crop residues and/or plastic sheets (Fig. 10.8). Mulch has the potential to conserve soil moisture under water-scarce conditions. It improves soil

Fig. 10.7 Precision crop planter—Analyzing benefits, constraints and policy options. (Source: Photographs and analysis by Authors)

[1] This is a next generation planter. Developed by Monosem, it ensures that land is used to its full potential while also protecting it. It can be used for maize, sugar beets, sunflowers, rapeseed beans, soybean and sorghum seeds. It keeps an inter-row distance of 45 to 80 cm, with a capacity of 6–12 rows.

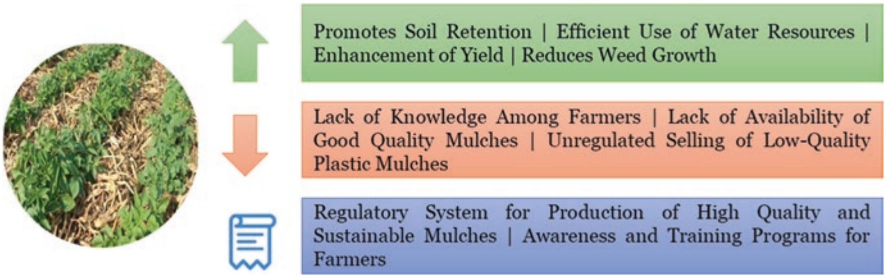

Fig. 10.8 Mulching—Analyzing benefits, constraints and policy options. (Source: Photograph and analysis by Authors)

environment and reduces soil erosion, water runoff, and weed growth. Natural materials for mulching include straw, sawdust, hay, compost, farm residues, and bark. Inorganic mulches are plastic, organic sheet, rock, gravel, etc. Growing evidence shows that retention of the residues increases crop yields. A study conducted in Punjab found maize crop growth, yield, and water-use efficiency (WUE) improved by the use of plastic film and straw mulch under varying irrigation levels.

Plastic traps or absorbs solar radiation, increasing soil temperature under mulch so the crops mature faster as compared to the crops grown on bare soil.

Organic sheet mulch is biodegradable whereas plastic sheet mulch is not and is therefore difficult to dispose of. However, biodegradable plastic mulch is a credible alternative to polyethylene mulch as it can reduce environmental pollution. Yet, it is expensive, with black mulch being the least expensive option.

In view of low market demand, only a few local companies manufacture plastic mulch sheets but the product is not prepared in line with proper mulching recommendations. Some companies import the plastic mulch sheets from China. Most farmers use local, low-cost, low quality plastic mulch sheets sold at local stores. These sheets not only contaminate the soil but also are labor intensive to install.

Water Storage (Farm Ponds)

Crops, vegetables and orchards are mostly irrigated with surface and groundwater in Pakistan. The extensive irrigation system depends on rivers, dams, barrages, and canals. However, climate change, low water storage capacity and cross-border disputes put stress on water availability. Currently, the water crisis is Pakistan's most critical problem. A lack of water storage facilities at farms significantly contributes to agriculture and water challenges. Farm water storage can be built at the farm and community levels in different forms such as artificial farm ponds or tanks after taking into consideration available resources and geographic features. The storage can hold rain and canal runoff water, which can be used later at critical crop production times, as well as for meeting the challenges posed by climatic change. During dry periods in "*barani*" (rainfed) areas, stored water can be used to maintain agricultural and economic productivity. Rainfed areas do not have supplemental irrigation facilities and other water sources like tube well or dug well. In those areas, farm

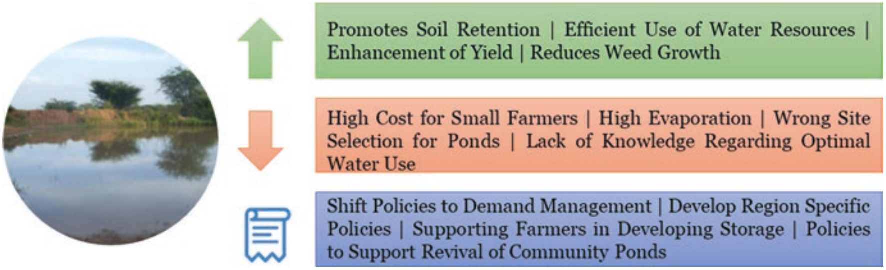

Fig. 10.9 Farm ponds—Analyzing benefits, constraints and policy options. (Source: Photographs and analysis by Authors)

or community ponds can act as crucial reservoirs, albeit capable of providing a rather limited quantity of water during critical shortages (Fig. 10.9).

Solar Water Pumping

Solar water pumping has many advantages such as independence from conventional energy, simple operation and maintenance, uninterrupted water supply during the day, feasibility in remote areas, environmental benefits, and long-lasting solar panel life. In Punjab, solar energy-run small tube wells have been installed at a few sites. The Punjab Agriculture Department has recently implemented an Asian Development Bank (ADB)-funded project titled, "Promotion of High Value Agriculture through Provision of Climate Smart Technology Package" to install solar systems for operating high efficiency irrigation systems like drip irrigation on 20,000 acres. A major limitation, however, is a lack of regulation on the use of solar powered pumps and to what extent they cause groundwater depletion. Yet, discussions with stakeholders and experiences in the fields show that a solar powered water pump can only be used for specific number of hours during the day and might not have negative impact due to over pumping. Research-based assessment is needed in this regard.

10.3.1.4 Key Benefits of RA

Regenerative Agriculture (RA) not only has technical merits, but also economic benefits, which can help foster change and adaptation. Farmers are not interested in the benefits highlighted in academic notions of competitiveness and inclusivity. They are more interested in real life practical factors that make a positive difference in their incomes such as through reduced costs or steady water availability. There is one rule of thumb for developing nature-based sustainable agriculture anywhere: it must be location-specific. It should be designed within the context of an existing farming system functioning in a specific agro-ecological region. A farming system proven successful in a given situation may not be so successful elsewhere. In other words, one size does not fit all situations due to unique local factors. Starting a climate-smart crop system requires farmers to (i) use quality seeds, adapted to the local climate and pests; (ii) diversify crop systems; (iii) use sustainable mechanization; (iv) apply soil and water conservation practices; (v) improve water management; and (vi) invest in agricultural knowledge transfer. Since sustainable agricultural practices need exceptionally low maintenance, it is essential for properly trained agricultural extension workers to educate and convince farmers that these methods are indeed profitable. Also, farmers need not only training in performing these recommended practices but also incentives to adopt them. The government, therefore, needs to formulate appropriate policies, which must include opportunities for business advancement, and the farmers should be made aware of them. The agricultural labor force should also be sensitized about the severity of climate change, and the need for environmentally sound "green" solutions. A holistic, cross-sectoral response is needed, which combines various development sectors in an effort to create awareness, educate and uplift the culture of production and consumption in the agriculture sector. The assumption is that RA reduces production costs and increases the yields and/or reduces the risk of crop failure due to drought, flood, locust and hailstorm. Some well-documented benefits of RA are as follows:

Enhanced Water Productivity—More Value per Drop
The growing water scarcity is largely driven by population growth, which means agriculture has to produce more and better-quality food with less water in the future. Policymakers need to understand the merits of RA, particularly its ability to enhance water productivity in a cost effective manner. Raised-bed cultivation and mulching are just two practices that save water and enhance water productivity both in actual (more crop per drop) and value terms (more value per drop). Farmers do not need to invest blindly in high irrigation efficiency technology (HIES), which is suitable only for certain terrains. Our research further highlights an important policy prescription: farmers will not adopt new technology unless motivated by (a) cost lowering incentives (in view of rising water prices), and (b) attracted by profitable market opportunities. Reducing water costs by following RA provides such an opportunity.

Resilient Food Production
The adoption of RA can make food production more resilient to weather and climate-related conditions such as droughts, floods and storms because these practices enhance soil health, reduce soil erosion and retain water. The diversified production systems and sources of income also help in maintaining food and nutrition security.

Environmental Health—Carbon Sequencing and Credits
We often talk about water footprints but not much about carbon footprints. It is true that an assessment of the carbon footprints of food production systems can significantly contribute in moving towards sustainability. Take the case of wheat and rice, two key crops grown in different ecological zones across the country that are fully integrated with the large, growing livestock sector. It is well documented that Pakistan is one of the lowest carbon emitters globally, yet the dependence on groundwater, high use of fertilizers and maintenance of the livestock directly

enhance CO_2 emissions. This highlights the importance of estimating the carbon balance inventory in terms of absorbing carbon (sinks or sequestration) and/or emitting carbon (emission) and identifying possible adaptation and mitigation options. The adoption of RA by farmers assures enormous benefits of capturing carbon (sequencing) through practices such as making raised beds, mulching, maintaining crop covers all along the crop cycle and developing biogas from the livestock sector. Furthermore, a case can be made for Pakistan to claim environmental credit and even begin carbon trading with India and China, the two biggest polluters. RA has the potential to reduce carbon emissions and capture carbon by (i) preventing deforestation and conversion of natural habitats; (ii) improving the role of aquatic ecosystems (e.g., watersheds, wetlands, coastal mangroves, seagrass meadows and coral reefs) in storing carbon through their conservation, restoration and sustainable management, and (iii) increasing the amount of carbon retained in plants and soils by adopting new practices in crop residue management, cover cropping, and tillage (Miralles-Wilhelm & Iseman, 2021).

Enhancing Nature and Biodiversity

RA can help in protecting or enhancing ecosystems and biodiversity in the following ways: (i) increasing habitat diversity; (ii) restoring aquatic ecosystems and wetlands and, (iii) improving water quality and reliability (Ibid).

10.3.1.5 Limitations of RA and/or PEDAVER's PQNK System

Despite the significant cost reduction and ecological benefits that this nature-based system provides, there are certain limitations and challenges to the PQNK approach, as is the case with most production systems.

First, RA/PQNK in Pakistan is underdeveloped. Presently, there is no value chain that could help farmers at the onset of adoption. Until the value chain is established, the farmers may not fully benefit monetarily. In Pakistan, 89% of farmers own less than 12.5 acres of land (FAO. Agricultural Census, Pakistan, 2010). Each season, these small farmers rely on getting inputs from the middleman on credit, which is paid off after the crop is harvested and sold to the same middleman. Thus, farmers, trapped in a cycle of informal debt, are risk averse and tend to avoid adopting a new production system without first seeing its results.

Second, the equipment required to prepare raised beds and the precision planters for the raised beds are not readily available to the farmers. Similarly, special harvest machinery will have to be designed for minimum plant residue, especially for rice, sugarcane and maize crops, which allows the farmers to plant the next crop immediately. It would be unfair to expect small farmers to invest in such technology, but service providers can fill this gap with the support of the government by making the machinery available on rent.

Lastly, farmers in general are unaware of PEDAVER's PQNK techniques. Technical knowledge on all aspects of farming is usually disseminated to the farmers through a network of field extension workers who are employees of the provincial agriculture departments in all provinces of the country. This network can launch PQNK-focused gender-sensitive, participatory extension campaigns through contacts with farmers' organizations, social media, printed materials, radio, television, mobile phones, field demonstrations, field days, study tours, and rural fairs in order to inform and educate farmers in the new methods of production under nature-based agriculture. Rural informal leaders such as village elders, mosque *imams*, and schoolteachers can be engaged to raise awareness and help promote sustainable practices. In view of the fact that rural women are also involved in farming operations, they should also receive necessary orientation and training.

10.3.1.6 Recommendations

In light of the limitations of RA and the objective to move the process forward, a lengthy consultative process has taken place in Punjab under PEDAVER/LUMS initiative, which is being supported by the National Planning Commission and the Ministry of Food Security and Research (MOFSR). The summary recommendations coming out of the consultative process are as follows:

- **Conducive Policy Actions:** Formulation of macro policies that support climate-smart agriculture and redesigning of sectoral policies for NbA or RA.
- **Two Key Training Areas:** Organization of training sessions in farm management and machinery operation and maintenance.
- **Streamlining the Production Process:** Creation of a public-private partnership with a company, to be governed by a board.
- **Support of Agricultural Service Providers:** Assignment of one service provider for every 1000 acres, who reports to the board. Service providers to be trained and financially supported.
- **Agriculture Engineering Tools:** Designing and dissemination of the technology based on local needs for adopting PQNK/CSA/RA (critical for the success of the program).
- **Adaptive Research at Universities and Strengthening Agriculture Extension and Education:** The creation of a PEDAVER Markaz or Crop Production and Marketing Company (CPMC) that will develop "training farms" for active learning at each Union Council/Village through the service providers who could function as future trainers.
- **Improve Market Linkages:** Elimination of the middleman in food delivery through the adoption of emerging COVID-19-triggered business models thus lowering the price of food for consumers and increasing returns for farmers.
- **Win-Win Outcome:** By following RA process: farmers sell at double the price; CPMC covers the cost and makes a profit on volume; the retailer buys and sets price on quality; higher income customers are willing to pay for organic or near-organic food; lower-grade food is much cheaper.

10.3.1.7 Institutional Support

As mentioned earlier, the National Planning Commission and the Ministry of Food Security and Research (MOFSR), with the support of donors, are now embracing the idea of RA but need solid evidence of the benefits before expanding it further. There are two ongoing projects: (i) The Climate Adaptation and Resilience for South Asia (CARE) is a five-year (2020–2025) regional project, funded by the World Bank and implemented by the Asia Disaster Preparedness Centre (ADPC), and (ii) The Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES), which has engaged the services of the Shahid Javed Burki Institute of Public Policy at NetSol (BIPP) to implement the project "Agriculture Policy Analysis to Support Climate-Resilient Policy Actions in Punjab." Agriculture needs to be repositioned towards inclusive and sustainable growth to transform itself into a competitive, sustainable, commercially viable and profitable activity. Another project is the Growth for Rural Advancement and Sustainable Progress (GRASP), funded by the European Union, being implemented by the International Trade Centre. This project will directly contribute to achieving the 2030 Agenda for Sustainable Development and Sustainable Development Goals (SDG). All of these projects contain program elements of RA and outline future actions on how to implement them.

10.4 The Way Forward

We have made the case that in future more and better quality food needs to be produced with less water. RA provides an excellent opportunity to produce more agriculture output with less water. Investments in raised bed technology, mulching and improvements in soil health can lead to significant water savings and, as such, provide an opportunity for low-cost solutions to mobilize an extra unit of water.

RA not only improves the productive efficiency of water use (more crop per drop) but also enhances allocative efficiency of water use (more value per drop). Most important, it reduces growing dependence on energy use in agriculture in view of the fact that groundwater pumping being energy intensive, increases the cost of production and reduces both income and agriculture competitiveness.

Pakistan is likely to face an increasing food import bill because experts estimate a 15% drop in the domestic wheat yield. This is due to an unprecedented rise in temperature in April and other factors such as shrinking acreage, poor application of fertilizer, water scarcity, limited certified seeds, all leading to further reliance on imported grain (Mahmood, 2022). Growing literature is pointing to the fact that the present development path cannot be sustained unless we go back to nature-based solutions by charting out a new development paradigm. The starting point is agriculture, the food we eat, and its critical link, water.

Nature Inspired Sustainable Agriculture (NISA) or RA can drive the transformation of the green economy by revitalizing the food production system and providing employment with better returns on per unit of land, water, labor input throughout the value chain. RA is being proposed as a strategic framework in reviving the agriculture sector. The action can be taken at basin or local community level with the objective of increasing the income and food. The repositioning of agriculture will create investment opportunities and enhance agricultural sector's contribution to national economy in many ways such as reduction in imports of farm inputs, increase in exports of high value goods with possibility of tapping the growing organic market, and minimizing the negative impacts of conventional farming on environment.

Globally, a large number of international initiatives including the UN Framework Convention on Climate Change (UNFCCC), and the UN Convention for Combating Desertification (UNCCD), the Convention on Biological Diversity (CBD) are supporting frameworks and policy initiatives that acknowledge improved soil, nutrient, water and livestock management practices as vital in reducing emissions and ensuring food security (Sanz et al., 2017). Donors and agencies like the World Bank, ADB, FAO and Consultative Group on International Agricultural Research (CGIAR) have taken a number of initiatives in developing climate-smart agriculture and water management with more reliance on Nature-based Agriculture (NbA) or RA.

At the national level, planners and policy makers in agriculture and related fields can boost the adoption of PQNK/CSA or RA by designing strategies for (i) public interventions; (ii) private investment; and, (iii) corporate leadership. Agricultural interventions, climatic conditions, economies, and local set-up vary from region to region. Hence, policy recommendations must be designed accordingly. An organization such as PEDAVER, highlighted in this chapter, is a good example that is fostering change through actionable solutions and trying to change the mindset of policy makers and farmers alike. Some resistance may come from multinationals that sell chemicals. In Pakistan, there were record sales of fertilizers in 2021 as farmers wanted to avail the subsidy, but instead the subsidy went to fertilizer manufacture companies.

The most influential and widely respected voices should be raised, especially among the research community, practitioners, and the media, to support this revolution in the making. This revolution holds promise and perhaps provides the only path towards water use optimization and higher agricultural production in an environment friendly manner. For this to happen, the proposed interventions need to be supported by conducting overwhelming evidence-based research on NbS (Raymond et al., 2017). From the academic side in Pakistan, Lahore University of Management Sciences (LUMS)'s Centre for Water Informatics & Technology (WIT) has taken the lead in piloting work in association with PEDAVER and now it is engaged in conducting field trials and their validation. Apart from PEDAVER, recently, RIZQ, a local civil society trust outfit has launched a pilot research project on RA on a 2.25 acres plot. The project goals are: (1) To establish a comprehensive repertoire of research centered on sustainable agriculture practices; (2) Analyze the economic feasibility and adaptability of Regenerative Agriculture (RA); (3) Develop model farms in south Punjab to showcase RA practices; (4) Develop a business model for small farmers based on Yunis Khan (Noble Laureate) social business concept and/or

IFAD 4 Ps model; (5) Transition farmers affiliated with RIZQ under the GRORIZQ Program to RA system. The pilot has successfully completed one wheat cycle and has currently transitioned towards direct seeding of rice. This initiative should be a great step towards an in-depth examination and evaluation of RA/NbS that could help in quantifying the much needed economic, environmental and social benefits of various interventions and approaches.

Equally important is the need for research on the business and economic value of RA. This is critical from the point of view of farmers since the economic returns of a proposed intervention will determine if the recommended technology is adopted or not. While the literature is full of actions that need to be adapted at the macro, meso and micro levels, it is short on how to implement and monitor policies. More organizations like PEDAVER are needed for grassroots level implementation that encourage farmers to adopt RA through incentives, tailor interventions to local conditions, and mobilize communities. This could be facilitated by field extension workers but they will first need intensive training in environment-friendly and cost-effective NbS or RA practices. The training should include PEDAVER field visits and unambiguous method and result demonstrations.

On the policy side, research and development resources should be allocated to support CSA/RA. It is important to integrate the knowledge of indigenous populations as their Traditional Ecological Knowledge (TEK) has the ability to address climatic risks at grassroots level (Hosen et al., 2020). NbS still requires more evidence, but at least some actions can be promoted through smart planning. If there is inadequate data in agriculture, start with the low-hanging fruit, that is, prioritization of the technologies and practices like raised-bed planting and mulching that have the potential to deal with future climatic conditions. Similarly, potential benefits of solar-powered water pumps and the huge benefits of small-scale community-based biogas plants can take off under a well-designed incentive program.

Realigning incentives and provision of financial resources is necessary to promote the adoption of RA practices. Globally, existing public subsidies and support for agriculture and fisheries are over \$700B/year while only 15% are supporting the provision of public goods through NbS (FOLU, 2019). Policy makers can begin with realigning these existing programs. The Organization for Economic Co-operation and Development (OECD) estimates that agricultural practices with potential harmful impacts on the environment receive up to \$100B/year in subsidies (Karousakis et al., 2017). Such subsidies should be redirected to facilitate producers in adopting methods that are environmentally friendly and mitigate climate change impacts. Policy makers can employ innovative approaches in agriculture that provide bridge or transitional funding.

According to a USAID report, the Government of Pakistan provides sizable subsidies to intervene in wheat procurement and border policies, and at times provides similar support to cotton and sugarcane. Further, large subsidies on irrigation and fertilizer are also given albeit at a high cost. Presently, these direct national subsidies are around Rs 42.6 billion, with another Rs. 170 billion in indirect subsidies. These subsidies have risen steeply because of the wheat crisis exacerbated by the war in Ukraine. The report highlights the fact that these subsidies tend to favor large farmers. These policies have led to higher domestic prices that impose a disproportionate burden on the poor (IFPRI and USAID, 2021). Further, the World Bank has calculated that Punjab is providing agriculture subsidies up to Rs. 157 billion. Therefore, in order to encourage the adoption of RA techniques, we need to convert these subsidies presently for environment-polluting inputs into "smart subsidies" that will help farmers and not multinationals. Finally, the proposed framework will not be applied satisfactorily until the policies at the macro and sectoral levels are realigned. Interestingly, most solutions for agriculture and the water sector lie outside each of these particular domains. For example, population control is a prerequisite to manage water scarcity and food security, which are largely driven by very high population growth rates. There is a limit to how many resources we can provide at a competitive price in the face of ever-increasing demand.

Governments and policy makers can also focus on shifting consumer preferences and trade practices in support of goods (for example, a surge in avocado demand affecting groundwater depletion in Mexico) that are environmentally friendly and less water intensive, but consumers should be aware of high unaccounted costs. Similarly, the transparency of food chains that can lead to increased sustainability needs to improve (Wognum et al., 2011). It is crucial to increase agri-food systems' resilience because of more frequent and intense climate-related events (FAO, 2021). Potential of NbS must be harnessed in order to make our present agri-food systems more sustainable and resilient to deal with declining agricultural productivity and environmental pressures.

Food losses and waste affect food security in a number of ways. The large amount of food wastage all along the supply chain also means loss of valuable resources (renewable and non-renewable) in terms of land, water, energy and other inputs that go into their production and consumption. Reducing food wastage "from field to fork" is sound and rational for developing an integrated and innovative strategy to save water. This will ease pressure on water and other resources and free up land and water for purposes other than food production. In view of the fact that the region is water scarce, this water can be used for other sectors and industries.

In Pakistan, the agricultural sector is the major user of water with a share of up to 96% of the total water demand. It is very important that water use efficiency improve in terms of not only production but also all along the supply chain. Water productivity is much higher for fruits and vegetables as opposed to traditional crops such as wheat, meat, and dairy products. On the other hand, fresh horticultural crops have a high water content (75–95%) and internal relative humidity of 95–98% (very high water activity), resulting in very high metabolic activity (FAO, 2008), which is the major contributing factor to high water loss in horticulture crops. Water loss has several negative effects including weight (economic) loss, quality deterioration, loss of water soluble components such as vitamins, loss of flavor components, loss of color intensity, etc. Water loss is accelerated at high temperatures and/or at low relative humidity (FAO, 2008). The adoption of NbS or RA practices by the farmers could considerably reduce these losses.

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Chapter 11
Water Pricing, Demand Management, and Allocative Efficiency

Mahmood Ahmad

Abstract Pakistan has moved from having excess water to having problems managing demand. It has gone through several distinct phases in its devolution to water scarcity which shed light on the nature of the issues shaping water policy discourse. Pakistan has under-invested in water demand management and needs to chart a new water strategy to address the underlying causes of problems, not just the symptoms. Productivity in terms of actual water use in Pakistan is among the lowest in the world, at the same in value terms (economic output per unit of water) is also quite low in Pakistan. A growing body of literature has highlighted the benefits of adopting technologies and practices such as precision land leveling, zero tillage, and raised bed-and-furrow planting, which enhance water productivity in both physical and value terms. There has been very little uptake of High Irrigation Efficiency System (HIES) technology whose adoption depends on two factors: appropriate water pricing and the profitability of agriculture, Neither are the case in Pakistan. The government should consider a broader framework that entails three aspects: (1) enhancing the marketable commodity (or yield) of crops for each unit of crop transpiration; (2) reducing non-beneficial atmospheric depletions and outflows that are not retrievable; and (3) enhancing the effective use of rainfall, water of marginal quality, and stored water. The chapter underlines need to increase the price of irrigation water and also provides case studies from Pakistan and other water scarce countries looking at the tradeoffs between productive and allocative efficiency in future policy paths.

Keywords Demand management · Water pricing · More crop per drop · More value per drop · Environmental cost · Water policy in Pakistan

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11.1 Introduction

A number of technical, policy, and environmental issues affect the Indus Basin. The Indus Basin is a supply-driven system with open-ended demand that comes largely from population and income growth and is now characterized by an erratic supply. Furthermore, cropping intensity far exceeds (120%) the original design capacity (50–70%), with an equal or slightly higher amount of water being stretched to irrigate larger parcels of land.

Another major concern is the reliability of existing irrigation systems to deliver water in a timely fashion when and where it is needed. During the winter seasons, low mean annual precipitation and temporal variability often lead to growing uncertainty about the river flows. Further, conveyance losses in canals and watercourses and at farm level add to growing water shortage, with the end result that only about 30% of water flowing through the system is available to farms. In addition, farmers at the tail end of the irrigation distribution system are vocal about increasing water shortages. The large irrigation system system is also facing problems of maintenance due to low-cost recovery from water charges and there is a lack of vision in rebuilding better using lower-cost indigenous technology.

Climate change, also a major concern for the Indus Basin, can best be characterized as too much water with flooding or too little water with droughts. The weather patterns of the last decade and especially the year 2022, with droughts and ongoing floods should serve as a wakeup call to revisit Pakistan's crop calendars. Finally, planners and policy makers continue to focus on costly supply-side solutions even though low-cost demand management options are readily available.

Is Pakistan a water scarce country? In our view, no. Compared to other countries, Pakistan is well-endowed with water resources. Instead, our failed policies, irrational use of resources, and, in particular, explosive population growth have led to this much-discussed water scarcity (Table 11.1). The agricultural sector uses 96% of water, wastes a larger part of it, and pays the least, while contributing only 20% to the GDP. On the other hand, the services and industrial sectors contribute 80% to the GDP while using only 5% of the country's water (Young et al., 2019). Furthermore, the way the irrigation network was designed is an in-built incentive to waste water and adopt and stick to low-value crops (Nawaz, 2019). In the future, the agricultural sector needs to produce more-diversified and better-quality food using less water to meet the growing demands from competing sectors including the environmental needs of water flow. We have enough water; we need policy corrections to improve productivity, allocate water efficiently and bring about better governance.

Table 11.1 Population v/s water availability in Pakistan. Source: MTDF (2005–10)

Year	Population (million)	Per capita water availability (m^3)
1951	34	5650
2003	146	1200
2010	168	1000
2025	221	800

Policy discourse needs to be redirected from the supply side to demand management, from large dams to small dams (or construction of a cascade of dams based on the run of the rivers), and towards the potential of low-cost water harvesting. During the last three decades, we have missed out on these supply-side options because our policy makers have persisted in a strategy of building large dams—with foreign financing—while neglecting to raise local financing through pricing water and other economic instruments which are being used globally. At the same time, the demand management options that could have mobilized an extra unit of water at a much lower cost were never considered, aside from a few piecemeal investments in canal lining and laser leveling, and now poorly designed High Irrigation Efficiency Systems (HIES).

This chapter makes the case that the demand side of the equation has not been prioritized in terms of mobilizing marginal units of water in a cost-effective way to meet not only growing agricultural demand, but also demand from competing sectors that are much more willing to pay for water. Defining Water Demand Management (WDM) in layman's terms: WDM encourages better use of existing supplies through a set of economic measures and better and efficient management as opposed to pushing for further increasing supply (Global Water Partnership, 2017). Some currently untapped supply-enhancement options include eco-based infrastructure rehabilitation, water harvesting, and the use of unconventional water. Unfortunately, planners and policymakers are still obsessed with grand supply-side options. However, change is coming slowly as traditional donors are starting to lay greater emphasis on water productivity and governance as key areas of reform.

11.2 Policy Options—Supply vs. Demand Management

Pakistan, like many other countries, moved from a position of having excess water to problems in managing demand. It has gone through several distinct phases in its devolution to water scarcity which shed light on the nature of the issues shaping water policy discourse.

The first phase—the pre-partition era—saw the creation of one of the world's largest contiguous irrigation systems, with an excess supply of water, developed in one of the oldest and most accomplished civilizations. The second phase begins with the Indus Basin Treaty, marked by the damming of rivers, the construction of the Tarbela and Mangla dams, and the associated link canals. This era also saw low-cost drilling technology become available, groundwater come into use as a source of supplementary irrigation, and the ushering in of the "green revolution", which was driven largely by the mobilization of sizable water supplies (both surface and groundwater), new wheat and rice varieties and increased use of fertilizers. But the continued demand for more water to meet the food security requirements of a rising population, combined with massive migration from rural to urban areas, led to such a significant drop in per capita water availability that Pakistan within a short span of time has joined the list of water scarce countries or approaching fast as detailed in Chaps. 3 and 4.

So now that the time to panic is upon us, there are two schools of thought on how to avoid the problems that will occur because of perceived water scarcities. The first school of thought believes the solution lies in building large dams (*The News* 2017). However, a growing number of multidisciplinary water sector scientists, and now even a few civil engineers, have begun to question the wisdom of investing in large projects that have huge investment layouts, uncertain benefits, poor environmental records and, most importantly, reduce the money available for a wide range of other investment opportunities (Ahmad, 2000; Kamal, 2009; Mustafa, 2010). Young (2017), while debating the need for more storage, highlights:

> Unlike many countries, in Pakistan the timing of flows is not vastly different to the timing of demand, although some storage is needed to capture the monsoon peak and release this water later in the Kharif season and in the early Rabi season. Additional storage would certainly yield additional useable water, but any increase in water use will inevitably reduce the flow to the sea, which is already at an environmentally unsustainable low level. Given Pakistan's low economic productivity of water in irrigation and rapid rates of reservoir sedimentation, it is hard to justify the costs of major new storages. Hydropower generation does justify new dams, but these could be run-of-the-river facilities (not storage), with lower social and environmental impacts.

In our view, in Pakistan, as in many other countries, supply options are reaching their physical and financial limits, but there is considerable policy space to promote water demand management options, providing a large set of tradeoffs between supply and demand management and also within demand management options, discussed in coming sections.

11.3 A Policy Framework for Water Demand Management (WDM)

Compared to supply management, Pakistan has under-invested in water demand management. Pakistan needs to chart a new water strategy to address the underlying causes of problems, not just the symptoms (Ahmad, 2000). Moreover, these demand management options should be eco-based solutions which would both cost less and add much-needed value to the larger economy. The equation is simple: agriculture uses 96% of available water—if even 5–10% of agricultural water was saved,[1] it would be enough to meet the growing needs in other competing sectors while also resolving challenges from climate change. According to a World Bank Report (2019), as agriculture continues to consume a major share of demand, much of the increase in demand will come from other sectors of the economy. Between 16 and 32% of the increase in water demand by 2050 could be due to climate change, mainly because of growing water requirements in agriculture (World Bank, 2019).

[1] *Water saving* refers to the capturing (in part or in total) of the water fraction that would no longer be available to a system, after that same system has used its allocated water.

The policy options are broadly categorized as improving productive and allocative efficiency of water use in agriculture also addressing issues related to the environment and climate change, as detailed in Fig. 11.1. In layman's terms, improving productive efficiency means getting more crop per drop while improving allocative efficiency often refers to more value per drop of water. The concept of climate change in water context can be "too much (floods) or too little water (droughts)" and rise in global temperature.

To Turton's work, we have added another key area of water management that highlights the importance of eco-services which include providing food, water, regulating climate seasons, pollination for crops and building soil health and, most importantly, recreational values. Young (2017), citing the case of Pakistan, highlights the importance of environmental flows, which are often ignored or not given the attention they deserve. First, the literature constantly mentions the perception that irrigation in the Indus Basin area is inefficient. However, the reality is, at the basin level, the Indus Basin's global efficiency is estimated to be as high as 84%, because water is picked up again and again by downstream users through groundwater use. According to Young (2017), only a small portion of water is lost through evaporation and transpiration or non-productive plant use, but the larger loss—rarely mentioned

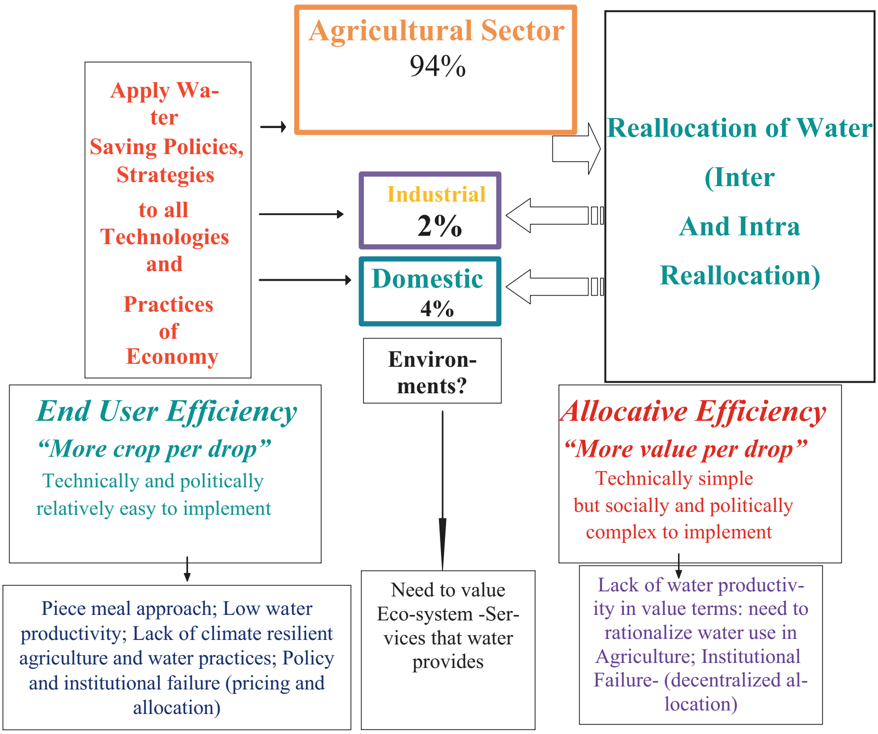

Fig. 11.1 Demand Management Policies. Source: Authors' work, adopted and updated from (Turton, 1999)

by researchers—is that the drainage water which returns to the river and the groundwater seepage which is pumped again are both of lower quality.

The second myth is with regards to the fact that water that flows to the sea is perceived as water wasted. Yet it has been well-documented for the last eight decades that the average flow to the sea has been declining, which has resulted in a poor ecological profile of the lower Indus and which has devastated eco-services that affect poor communities that rely on fishing and eco-tourism, not to mention its contributes to improving the role aquatic systems such as wetlands, coastal mangroves, seagrass meadows in carbon sequestration and sustainable management of coastal regions.

11.3.1 Water Productivity

11.3.1.1 More Crop per Drop

Productivity in terms of actual water use in Pakistan is among the lowest in the world. To support this argument, two figures are presented: Fig. 11.2A, highlights cotton water productivity in Pakistan in comparison to other countries—the most important crop for value added exports[2]—needs a sizable amount of water to produce one ton of seed cotton, especially when compared to India and China, our main competitors. Furthermore, India uses green (rainfed) water in cotton production as opposed to Pakistan, which uses expensive canal or groundwater.[3]

Pakistan produces 0.13 kg of cereal per cubic meter of water (m^3) as compared to 1.56 kg/m^3 in the USA, 0.82 kg/m^3 in China and 0.39 kg/m^3 in India (Kumar, 2003). Even within South Asia, as can be seen in Table 11.2, the level of water productivity is very low, with average productivity of 0.23 and 0.36 per m^3, for rice and wheat, with Pakistan at .25 and .40 per m^3 respectively as opposed to the 1 Kg/m^3 as recommended by the FAO (Haq, 2013). To put a positive spin on this situation, low productivity in Pakistan provides enormous potential—fulfilling it would result in more income, better food security, and more exports.

11.3.1.2 More Value per Drop

As with actual water productivity, in value terms (economic output per unit of water) is also quite low in Pakistan. Figure 11.2B shows water productivity in value terms with rice the lowest and maize the highest. It should also be noted that vegetables, sugarcane and cotton are also water intensive. The country generates only \$2 per cubic meter of water, as compared to \$19 for East Asia and the Pacific,

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[2] It refers to export-oriented export valued at economic prices using our domestic resource such as land, labour and capital all valued at their economic value.

[3] An unpublished paper, for ICID conference in Lahore.

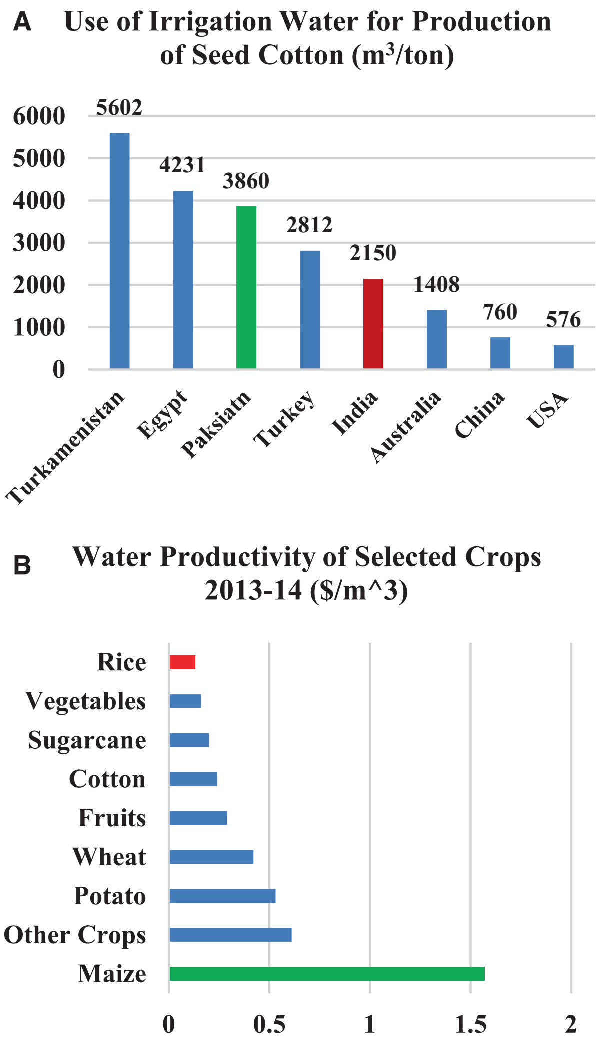

Fig. 11.2 A Water productivity of selected crops. Source: Authors' work, using data from *Pakistan: Getting more from water*, World Bank, 2019

ranking in the ten lowest countries of the world. A donor-supported reform process set a target to increase it to $5 by 2023 and to $12 by 2047. A World Bank report (2019) highlights that such a paradigm shift could help the country's agriculture survive in an era of water scarcity. The report also shows that physical crop water productivity varies between and within locations and systems by factors of from 0.2 to 20 kg per cubic meter, and economic crop water productivity varies by factors of from 3 to 30 US cents per cubic meter.

Table 11.2 Water productivity in South Asia. Source: (Haq, 2013)

Country	Average yield of Rice (t/ha)	Average Yield of Wheat (t/ha)	Water productivity* kg/ m^3 Rice	Water productivity* kg/ m^3 Wheat
Bangladesh	3.501	2.001	0.3	0.34
Pakistan	3.501	2.381	0.25	0.4
India	2.981	2.841	0.25	0.48
Nepal	2.912	1.981	0.24	0.32
Bhutan	2.111	1.141	0.17	0.18
Sri Lanka	3.371	NA	0.28	NA
Afghanistan	1.793	2.64	0.15	0.44
Maldives	0	NA	NA	NA
Average	2.88	1.85	0.23	0.36

Based on author's work reported in the 9th Annual Report (2016) of the Shahid Javed Burki Institute (BIPP), the key policy steps needed to enhance water productivity are, among others, (1) enhancing the marketable yield of crops for each unit of crop transpiration (2) reducing non-beneficial atmospheric depletions, and (3) enhancing the effective use of rainfall. Figure 11.3 outlines the actions needed at each level and the overall framework.

11.3.1.3 Rationale for Increasing Water Productivity

Cai and Rosegrant (2003) outline the need to enhance water productivity in agriculture, as the global population, which reached 6 billion in 1999 and is expected to reach 7.8 billion in 2025, is already putting greater pressure on limited water availability as demand in agriculture and other competing sectors grows. Irrigated agriculture, which accounts for 72% of global agriculture—and 90% for developing countries—has to produce more and better quality food with less water. Many countries with growing water scarcity have underinvested in rainfed agriculture, with estimates that water productivity will have to increase 30% and 60% from rainfed and irrigated agriculture, respectively, to meet food security demands.

To achieve the sustainable agricultural growth necessary for food security, all three levels—the basin, the system, and the farm levels—need to be considered. Given the scope of this chapter, we will focus on further elaborating the necessary actions at the farm level. There is growing literature coming up starting with Resource Conservation technologies to Regenerative Agriculture that highlight the benefits of adopting technologies and practices such as precision land leveling, zero tillage, and raised bed-and-furrow planting. After the success of tubewell adaptation in Pakistan, laser leveling is another success story, with 60% of farmers adopting the technology, and with groundbreaking localized versions being improvised—replacing costly imported technology. On the other hand, High Irrigation Efficiency Systems have been slow to take off because of the high initial cost, a lack of trained

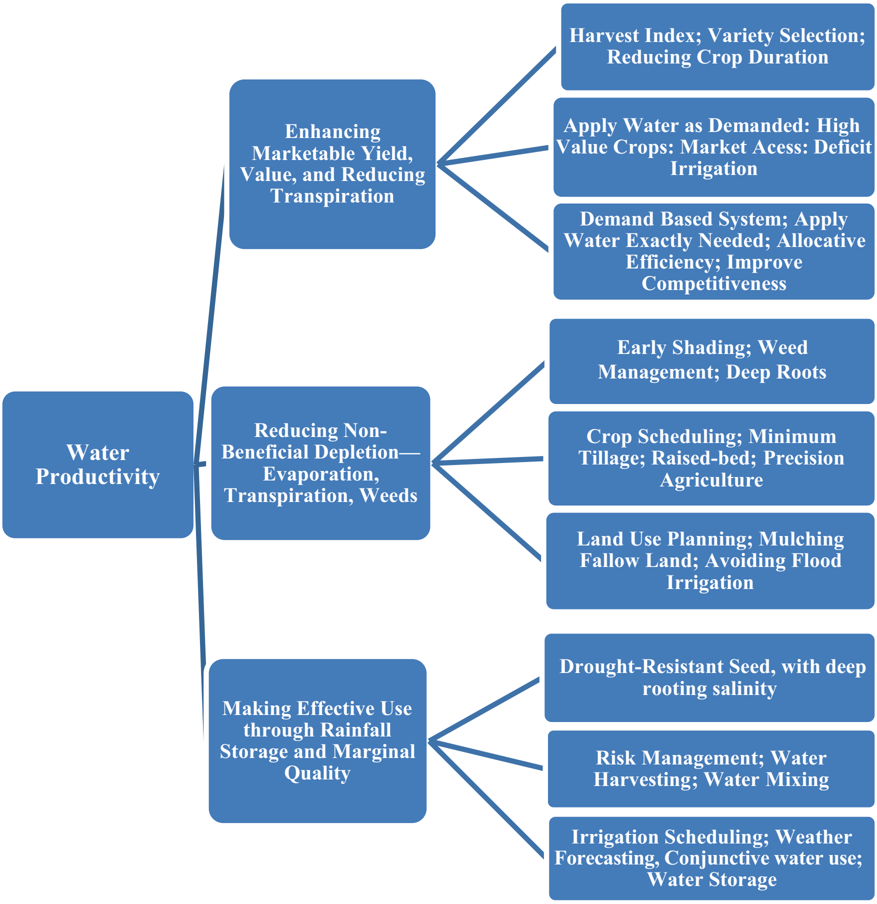

Fig. 11.3 Actions to increase water productivity. (Source: Author's work and analysis)

manpower to run the system. Only 150,000 ha are using these systems and their use needs to be expanded (See Chap. 10).

11.3.2 Water Pricing and Allocation—An Unfinished Policy Action

As in many countries, in Pakistan government plays a key role in managing water resources, but poor governance is reflected in the inefficient use of water and the inability to recover costs even for operating and maintenance expenses (let alone investment costs). On the other hand, the cost of new projects continues to rise but the quality of the service provided to end users is declining. Such a state has led to a search for alternatives that make water allocation and management more efficient. Dinar et al. (1997) outlined the basic principles on how to treat water as an economic good and about allocating it among competing sectors, using marginal cost pricing, social planning, user-based allocation, and water markets. However, there is not just one way to set water prices; options range from cost recovery to full cost pricing. Within this broad framework and keeping in mind our overall policy objectives, we have outlined three financial, economic and societal goals for sustainable water resource management.

- Financial: Meeting financial objectives to generate sufficient revenue to meet the operating and maintenance costs of irrigation systems, and to avoid the well-known trap Pakistan has been caught in (build-neglect-rebuild). At the very least, operation and maintenance costs should be met.
- Economic: Meeting economic objectives by encouraging water allocation to the most water-efficient crops or other high-value agricultural and non-agricultural uses. This kind of allocation would maximize the economic growth benefits of a scarce resource. Again, this should recover the original investment costs of each system, in addition to providing revenue for operation and maintenance (O&M) costs.
- Taking the environment into account. Incrementally moving towards full cost pricing that will also minimize the environmental problems with irrigation, especially those coming from the excessive use of water.

Figures 11.4 and 11.5 highlight the building blocks of pricing water resources: both costs and benefits. We often try to balance these out; in some cases, the full costs or the full benefits are not accounted for, which often explains the poor returns on investments (Rogers et al., 1998). These methods differ in their implementation, the institutions they require, and the information on which they are based. There is a growing literature on irrigation water pricing (Sampath, 1992). Several studies (Sampath, 1992; Dinar & Subramanian, 1997; Ahmad, 2000, 2005) focus on the water pricing methods in various countries.

From an economic perspective an ideal price would be where value (Fig. 11.5) would just equal the full cost of water (Fig. 11.4) as classical economic models postulate, meaning the social welfare function is maximized.

In Pakistan, to put the pricing debate in the correct context, before partition the sub-continent recovered almost all of O&M costs as well as part of the investment cost from irrigators. Then, in 1970, politics intervened: large farmers holding political power started to raise the fear that any spike in the water price would negatively affect private profitability (which was not true), and water charges started to fall below what was needed to fund and maintain the huge irrigation infrastructure (Ahmad, 2000). Farmers, especially the smaller farmers at the tail ends of the canals, held the view that they were willing to pay enhanced water tariffs provided that service was rendered (See Case Study 2 on Sindh). In other words, it is not the water per se but the service (the delivery system) that should be priced if we want to sustain this vital service in the face of serious public sector financial constraints and

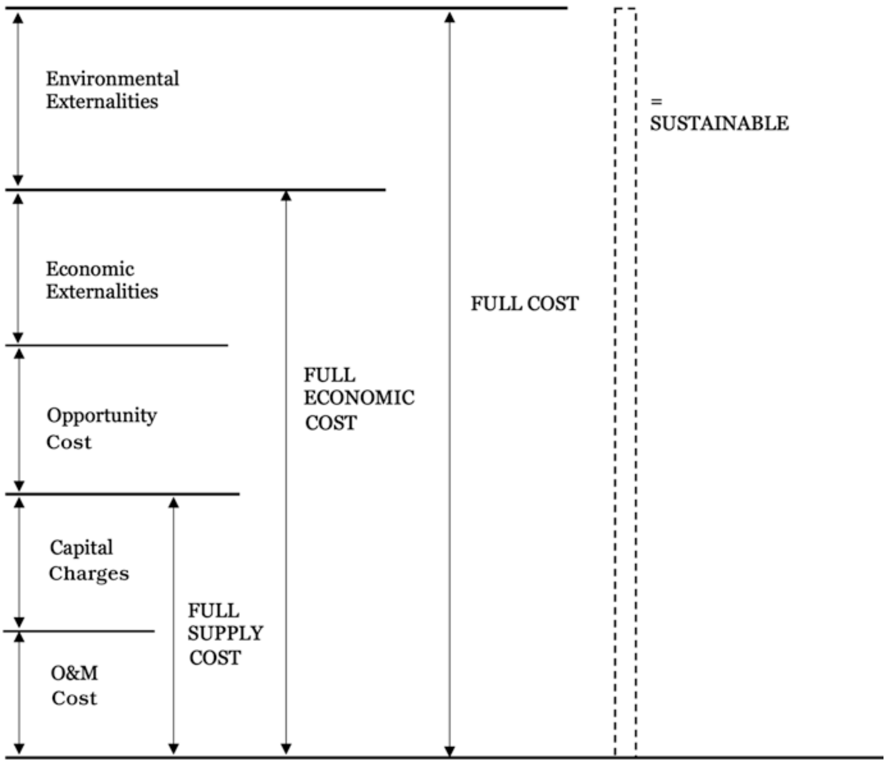

Fig. 11.4 Types of costs in water management. (Source: adopted from (Rogers et al., 1998))

ever-growing competition for water. The growing gap between the required total O&M cost and the income from water payments illustrates the problem: in the year 2003, only 28% of the cost was recovered, and even that fell to a mere 9% in the year 2016 in Punjab (Qamar et al., 2018). On the other hand, the budget allocated to run the system continues to climb, supporting farmers' arguments that water charges are raised to support and extend an already bloated bureaucracy.

So in Pakistan, the institutional character of irrigation pricing is still following the policy discourse of "build-neglect-and-rebuild" (Briscoe & Qamar, 2008). To fully recover the cost of water, user fees need to be 1% of the value of the stock of the infrastructure. This makes it Rs 1800/hectare for Punjab. Considering just simple maintenance and operations, at least 0.5%, or Rs 900/hectare is required. The actual *abiana* (water rate) collected in Punjab is Rs.150/hectare (World Bank, 2005). These numbers reflect the real water dilemma: an attitude that creates new water assets without a sound financial plan that recoups the cost from end users.

The study on water Pricing and Implementation Strategies for the Sustainability of an Irrigation System within the Command Area of the Rakh Branch Canal is one

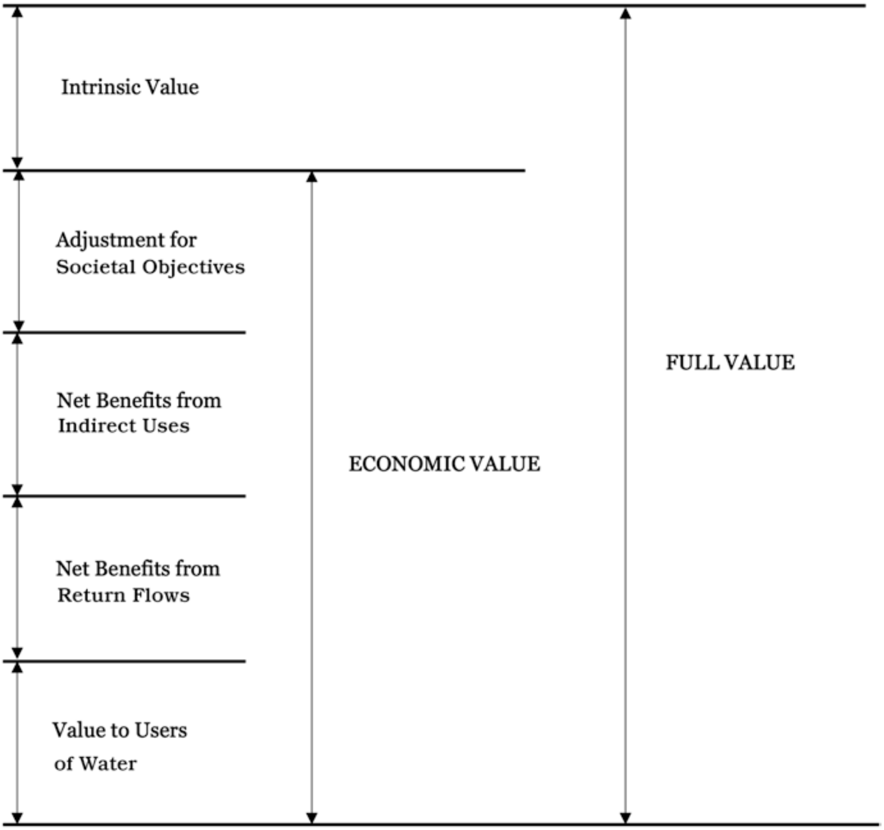

Fig. 11.5 Types of value or benefits in water management. (Source: adopted from Rogers et al., 1998)

of the few that compares current water charges with prices and also considers the cost of just maintaining the infrastructure in Punjab. Their work clearly shows that the irrigation water in the command area of Rakh branch canal has been severely underpriced ever since the flat-rate irrigation pricing system was introduced. The study shows current prices, the rates for each crop, and compares the water used.

Figure 11.6 shows that sugarcane—which consumes the most water (25,406 m^3 per hectare compared to rice at 14,478 m^3 and wheat at 4,065 m^3)—being priced at Rs 333.6 per acre. In order to recover the O&M cost, it would need to be increased to Rs 945.1 and to recover the full cost of supplying water the rate would need to increase to Rs 2852.8. Still, this figure includes neither the opportunity cost, nor the economic and external environmental costs. Pilot work at WIT/LUMS using extended versions of the policy analysis matrix show that both rice and sugarcane lose their comparative advantage if these costs were fully accounted for.

The International Water Management Institute (IWMI) has undertaken an in-depth study on the implications of alternate water charging policies in Pakistan. The study is based on data sets collected through household-level surveys from 891

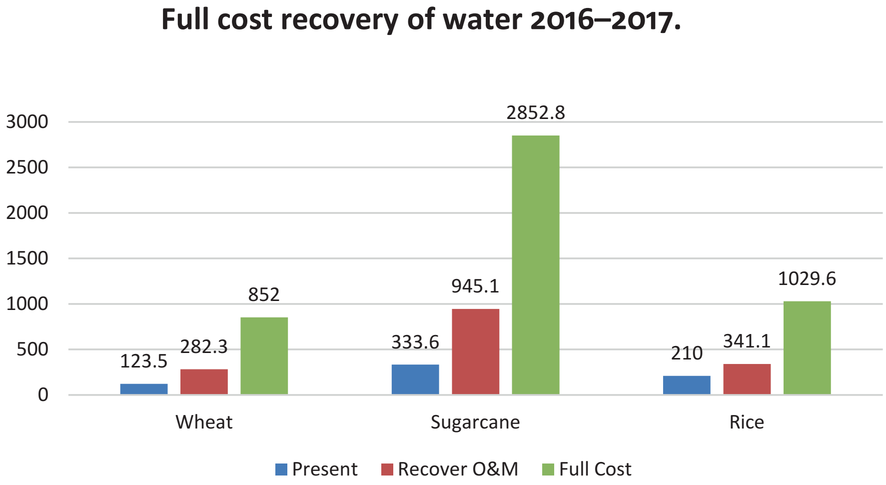

Fig. 11.6 Full cost of recovery of water. (Source: Author's work using data from Qamar et al., 2018)

farm households from 10 canal distributaries in four large scale surface irrigation systems in the upper Indus basin (the Upper Jhelum Canal system, the Lower Jhelum Canal system, the Lower Chenab Canal system and the Hakra canal system). The survey covered the 2001–2002 agricultural year. The key findings include (1) the average annual water charge per ha (area weighted) was Rs 420 per hectare in 2001–2002 across surveyed households; (2) the average per hectare water charge was found to be inversely related to land size categories; with landholders of between 1–5 hectares paying significantly more than the overall average, and those with more than 10 hectares paying less than the overall average; (3) average groundwater cost per hectare is also inversely related to farm size categories, with the smaller-sized farms using more groundwater and incurring higher costs and vice versa.

According to the IWMI report, these policy changes could be implemented within existing ministries, such as Ministry of Agriculture and Ministry of Irrigation with better coordination mechanism in place. Major benefits would include: (a) mobilizing more funds for the operation and maintenance of irrigation systems, leading to increased efficiency in water supply and productivity; (b) small and poor landholders benefiting most with cost reduction; and (3) changing existing inequities in water charges.

11.3.3 Technology Take-off and the Price of Irrigation Water

The cost of water and the adoption of modern technology are real issues in many countries of the region. The adoption rate of a system will depend to a large extent on the rate of return on each technology. The financial returns of a new technology are a function of the amount of water saved and the cost of water to the farmers. For example, in Yemen, the high investment cost of $3100 per ha to $4000 per ha is difficult to recover given the lower value of the water that would be saved. The low value of water is reflected in the high subsidy of diesel. Furthermore, in most areas water, not land, is the binding constraint. Any water saved because of the adoption of efficient technologies would simply encourage farmers to bring additional land under cultivation (Ward, 1995).

In the case of Iran, according to IWMI (Perry), the value of water use in agriculture is $.004 per cubic meters, one of lowest in the world, while the cost of saving water through adoption of modern technology is estimated at $ .11 per cubic meter. This means that as long as the cost recovery value of water is less than $. 11 per cubic meters, farmers have no incentive to adopt modern technology. In other words, in the absence of increased water charges, instituting a cost-recovery regime (volumetric or otherwise modified) would not have any effect on either water saving or on intra-sectoral allocation (that is, water going to high value crops).

In the case of Pakistan, problems in scaling up HIES face the same dilemma—farmers may well be aware of technological options, but they will not invest in them unless they are pushed by (1) cost incentives (rising water prices); (2) pulled by profitable market opportunities; or (3) water is scarce. It is clear that both technology transfer and market development and incentive questions need to be addressed. If water productivity-enhancing technologies or management practices generate more on-farm costs (including uncertainty or risks) than additional benefits, their adoption may not be a priority for some or all farmers (as the farming community itself is not homogenous) (Giordano et al., 2017).

We close this section with five key policy actions to improve irrigation efficiency as recommended by FAO along with other innovative demand management options.

- Move to raised bed technology with zero tillage, mulching, and intercropping
- Reduce seepage loss through canal lining, especially where groundwater is saline.
- Reduce evaporation by avoiding mid-day irrigation
- Promote deficit irrigation and
- Increase water harvesting

11.3.4 Water Allocation Among and Within Sectors

When water is used for production, low water costs allow for the cultivation of water-intensive crops, which would not otherwise be grown if water commanded a high cost. Thus, the cost of water may be a factor which determines the cropping pattern of an irrigated area, along with farmers' capacity to produce certain crops, particularly popular food crops. Crops such as rice, for example, require large amounts of water, and are often produced where the cost of irrigation water is low. As water scarcity and its rising cost become a factor, farmers would allocate their scarce resources to growing commodities that generate the highest returns on water. Based on analysis from Chaudhry et al. (2009) (Table 11.3) sugarcane does not have

Table 11.3 Key policy indicators sugarcane versus cotton

	Sugarcane	Cotton	Comments
Domestic resource cost	1.14	.57	Cotton has comparative advantage but SC does not
Value added per acre (Rs)	10,222	19,709	Cotton adds almost twice value added
Water productivity (Rs per inch of water)	724	1383	Cotton water productivity is much higher

a comparative advantage in southern Punjab, but high private profitability compared to cotton gives farmers an incentive to grow sugarcane. Yet the research shows that if water was priced according to the opportunity cost, growing sugarcane would not be the most economical option, since it would cost Rs 114 in investments of land, water, and labor to add just Rs 100 to the economy—clearly a losing proposition. On the other hand, investing Rs 57 into cotton provides a return of Rs 100, far greater than that of sugarcane. Further analysis reveals that the water productivity of sugarcane is almost half that of cotton. The message is that water pricing plays a key role in improving allocative efficiency and at very little cost compared to the other policy options being pursued.

It would be interesting to compare water pricing for other uses with that of agriculture.

According to Nawaz (2018), agriculture uses a whopping 60,000 liters at a price of one Rupee (.0067 cents), whereas domestic and industrial water, provided by the public sector, uses 350 and 85 liters of water for same value (Fig. 11.7). Last but most importantly, multinational companies sell 1 liter of bottled water at PKR 50 all over the country, which amounts to 0.02 liters per 1 PKR. It is very difficult to obtain the actual extraction cost with so many multinational and local brands competing. In Pakistan, as in other countries, bottled water is a lucrative market where groundwater is being misused by big business: from low-cost extraction to solar technology (See Baluchistan Case Study below).

11.3.5 Water and Ecosystem Services

The points discussed in the above sections can be summarized as policy failure (subsidizing the key resource, water) and institutional failure (poor governance), than a case can be made that pervasive market failure, the externalities (unpaid cost) generated from non-point sources are quite dominant in agriculture sector, ground water depletion, and failure to recognize the eco-services water provides are good example (Ahmad, 2000). This section highlights the often-overlooked ecological benefits that water provides: food and fresh water, regulation of the climate, water purification and aesthetic and recreational needs. These benefits are linked to human wellbeing by securing access to resources, providing the basic material required for a good life (i.e., sufficient food) and access to clean water, as well as delivering

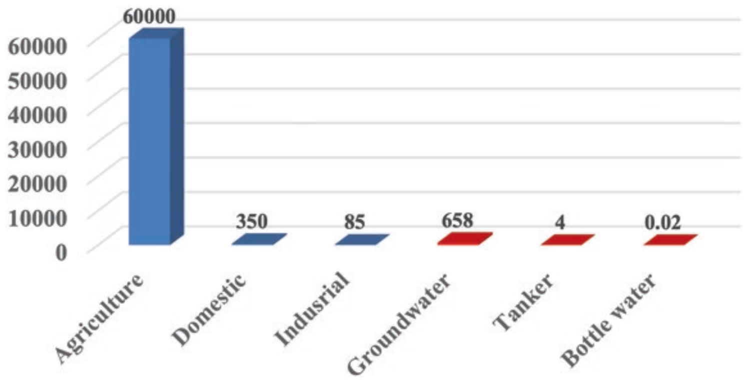

Fig. 11.7 Water pricing (liter/PKR). (Source: Author's work using data from Nawaz, 2018)

more intangible aesthetic, spiritual, educational and recreational (Millennium Ecosystem Assessment, 2005).

The deterioration of the ecosystem can have a serious adverse impact on Pakistan's economy, for example the question of needed environmental flows has still not been considered on its economic merits—badly affecting ecology downstream beyond Kotri. The environmental benefits that mangroves bring in terms of carbon sequestering are barely accounted for. TEEB (2010) and Bennett et al. (2009) highlight the fact that to achieve water and food security, the value of the ecosystem and the benefits of different options need to be worked for all investment possibilities or alternatives, including tradeoffs.

Pakistan would be better off investing in groundwater than investing in mega projects. According to Hussain and Abbas (2019), the groundwater system underneath Pakistan's flowing rivers in the Indus plains has at least 400 million acre feet (MAF) of good quality water, which amounts to more than 3 years of the mean annual flow of the Indus (or 1000 days of storage, after excluding polluted areas). They further explain that the quality of this valuable resource is being deteriorated through arsenic contamination of the groundwater. Such uninformed groundwater pumping, besides raising the cost of pumping, causes the deterioration of the quality of the aquifers, increases secondary salinization, and causes the loss of fertile soils. The policy message here is that if groundwater was managed properly and considered to be a possible investment alternative, the large sums spent on dam construction could have been used for other investments in the water sector.

11.3.6 *Missed Opportunities—Unconventional Water Use Options*

Whereas some countries have benefited a great deal from using technology and best practices to mobilize a marginal unit of water, both in terms of supply and demand management, there has been little to no policy debate on these issues in Pakistan.

These include: watershed management, wastewater management, reuse of drainage water, rainwater harvesting, and using eco-practices in water management or the circular economy in the water sector. Because of the growing water shortage, many countries, unlike Pakistan, are relying on non-conventional water resources such as drainage water and urban and industrial wastewater. Israel, for example, has successfully managed to meet large part of its agricultural needs using wastewater as explained in later section.

Pakistan can also benefit from global experience in policies that promote water scheduling and supplementary irrigation. Oweis and Hachum's (2012) extensive work in Syria showed that a small incremental dose of water (supplemental irrigation) during water-stressed periods could reduce the yield gap. Droughts, which now are common phenomena under climate change, apparently have limited impact when farmers store water, either on or below ground, and harvest rainwater.

For Pakistan, water storage at the farm level is as important, perhaps more than water storage via large dams. This would allow farmers more control on when and where to use water, make water available on demand, and also give them the flexibility to balance water and other agro-input requirements during critical periods of crop growth. This would also provide greater opportunities for crop diversification and thus increase both the productive and allocative efficiency of water. In the plains of Punjab, KPK, and Sindh, sometimes the farmers do not need water, particularly during the winter and monsoon rains (Qureshi & Ashraf, 2019). Water given on supply basis with existing *warabandi* system (water distribution) sometimes leaves farmers no choice but to stop this unwanted water, called "awara pani" in the local language, or "unattended water." Storage at the farm level in the form of community ponds near the villages would help not only provide water on demand but also help in recharging groundwater.

Turning Wastewater in Generating Values—Case of Israel

In Israel, wastewater has been transformed into a valuable water resource, reducing waste and garnering tremendous environmental benefits. The price of treated wastewater per cubic meter has been set below that of fresh and brackish water to provide an incentive for farmers to use it (Fig. 11.8). This triggered a major policy shift and provided an incentive to shift fresh water to urban use—one example of how a pricing tool can be designed. The end result is that recycled water, which in 1985 formed a minor share of the water used in agriculture, now is the major source of water used in agriculture, with the expectation that all agricultural water demand can be met through recycled wastewater.

The present crisis calls us to learn from mistakes and accept the need to shift from past development paths, assess where things went wrong and chart a strategy that fulfils the potential value in the water supply chain. Today, we find ourselves in a moment of reckoning, in which we must address three main issues facing the water

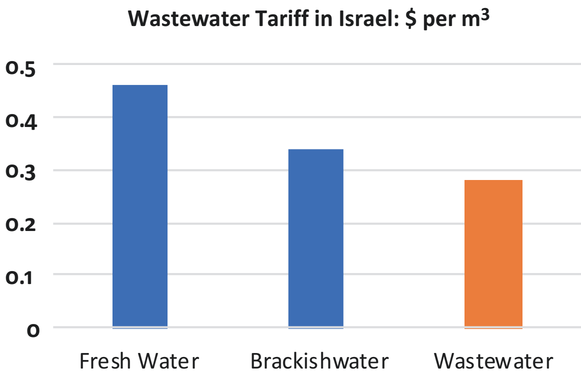

Fig 11.8 Wastewater tariff in Israel: \$ per m^3. (Source: Marin et al., 2017. Released under CC-BY-SA license)

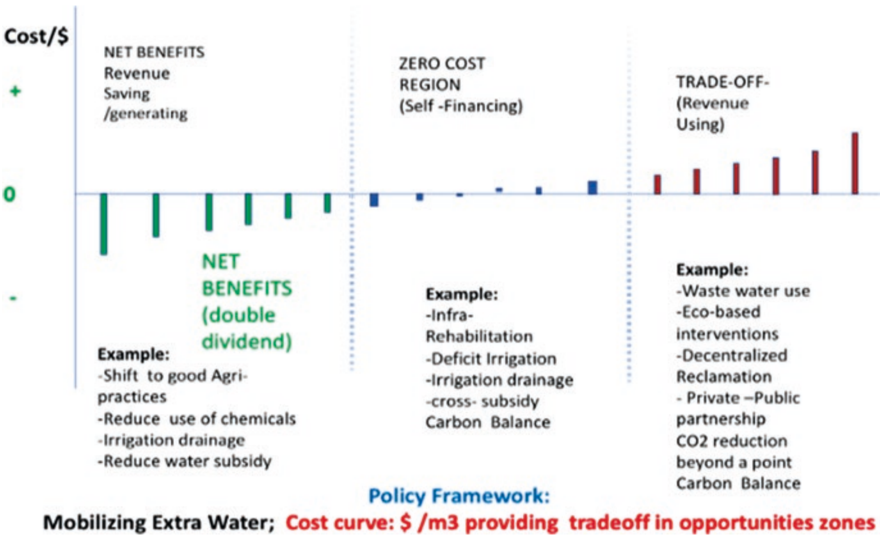

Fig. 11.9 Cost curve. (Source: Author's work and analysis)

sector: shifting emphasis from supply to demand management, water value addition by improving the productive and allocative efficiency of water use, and promoting and adopting eco-based technology and practices. Promoting such a strategy would bring huge benefits to the end user in terms of profitable and competitive agriculture business with cost reduction and provide water for other uses. Figure 11.9 shows the enormous tradeoff such a strategy would entail. The graph is based on data and study from India, where conditions and issues are fairly similar.

11.4 Key Lessons

- Is Pakistan a water scarce country? The answer is absolutely not. If water use in agriculture can be rationed and better governance can be brought to its management, there is enough water available to meet competing demands.
- In fact, availability of water after the completion of the Tarbela Dam has increased as shown by the supply of water.
- Pakistan has underinvested in demand management options where an additional unit of water can be mobilized at either at a much lower cost, at no cost or even at net benefits.
- The piecemeal approach to improving the productive efficiency of water use had mixed results. There was very little uptake of HIES technology. Widespread adoption of this technology depended on two factors: water pricing and the profitability of agriculture. Neither of these factors held in Pakistan.
- In order to improve water availability, the government's priority is to enhance water productivity. The government should consider a broader framework that entails three aspects: (1) enhancing the marketable commodity (or yield) of crops for each unit of crop transpiration; (2) reducing non-beneficial atmospheric depletions and the outflows that are not retrievable and are lost; and (3) enhancing the effective use of rainfall, water of marginal quality, and stored water.
- The new policy priority should be directed at better resource mobilization to develop and maintain irrigation infrastructure in Pakistan, since the cost of no or little action will be huge.
- Creating economic incentives is key: Economic incentives include market prices, taxes, subsidies, and other regulatory instruments that are designed and implemented to play a major role influencing the use of both surface and groundwater.
- In the short- and medium-term, water charges should be increased to cover O&M costs. According to the World Bank's calculations, doubling water rates for two consecutive years, with a 75% increase in the third year, would bring abiana revenues to a level that would cover actual O&M expenditures at the 2015–16 level.
- Time is running out to develop sustainable groundwater polices and implementable laws and regulation. With greater water demand from competing sectors, a stricter regulatory framework is needed, in addition to innovative solutions, that address the issues of solar energy, virtual water exports, and drought management.
- Use or redirect environmentally harmful subsidies to promote cost effective nature-based solutions in agriculture and the water sector. Key areas such as fossil fuels, water, agriculture, and transport can generate significant benefits for the eco-system while minimizing the fiscal cost to taxpayers and the cash-starved government.

- A new structure of governance is needed if we want serious reform in the water sector. As long as the agricultural sector is the major water user, there is no justification for so many other water-related ministries. The main stakeholder—the farmer—does not get the services Ministry of Irrigation (MOI) is expected to provide. Governance in the water sector should only be determined based on need, service delivery, accountability, and financial discipline.
- Rebuild Irrigation Infrastructure Better: The frequency of floods and droughts has increased over time, especially extreme floods that require the rebuilding of infrastructure in the post-disaster phase. Build Back Better provides opportunities to use eco-friendly technologies that will ensure greater resilience of the infrastructure to future floods and drought, with the advantage that these interventions are also water smart.
- Moreover, the optimization of water resources is a major issue for the country and a national water policy was adopted by the government in 2018. In the implementation phase, the focus at the macro levels should be to not avoid further postponing key reforms: (1) ration water use in agriculture (2) water costs and values rationalized (3) unbundle water rights from land rights as a starting point in developing prudent water allocation policy.

11.5 Case Studies

Case Study 1 Baluchistan a special case of water mangement in Pakistan

In order to help increase fruit production in the province, the government (Government of Balochistan, 2019) introduced a policy of subsidizing the pumping of groundwater through electricity-powered tube wells. Farmers were to be charged a very low fixed cost (currently Rs 6000 per month regardless of the hours worked or the amount of water pumped). The difference between the price charged and the actual cost is to be shared between the provincial and federal governments (ibid.). This policy—after growth in fruit production and the increased installations of tubewells in the province—has resulted in a huge fiscal drain on the government, currently about Rs 8 billion per year, as well as overexploitation of the aquifer and a rapid lowering of the groundwater table. Farmers' response to the falling water table is to dig deeper and install larger-capacity tube wells, both of which exacerbate the overexploitation of groundwater as well as increase the fiscal cost.

The context to this is that 30 years ago a few progressive farmers invested in a technology called a "jack pump," which triggered this process. In the next phase, this inefficient technology was replaced with submersible pumps from Italy, which later were replaced by solar-powered systems, causing another set of problems. Because of the unreliability of the power supply, solar-powered technology was adopted by farmers and now the farmers use both solar power and municipal power. Unfortunately, solar-powered pumps have been promoted without putting an appropriate regulatory framework into place, and this has resulted in an unaccounted environmental cost. Furthermore, CPEC and urbanization is putting enormous pressure on dwindling water resources.

11.5.1 Actions at the Micro Level

In addressing these issues, evidence based policy research is needed to better understand where the demand for water comes from. Based on author's FAO lead ongoing climate-smart policy work in Baluchistan the needed policy actions include:

1. Typology of ground water technology and its detailed costs (financial and economic) with and without solar options.
2. Hydrological profile of ground water in different regions.
3. Cropping patterns and how they change over time.
4. Preparing financial and economic budgets, using different identified technologies and cropping patterns in calculating farm income analysis, water productivity and improving allocative efficiency of water use for these crops.
5. Simple spreadsheet based analysis to communicate policy tradeoffs with stakeholders in developing a climate smart agriculture and ground water management policies.
6. Train and involve young professionals from the MOA and Planning Department to be part of the above policy work.

11.5.2 Actions at the Macro Level

In Baluchistan, the water dynamic also needs to be understood, since it is different from that of the Indus Basin and perhaps a different perspective is needed to address these issues. For example, Baluchistan has an 18-river system that is being managed (or mismanaged) as opposed to one main river in the Indus Basin. Furthermore, groundwater contributes only 7% to the overall supply, which illustrates the need to invest more in building storage for storm water.

Further, prudent policy interventions are needed to manage both the *salaba* and *kushaba*[4] lands. The policy options entail using large volumes of water to promote water harvesting at all levels—from farm and community levels to community-based small dams. On the other hand, large farmers and associations of small farmers living in key fruit production areas need to collaborate to reduce groundwater extraction in overexploited areas, and enhance recharge (evaluation of delayed

[4] About 50% of the area is irrigated through *sailaba* (flooding) and *khushkaba* (water harvesting), the other 50% through canals, karezes, springs and tubewells.

action dams, leaky dams, and other structures), combined with support for alternative energy and productivity enhancement (Draft Agriculture Policy 2019). In contrast with investing in HIES in Punjab—without much thought to its terrain—and getting mixed results, there is a perfect economic case to invest in such technology in the highlands of Baluchistan. There is also a pressing need to introduce a system of realistic (i.e., which fully recoups the cost of water) pricing to privately extract water from public aquifers.

Case Study 2 Climate Change and Water Shortage in Sindh- Farmers Response in Omerkot District of Sindh

Like other provinces agriculture drives the economy of Sindh province and water shortage is at the heart of the problem. At same time, proper drainage has not been developed in spite of huge investments made by donors (WB and ADB). Sindh, is very famous for growing the dandi cut variety of chili pepper, which commands a premium price in the international market. But production and growth has slowed down in the prime districts of Omerkot and Mirpukas.

The province and farmers are at the tail end of Indus Basin often complain they have less water. Farmers have coped with these problems through acting collectively. Progressive farmers in the Omerkot district of Sindh, led by Mr. Mustafa are trying to practice sustainable agriculture and are dealing with water challenges by:

- Continuously remodeling their water courses, and digging water courses deeper and deeper to access water at the tail, even though it entails pumping the water instead of using the flow of gravity, which is cheaper.
- Investing in storage ponds that are larger than specified by the Sindh Irrigated Agriculture Productivity Enhancement Project (SIAPEP) program supported by World Bank.
- Capturing unused water when there is excess supply (Awara Pani).
- Diversifying cropping patterns (farmers responding to markets by growing a cropping mix with more income).
- More investment in mango orchards, moving from traditional to high-density farms, thus increasing income and reducing the enormous risk they face with vegetables.

The greatest impact of water shortages is reported in the villages located at the tail reaches of the irrigation canals. In the opinion of these villagers, the shortage of irrigation water is mostly man-made, caused by unfair water distribution and lack of equity. They stated that because the upstream users in the area tamper with available water shares so less and less flows to downstream users, the land has become dry and impossible to cultivate. According to these villagers, other powerful individuals in the area also divert water to their land and the villagers cannot get it back.

Another water related innovation is the successful running of the community-based weather station in Kunri, demonstrating how farmers are looking at local solutions to address climate change.

Progressive Community Based Weather Station in Umerkot—Creating a Resilient and Climate Smart Agriculture

Given how critical it is to dry chilies properly, farmers in Kunri area are prone to devastation of their entire crop because of rains. Farmers lose two out of every five crop seasons because of them. According to progressive farmer Mahmood Khan, who lives in the Naukot area, if a proper rain forecast was provided to farmers during this critical period, losses could be minimized at both the farm and national levels. Mr. Khan is one of the few farmers who uses computers to plan his farm budget, and track weather patterns in the region to minimize post-harvest losses. He was very proud to explain that two seasons before, when rain had destroyed most of crops in the region, he was able to, through the internet, assess rain forecasts. He instructed his manager to take the necessary measures to cover the crop from expected rains. While his manager was very skeptical of this assessment, the preventive measure turned out to be instrumental in saving most of his produce in the region. He emphasized that support from the government, specifically with regard to the dissemination of information on production and post-harvest losses, is totally lacking and advise in this direction could impact farm income, providing sustainable delivery of volume for exports and benefiting both producers and consumers.

Case Study 3 Is India exporting Rice or Water?

In the mid-1960s, India was highly deficit in food grains. However, with the introduction of high-yielding Mexican dwarf varieties of wheat along with guaranteed minimum prices on agricultural commodities, there was a major increase in food production. The policy support of an effective procurement was also a major factor in this enhanced food production. The shift in cropping patterns that occurred because of the introduction of high yielding dwarf varieties made India self-sufficient and also a major exporter for rice and an on-and-off exporter of wheat. As compared to wheat, rice production is very water intensive—using 1670 liters of water per kilogram, critics often say the country is virtually exporting water.

A few years ago, Columbia University-led research said many parts of India experience “chronic water stress due to heavy-water extraction for irrigated agriculture,” noting that in the states of Punjab and Haryana in particular, growing rice requires increasing amounts of irrigation.

India uses more groundwater than anywhere in the world—24% of the global total—and 1 billion people there live in water-scarce areas (Gerretsen, 2019).

An unpublished report discussing the crop diversification project in India reiterated that the depletion of underground water resources, the deterioration of soil health, the deficiency of macro and micro nutrients, the toxicity in soils at several places in the intensively cultivated areas, the pollution of soil, water and air, and the decline in total factor productivity in field crops, etc., started happening by the early 1980s. Now, after three-and-a-half decades of extensive exploitation of the state’s soil and water resources, the situation has become so serious that more than 70% of the water required to irrigate rice crops comes from tubewells. The canal water supply is less than 30% of the water required by this crop (2.5 million hectares).

Through excessive pumping of groundwater, there is more extraction than recharge. As a consequence, the water table in the central Punjab is receding at an average rate of over 42 cm per annum. Furthermore, according to this report, it is estimated that if groundwater withdrawal continues at this rate, soon it will render the production of rice, as well as of wheat, totally uneconomical and will have a serious impact on the economy, ecology, and resource base of the state. This will have disastrous nationwide consequences, with more than 10% of the centrifugal pumps in central Punjab becoming dysfunctional and underground water shown to have selenium and other toxic contents, making it unfit to drink even by animals. In fact, nowhere in Punjab is the water free from chemical residues and harmful elements.

The final analysis is that short term gains were achieved at the cost of long term options for rational use of valuable resources—in fact, Indian Punjab has exported virtual water all these years. While the environmental cost was never officially accounted for, future generations will, in fact, pay for it. If the situation is not corrected and these problems are not handled with vision and determination, the economic conditions of the rural populations cannot be ameliorated and the poverty of rural populations dependent upon the agricultural sector cannot be alleviated. This will soon have a serious negative impact on the social fabric of the society in Punjab.

The often proposed action to ration water use by agricultural/rural populations, through restructuring production patterns that promote moving from low- to high-value crops and from industrial to nature-based agriculture that uses far less water (See Chap. 10). The case provides policy lessons for Pakistan, as major rice exporter, country is beginning to face similar groundwater management issues, but in our view country is in a better position to rationalize water use policy towards rice cultivation.

Case Study 4 Morocco—Improving productive and allocative allocation

Pakistan and Morocco followed different policies to meet their food security objectives. Pakistan followed an incentive policy to promote wheat, whereas Morocco invested more in growing high-value crops for export, thus paying to import food. The World Bank study concluded that Morocco could achieve self-sufficiency in cereals by 2017, if Moroccan farmers made reasonable increases in cereal productivity and increased the amount of their cultivated area. However, it turns out that the cost of increasing cereal production by transforming or converting land use to grow high-value crops (i.e. the forgone revenues from reduced production of high-value crops) would climb from $21 million in 2007 to $6 billion in 2017 (the year self-sufficiency would have been attained). According to the study, the total value of income forgone in order to enforce national cereal self-sufficiency over an 11-year-period would be a staggering $16 billion. While the tradeoffs between producing high-value crops and cereals vary by country, a drive towards greater self-sufficiency comes at a great cost in terms of forgone income and this cost can increase exponentially.

The important question is this: despite the fact that Pakistani producers have enjoyed a consistent comparative advantage in growing high value crops, why haven't their agricultural exports performed as well as Morocco's, Egypt's, or Jordan's? All three of those countries have been able to capture a greater share of the growing demand in export markets. To a large extent this can be attributed to the fact that this comparative advantage was not translated into competitive advantage, particularly because the large number of small-scale farmers were ignored. A large quantity of Pakistan's exports remain in their raw form without much value added and most products (asides from rice and cotton) also stay in low-end markets. In the context of our chapter, among other policy options, we did not improve either the productive or allocative efficiency of water used in agriculture, an instrument that was very effectively used in Morocco, Jordan and Israel.

The experience of Morocco, Egypt, Jordan, and Israel provides lessons for Pakistan in how to shift policy in order to expand horticultural exports and add value to per unit water used. First, current policies and subsidies in Pakistan encourage farmers practice a rigid cropping system rather adopting a diversified cropping pattern. Ninety percent of the cropped area in Punjab grows major crops (dominated by wheat), while only 9% is devoted to higher-value crops. The fiscal cost of supporting the wheat subsidy has been very high, the direct cost of which is now more than Rs. 5500/ton. Indirect costs are also substantial and include ground water depletion, physical losses because of poor storage and high spoilage; pilferage; over-production of wheat and a consequent under-production of other higher-value commodities; diversion of credit from the banking system; and a disincentive to the private sector to build storage facilities that would also be available for other crops besides wheat. There is an effort through the World Bank SMART project to bring policies adopted by Morocco to Pakistan.

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Chapter 12
Wastewater Treatment in Pakistan: Issues, Challenges and Solutions

Fozia Parveen and Sher Jamal Khan

Abstract Currently able to treat only 1% of its wastewater, Pakistan is far from its commitment under the sustainable development goals (SDGs) to treat up to 50% of its wastewater. The rapid urbanization of cities without corresponding improvements in infrastructure to collect and treat wastewater leads to poor quality water and sanitation. The organizations responsible for wastewater treatment are also responsible for providing quality drinking water, i.e., WASA (Water and Sanitation Authorities). This has resulted in untreated wastewater being used for irrigation, and heavy contamination of ground and surface drinking water, thus leading to disease. Decentralized wastewater treatment plants and nature based systems need to be introduced to both cities and villages so that water can be reused in a healthy and sustainable way. Industries are now beginning to adhere to compliance standards while cities are becoming aware that open drains are not a long term solution to this problem. In short, Pakistan needs to consider the long-term benefits of wastewater treatment instead of its short-term costs, and make it a priority.

Keywords Wastewater · Rapid urbanization · Water and sanitation · Compliance standards · Decentralized wastewater treatment · Membrane bioreactor plants in Pakistan

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12.1 Introduction

Pakistan has the highest rate of urbanization in South Asia. The percentage of the population living in urban areas increased from 32.5% (43 million) in 1998 to 36.4% (75 million) in 2017. The United Nations Population Division estimates that by 2025, nearly half the country's population will be living in cities. Normal population increases account for 70% of urban growth, while rural to urban migration constitutes 20%; the remaining 9.7% is because of reclassified boundaries and 0.7% is due to other factors.

It is the cities of Pakistan that generate high GDP and federal tax revenues. Indeed, 10 major cities generate 95% of its tax revenues. Karachi alone contributes 12–15% of Pakistan's GDP and 55% of federal tax revenues. The urban multidimensional poverty is one-sixth of that of rural areas and therefore the influx of people in the cities is very high. However, with population growth, more factories and industrial output, and the growth of urban areas, the amount of wastewater and solid waste has also increased. This makes the sustainable development goal (SDG) of treating 40–50% of wastewater instead of the current 1–2% even more urgent than ever (Fig. 12.1).

Wastewater contains nutrients, pathogenic bacteria that dwell in the human intestinal tract, and other toxic compounds that impact the health and the environment (Metcalf and Eddy, 2003). Nitrogen containing wastewater adversely affects bodies of water and contributes to dissolved oxygen (DO) depletion, toxicity, eutrophication and methemo-globinemia (Lim et al., 2007). Therefore, it is important to treat wastewater before it finds its way to freshwater. The growing demand for clean water means we need stringent effluent limits and a more advanced wastewater treatment system (Liang et al., 2010). Activated sludge treatment is one of the most widely used methods to treat wastewater. In this process, soluble and insoluble

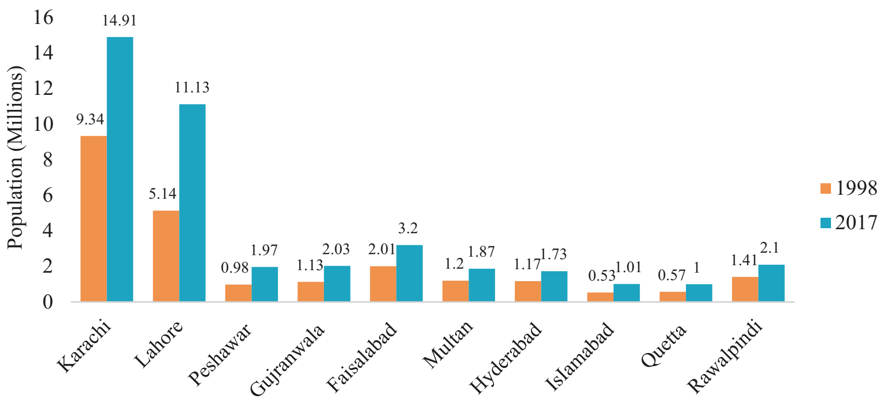


Fig. 12.1 Increase in population in major cities of Pakistan. (Adapted from Pakistan Population Census 2017, Bureau of Statistics, Government of Pakistan (2010), in public domain)

organic contents are removed from wastewater by being converted into a flocculent microbial suspension that settles to the bottom via gravity (Ramothokang et al., 2003). Conventional activated sludge treatment consists of primary, secondary and tertiary treatment. In primary treatment, sewage is simply kept in a basin that results in the settling of heavy solids leaving only light solids and oil to come to the surface. The heavier material is left behind in the basin while the rest of the wastewater moves to secondary treatment, in which dissolved and suspended biological matter is removed. Finally, in tertiary treatment, sewage is further treated through physical or chemical disinfection. The treated water can then be discharged into streams or used to recharge groundwater or irrigation (Fig. 12.2).

Biological treatment is a treatment system in which the natural role of bacteria is utilized for bioconversion; the biological flocs and biofilms are used for degrading or adsorbing dissolved colloidal, settleable, and particulate matter (Henze et al., 2008). Biological treatment processes include both aerobic and anaerobic systems. Aerobic systems use a mixture of microbes to transform organic and inorganic pollutants into harmless byproducts that can be released easily into the environment. Aerobic technologies, which require oxygen, are mostly indicated for treating municipal and industrial wastewater. However, the use of anaerobic systems is growing because of their low construction, operation, and maintenance costs. However, biomass production is low and the effluent requires more treatment afterwards because of high chemical oxygen demand (COD) along with the presence of nutrients and pathogens.

Membrane bioreactor technology combines activated sludge treatment with membrane filtration, where removal is achieved by filtration rather than gravity (Hasar, 2009). Membrane bioreactors come in various configurations and designs to ensure maximum filtration.

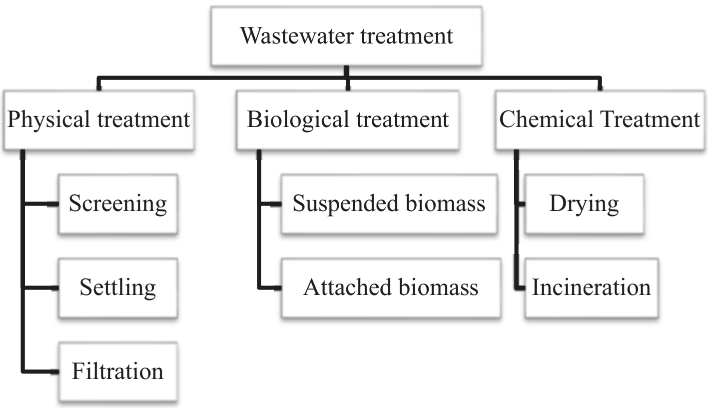


Fig. 12.2 Wastewater treatment processes. (Adapted from Metcalf and Eddy)

Regardless of the process selected for wastewater treatment, a centralized wastewater treatment (e.g. conventional activated sludge treatment systems for cities) system can be established or decentralized systems (e.g. septic tanks) can be employed in places that are closer together and where operation and maintenance issues can be tackled easily. In general, wastewater treatment can be classified as presented in Table 12.1 (Metcalf and Eddy, 2003).

In Pakistan, domestic waste is either discharged directly to a sewer system, a natural drain or water body, a nearby field, or an internal septic tank. It is estimated that only some 8% of urban wastewater is treated in municipal treatment plants. This treated wastewater generally flows into open drains, and there are no provisions for reusing treated wastewater for agriculture or other municipal uses. The treated/untreated wastewater then mixes with commercial and industrial waste, complicating the issue further. Figure 12.3 shows ten large urban centres which produce just under 60% of total urban wastewater.

Table 12.1 Wastewater treatment processes and their degree of treatment. (Adapted from Metcalf and Eddy, 2003)

Level of treatment and wastewater treatment processes			
Primary treatment	Secondary treatment	Tertiary treatment	Advanced treatment
Screening Grit removal Sedimentation Comminution Flotation Flow equalization pH correction Imhoff tank	Activated sludge Extended aeration Aerated lagoon Trickling filter Rotating bio-disc Anaerobic reactors Stabilization ponds Constructed wetlands aquaculture	Activated sludge Nitrification Denitrification Chemical precipitation Disinfection Filtration P removal Constructed wetlands	Reverse osmosis Electro-dialysis Carbon adsorption Ion exchange Hyper-filtration Oxidation Detoxification

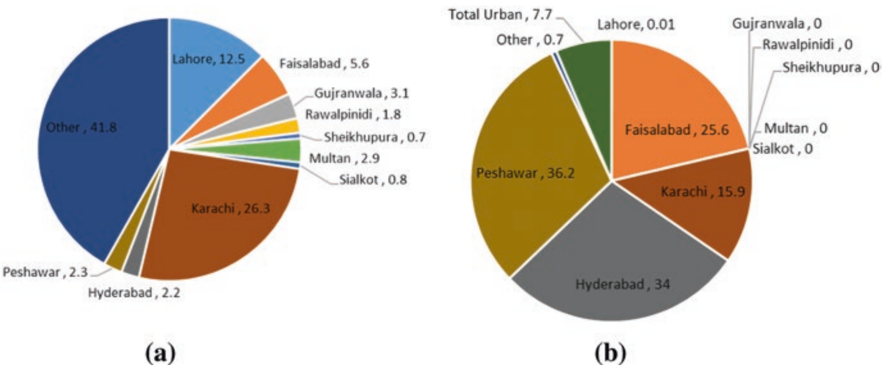


Fig. 12.3 Wastewater produced annually by major towns and cities of Pakistan (**a**) percentage of total waste produced, (**b**) percentage of total waste treated. (Source: Authors' work using data from Master Plan for Urban Wastewater (Municipal and Industrial) Treatment Facilities in Pakistan. Final Report, Lahore: Engineering, Planning and Management Consultants, 2002)

We also lack continuous water treatment facilities. There is plenty of evidence that groundwater and surface water quality have deteriorated. Groundwater contamination is also correlated with heavy fertilizer and pesticide use in many rural and peri-urban areas. The inability to treat wastewater can also impacts natural biodiversity, particularly in underwater environments. In the early 1980s, Pakistan produced 272,000 tons of fish from the sea and 60,000 tons from inland water bodies (IUCN, 1994), while currently it produces 668,000 metric tons from the sea and 284,000 tons from the inland water bodies (GOP, 2010). Other sectors will also eventually be affected.

12.2 Transboundary Basins and Water Quality

12.2.1 Kabul River Basin

Pakistan is also home to water basins which are very important for the region's economic growth. The inability to treat wastewater is reflected at the Kabul River Basin (KRB). The transboundary KRB, shared between Afghanistan and Pakistan, is home to over 50 million people. Originating in the Paghman mountains west of Kabul, the Kabul River flows eastward through Kabul and Jalalabad. Its major tributary, the Kunar River, is a transboundary river shared between Afghanistan and Pakistan. The Kunar originates in Pakistan (where it is referred to as the Chitral River), flows southward through Afghanistan, joining the Kabul River near Jalalabad, and then re-enters Pakistan in the Khyber Pakhtunkhwa (KPK) where it eventually joins the Indus River. A significant portion of the annual discharge of the Kunar River, and the Kabul Basin by extension, originates in the Chitral catchment in Pakistan (up to 60–70%; Khattak et al., 2016). The waters of the Kabul River provides the ecosystem with irrigation, effluent discharge, aquaculture, water for domestic use and recreation. This requires that the water quality be good enough to prevent adverse public health outcomes. In the past two decades, population growth and increasing industrialization have led water quality to deteriorate, leading to lower crop yields, periodic fish kills, and skin diseases. While there are anecdotal reports of the Kabul river's deterioration, there is very little literature on the subject. Historically, contaminated water was dumped into the river to be diluted. Because of severe contamination, the river can no longer dilute pollution in the way it did before, therefore treatment of wastewater is inevitable.

A recent study at one particular spot on the river showed extremely low levels of dissolved oxygen along with high levels of COD and BOD, severely impacting aquatic life (Shah et al., 2019). Another study explored the impacts of the Kabul River's major tributaries on its main branch. For example, the flow from the Swat River was shown to contribute to higher downstream concentrations of various contaminants and increased eutrophication (algae formation) (Barinova et al., 2016). Not only had organic pollution increased, downstream the river had become eutrophic and meso-eutrophic (Khuram et al., 2014). Initial attempts to model water quality have led to similar conclusions. Higher concentrations originating upstream and point sources of microbial pollution are major contributors Kabul River Basin contamination (Iqbal & Hofstra, 2019).

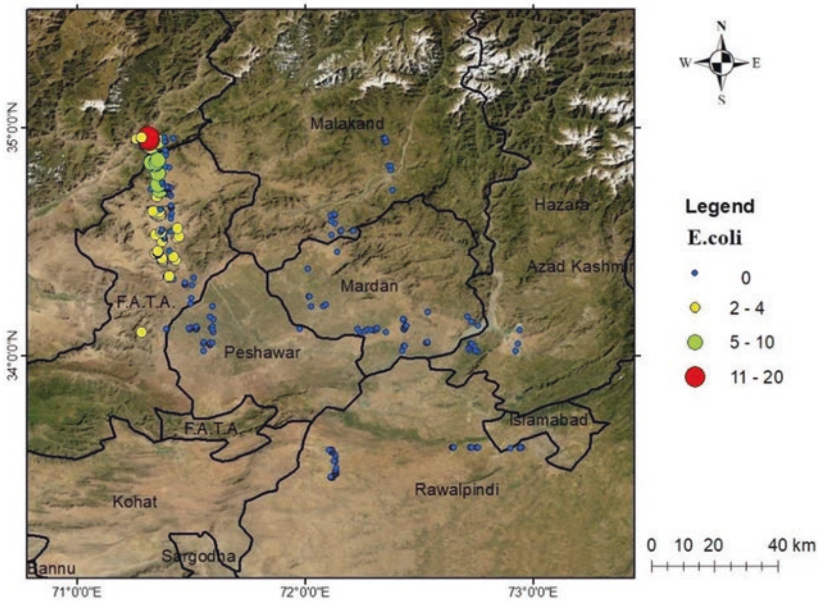
Water pollution is not new to the basin. In 1977, a United Nations Industrial Development Organization studied part of the river to investigate the impact of industrial effluents upon water quality. At the time, the river suffered from severe industrial pollution and it was recommended that effluents should be treated before being dumped into the river (Karns, 1977). And in 1992, the Sarhad (now KPK) Provincial conservation strategy program prioritized pollution in the Kabul river.

A more recent study by PCRWR showed that many samples contained *E.coli* and Total coliform, indicating the presence of human and animal faeces. Figure 12.4 shows that the water is more contaminated when it enters Pakistan from Afghanistan than when it reaches the areas downstream. *E.coli* and Total coliform are detected at various sampling points especially in the FATA region of Pakistan. Total coliform was also detected at many points in the basin. There were a variety of samples, including 123 from bores, 94 from hand pumps, 69 from open wells, 42 from tap water, and 91 from tubewells. Water quality sampling is usually performed only on drinking water samples, since water from open drains is assumed to be of low quality and is not used for drinking in any case (Imran et al., 2018).

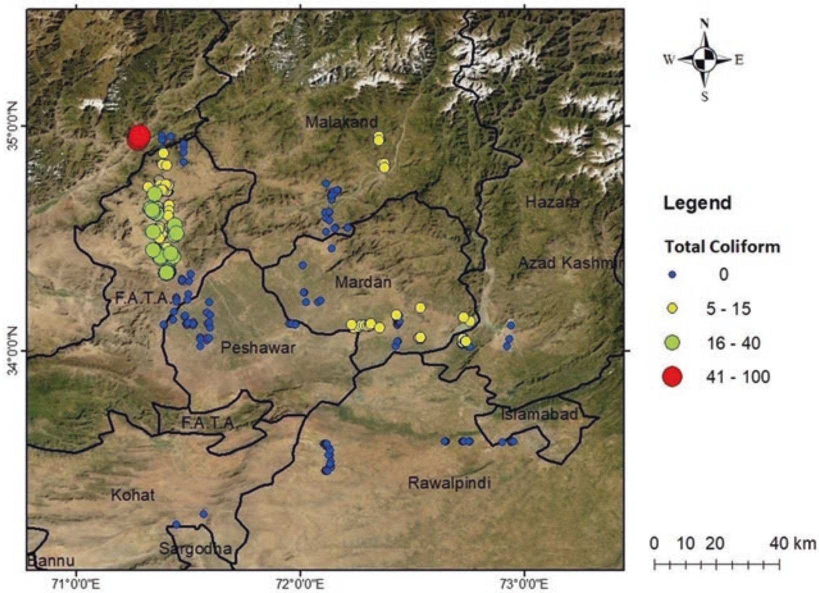
12.3 Wastewater Re-use

12.3.1 Irrigation

An estimated 32,500 ha—mostly used to grow vegetables—are irrigated with wastewater, most of it untreated (Jiménez et al., 2010). Farmers use wastewater to irrigate their crops for many reasons: reusing wastewater can contribute to farmer incomes by increasing productivity, resulting in food security and making their livelihoods more stable (WHO, 2006a, b; Jiménez et al., 2010; Qadir et al., 2007). In some cities, farmers use untreated wastewater because groundwater and treated wastewater are too saline (Wichelns & Qadir, 2015). Using wastewater also allows crops to be grown in urban and peri urban areas. In Quetta, Pakistani farmers were willing to pay 2.5 times more for access to wastewater in comparison to freshwater since it allows more crops to be harvested per year (Jiménez et al., 2010). Van der Hoek et al., (2002) have estimated the direct benefits to farmers from nutrient reuse and fertilizer savings in Haroonabad, Pakistan. They compared vegetable production using both freshwater and untreated wastewater and found that the gross margins with wastewater were significantly higher, because farmers spent less on chemical fertilizer and achieved higher yields. No other costs or benefits were measured, but a potential tradeoff calculation showed that each cubic meter of wastewater used for irrigation released three to four times the volume of freshwater for use elsewhere, generating a net monetary gain for society. On the other hand, the reuse



(a)



(b)

Fig. 12.4 *E.coli* (**a**) and Total coliform (**b**) mapping from a PCRWR study of drinking water sources showing significant contamination. (Source: Author's work using data from Imran et al., 2018) of wastewater—particularly untreated or partially treated wastewater—may result in substantial risks to public health and surrounding ecosystems, especially in urban and peri urban areas of Pakistan where wastewater industrial effluents are mixed with municipal wastewater.

Untreated or partially treated wastewater contains a high concentration of excreta related pathogens and disease causing agents such as bacteria, nematode eggs, viruses and protozoa (WHO, 2006a, b). Farmers who used wastewater have reported several public health issues (Hussain et al., 2002).

As mentioned above, using untreated wastewater for irrigation is common in most parts of Pakistan. The main crops cultivated in these areas are vegetables, fodder, and wheat. In Faisalabad, the third largest city in Pakistan, more than 2000 ha of agricultural lands are irrigated with untreated wastewater. There, farmers prefer to use untreated wastewater rather than treated wastewater because it is considered to be more nutrient rich and less saline than treated wastewater. There are two main sites in Faisalabad: (1) the Narwala Road Site and (2) the Channel 4 Site. Farmers combine the wastewater with brackish groundwater at the Channel 4 site because of the toxicity of the wastewater (Ahmadi, 2012).

Because of the alarming rates of industrialization and population growth, along with a lack of treatment facilities in Pakistan, drinking water quality has continuously deteriorated. Only 20% of Pakistanis have access to clean drinking water, while the rest of the population is forced to drink contaminated water. The primary source of contamination is sewerage (fecal) which is extensively discharged into drinking water supplies. The secondary source of pollution is the disposal of toxic chemicals from industrial effluents, pesticides, and fertilizers from agricultural sources into water bodies. Anthropogenic activities cause waterborne diseases that constitute about 80% of all diseases in Pakistan and are responsible for 33% of deaths (Daud et al., 2017). Industrial wastewater mixed with sewage poses bigger health risks because of the presence of heavy metals; some reports are presented in Table 12.2.

The State of the Environment report of 2005 explained how the textile, leather, tanneries, and sugarcane industries are some of the major contributors to water pollution in Sindh and the rest of Pakistan. There are more than 76 factories with an installed capacity of 360,000 tons of sugar per day. Several hundred thousand cubic meters of wastewater is generated per day and discharged into water bodies without any treatment. Out of 34 factories in Sindh, only two had installed mechanisms to treat wastewater. The factories that install wastewater treatment systems do so either because of international pressure or for export purposes.

12.4 Impact of Wastewater Treatment Inefficiency

Although cities like Islamabad have wastewater treatment systems, they also face glitches from time to time. Similarly, wastewater treatment plants, such as Faisalabad's, that have been installed with the help of donor agencies have faced

Table 12.2 Analysis of various water samples from across Pakistan, showing contamination of drinking water and disposal of wastewater in freshwater samples

City	Sample site	Description	Results	Reference
Lahore	Outlet of five industries (Pensy Garments, Taiga Apparel, Comfort Knitwear, Humbul Textile, Nishat Linen) before they discharge into the Hudiara drain.	TSS, TDS, pH, BOD, COD, and concentration of heavy metals heavy metals (Cr, Hg, Ba, Fe, Mn, Cl, B) was analyzed	The results varied but it was shown that most of the TDS, COD, and BOD values were above the permissible limit. The same was true for chloride ions as well. If wastewater is being directly discharged it will impact freshwater resources	Asghar et al. (2018)
	Drinking water in the southern areas of Lahore was supplied by WASA from four tube wells and eight household connections; two samples were taken from each tube well.	Total coliform and fecal coliform, pH, turbidity, hardness, and total dissolved solids were analyzed for each sample. The drinking water quality of southern Lahore's urban areas was evaluated before and after monsoon season	The physicochemical parameters were satisfactory but 50–62.5% of the samples had bacteriological contamination before monsoon season, which rose to 75% afterwards. The city's main water and sewer sources are very close to one another and leakage often causes drinking water contamination.	Haydar et al. (2009)
Faisalabad	Wastewater irrigated soil and crops in a semi-arid region in Faisalabad, Pakistan	Potentially toxic elements (Cu, Cr, Mn, Fe, Pb, Zn, Ni) were analyzed in five different crops (corn, rice, wheat, sugarcane, and millet), alongside the multi targeted risks analysis.	The mean values of Pb and Zn were higher in crops than the FAO thresholds for food additives and contaminants. Potential Ecological Risk Index (PERI) was found to be higher than the maximum limit (PERI > 600) for all samples.	Mahfooz et al. (2020)
	Industrial zone of the city	Sixty groundwater samples were collected from the study area and analyzed for chemical parameters and heavy metals such as total hardness, alkalinity, cadmium, arsenic, nickel, lead, and fluoride	The industries are largely responsible for the contamination of groundwater, rendering it mostly undrinkable. Drinking this groundwater may cause health issues such as cancer, hepatitis, dental problems, gastrointestinal illness, nausea, eye/nose irritation, etc. the long-term trends of all the groundwater quality parameters revealed that contamination is increasing and this trend needs to be reversed.	Nasir et al. (2017)

(continued)

Table 12.2 (continued)

City	Sample site	Description	Results	Reference
Twin cities	Islamabad and Rawalpindi	About 130 samples were collected from nine areas to analyze microbial contamination in Rawalpindi and Islamabad's drinking water	56.1% of water samples were found to have microbial contamination. Microbial contamination for fecal coliforms, *E. coli*, and total coliforms was 23.8%, 20%, and 12.3%, respectively. The WASA supply lines were the most highly contaminated, followed by the capital development authority lines and boring water, with less contamination in tanker water	Shoaib et al. (2016)
Islamabad	Water filtration plants in Islamabad	32 samples were collected from different water filtration plants throughout Islamabad	More than half of the samples were contaminated with total coliform, fecal coliform, and E. coli	Hisam et al. (2014)
	–	271 drinking water samples were collected.	77% of the total samples collected were biologically contaminated and unfit for human use.	Sun et al. (2001)
	–	–	Samples were contaminated with total coliform, fecal coliform, and E. coli	Ahmed et al. (2015)
Rawal Lake (Source of drinking water for Rawalpindi)	Rawal Lake and its tributaries	–	*E. coli* population in four streams (input waters) feeding the Rawal Lake ranged from 25–57 (mean 36) fecal coliform per 100 mL. In the Rawal Lake water columns, it ranged from 12–65 (mean 25) fecal coliform/100 mL. The values indicate high contamination and were caused by domestic and poultry waste entering the feeding river.	Mashiatullah et al. (2010)
Peshawar	Water samples were collected from tube wells and storage tanks to determine the drinking water quality in rural areas of Peshawar.	Just 13% of the samples were negative for bacterial contamination, 40% were at satisfactory levels, and 47% were highly contaminated with *E. coli*.	Higher biological contamination indicates that wastewater treatment systems are inadequate and/or that the freshwater supply system has mixed with wastewater drains and pipes.	Zahoorullah (2003)

Nomal Valley, Gilgit-Baltistan	–	The pH, temperature, turbidity, hardness, odor, taste, and alkalinity were within the WHO's recommended ranges. But the microbial examination showed that all water samples were highly polluted.	The valleys in GB lack proper wastewater treatment and septic tanks have traditionally been used. Some of those tanks are shallow and not lined, which might contribute to the bacterial contamination of water.	Ali and Akhtar (2015)
Quetta	–	Drinking water quality of different colonies in Quetta city revealed that the pH, TDS, and hardness value of all samples were within the WHO range but that 50% of the samples were found to have high EC value and COD of all samples was above the WHO's critical limits.	–	Butt and Khair (2014)
Karachi	Orangi Town Karachi	All samples were highly contaminated with total coliform, fecal coliform, and *E. coli*. This indicates poor water supply and sewage infrastructure	–	Alamgir et al. (2015)
	Gulsha-e-Iqbal Karachi	Total coliform, faecal coliform and E.coli were present.	–	Hussain et al. (2016)

sustainability issues once the donor involvement or funds have been exhausted. In fact, even a metropolitan city like Karachi has failed to improve its wastewater treatment. According to Sindh's water commission, Karachi produces more than 450 million gallons a day (MGD) of sewage. This includes liquid waste produced by households, businesses, hospitals, and industrial units. This waste then passes through drainage channels to empty out into the Lyari and Malir rivers and ultimately it all ends up in the ocean. While on paper, there are three plants (with a combined capacity of 150 MGD) in the city that should be able to treat 33% of the wastewater, in reality even those three plants are non-functional.

It is concerning that the Industrial Trading Estate (SITE) and Korangi Industrial and Trading Estate (KITE), two of the biggest industrial estates in Pakistan, lack effluent treatment plants. Karachi is home to 70% of Pakistan's industry; approximately 70% of wastewater, (i.e., $>0.242 \times 10^9$ m^3/yr) reaches the Arabian Sea without any form of treatment. Among the industries established in the industrial zone of Karachi, 16% fall under the more polluting category while 59% can be classed in the somewhat-polluting category. Only a portion of the generated industrial effluent from this zone goes to a treatment plant (TP1), which is itself operating at half-capacity because of the inadequate sewage piping that was mentioned previously. The Karachi Water and Sewerage Board (KWSB) has suggested setting up additional treatment plants, but those projects are in a state of limbo as well.

National policies that are relevant to wastewater services in Karachi include the National Water Policy and the National Sanitation Policy. Neither Sindh nor Karachi has formal policies regulating the water supply and sanitation (WSS) sector. In the absence of such a framework, fiscal support to the Karachi Water and Sewerage Board (KWSB) has been ad hoc and often aimed at addressing its immediate financial difficulties rather than funding longer-term goals or transformation. The same can be said for water organizations all across Pakistan such as water and sanitation authorities (WASAs). Their dual responsibilities of providing clean drinking water while also treating wastewater means that wastewater treatment is constantly given short shrift.

This has resulted in several issues and challenges in Pakistan. Some of these challenges are summarized below in Table 12.2.

12.4.1 Waterborne Diseases

More than 50,000 children die every year in Pakistan because of waterborne gastrointestinal tract infections such as diarrhea and typhoid fever. Such water- and hygiene-related infections cost Pakistan's economy 380–883 million USD of the Gross Domestic Production (GDP) annually. Therefore, controlling water contamination and achieving water quality standards is essential to protecting public health, preserving water resources, maintaining recreational waters, and monitoring treatment processes. Water pollutants are either oxygen-demanding, algae-promoting, infectious, toxic, or simply unsightly. Water contains a variety of chemicals—physical and biological substances that are dissolved or remain suspended in it. These chemicals or microscopic organisms may be harmful for some industrial processes while not affecting others. Pathogenic microorganisms can render water dangerous for human consumption. Thus, water quality requirements are established in accordance with the end use of water. Quality is usually judged by the degree to which water satisfies the physical, chemical, and biological standards set by the user.

Inadequate quantity and quality of potable water and poor sanitation facilities and practices are associated with a host of illnesses such as typhoid, intestinal worms, and hepatitis. While newspapers report on poor quality and sanitation from time to time, even the major cities of Pakistan have yet to introduce a decent wastewater treatment system. For example, with a population of 11 million people, the city of Lahore dominates the Lahore district and is one of the five big cities (along with Faisalabad, Gujranwala, Rawalpindi, and Multan) of Punjab that has a Water and Sanitation Agency (WASA). While the main source of water in Lahore is the Ravi River, eight drains were built by the Department of Irrigation to store rain water and prevent water shortages. These drains (Shahdara, Mian Mir, Iqbal town, Garden town, Sattu Katla, Charrar or Ruhi Nallah, Hudiara, Chota Ravi) were designed to dump rain water into the River Ravi. However, lately, municipal and industrial waste (from 270 industries) has been dumped into these drains instead of rain water, which eventually finds its way into the River Ravi, thus contaminating a major source of drinking water for the district of Lahore. This also contaminates the groundwater, which is Lahore's second main source of drinking water.

12.5 Wastewater Treatment Regulation

Under section 227 of the Pakistan Penal Code, 1860, "Whoever voluntarily corrupts or fouls the water of any public spring or reservoir, so as to render it less fit for the purposes for which it is ordinarily used, shall be punished with imprisonment of either description for a term which may extend to three months, or with fine which may extend to five hundred rupees, or with both." Similarly, the Canal and Drainage Act of 1873 gives most canal-related authority to the provincial government and penalizes offences under section 70 of the act. Corrupting or fouling the water of a canal and rendering it unfit for use can be punished with imprisonment of up to 3 months. The major wastewater regulations include the national environmental quality standards, the national sanitation policy, and the water policy.

National Environmental Quality Standards (NEQS) of Pakistan
Pakistan's Standards vs. Jordan's Standards

The federal government enacted the Pakistan Environmental Protection Act (PEPA), 1997, prior to the enactment of the Constitution (Eighteenth Amendment)

Act, 2010. PEPA 1997 established a comprehensive framework for environmental conservation and management. The provinces have assumed full responsibility for environmental protection under the 18th Amendment, while the overall responsibility for regulatory enforcement rests with the PakEPA. Pakistan's Environmental Protection Council (PEPC) approved NEQS in 1993, in which uniform standards were applicable to all kinds of pollutants. The initial standards had 32 parameters for liquid effluents and 16 parameters for gaseous emissions. The same 32 parameters were revised regarding discharge into inland water, into sewage treatment, and into the sea for municipal and liquid industrial effluents and industrial gaseous emissions. The standards were made less stringent where applicable. Given that only 2% of wastewater is treated, most discharge into freshwater is not within the limits defined by the NEQS. Defining only 50 or so parameters is not enough, since thousands of chemicals are being used at either the household or industrial level. For most of the parameters not defined under the NEQS, WHO or FAO or other global guidelines and limits are considered. Lack of a standard list provides room for the existing inefficient systems to operate poorly. The EPAs lack the human resources for monitoring and surveillance, allowing underreporting and monitoring of these parameters.

Since there is evidence wastewater is used agriculturally in many parts of Pakistan, regulations and standards need to evolve.

Unlike Pakistan, Jordan has three categories of standards just for reclaimed wastewater. The limits are defined for end use and for discharge into water bodies and *wadis*. For cut flowers and for irrigation there are three sub categories: A (Cooked Vegetables, Parks, Playgrounds and Sides of Roads within city limits), B (Fruit Trees, Sides of Roads outside city limits, and landscape) and C (Field Crops, Industrial Crops and Forest Trees). The emphasis on wastewater treatment and proper reuse is reflected both in their laws and in practice.

Pakistan also needs to change its standards so that it has more specific guidelines according to end use, in order to reduce the health and safety issues that arise because of untreated wastewater. Even the WHO revised its guidelines for the safe use of wastewater, excreta, and grey water in 2006 (Technical Report Series 778, pp. 1–74) (Table 12.3).

Table 12.3 Revised WHO guidelines for safe use of wastewater

WHO-1989	WHO-2006
E.coli <1000MPN/100 ml	E.coli threshold varies depending on a set health-based target.
Depends on one single approach (WWTP)	Depends on a multiple barriers approach (drip irrigation)
Does not provide feasible risk-management solutions or guidance.	Provide an integrated approach that combines risk assessment & risk management to control water-related diseases.
Unachievable under local circumstances.	Can be adopted according to local socio-economic conditions.

The consequence of less stringent rules is heavy contamination of surface and groundwater specifically in cities that are hubs for industrial activities such as Faisalabad and Kasur, etc. A study was conducted to document the impact of wastewater on surface and groundwater, agricultural soil, crop growth and human health in the city of Faisalabad. The city's wastewater flows into the Ravi and Chenab rivers through the drainage system comprised of the Madhuana and Paharang drains and city municipal channels. WASA treats part of the channels through oxidation ponds. The average volume of wastewater disposed from the city is 5.28 m^3/sec, which, after including disposal from other towns, reaches 7.29 m^3/sec. Wastewater analysis of the drains (Fig. 12.5) showed that most of the samples exceeded the limit for COD, BOD, TDS, and SO_4. The chemical quality of irrigation water with respect to TDS, Na, HCO_3, Cl was entirely unfit for use. The concentrations of heavy metals in irrigation wastewater were within permissible levels. Contrary to the general perceptions of the farmers, all soil samples were deficient in organic matter, with the deficiency increasing with depth. The soils irrigated with wastewater from the Paharang and Municipal drains were also found deficient in phosphorus and potassium. Excessive nickel (Ni) was found in the soil, particularly in soil irrigated by the Madhuana drains, and Cadmium (Cd) was in the soil irrigated by wastewater from the municipal drain.

The vegetables grown with untreated wastewater were contaminated with Chromium (Cr), Lead (Pb), Cd and Iron (Fe.) The vegetables irrigated with industrial wastewater showed higher contents of these heavy metals. Wheat, sorghum, berseem, lettuce, mint, and turnips had more contaminant uptake capability whereas sugarcane and barley showed the least contamination.

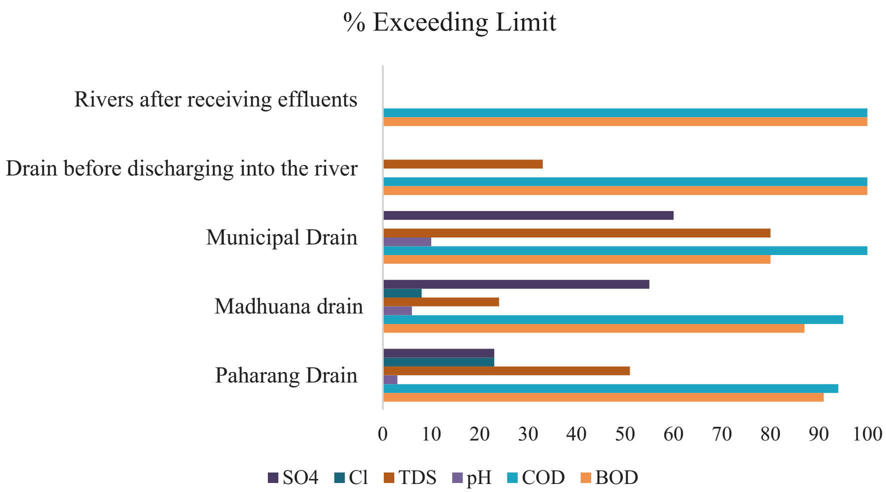


Fig. 12.5 Wastewater analysis of the drains from study on the impact of wastewater in Faisalabad

Fish reared in groundwater showed toxic levels of all heavy metals except Cd and Manganese (Mn). The concentration of lead in particular was very high. Similarly, all samples of fish farm water exceeded the permissible limit of TDS and HCO_3.

Human blood analysis indicated the presence of a few cases of Hepatitis E for all types of drinking water sources. Moreover, only one typhoid case was seen. The human blood sample size (100 Nos) was too small to reach a general conclusion. According to doctors, 30–40% of patients were suffering from waterborne diseases. Nearly 75% of industries reported having proper effluent management systems while less than 25% of them actually did.

Irrigation with untreated wastewater should be stopped immediately. Low-cost water treatment facilities are needed for industrial units and strict implementation of environmental policies must be ensured. With wastewater treatment facilities, nearly 7.27 m^3/sec (1,85,868 AF/year) of the wastewater which is currently being disposed of could be used for irrigation, closing the gap between water demand and supply. Groundwater quality in Faisalabad was very poor. Extension, regulation, and rehabilitation of water supplies is sorely needed for all residential areas, including the establishment of necessary treatment facilities (Imran et al., 2018).

However, there are initiatives such as the Alliance for Water Stewardship, that have provided incentives for industries to comply with national standards.

Alliance for Water Stewardship (AWS), Pakistan

The Alliance for Water Stewardship (AWS) is a global collaboration between businesses, NGOs, and the public sector, aiming to contribute to the sustainability of local water resources through the adoption and promotion of a universal framework known as the “International Water Stewardship Standard” or the “AWS Standard.” In simple words, the members of the alliance have developed together a credible sustainability standard for freshwater resources.

AWS defines water stewardship as the use of water that is socially and culturally equitable, environmentally sustainable, and economically beneficial, achieved through a stakeholder inclusive process that includes both site- and catchment-based actions.

The idea of water stewardship is not new and is very much consistent with the concept of Integrated Water Resource Management (IWRM), except that water stewardship is mainly a bottom-up approach that focuses on major water users while IWRM is top-down, usually initiated by the public sector through policies. The adoption of water stewardship through the AWS Standard leads to a coherent approach for the private sector to work on water rather holistically while engaging with a variety of other water users. In Pakistan, where there is a considerable trust deficit, it bridges the gap between the private sector and the public sector through a practical framework.

The AWS Standard follows a simple logic of plan, do, check, and act and is built around five steps. Any site implementing this standard must do the following:

1. Gather and understand water-related data
2. Commit to water stewardship and create a water stewardship plan
3. Implement their plan
4. Evaluate their performance
5. Communicate and disclose progress with stakeholders

Each step has a series of criteria and indicators. Following the steps and criteria will lead to improved performance in five areas:

1. Improved water governance
2. Sustainable water balance
3. Good water quality
4. Healthy status of important water-related areas
5. Access to water, sanitation and hygiene (WASH) for all

For more details, the standard can be downloaded from a4ws.org.

It is important to note that the AWS Standard is not prescriptive and does not offer numerical values for benchmarks as other standards do; rather, it provides a practical framework for implementation. In Pakistan, AWS, in collaboration with WWF Pakistan, launched the AWS Standard in 2015. Nestle Pakistan was its earliest adopter and began implementing it at their Sheikhupura site. In 2017, the Nestle Sheikhupura site not only became the first AWS-certified site in Pakistan but was the first of any of Nestle's sites around the world to receive AWS certification.

Simultaneously, WWF in collaboration with International Labour Organisation (ILO) began an EU-funded project, "International Labor and Environmental Standards Application in Pakistan SME's," where one of their objectives was to facilitate implementation of the AWS Standard in the textile and leather sectors. Fortunately, in 2020, two US Group sites received their AWS certification, the first in the textiles sector. As of early 2022, a total of eight sites have been independently certified in Pakistan and more have registered. As the momentum builds, more examples, good practices and initiatives will be brought to light that demonstrate the benefits of collaboration and on- and off-site interventions.

As a matter of fact, member organizations and enthusiastic water stewards convene on a yearly basis to discuss opportunities, share knowledge and exchange ideas with regards to water stewardship through the Pakistan Water Stewardship Network (PWSN). Such national networks feed information into the international alliance to keep the standard and system as inclusive, robust, resilient and credible as possible. More details regarding PWSN's objectives are given in Fig. 12.6.

While it is true that AWS is a voluntary sustainability standard, such systems, if correctly adopted, can produce the envisioned change we wish to see in the water sector in Pakistan. The framework can be used by both the private and the public sector simultaneously to ensure consistency. This in turn will also fit in with all the

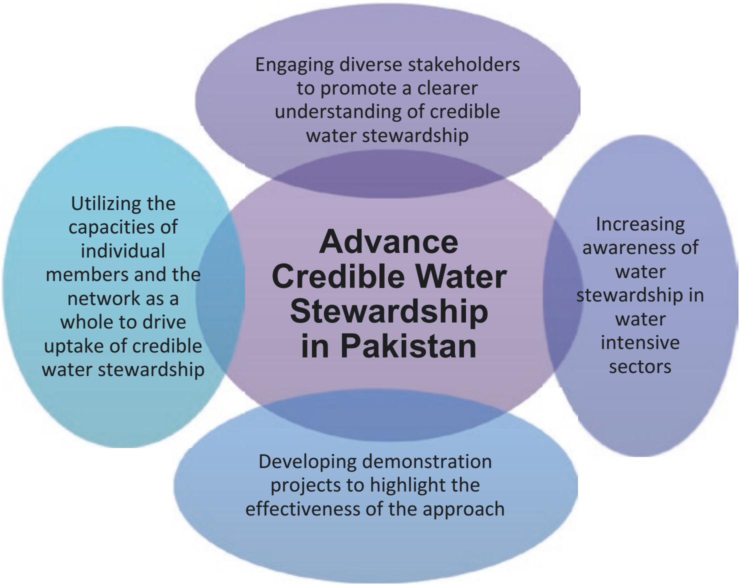


Fig. 12.6 Key objectives of Pakistan Water Stewardship Network (PWSN). (Source: Authors' own work elaborating on AWS Pakistan principles)

work being done globally in water stewardship by those using the AWS Standard. As a matter of fact, voluntary sustainability standards are increasingly being recognized by governments as tools to help them achieve macroeconomics objectives, either through their inclusion in national regulatory frameworks, their use in sustainable public procurement or their embedment in trade policies (Bermúdez, 2021). This can further catalyse public-private partnerships and collaborations which can eventually build trust between these very important sectors.

12.6 Wastewater Treatment Initiatives

Overall, there is effectively no national policy on wastewater treatment and reclamation in Pakistan. Moreover, economic incentives have not been introduced for industries to acquire environmentally-friendly technology. Wastewater disposal problems tend to stem from distortions due to economy-wide policies, institutional failures, and poorly-targeted environmental policies. There are many private consultancies now that provide decentralized wastewater treatment solutions for industries and many industries now comply with wastewater treatment standards through the installation of membrane bioreactors; this attitude is also shifting beyond industries and businesses.

Some voluntary interventions also exist that are serving as a glimmer of hope for a sustainable future in Pakistan, such as the NUST MBR plant which is successfully operating as a model site for MBR plants in Pakistan.

12.6.1 National University of Science and Technology (NUST), Membrane Bioreactor (MBR) Plant: Establishment to Operation

Because of reduced surface and groundwater supplies, water availability for landscaping and horticulture at the National University of Sciences and Technology (NUST) was a serious issue. Horticulture used 50 m^3/day and 100 m^3/day of water in the winter and summer, respectively. Lab-scale MBR systems have been successfully constructed and operated since 2008 at the Institute of Environmental Sciences and Engineering (IESE), School of Civil and Environmental Engineering (SCEE), NUST, Islamabad. The performance of laboratory-scale MBR units in the IESE-SCEE laboratory demonstrated their performance efficiency and reduced footprint. Therefore, a first of its kind pilot MBR was installed to provide high-quality treated water (reuse water) from a decentralized wastewater plant for the university campus to meet non-potable water demand. On January 21, 2016, the MBR plant was successfully completed and commissioned. This facility uses a submerged PVDF hollow fiber membrane (Cheil Industries, Korea), with a surface area of 95 m^2 and a pore size of 0.03 mm, to reclaim 50 m^3/day of wastewater.

The MBR project was envisaged by Dr. Sher Jamal Khan who worked together with technical experts and local companies such as 3 W systems (Pvt) Ltd. Lahore, on the plant design, equipment selection, and operational procedures. The construction was followed by the Membrane Package System (MPS) skid and bio-tanks along with the drum screen and primary clarifier. A few parts of the plant were fabricated on-site. This was followed by the installation of pumps, instruments, program logic controllers (PLCs) and their electrical connections. The automation of the plant with software (PLC and (Supervisory control and data acquisition) SCADA) took almost 6 months and the plant was ready for water treatment and testing in October, 2015.

12.6.2 Operation of the NUST MBR Plant

The schematic diagram and pictorial view of the NUST membrane bioreactor plant are shown in Figs. 12.7 and 12.8. After the completion and testing of each unit and procedure, the MBR plant was finally commissioned on January 21, 2016. Wastewater goes into the membrane tank after passing through the coarse screen, primary clarifier, and drum screen. The setup is automated and can be handled online. As a demonstration facility, the fully automated plant can even be operated via a smartphone.

Activated sludge from Islamabad's I-9 wastewater treatment plant was used to inoculate the MBR plant. For the first 7 days, the MBR was operated in batch mode with artificial feeding to stabilize the sewage sludge. When the concentration of Ammonium-N in the supernatant dropped below 1 mg/L, the acclimatized

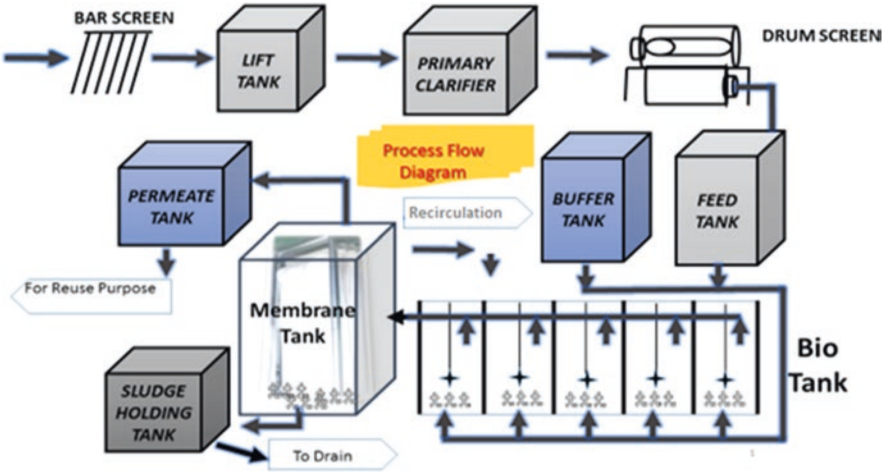


Fig. 12.7 Schematic diagram of NUST MBR Plant. (Authors' work using Khan et al., 2019)

Fig. 12.8 Pictorial view of NUST MBR Plant. (Source: Authors' work)

condition was reached and the membrane operation was started. The membrane initial flux was set at 10 liters per square meter per hour (LMH), then gradually increased to 12 LMH, 15 LMH, and eventually 20 LMH, all while evaluating performance and the characteristics of the sludge under each flux. When mixed liquor suspended solids (MLSS) in the membrane tank reached 10,000 mg/L, sludge waste equivalent to 80 days of sludge retention time (SRT) was introduced. SRT was frequently reduced with an increase in flux, i.e., increase in the organic load rate (OLR). For the hydraulic retention time (HRT) of 4.50, 3.75 and 3.00 hours, which are equivalent to 10, 12, and 15 LMH fluxes, respectively, one of the five bio-tanks was employed in addition to the membrane tank. However, when the plant was run at 20 LMH flux to sustain the HRT at 3.00 hours, another bio-tank was attached to the membrane tank. Sludge recirculation from the membrane tank to the bio-tank(s) was adjusted at a rate of three times that of flux (product water). The concentration

Table 12.4 Operating protocol used for NUST MBR operations

Days	Flux (LMH)	HRT (days)	SRT (days)
1–20	10	4.5	–
20–30	12	3.7	–
30–40	15	3.0	–
40–53	15	3.0	80
53–76	15	3.0	40
76–94	15	3.0	30
94–107	15	3.0	20
107–127	15	3.0	15
127–174	20	3.0	20

of dissolved oxygen (DO) within the membrane tank and bio-tanks was kept at 3 mg/L.

The MBR's treatment performance was evaluated at fluxes of 10, 12, 15, and 20 LMH. The operational conditions of the NUST pilot scale MBR plant are reported in Table 12.4.

To generate biomass, the membrane bioreactor was first fed with synthetic wastewater as a sequencing batch reactor (SBR). During acclimation, the membrane tank had an MLSS concentration of 2000 mg/L, and COD removal of 85% was observed. Organic matter in the NUST campus wastewater was observed to be highly biodegradable. COD removal increased with a sudden increase in MLSS concentration because of membrane rejection. During this unstable state, 85% of the average COD removal was obtained, and removal was enhanced above 90% under all combinations of flux as steady-state conditions were achieved, which was also reported in other MBR research (Williams & Pirbazari, 2007). However, COD removal efficiency was marginally reduced with reduction in SRTs to 15 and 20 days, due to lower microbial concentrations, which could be attributable to greater synthesis of extracellular polymeric substances (EPS) (Pollice et al., 2008).

The biomass concentration was initially higher in the membrane tank because sludge wasn't wasted. When the MLSS concentration reached 10,000 mg/L, wastage was initiated. The concentration of the biomass in the membrane tank decreased as the sludge waste increased (lowering the SRT). In the membrane tank, the MLSS concentration was kept between 8000 and 10,000 mg/L. At 15 LMH flux and 80, 40, 30, 20 and 15 days of SRT, the average MLSS concentration was 10,400, 9500, 8600, 8200, and 7500 mg/L, while at a flux of 20 LMH and SRT of 20 days, the concentration was 9000 mg/L. The concentration of biomass in the membrane tank was also higher as compared to the bio-tank, due to the full rejection of suspended solids from the membrane. On the other hand, when the plant was running at a lower SRT, the ratio of MLVSS to MLSS was found to be better.

The amount of extracellular polymeric substances (EPS) within the sludge determines how biofouling affects the membranes. EPS are macromolecule

Table 12.5 Summary performance of NUST membrane bioreactor plant

Experiment	Phase I	Phase II	Phase III	Phase IV	Phase V	Phase VI
SRT (days)	80	40	30	20	15	20
Net flux (L/m^2.h)	15	15	15	15	15	20
MLSS (mg/L)	10,000	10,400	9500	8600	8200	7500
MLVSS (mg/L)	7500	7488	6745	5934	5494	5437
COD removal (%)	94.5	94.1	93.6	91.1	90.0	93.3
Phosphate phosphorus Removal (%)	85.6	82.4	82.2	81.5	80.5	83.9
Nitrate-nitrogen removal (%)	99.9	99.9	99.9	99.9	99.9	99.9

polymers released by microorganisms under a variety of circumstances (Ahmed et al., 2007). EPS (both bound and soluble) was found and regarded as a significant foulant in the case of membranes (Jinsong et al., 2006). The loosely and tightly bound EPS, producing SMP and bound EPS, were referred to as soluble EPS in this study. Proteins, lipids, nucleic acids and carbohydrates are among the components found in the EPS matrix. Despite this, the sum of carbohydrates and proteins designated full EPS or SMP due to its dominance over other elements (Bura et al., 1998). The protein and carbohydrate content of SMP and bound EPS were analyzed in sludge produced from the MBR. In SRT of 80, 40, 30, 20 and 15 days, and flux of 15 LMH, the average B-EPS and SMP were 34, 41, 50, 56, and 62 mg/g-MLVSS and 69, 77, 89, 101 and 108 mg/L, respectively, while in the final stage of 20 days SRT and 20 LMH flux, B-EPS and SMP were 55.7 mg/g-MLVSS and 123 mg/L.

Trans membrane pressure (TMP) started from 5 kpa with an initial flux of 10 LMH and increased to 17 kpa with increase in flux to 10 LMH and 12 LMH. By increasing flux from 12 LMH to 15 LMH, TMP was also increased from 17 to 19 kpa. When flux was further increased to 20 LMH, the largest TMP jump was observed. Higher TMP may be because of a higher fraction of pore clogging induced by fine particles in the case of lower SRT (Chuang et al., 2011). In comparison to the longer SRT of 20 days under flux of 20 LMH, fouling of membrane in terms of TMP was extreme at SRT of 15 days under 15 LMH flux, owing to the mutual impact of strong EPS production and fine particulate matter in the MBR sludge. TMP was under steady-state condition for 35 days when an SRT of 20 and flux of 20 LMH were applied in the last phase of the study, according to the TMP profile. Membrane filtration eventually demonstrated a TMP surge and entered the irreversible fouling study, bringing the total run time to 174 days. COD, nitrate-nitrogen (NO3—N), and phosphate-phosphorus (PO_4^{3}—P) removal, as well as MLSS and MLVSS concentrations, are summarized in Table 12.5.

12.6.3 Future Perspectives

Presently, the MBR plant is meeting national effluent discharge standards (NEQS) as well as US-EPA reuse standards and fulfilling NUST's horticultural water requirements successfully. Furthermore, Pakistan's MBR market is currently extremely small, and this MBR project has helped market MBR to real estate developers, municipalities, housing societies, and industrial uses. In Pakistan, there is a real opportunity for this technology in the coming years. The following factors are driving the MBR technology's growth: (i) rising water scarcity, (ii) technical acceptability, (iii) increasingly stringent discharge quality regulations, (iv) the high quality of produced water, (v) lower investment costs and (vi) the opportunity to upgrade existing WWTPs. If we consider our adjacent cities of Rawalpindi and Islamabad Capital Territory (ICT), there are numerous private housing societies, a number of four- and five-star hotels, hospitals, multi-story shopping malls and a large industrial sector who can all be key clients for the MBR.

Other observations about Pakistan include:

1. Inadequate mechanisms for solid waste management and wastewater treatment exist since the extensive use of plastic contributes to urban flooding because it clogs the canal and drainage systems
2. Climate change, which leads to either too much (flash floods) or too little water (dry seasons), underpins the weak preparedness to meet new water and waste management challenges
3. Coordination between institutions is necessary in order to reduce the impacts of environmental pollution
4. We need to identify and implement simple nature-based solutions such as wetlands and low-cost technologies to address problems
5. Policy actions need to be defined for the short-, medium-, and long-term and sustainability of WASH projects

12.7 Conclusions

In Pakistan, domestic waste is either discharged directly to a sewer system, a natural drain or water body, a nearby field, or an internal septic tank. It is estimated that only some 8% of urban wastewater is treated in municipal treatment plants. We lack continuous water treatment facilities. There is plenty of evidence that groundwater and surface water quality have deteriorated over time. An estimated 32,500 ha—mostly used to grow vegetables—are irrigated with wastewater, most of it untreated. Farmers use wastewater to irrigate their crops for many reasons: reusing wastewater can contribute to farmer incomes by increasing productivity, resulting in food security and making their livelihoods more stable. Using untreated wastewater for irrigation is common in most parts of Pakistan. The main crops cultivated in these areas are vegetables, fodder, and wheat. Due to the alarming rates of industrialization and population growth, along with a lack of treatment mechanisms in Pakistan, drinking water quality has continuously deteriorated. Only 20% of Pakistanis have access to clean drinking water, while the rest of the population is forced to drink contaminated water. The primary source of contamination is sewerage (fecal) which is extensively discharged into drinking water supplies. The secondary source of pollution is the disposal of toxic chemicals from industrial effluents, pesticides, and fertilizers from agricultural sources into water bodies. An estimated 250,000 children under 5 years of age die every year in Pakistan because of waterborne gastrointestinal tract infections such as diarrhea and typhoid fever. Such water- and hygiene-related infections are costing Pakistan's economy 380–883 million USD of the Gross Domestic Production (GDP) annually. Therefore, controlling water contamination and achieving water quality standards is essential to protecting public health, preserving water resources, maintaining recreational waters, and monitoring treatment processes. Inadequate quantity and quality of potable water and poor sanitation facilities and practices are associated with a host of illnesses such as typhoid, intestinal worms, and hepatitis.

Wastewater treatment systems, whether centralized or decentralized, advanced or basic, nature based or engineered, need to be put in place for municipal, industrial, and hospital wastewater so that contaminants do not reach the fresh water system and create bigger social and ecological issues for the country. The government needs to prioritize wastewater treatment and its reuse and the existing rules and regulations need to be enforced. The focus of the Water and Sanitation Agency (WASA) is provision of clean drinking water and the land allocated for wastewater treatment is still unused. The introduction of wastewater treatment systems as per the policy is also yet to become a priority, as pricing, billing, control of groundwater extraction and efficient irrigation systems are still a challenge. In short, there are multiple structural, institutional, and administrative issues that need to be tackled and policy reforms need to be implemented for both the public and private sectors if we want to improve the quality of our water.

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Chapter 13
The Water, Food, and Energy Nexus: The Key to a Transformative Agenda

Mahmood Ahmad and Tabeer Riaz

Abstract The Water-Energy-Food nexus has emerged as a new perspective to clarify the complex and interlinked relationship between the global resource system and the potentially conflicting imperatives of substantial investments associated with energy, water, and food security. The World Economic Forum was among the first organizations to introduce the concept of the Water-Energy-Food nexus as a key development challenge. This chapter will focus on the continuous interactions between these three core sectors of the nexus. In general, food production relies on water and energy, while the extraction, treatment, and distribution of water require energy, and energy production itself necessitates water. Action taken in any of these sectors affect the others, making the optimizing of this link a key challenge. The nexus' importance is further highlighted by its centrality to sustainable development. To ensure water and food security, and sustainable agriculture and energy production, an integrated approach between these critical domains is needed. In Pakistan and other developing countries, the demand for food, water and energy are constantly increasing due to rapid population and economic growth in combination with accelerated urbanization and changing lifestyles. The dynamic interventions in the nexus could possibly change the dimension and outcomes of the sectoral interactions.

Keywords Water-Food-Energy (WFE) Nexus · Integrated approach · Sustainable development · Food security · Water security

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13.1 Introduction

Globally, as well as in Pakistan, the three sectors—agriculture (erratic supply), energy (rising cost) and water (floods or droughts)—are affecting the livelihood and economies both for developed and developing countries. Rising energy prices and supply chain disruptions are making serious dents in consumer budgets as energy costs have almost doubled. The recent drought in Europe, with both producers and consumers facing rising food prices, is the leading cause of Britain's double-digit inflation. On the other hand, in Pakistan record temperature increases during March resulted to a failure to meet the crucial wheat target, posing a significant food security concern. At the same time, most of country's major reservoirs that store water were running low and unable to generate as much energy as needed, leading to electricity load shedding. Furthermore, the 2022 monsoon has played havoc with floods, comparable to those in 2010. As a result, the economy as a whole is faltering on many fronts. The impacts of climate change, regional conflicts, and lingering COVID-19 complications are pushing country to reposition the way it approach these three critical sectors. These circumstances have sparked discussions on addressing these issues holistically, using an integrated approach to set a new and sustainable policy discourse.

The unprecedented rates of population growth in urban, peri-urban, and rural areas of Pakistan have severely impacted land, water, and energy provision and distribution, resulting in a disorganized extraction of natural resources, poor water and sanitation conditions, and an overall depletion in standards of living. Increasing pressure on the resources needed for socio-economic development has resulted in growing and competing demand for energy, food, and water. Policies and development strategies are very much sector-driven, with key sectors such as water and agriculture planning and executing their projects in silos, resulting in inconsistent outcomes, often pushing policy actions that are hampered by conflicting interests, resulting in further missed opportunities for enhanced synergies. As these aspects are closely linked, they need to be tackled by an integrated approach known as the Water-Energy-Food (WEF) nexus.

Water is the main constraint to agricultural growth and the economy at large. But demand for it is also growing in other sectors, including the energy sector, and this is not often evaluated or documented. Water-food linkages are well documented: 96% of water is used for agriculture, but a large part of that is wasted. In addition, the water used for agriculture has very little added value, adding only two dollars of value as compared to eight dollar in the United States. The goal of achieving food security is still very elusive. According to the United Nations, by 2030 the world will need at least 30% more water, 45% more energy, and 50% more food (UN, 2014). Food production in Pakistan has dismal output—in July 2021, the food import bill was USD 6.47 billion, a 22.24% increase from 2020. In order to achieve the growth needed for food production, there must be affordable and reliable water and energy supplies. However, both of these resources have been mismanaged.

Energy and water are both essential ingredients for economic development and food production. The connection between water, energy, and food is simple: water needs for agricultural and domestic use are now largely met through groundwater, and energy (electricity and diesel) is required to pump that groundwater. Due to growing scarcity in water and energy, making progress exclusively in one area will adversely affect progress in the other areas. For example, considering food security to the exclusion of other areas will negatively impact desired outcomes for water security, environmental sustainability, and energy stability. Indeed, the present global crisis of rising food and energy prices because of the war in Ukraine has illustrated this link. There are two dimensions to this. First, the world continues to depend on fossil fuels to propel its economies, leaving it quite vulnerable. Secondly, and more relevant for our purpose, Pakistan's food production has become more dependent on fossil fuels, so when energy prices go up, food prices also go up.

The agriculture, water, and energy nexus is best represented by the great dependence of agriculture on tubewells in Pakistan, which in turn depend on energy provided either by electricity or diesel. On the one hand, farmers' unlimited access to groundwater results in energy waste and overexploitation of groundwater; on the other hand, groundwater depletion leads to higher pumping costs (growing energy bills), but an unreliable electric supply acts as a limit on how much they are able to pump. Farmers respond by switching to imported fossil fuels (diesel) that are subject to price instability. In fact, in this instance the nexus is a vicious circle that highlights how important is to decouple agriculture from the price of fossil fuel.

This chapter, among other aspects of nexus, will highlight the need to decouple energy and food prices. This can only happen if more incentives are created to use renewable energy in agriculture.

13.1.1 The Green Economy and the Nexus Perspective

Figure 13.1 highlights the interlinkages between water, food, and energy, which impact the development of green technology and growth. In setting the agenda around the WFE nexus, it should be acknowledged that these interactions maybe affected by external drivers and pressures, such as environmental degradation, natural hazards, vulnerabilities, and risks. This reflects the current situation where all these integrated sectors are affected by climate change risk. There is a need to develop systems to make eco-efficiency (green economy) a priority, especially in sectors such as agriculture, water, and energy, which promote low-carbon economic development. Ultimately, doing this will enhance national and regional efforts to green the economy and reduce greenhouse gas (GHG) emissions.

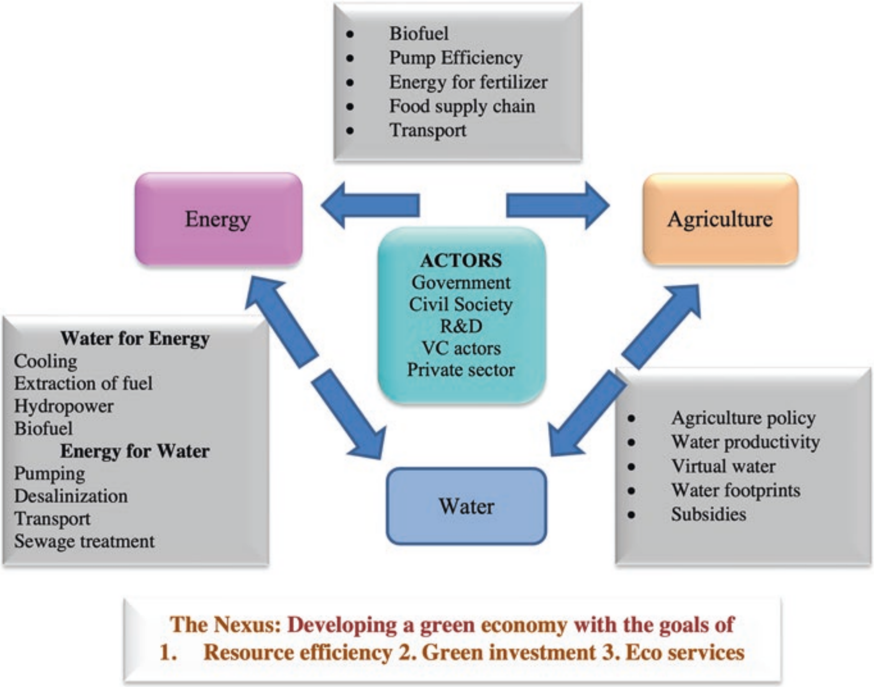

Fig. 13.1 Interlinkages of energy, water and agriculture. Source: Authors' work and analysis

13.1.2 Sustainable Development Goals (SDGs) and the Nexus Approach

In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development in order to end poverty, ensure prosperity for all, and to protect the planet. Figure 13.2 outlines the necessary actions in each component of the nexus. The integration of issues related to water (SDG 6: Clean water and sanitation), food security (SDG 2: Zero hunger), and energy (SDG 7: Affordable and clean energy), are essential to managing natural resources in an integrated way and to achieve SDGs under the NEXUS approach.

13.1.3 Global Initiatives and the Nexus

The WEF Nexus has emerged as a new perspective to organize large-scale investments globally. The World Economic Forum is considered to be a pioneer in identifying the interlinkages between water, energy and food as a key

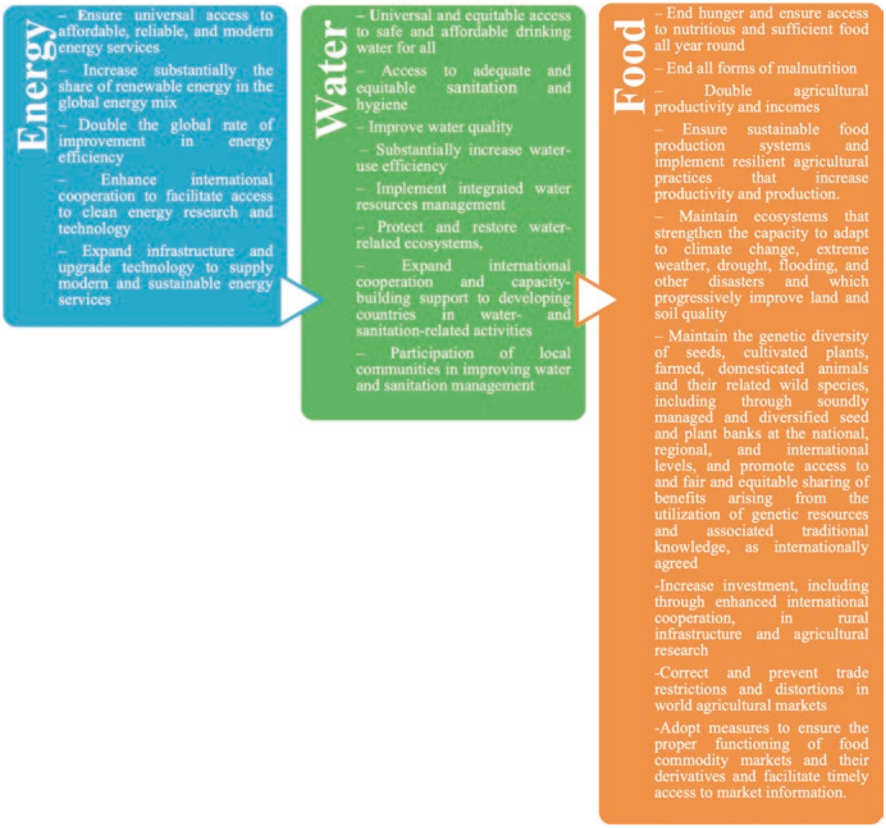

Fig. 13.2 SDGs of each component in WEF Nexus. Source: Authors' work outlining SDGs—UN department of economics and social affairs

development challenge and proposing innovative solutions at the Annual Meeting in Davos—2008 (World Economic Forum, 2011). The World Economic Forum introduced the Water Initiative as a starting point to explore the relation of water security with food and energy system, climate change and economic growth.

The United Nations Economic Commission for Europe (UNECE) has established a methodology to evaluate the water-energy-food-ecosystems nexus in transboundary rivers and aquifers (UNECE Task Force on Water-Energy-Food-Ecosystems, 2013). This method identifies the "complex chains of cause-effects that link human interventions to environmental degradation and availability of resources" with a consultative and open-ended process. Figure 13.3 illustrates the WEF Nexus which depicts a range of typical interactions and cross-sectoral connections.

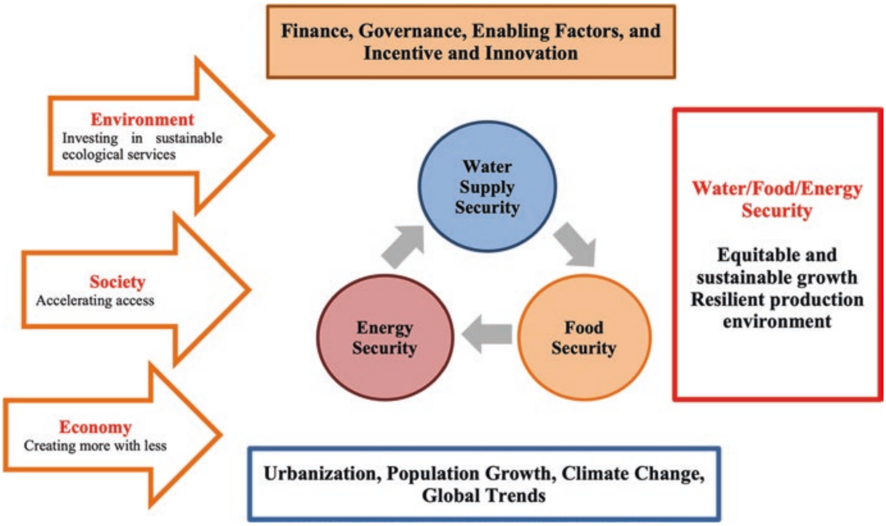

Fig. 13.3 The WEF Nexus. Source: Authors' work based on methodology outlined by UNECE Task Force on Water-Energy-Food-Ecosystems, 2013

13.1.4 Pakistan's Vision 2025 and the Nexus

Pakistan's Vision 2025 acknowledges that the sufficient availability of water, food, and energy are integral for economic sustainability and development. The additional demand in key sectors needs to be met, keeping in view emerging approaches because of the severe impact of ongoing climate change. The Government of Pakistan, soon after announcing the Vision 2025, signed multiple regional and global commitments in 2013 and 2014 to achieve Sustainable Development Goals (SDGs). The following areas were identified as priorities (and are still in dire need of action):

- Meeting the basic needs of a growing population, including in particular their access to essential services—health, education, energy, water, and sanitation.
- Providing the social, legal, and physical infrastructure needed to empower people and ensure that they are able to live their lives with dignity, and that human rights are protected, lives are secure, that there is full employment (i.e., over 1.5 million additional decent jobs are created every year), women are empowered, and poverty and hunger are eliminated.
- A responsible and accountable government and public sector.
- An entrepreneurial private sector that can generate the required number of jobs.
- Ensuring that the economy can engage effectively with and benefit from the opportunities emerging outside Pakistan's borders, especially regional opportunities.
- Ensuring competitiveness in a modern world that has shifted towards a knowledge economy.
- Protecting natural resources and addressing climate change.

13.2 The Need for Change and a Nexus-Transformative Agenda

Agriculture has the capacity to meet the economic needs of both present and future generations while ensuring profitability, environmental health, and social and economic equity (FAO, 2013). One key goal is to produce food using less energy-intensive practices and ultimately replacing the use of fossil-energy with bio-energy. The starting point for a transformative agricultural process is based on rational use of energy and water. For example agriculture or meeting food security objectives would entail producing more food with less water. As the sector is becoming more energy intensive, a shift to renewable energy is needed to reduce this dependence.

The strategies and policies intended for climate mitigation and adaptation are influenced through the management of water, food, and energy security as highlighted above in the framework. A few of the adaptation measures have a positive impact on water, energy, and food resources, such as water-use efficiency, renewable energy, and growing biofuels on wasteland. On the other hand, other adaptation and mitigation measures, such as extensive groundwater pumping, desalination plants, inter-basin transfers of water, and growing biofuels may increase nexus challenges (WWF, 2015). The strategy emphasizes the need to take up more sustainable, productive, and profitable ways of production that do not damage the soil, health, and water quality.

13.2.1 Energy Security

In Pakistan, the federal government kept energy security as a priority in its development agenda of Vision 2025. Energy security thus needs to be integrated with water and food security. Over the last few years, introduction of modern technologies in water, energy, and agriculture have created strong dependencies between these three sectors. (Siddiqi, 2014).

Agriculture depends on groundwater, which in turn depends on energy (diesel and electricity), with the result that groundwater depletion and the high cost of pumping negatively affects the competitiveness of the agricultural economy. There are two implications of groundwater depletion: first, as water is pumped at greater depth, the cost of pumping increases, as is well-reflected in farmers' financial budgets, incomes, and sector competitiveness as a whole. And though the cost to society in economic terms can be much higher, currently that is not taken into account. The second implication is that—looking further into the future—as agriculture becomes more energy intensive, using more energy to pump a unit of water, with already low pumping efficiency, greenhouse gas emissions will increase. Future estimates for Pakistan suggest that because of increasing energy use, CO2 emissions from the energy sector will rise from 157 to 2685 MMT, signifying the need to either reduce the energy footprint or move towards fossil fuel-free groundwater extraction (Qureshi, 2014). As a starting point, reversing groundwater trends to sustainable levels is of paramount importance. In our view, it would be valuable to start a pilot program to estimate the net carbon balance for energy in groundwater use by using these adaptation and mitigation policies.

The Thar coalfield located in Sindh is the largest in Pakistan and the sixth largest in the world (Masih, 2018). According to Siddiqi, 2014, while the coal deposits of the Thar desert in Sindh are a promising energy source, extracting that energy will put more pressure on the already arid region's water resources, since water is used to both mine and process coal (ibid).

Other sources such as thermal, hydropower, and nuclear plants account for 59.4%, 30.52% and 7.8%, respectively, of the energy generation capacity, but they also require water for evaporative cooling (F. D. GoP 2020–21). While hydropower does not consume water, energy demand patterns determine reservoir releases, which means they are then unable to meet irrigation demands, resulting in a negative impact on the agriculture sector (see case study 3). Modelling suggests that optimizing dam operations (including Diamer Bhasha) for hydropower would increase energy production by 10% but would reduce agricultural production by two-thirds (Young et al., 2019). The months of April and May of 2022 have been reported as some of the hottest on record, yet snow is melting slowly, thus creating, as we write, another serious energy crisis, with reservoirs at levels too low to generate feasible energy supplies. This questions the wisdom of investing in ten large dams with the growing risk of erratic flows (as in 2022), when there is not enough water to fill dams to generate electricity. On the flip side, as advocates of building more large water storage structures point out, monsoons (such as those in August 2022) are also capable of filling these reservoirs, and in fact, current storage does not capture all of the flow. This issue has been discussed more extensively in Chap. 7.

Another aspect to the nexus is that the waste from one component work as a resource for the other (e.g. manure works as a fertilizer for the crops, manure generates biogas offering a renewable energy source and by-products from crops are used as animal feed). These integrated systems provide multiple opportunities to increase overall production and farmers' economic resilience. It is important to develop production systems that can effectively fulfil the energy requirements of smallholders farmers.

Al-Iqbal Foundation—A Biogas Plant Success Story from Mailsi, Pakistan

The Al-Iqbal Foundation, a farm in Mailsi, Vehari District,Punjab, is run by a young woman, Iqra Zaheen, who is a local resident of Mailsi. She is pursuing a master's degree in climate change from Mohammad Nawaz Sharif University of Agriculture (MNSUA), Multan. The British Council's COP26-Challenge Fund selected her biogas installation project. Presently, there are four biogas

(continued)

plants operational on the farm, funded by the British Council and with technical support from the Punjab government. This farm provides biogas to 20 families in the village who bring manure on their allocated days. This has been a great initiative in reducing GHG emissions by capturing CH4, replacing natural gas with biogas and using bio-fertilizers. Iqra and her brother are working on further interventions that may help in mitigating climate change, such as nature-based practices for growing crops. The biogas project currently benefits 20 families, the local mosque and more than 2000 people. During our visit to the biogas plant, engaging in conversation with Iqra revealed her passion for helping her community and making efforts to combat the effects of climate change. Iqra's story showcases the benefits of biogas technology.

In 2018, a study estimated potential livestock manure production to be 417.3 million tons (Mt), which could generate up to 26,871.35 m3 of biogas, with the potential of producing 492.6 petajoules (PJ) of heat energy and 5521.5 megawatts (MW) of electricity. In addition, there is space available to install five million biogas digesters on different farms in the country (Khan et al., 2021). Taking full advantage of this potential should be a priority to get Pakistan to a more sustainable future. Depending on the size of the plant, approximately 45 thousand to 2 *lakhs* (two hundred thousand) and 17 thousand to 80 thousand can be saved per year by using less LPG or wood, respectively. A 20–25 cubic meter plant can save up to 65 to 70% of the diesel needed to operate tubewells. The use of biogas not only has the potential to reduce GHG emissions but also offers a viable solution to mitigate Pakistan's ongoing energy crisis. There is a dire need to implement national programs in this regard.

Moreover, solar energy water pumping has many advantages, including non-dependence on conventional energy, easy operation and maintenance, uninterrupted water supply during the daytime, feasibility in remote areas, environmental benefits, and lasting panel life. In Punjab, smaller tubewells that run on solar energy have been installed in a few areas. The Punjab Agriculture Department has recently implemented an ADB-funded project titled, "Promotion of High Value Agriculture through Provision of Climate Smart Technology Package," for the installation of solar energy systems to operate high efficiency irrigation systems (drip irrigation) on 20,000 acres. Many farmers have also installed Solar Irrigation Pumps (SIP) through private investments. However, we do need to monitor our aquifers before installing more tube wells.

13.2.2 Water Security

According to a World Bank report, water insecurity is not the same as water scarcity. It is stated that while 32 countries may have low water availability per person compared Pakistan, it is worth noting that 26 of those countries have a greater average per capita Gross Domestic Product (GDP). Water security can be defined as the capacity or resilience of a society to access enough water both in quantity and quality terms. The basic parameters are per capita availability, which is largely driven by population growth, but it can also be defined based on physical, economic, and environmental access. Water security depends first and foremost on good governance, peace and political stability, transboundary cooperation and innovative financing.[1] In the nexus context we need to provide adequate water to meet current and future food needs and explore the possibilities of using available water to generate low cost energy that preserves the ecosystem. This is absolutely necessary to provide enough food.

The major challenge faced by Pakistan is to coordinate access and manage the water needs of various sectors—primarily agriculture, but also industries, municipal services, and the environment. The demand for water is increasing from all sectors as a result of population increase, economic growth, and climate change. Increasing demand highlights the need for better cross-sectoral management. Water security is compromised mostly because of poor water resource management, insufficient irrigation, and municipal water services, and a lack of additional domestic water supply and sanitation services. This poor management of water resources results in widespread environmental degradation, negative human health impacts, and sluggish economic performance, especially from irrigated agriculture. Yet water insecurity continues to increase because of a supply-oriented policy approach that has huge costs and uncertain benefits. This approach only veils the problem of water use inefficiencies (Batool & Mufti, 2020).

Water security largely depends on our future water use in agriculture. Agriculture mainly relies on energy consuming groundwater pumps to meet their irrigation needs. In Punjab, a million tubewells are reportedly installed, and energy use in pumping water and other farm operations account for almost one-fifth of the province's energy consumption. The complicated link between energy, irrigation water, and agriculture needs to be investigated with good quality data and policy interventions.

Finally, water and energy linkages are best illustrated by CPEC projects in Baluchistan, where water has become a major constraint to development in the Gwadar area, where the demand for water is reflected in the willingness to pay for this valuable resource. A typical water trader in semi-urban Punjab is selling a 4000-liter water tanker for Rs 1500 to 2000, while in Baluchistan, under CPEC, that same amount is being sold for Rs 26,000, indicating the inherent inefficiencies in managing water, energy, and economic development. The high cost of supplying

[1] https://www.unwater.org/app/uploads/2017/05/unwater_poster_Oct2013.pdf

Groundwater and the Nexus Approach: The Case of India

Groundwater is the most powerful component of the water, food and energy nexus. Groundwater is used by all kind of farms. Its usage has increased food production and has led to a significant increase in farm incomes for small farm holders. Groundwater extraction in India is largely fueled by electricity and diesel, and interestingly, the government provides subsidized rates on both to farmers. To a large extent, the level of the subsidy determines the depletion of the resource. In India, the depletion rate for groundwater is much higher as compared to Pakistan.

In India, growth in electricity consumption in the agricultural sector has outpaced growth in other sectors. While there has been a 12-fold increase in overall electricity demand, agricultural electricity demand has increased 25-fold from 1950 to 2010. India's net electricity subsidy is close to USD 9 billion and is rising year by year. Madhya Pradesh and Haryana are by far the biggest states to benefit, receiving more than 60% of the subsidy.

Agriculture is often blamed for the poor state of electric utilities as farmers receive poor quality service. Higher energy costs to pump groundwater will certainly hurt small scale farmers (and domestic users) that rely on it. It is unlikely that in the short term, sharp increases in the energy price will lead to sharp declines in food production, or rapid increases in world food prices, and also unlikely to help stop or reverse the ongoing degradation of groundwater ecosystems.

Overall, it may be said that India's irrigation sector is dependent on groundwater. Using more groundwater than can be sustainably recharged is leading to groundwater over-exploitation in most states. And much of the groundwater is pumped using electricity, which is subsidized by the government in most of the states.

Adopted from: Aditi Mukherji, IWMI, 2012, Innovations in managing the agriculture-groundwater and energy nexus Evidence from three states in India, Water for a food-secure world www.iwmi.org

water is pretty much embedded in the cost of energy used for deeper pumping or transporting water to end users.

The World Bank report has suggested a series of actions to set a course for the future.

1. Establish provincial-level regulatory frameworks for groundwater access and management.
2. Analyze the synergies and antagonisms between current national energy and water policy frameworks to inform policy implementation.
3. Increase coordination between government departments at the federal and provincial levels.
4. Strengthen the capacity for joint energy–water analysis that considers economic and environmental outcomes.

5. Expand solar and wind power investment where sensible. Explore the feasibility for small-scale hydro on irrigation canals. Continue major Hydel Energy Power (HEP) investments with a run-of-the-river focus.

13.2.3 Food Security

Many new interactions have emerged between the water, energy, and agriculture sectors that are poorly understood. In Pakistan, water and energy have traditionally been interlinked through hydropower plants and large multipurpose dams. But this linkage is equally important at the farm level, where huge irrigation infrastructure has been built to spur agriculture growth. It is also fundamental to look at the real benefits coming from the efficient use of water (more value per drop), which is very low in Pakistan compared to other countries. And we have not made the last-mile efforts to get the maximum benefits at the farm level from each drop of water. On the other hand, contemporary agriculture is becoming more and more water and energy intensive, both for farm operations, and to operate irrigation pumps. As mentioned above, a million tube wells have reportedly been installed in Punjab alone. The point is that large investments in water and energy sectors have yet to spur the potential benefits in agriculture.

Scarcity and overexploitation create complex challenges and limit agricultural productivity, making food security difficult to achieve. In 2018, the government approved a comprehensive national food security policy, as a most critical element of national security. The policy aims to enhance food availability, enable food utilization, improve food access and ensure food stability by promoting a sustainable food production and distribution system across Pakistan. The present shocks—whether because of climate change, COVID-19, or regional conflicts—has exposed the inherent weakness in the food system.

Chapter 10 highlighted that the five most likely risks facing the agriculture and water nexus are low productivity, extreme weather—too much or too little water—biodiversity loss, climate action failure, and poor management of our watersheds. To this we add the high energy costs that affect farm profitability and competitiveness. Regenerative Agriculture or Nature-Based Sustainable agriculture (NBS) can address many of these concerns simultaneously. Indeed, they offer a win-win situation by countering environmental degradation, biodiversity loss, and climate change (through mitigation and adaptation) and help to reduce the risk of disasters. While NBS may not always be the silver bullet, it is an important part of a strategy for long-term sustainable development, and a critical element in moving towards a decarbonized world (see Chap. 10). The approach is to produce green and healthy food, using natural centuries-old techniques of using nature-based nutrients (microbes) for plant growth rather than environmentally polluting purchased inputs. This meets food security goals through better water and energy management technologies and practices as detailed in Table 13.1.

Table 13.1 Smart Agricultural Practices and Technologies

Agricultural practices/technology	Food smart	Water smart	Energy smart
Mulching with crop residue/organic matter	*	*	*
Crop rotation to manage soil fertility	*		
Low or zero tillage		*	*
Cover crops		*	*
Low to no chemical fertilizers and pesticides	*		*
Organic fertilizers and pest control methods	*		*
Planting on raised beds	*	*	*
Precision planting	*		*
Crop rotations and diversifications	*		
Tree rows/hedge rows	*		
Integrating animals on the farm for manure	*		*
Water conservation works (earthen/masonry)		*	
Laser land levelling		*	*
Farm ponds		*	
Waterways or diversion ditches/channels		*	*
Soil or stone bunds		*	
Contour levelling/terracing	*	*	

13.3 Case Studies

13.3.1 Case Study 1: The Impact of Energy Subsidies in Oman[2]

At present, fodder crops are extensively cultivated in the Al-Batinah Region of Oman as cash crops for the domestic market and for export (or smuggling) to neighbouring countries, particularly to the UAE. The most dominant fodder crop is Rhodes Grass (RG), which comprises 9.34% of the total cultivated area in Al-Batinah. In contrast, dates are not as profitable. However, farmers seem to be torn between dates' supremacy as part of their cultural heritage and their deteriorating profitability due to costly operations, low prices, and the diminishing consumption of local dates because of their lower quality. On the other hand, farmers want to continue fodder production to feed their livestock and to maximize their profits. Farmers have also mentioned that the surplus income they gain from selling fodder helps in covering farm costs. This evolving cropping pattern is largely driven by subsidies provided to the energy sector.

Keeping in mind the cropping pattern of the region, if we look at the government support, we observe that subsidies may have increased and decreased for certain inputs, but the overall incentive structure has not changed much over time. Based on data from 2008, Fig. 13.4 shows the impact of energy subsidies on existing cropping pattern. The subsidized price of electricity is about 0.010 OMR per kWh, whereas

[2] Based on author work for FAO funded project in Oman.

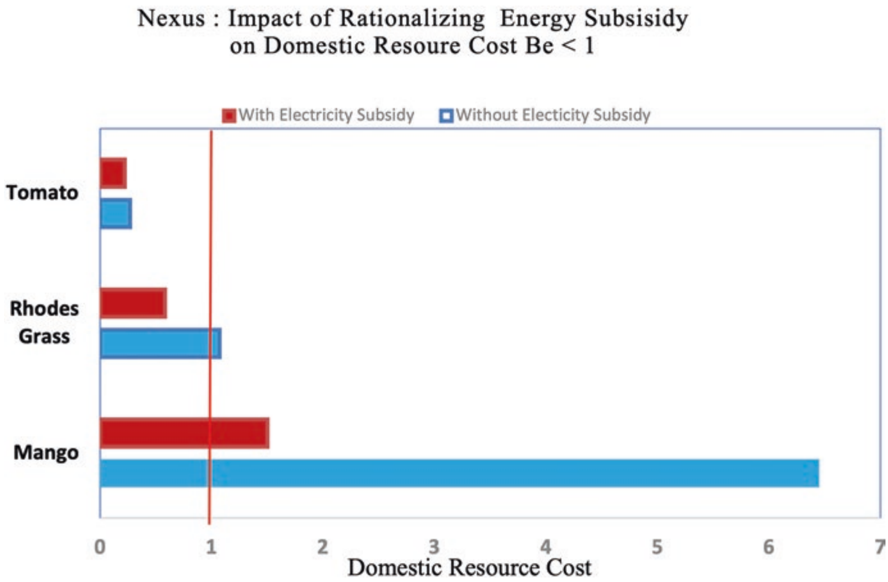

Fig. 13.4 Impact on domestic resource cost. Source: Authors' work and analysis

the actual production cost of electricity is about 0.035 OMR per kWh. The Domestic Resource Cost (DRC) has been used as an economic instrument that measures the comparative advantage of growing crops. In simple terms, it estimates the value added per unit of using domestic resources such as land, water and energy. The DRC was calculated based on commercial rates charged to other sectors. A number of policy scenarios were developed, to assess the impact of the actual production costs of electricity on economic efficiency measures or the DRC of each crop. It was revealed that lemons, bananas, potatoes, onions, dates, and rhodes grass are highly sensitive to changes in the electricity price because they consume a huge amount of groundwater. Therefore, the study highlights the importance of the WEF nexus in the sustainable growth of a strategic crop such as date palms. Energy subsidies are a key factor in the decline of date palm cultivation because farmers prefer to grow rhodes grass, since the water or energy subsidy provides incentive to grow much more profitable crops that also have high demand. If energy subsidies are eliminated, it would make lemons, bananas, potatoes, onions, dates, and Rhodes grass uneconomical to grow. The graph was recreated to show that with the removal of subsidy, only tomato production made economic sense since Rhodes grass and mangoes would have no comparative advantage.

13.3.2 Case Study 2: WEF Nexus—The Potential of Making the Thal Desert Bloom in Punjab, Pakistan

The Thal is a desert in the west of Punjab in Pakistan, with an area of five million acres with a topography consisting of large sand dunes. The desert comprises District Bhakkar and Layyah and some parts of District Jhang, Khushab, and Mianwali. This land has been barren for centuries. The soil is sandy and has a small water holding capacity. Conventional irrigation practices on this kind of soil are inefficient, leading to huge water wastage through seepage. The main agricultural activities in the region are cattle rearing, and the cultivation of fruits and gram (chickpeas). These commodities are important for a country that is losing potential export and import substitutions, since import costs can be minimized or eliminated if local production is incentivized. Pakistan imported USD 7 billion worth of food last year, with the most spending on pulses and edible oils. The huge potential for comparative and competitive advantage of growing *gram* has largely been overlooked in the region. If the country needs to spur growth using available water and energy with low cost options, then growing gram and citrus can be highly profitable. The cultivation of these high value commodities in the Thal Doab illustrates how the WEF nexus can benefit the country. Indeed, as seen below, farmers managed to turn a desert into green and productive land.

A farmer planted a grand orchard covering an area of 15 acres in the Thal desert, growing citrus, guava, and dates. The lush trees of the orchard are a contrast from the rest of the region. He adopted the technique of drip irrigation to become successful. With drip irrigation, fruit trees are getting only the required amount of water with minimal wastage. Overall, this region has an advantage in using drip irrigation since it doesn't require levelling of the undulating sandy soil, which would have required a huge capital investment. The upper layer of the sandy soil is very fertile, with no waterlogging or salinity problems. Also, the desert environment is less welcoming to insects, pests, and other diseases because of the extreme weather conditions.

In a few parts of the desert, canal water is rarely available. In those cases, farmers use groundwater since it is available at an appropriate depth and mainly recharged by the Indus and Jhelum rivers. The farmer mentioned above has also installed a pump to extract groundwater and he is operating the pump using solar energy. He proudly reported that using solar power has saved their lives as it is cost and environmentally friendly.

In short, the farmers are using low cost technology that is more appropriate for the region, driven by solar energy which saves costs in the medium term, reduces carbon emissions, and, most importantly, producing high value products both for domestic and export markets. This is a true nexus success story.

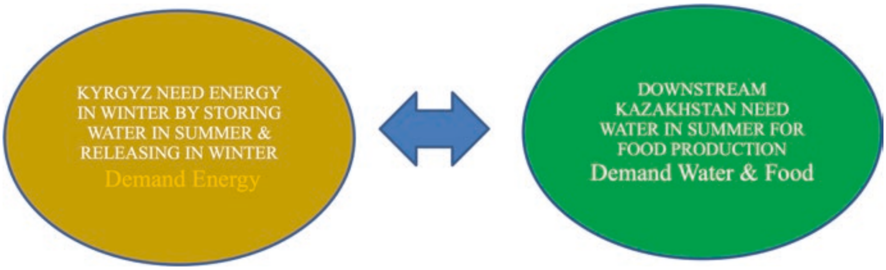

Fig. 13.5 Balancing energy, food, and water demands in Kazakhstan-Kyrgyzstan. Source: Authors' work and analysis

13.3.3 Case Study 3: Nexus in Central Asia—A Case of Transboundary Issues

The conflict between Kazakhstan-Kyrgyzstan highlights that our Central Asian neighbors are competing for scarce land and water resources. Before independence, water allocation and distribution was a national problem. But after the collapse of the Soviet Union, water resource management became an international problem. The relations of the five former Soviet Republics in Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) continue, predominantly, defined by water. The pre-independence water flow from the Toktogul reservoir followed an irrigation regime, with nearly 75% of the year's water released in the summer and the remaining 25% in the winter. This mostly met Kyrgyz requirements as the electricity generated was fed into the integrated Central Asian Power System to be used by all.

Now, with independence, the governments trying to improve water sharing agreements. The Kyrgyz Republic attempted to become self-sufficient in energy (releasing water in the winter) by storing water in the summer, when snow melts produced a larger flow of water. In the summers, Uzbekistan and Kazakhstan need water to produce food in their attempt to become self-sufficient in food production by storing water and constructing more storage. This was a clear case where demand and supply does match for the upper and lower riparian during wet or dry years (Fig. 13.5).

The proposed solution was to trade energy for water and food. USAID was largely instrumental in the Kyrgyz republic, Kazakhstan, and Uzbekistan concluding a new Long Term Framework Agreement in 1998, which has been renewed on an annual basis. Kyrgyzstan would be compensated in cash for not storing water during the summer and would be compensated with energy from Kazakhstan, using market-based pricing in the winters. Economic analysis clearly shows that the net benefit for the basin is higher when the reservoir follows an irrigation regime than when it follows a power regime. For these kinds of agreements to hold, there needs to be a continuing commitment at the highest levels among the affected riparian countries.

13.4 Conclusion

We should learn from past mistakes in which planning and policy development happened in silos with little to no coordination, in order to integrate nexus thinking in broader processes about sustainable development and natural resources management—international, regional, national, and sub-national.

Under this proposed paradigm shift, focused interventions will target specific technological, managerial, and operational issues. Resilient crops, which yield more with less water and energy use, are less prone to spoilage and require less energy to store. Also, moving from long to short supply chains promote local production (using less energy for transport and enhance local incomes). A case made in Chap. 10 is further supported in this chapter: that Nature Based or Climate Smart or Regenerative Agriculture provide the best options for a sustainable future.

Using renewable energy can not only benefit agriculture at the production stage, but all along the supply chain such as with the use of biogas and other post-harvest operations. Finally, we need to decouple agriculture and water sector's dependence on imported fossil fuel based energy. For example, rising food prices to a large extent because of rising energy costs. Transition to renewable energy sources will result in lower production cost and reduce our dependence on fossil fuel.

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Chapter 14
Pakistan's Transboundary Water Governance Mechanisms and Challenges

Erum Sattar and Syed Azeem Shah

Abstract In the realm of national and international treaties and water-sharing instruments, Pakistan faces significant challenges—that will only be exacerbated by the accelerating forces of climate change. In this chapter, we consider these at various scales ranging from international water law, bilateral treaties, and finally at the sub-national level across Pakistan's federal constitutional structure of provincial boundaries. We find that Pakistan is currently a relative non-participant in the developing norms of international water law and suggest that it begin to take seriously the potential power of being an active participant in the negotiation, development, and application of international legal instruments. Such participation, we suggest, will unlock the power of the collective in a way that can begin to address the governance challenges faced by the Indus Basin's four co-sharers: Pakistan, India, Afghanistan, and China. In the realm of bilateral water-sharing, Pakistan and India signed the Indus Waters Treaty 1960 (IWT/Treaty) under the aegis of the World Bank. While hailed and acknowledged as a significant success, that continues to hold despite rising challenges from significant upstream development of hydropower projects by India in its Kashmiri territory, threats to watersheds from deforestation, and the forces of global climate change, we find that the significant political challenges the IWT faces will only be exacerbated unless both countries begin to earnestly work on building on the aspirations of the Treaty at the time of its signing. And finally, but no less significantly, we find that interprovincial water-sharing relations between Pakistan's federating units remain mired in controversies that predate Independence in 1947 and suffer from rising distrust despite the adoption of the 1991 interprovincial Water Accord (Accord) and its operationalization through the Indus River System Authority (IRSA). We suggest that Pakistan needs to move towards a new normal in which one set and scale of norms and trust-building from the international

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to the regional (spanning the four co-sharing countries of the Indus River Basin: Pakistan, India, Afghanistan, and China) bilateral, and subnational become complementary processes. We hope our analysis contributes to such a cooperative and sustainable water future.

Keywords Water treaties · Water-sharing instruments · International water law · Watersheds · 1991 Water Accord · Water governance · Indus Waters Treaty

14.1 Introduction and the Indus' Geo-Strategic Context

14.1.1 Brief Introduction on Asian Water Data and Pakistan's Rising Water Insecurity

The Global Climate Risk Index for the nearly two-decade period from 1998–2018 ranks Pakistan as the world's fifth most vulnerable country to climate change. This means that the country has already experienced extreme weather events such as storms, floods, and heatwaves (Eckstein et al., 2019) with the summer of 2021 bringing both flooding and flash floods to the mountainous regions (perhaps unfortunately more common) but also bouts of extremely damaging urban flooding. Water is particularly vulnerable when its hydrological challenges are combined with unsustainable practices, as we'll see below, especially because the "Upper Indus Basin is understood to be one of the highest meltwater dependent river basins of the world. Estimates of annual water flows received from glacial as well as snowmelt range between 60–70% which, given current use patterns and the significant vulnerability this demonstrates to climate change, may not be understood as acutely as will be necessary going forward" (Mukhopadhyay & Khan, 2015). An earlier study of water supplies to the Chenab river, one of the Indus tributaries allotted to Pakistan under the IWT, found that the average snow and glacier runoff contribution to the annual flow of the Chenab River is about 49% (Ahluwalia et al., 2015). Given that even these minimum baseline estimates for the sources of the Indus' River waters are so high, its critical dependence on meltwaters—and the nexus with a rapidly warming global climate—leaves the country particularly vulnerable to larger forces that leave the country's water security vulnerable (at least as it is currently structured and understood—more on our proposed responses both nationally and internationally below).. Further, given that a study on the impacts of climate change on the hydrology of the upper Indus found that extreme discharges are very likely to increase in intensity and frequency in most of the upper Indus basin (Lutz et al., 2016), we suggest the country's planners begin immediately to tackle the significant disruption leading us to a new normal.

While developing countries, especially those participating in global climate change negotiations, continue to point out they are not responsible for the amount of carbon emissions in the atmosphere and should therefore not be responsible for having to help aggressively in the required mitigation; nevertheless, we suggest that it is in Pakistan's own enlightened self-interest to navigate a more sustainable water pathway forward. After all, it is Pakistan's policy makers who are responsible for the country's overall economic and social development, grounded in water and environmental stability. The facts are clear on the challenges we are facing, both now and in the future. Over the next few decades, as climate impacts accelerate affect both glacier and snow packs as well as monsoon patters, extreme flood events are likely to occur more frequently (Briscoe & Qamar, 2008).

An important aspect of the changing water flow patterns is that while currently earlier warming leads to increased and early snowmelt, later cooling will lead to decreased and delayed glacier melt in the near future. What is clear is that both snow and glacier melt regimes are changing such that the hydrology of the Upper Indus Basin will be altered and affect the timing of downstream water availability (Hasson et al., 2017). As will be clear when we discuss the IWT below, one of Pakistan's prime concerns was that the Treaty guard against any ability on the part of upstream India to alter the flow regime of the rivers assigned to Pakistan. It is perhaps ironic that forces much larger than any potential ability of India to alter the natural flow regime may be beginning to play out in the Indus in other ways. Tackling the threat from climate change may require greater efforts and larger coalitions between regional and global states than even the long and gargantuan task of negotiating the IWT between these two neighbors.

A comprehensive new study of the Hindu Kush Himalayan ("HKH") mountain range shows that it is severely threatened and its deteriorating condition will endanger the lives and livelihoods of the people who depend on it (Wester et al., 2019, 2020). This means that a water crisis is looming for 270 million people in South Asia who depend directly on the waters that come down from melting glaciers (Albinia, 2020). Under optimistic warming conditions, by the end of the century, a third of the Himalayan ice cap is likely to disappear; whereas with less dramatic cuts in carbon emissions, half the HKH ice cap is expected to disappear by 2100 and if carbon emissions are not cut at all, the outlook is even more bleak: two-thirds of the ice mass will be lost.—Further, the fact that the melting is accelerating is well-documented, with the rate of glacial melting having doubled since the turn of the millennium (Carrington, 2019a, b). Given the Indus' high dependence on meltwaters this will mean that Pakistan will need to learn to adapt to receiving significantly less water than it has historically and on which it has built a massive irrigation-based economy. With the country's population projected to rise to 403 million by that time, it will face increased pressures on a dwindling resource base—that should be of major concern to the country's planners (Gramlich, 2019).

The impacts of rising temperatures on the world's rivers, rainfall patterns, and sea levels in the twenty-first century is a critical challenge confronting humanity. Added to this threat are the rising demands that humans are placing on dwindling and increasingly disrupted supplies. There is a growing recognition that a significant number of people around the world depend on transboundary river systems that rise in the mountains and water the lowlands. A recent study on some of the world's major rivers – the Ganges-Brahmaputra-Meghna, Yangtze, and Indus rivers in Asia, the Nile and Niger in Africa, the Euphrates and Tigris in the Middle East, as well as the Colorado River in North America—found that just by the mid-century, 1.5 billion people living in the lowlands will depend on the flows of these river (Viviroli et al., 2020). While the challenges to water supplies are immense, it is crucial that the world come together to implement sustainable development strategies that will ensure that the water towers that so much of the world's population depends on endure.

The water-sharing challenges facing Pakistan in this climate are also immense. The country's overwhelming and singular dependence on the Indus river and its tributaries, which cross international and national boundaries, has been stated to be a significant danger, akin to a gamble on the long term health and viability of the rivers for its growth and stability (Lieven, 2011). Given the country's vast reliance on transboundary river flows, we must note another aspect of its geographical vulnerability: only about 46%of Pakistan's renewable surface water flows originate within the country. While a slightly higher percentage of groundwater is produced internally at 56%, nevertheless, the overall dependence on water produced outside the country is still high. At the same time, one of the gaps in transboundary water governance remains the lack of legal and political instruments to manage and share surface and ground water in an integrated way. Further, only an estimated 47% of the Indus' drainage basin lies within Pakistan, while the remaining 53% falls within India (39%), China (8%), and Afghanistan (6%), highlighting the need to collaboratively manage the waters across the Indus watershed (FAO, 2011).

With this challenging backdrop at the forefront of many minds, it is important to remember that all is not lost. Advancing technology is making it easier, more accurate, and more efficient to measure specific river flows and tackle the great unknowns of groundwater. Furthermore, courage can be taken from the steady progression of international norms dealing with water resources that are shared by two or more states. The concept of "law" on the international stage is significantly different from that of its siblings at the state level. At the international level, law is inseparable from the patterns, practices, and actions of individual states as they interact with other states. This unique legal structure is likely to become increasingly relevant to states, such as Pakistan, that share significant water resources with other states. The following sections will offer background on the Indus' historic and current context, international water law, and Pakistan's approach to international water treaties, followed by a detailed discussion of subnational and interprovincial water sharing with the country.

14.1.2 The Indus' Historic and Changing Geo-Strategic Context

The Indus context has, throughout history, always been much more about geostrategic interests than water per se. Going back to the nineteenth century, the British empire was focused on settling the fertile lands of the newly conquered Punjab to protect its domains from the advancing interests of Russia as part of the Great Game (Ali, 2014). It is important for us to be aware of these broader social forces which go back several centuries to contextualize the outside forces and actors that have, over long periods of time, played direct and indirect roles in how the waters of the region are shared and managed. At the end of colonial rule, with the advent of Independence and the Partition of the Subcontinent in 1947, Pakistan and India found themselves caught within the rational logic of the spread of the Indus' waters through the creation of what has become the largest contiguous gravity-fed canal irrigation network in the world, spread over 36 million acres (Bhatti & Kijne, 1990).

In its latest iteration, the Indus system continues to be a part of Pakistan's broader geo-strategic goals, but now one that fits within One Belt One Road (OBOR) and specifically the China-Pakistan Economic Corridor (CPEC). The overall objectives of these ongoing and multi-year collaborations is a more integrated economic region spanning Iran, Central Asia, Afghanistan, and potentially a broader group of countries. While much work on increasing connectivity is envisaged, Pakistan's ongoing water and power projects on the Indus, such as large storage dams and hydel projects, are a major site of collaboration with Chinese companies and contractors working in tandem with Pakistani firms (CPEC Secretariat, 2021). In particular, a significant joint-venture has been signed between Pakistani's Water and Power Development Authority (WAPDA) and Chinese firms for the construction of the flagship Dasu Dam 4320MW hydropower project (Kiani, 2019). While large infrastructure projects materialize over long periods of time, the challenges to collaboration between the two countries remain significant, with CPEC in the cross-hairs of non-state actors who continue to put the lives of contractors, workers, and ordinary citizens tragically at risk (DAWN, 2021). For the sake of greater national and regional stability, we hope that such forces can be stopped. As for the Indus specifically, we note that while water projects have always been both political and strategic, this new level of physical danger on these projects cannot be allowed to become the new normal.

14.2 Role of International Water Laws and Customary International Water Law

One of the core principles of international water law as it is recognized today is that of "no harm" (Zeitoun, 2015). Building on the concept of no harm, the theory of "limited territorial sovereignty (and integrity)" posits that while every riparian state has a right to use the waters of an international watercourse as it flows through the state's territory, such states are also under a corresponding duty to ensure that such use does not significantly harm other riparians and co-sharers (Salman, 2007). It may be safe to say that this principle—as it has evolved and been inspired by norms and equity-based rights—provides the foundation from which modern international water law is being constructed today (McCaffrey, 2019). The important point to understand that law—and especially international law—is not static. Law changes as humans and society evolve. This will undoubtedly be the case for international water law; and hopefully the arc of change will bend towards equality and justice such that each state is interdependent with others; such that they can move towards, as a first step, joint and equal management of the shared watercourse—or, barring that for the time being given political mistrust—that they can at least recognize that all have interests in shared watercourses that must be balanced against those of others in a judicious and fair way. At its core, limited territorial sovereignty means that each riparian has an equal right to use and an equal right not to be significantly harmed. While the no harm principle that is embodied in the case of limited territorial sovereignty seems almost paradoxical initially, (Salman, 2007), the existence of harm is defined as more than just a disruption to the status quo, and it is contingent on the use(s) of other riparians and the reasonableness of all riparians. As a legal theory in rooted in equity, limited territorial sovereignty does not provide a prepackaged test to be applied wherever a dispute may arise between riparian states, and requires tailored application on a case by case basis (McCaffrey, 2019). It is precisely this flexibility, which does not require adherence to other norms such as prior developed uses, that gives the theory its power to help craft tailored solutions. We suggest that this flexibility helps the four co-sharers of the Indus, Pakistan, India, Afghanistan and China—given that their history of political contentiousness does not always allow them a way to come together for the common good—find a slow and steady path to do so. Given that in recognition of its qualities, this theory provides the load-bearing structure for the major international instruments in operation today, the Indus' co-sharers can be confident that their efforts to build on it in their context are in line with the broader developing norms and direction of international water law. Two of these instruments will be the focus of the next Sect. 14.2.1.

14.2.1 The Helsinki Rules, the UN Watercourses Convention and Co-evolving International Water Law

Numerous international instruments are relevant to international water law; nonetheless, given the scope of this chapter, we have selected just two for analysis here. The two selected are arguably the closest embodiments of international water law as it is recognized today. One caveat that we would like to offer is that of the increasing importance of the International Law Association's ("ILA") "Berlin Rules," which were adopted in 2004. The Berlin Rules are significantly more progressive than the ILA's previous instrument, the Helsinki Rules, that are detailed below. Among other things, they address not only international watercourses but assert that these principles could be applied to internal watercourses as well (Salman, 2007). As may be clear given the particular focus of this chapter on both international and internal treaties governing water-sharing across borders and at different scales, we hope that soon countries will become active participants in the shaping and application of these international instruments, whether they are negotiating internal or external water-sharing agreements. —We feel strongly that this is the best possible pathway to resolve current problems and future challenges. In addition, this helps involve countries in the ongoing conversation about the development and future directions of international norms and instruments, and the benefits of being able to help shape the conversation that can only come through an involvement in the process and with seats at the table.

14.2.1.1 The Helsinki Rules

Central to the current consensus on international water law—though not fully reconciled—are the principles of "equitable utilization" and "no harm" or "no significant harm." Together, these principles constitute the backbone of the theory of limited territorial sovereignty. In 1966, the International Law Association ("ILA"), an international non-governmental organization founded in 1873 with the objective of, among other things, studying, clarifying and developing international law memorialized its decade-long work on international watercourses and enshrined the principle of equitable utilization as the backbone of international water law under the "Helsinki Rules on the Uses of the Waters of International Rivers" (the "Helsinki Rules"). The Helsinki Rules also gave prominence to the principle of no harm. While the Helsinki Rules do not specifically refer to the principle of no significant harm, the rules announce several factors by which equitable utilization can be established; and the no harm principle is envisioned within several of these factors (Salman, 2007; McCaffrey, 2019).

Importantly, although it is highly reputable, ILA is not a law-making body, nor is it an official branch of the United Nations. Therefore, the Helsinki Rules do not constitute binding legal obligations as a court ruling might (Salman, 2007). However, ILA's goal from the beginning was not to simply create international law; instead its goal was to *restate* and *develop* it as it stood, and in the direction it was going at the time (Daoudy, 2008). In general, when a scholarly body like ILA provides an international legal instrument like the Helsinki Rules, the true test of whether it is accurate or not comes from subsequent treaty and state practice. In this case, it is widely understood that the Helsinki Rules were pivotal in the codification and further development of international water law (Bourne, 1996). To reinforce this point and to highlight the indicative directionality and relevance of the Helsinki Rules, it is important to recall that until the adoption of the UN Convention 30 years later, they remained singularly authoritative and the most widely quoted single set of rules for both regulating the use and protection of international watercourses (Salman, 2007).

The Helsinki Rules are extensive, comprising six chapters, and, among other things, noteworthy is its inclusion of environmental considerations in Chap. 3, as well as its detailed procedures for dispute resolution in Chap. 6. Additionally, the rules were the first international instrument addressing groundwater (Salman, 2007) and given the critical need to begin to put in place sustainable groundwater extraction practices in the Indus basin, co-sharing countries must put this on their negotiating horizons. Having access to the Helsinki Rules and building on them becomes more important than ever. Some authorities have gone as far as to posit that the Helsinki Rules have already gained acceptance as customary international law. Given that the Helsinki Rules constituted the foundation for the U.N. Watercourses Convention this reading may be warranted and they remain an important resource for the understanding and interpretation of international water law today (Salman, 2015).

14.2.1.2 The 1997 United Nations International Watercourses Convention

Likely the most authoritative international legal instrument on international water law, barring, of course, specific treaties between individual states, the 1997 U.N. Convention on the Law of Non-Navigational Uses of International Watercourses ("Watercourses Convention") was the product of more than twenty years of academic, political, and practical endeavor (Salman, 2015; Oral, 2019). Under the auspices of the U.N., work on non-navigational uses of international watercourses began in 1970 following General Assembly Resolution 2669. Resolution 2669 tasked the International Law Commission ("ILC"). The International Law Commission was created by the U.N. General Assembly by adopting Resolution 174 (II) in November 1947. The ILC was created with the objective of promoting the progressive development of international law and its codification and was also asked to study and help develop the law of international watercourses. Once it was within its purview, the ILC dedicated the better part of twenty-three years to the subject of non-navigational uses of international watercourses during which the Commission appointed five different Special Rapporteurs, such that the lengthy deliberation naturally led to a significant metamorphosis in its views (Weiss, 2012). The end result was a comprehensive, and in some ways progressive, set of draft articles that were taken up, debated—modified—and then adopted by the U.N. General Assembly in May 1997. Article 36 of the Convention set the number of state ratifications, acceptances, approvals, or accessions at thirty-five before the Watercourses Convention would enter into force; and on May 19, 2014, Vietnam became the thirty-fifth party to the Watercourses Convention; as of September 2020, thirty-seven states are now party to it.

The significance behind this development is twofold. First, on a symbolic level, the global community now has a fully functioning treaty—binding to the state parties who joined—that addresses non-navigational uses of freshwater resources. Second, with the convention in force and a growing number of sates becoming party to it, international tribunals and even other non-state parties are more likely to turn to the Watercourses Convention for more than just mere compliance. The knock-on effect will likely be a quicker development of customary international law in the area of international watercourses and these developments themselves should be of significant interest to the Indus basin states such that, as we recommended, they should become willing participants in both its development as well as its interpretation. Critically, the International Court of Justice ("ICJ") has already endorsed the basic principles of "equitable utilization" and "no harm" found in the Watercourses Convention in both the *Gabcikovo-Nagymaros* and the Case Concerning Pulp Mills on the River Uruguay (*Argentina v. Uruguay*) (n 35) and the Case Concerning Pulp Mills on the River Uruguay (*Argentina v. Uruguay*) (Judgment). Important for Indus basin states to note is that, as international tribunals are beholden to their perceived legitimacy by states, a wider array of tribunals and dispute settlement bodies are likely to be emboldened to rely on the Watercourses Convention and its core principles as international law. Broadly, we reiterate that both legitimacy as well as bargaining power are likely to be enhanced for any given state when it is perceived as a responsible actor in the international realm and amongst other states. As the case of Pakistan's deep experience in the negotiations that led up to the signing of the IWT may make clear, the treaty came about with the active involvement of the international community, other nation states, and international organizations. It can finally begin to build on this experience to help develop and influence broader norms rather than being narrowly limited to IWT implementation and dispute settlement. Pakistan needs to to finally move towards and adopt a more expansive view of and approach to international water law and principles.

14.3 Pakistan's Approach to International Water Law

14.3.1 History—Colonial Roots—The Control of Surface Water

We will briefly lay out the historically structured roots of the present overreliance on the basin that suggests that absent significant changes in practice, the stress on the basin, its peoples and ecosystems is only going to get more acute.

Starting in the nineteenth century, British colonial rulers laid the roots of the present system of surface water control in the Indus basin that resulted in the adoption of the Canal and Drainage Act 1873 ("CDA/Act") in the Indian Subcontinent (Ali, 2014, 1988). The colonial-era legislation that Pakistan inherited at Partition in 1947 remains the extant law of the land in the seventh decade after independence for the apportionment of canal water in the country. It is this Act that set modern-day Pakistan on its present trajectory of having the world's largest contiguous irrigation network. Given the sheer scale of the irrigation network, it may be easy to forget that the FAO characterizes approximately 92% of the country's area as semi-arid to arid, which means that by definition it faces extreme shortages of precipitation (FAO, 2011). Further, it is important to remember that it was Partition that also rent asunder the irrigation network, which was originally designed to be a single interconnected unit, thus creating Pakistan's largest transboundary water sharing and governance challenge.

14.3.2 Pakistan's Participation in International Water Law and the IWT

Since gaining independence in 1947, Pakistan has been an active player within the realm of international law; its dispute with India over the Kashmir region was first taken up by the United Nations Security Council in 1948 (Korbel, 1949). In the realm of international water law, Pakistan's downstream geographic location makes it the lower riparian with respect to its two largest international river systems—the Indus and the Kabul. And, as one might expect, Pakistan has approached international water law primarily through the lens of its geographical location vis-à-vis upstream states since the control of territory to a large extent determines and influences the international water law doctrines that a state adopts and advances (Haines, 2016; Sattar, 2017). However, even from its earliest days, when IWT negotiations had not yet begun and the Indus Waters dispute was recognized as being a significant threat to regional and global peace, the limits of Pakistan's claims to the uninterrupted flow of the waters of the Indus by virtue of its prior developed uses were recognized. The prime limitation was that, a sovereign state, in this case India, would have to submit to the legal authority of another entity. In international water law, politics is always a reality that states wanting to invoke international legal principles must contend with (Lilienthal, 1951).

Notwithstanding, Pakistan has not always taken an absolutist position on internationally shared waters, with the IWT as a hallmark example. Commonly touted as the most successful international instrument between Pakistan and India (Bhatti & Farooq, 2019), the IWT predates both the Helsinki Rules and the UN Watercourses Convention. Yet time and again, the IWT has been noted for its equitable apportionment. Of particular relevance, Article IV memorializes several of the current core principles of international water law. Article IV addresses the two main principles of "equity" and "no significant harm" (or "no material damage" as noted in the IWT). Article IV also touches on the increasingly relevant concept of "consultation," and it even hints at limited environmental protection. Furthermore, the IWT established a permanent commission under Art VIII to serve as an agile conduit of cross-border cooperation. Finally, the IWT has robust dispute resolution measures outlined in Art IX, which have been employed on several occasions, as seen below. While it is clear that the IWT aligns for the most part with the norms of international water law as they are currently being developed, its provisions have been found wanting in terms of adaptability to changing conditions. Perhaps unlike the aspirations of its negotiators and authors, the IWT is currently facing significant threats.

Overall, the legal and political instruments to manage rising water-sharing complexity remain limited. And while Pakistan is dependent on river flows across international borders it has concluded a treaty only with its eastern neighbor, India, in the form of the iconic IWT. Given that there is only one extant treaty, it necessarily forms the foundation of the country's institutional edifice for transboundary surface water governance, despite some significant gaps that have recently become more obvious. In the case of transboundary water agreement with India, water experts from both India and Pakistan hold the IWT as a success story on water cooperation. At its inception, the IWT certainly held more hope and even until relatively recently, Pakistani experts have agreed that the treaty was a good and stable instrument that, even with its ups and downs, has held up well over time (Mahmood, 2018). There has also been general consensus that for the issues that were perhaps less well understood at the time of its signing—such as the importance of groundwater aquifers, transboundary pollution, and climate change—a consensual dialog process could be put in place to widen the scope of water cooperation between the neighbors (Suhardiman et al., 2017).

Essentially, because the treaty was designed in 1960, it does not provide for changes in water availability due to climatic changes, increasing demands, environmental flows, groundwater development, and technological advancements. These all have changed considerably since 1960 and there is a need to strengthen and extend the IWT, particularly its sections on future cooperation that can be significantly expanded to cover new and emergent areas such as groundwater governance (Lotia & Alam, 2016). On a broad level, the IWT fails to address two issues; the division of shortages in the dry years, when flows are almost half as compared to the wet years; and the cumulative impact of storage on the flows of the Chenab River into Pakistan. These uncertain supplies would further be affected by climate change and need to be studied. The experts are also of the view that it would not be in the interest of either country to reopen the treaty or challenge its validity; but that they should begin a serious and sincere dialogue with a new spirit to resolve issues in light of new highlighted dimensions of water policy (for example, the need for environmental flows) (LEAD-Pakistan, 2016). We must, however, acknowledge that there is a significant gap between the high hopes of water experts and any potential progress on the IWT, because of the mistrust and political tensions between the two countries.

Coupled with growing human reliance on available supplies, an issue of quantity, there is also a growing appreciation of the fact that the quality of water, even in the upper reaches of the mountains, is under threat and being increasingly degraded (McNeil Jr., 2019). While the coupling of these issues goes to the heart of the international and national transboundary water challenges Pakistan faces, instruments in place to address them remain limited mostly to the regulation of surface water flows without dealing with issues such as underground aquifers or water quality. Meanwhile, disruptions in the South Asian monsoon as a result of climate change are still unaddressed in existing water sharing agreements (Ashfaq et al., 2009). These gaps in regulation typify the IWT, especially since it was negotiated and operates in a climate of geopolitical distrust that continues to deteriorate.—

While there are significant ongoing and anticipated impacts of climate change on the stability of the IWT that have consequences for Pakistan, the country must remain open to recasting transboundary water issues as an opportunity for cooperation, not conflict. Both Pakistan and India should see this as an opportunity to bilaterally benefit and a catalyst for broader regional cooperation. There are increasing calls for IWT to be more structurally enhanced, since the attrition in a project-by-project contestation between the two neighbors does not lead to a more stable relationship capable of withstanding growing pressures (Qamar et al., 2019).

On Pakistan's western border, efforts have been underway with Afghanistan to build and improve upon the IWT model for a cooperative framework. These efforts have involved experts from both countries along with external experts and agencies who are familiar with both countries' water systems (Ahmad, 2010). Given how little scientific and technical information that all parties had about the Kabul river, work has been undertaken to study and model it (Shah, 2015). While work has been ongoing to reach a consensual water-sharing agreement with Afghanistan (Shah, 2017), recent dramatic changes in the country's governance has put these efforts on hold as the political situation, as of 2021, is still unclear. However, as the governance landscape within Afghanistan becomes clearer over the coming months, Pakistan must make efforts to engage with Afghanistan both through experts and through official channels to draw up an agreement similar to the IWT which is both prudent and flexible, and which takes into account the already-evident reality of reduced supply.

14.3.2.1 The Growing Threats to the Indus Waters Treaty 1960

As with real estate, location matters. So too does it with water, since it can be controlled as it flows downhill across the land. The territorial division of the subcontinent and the emergence of the two nations of India and Pakistan in 1947 meant that India, as the upper riparian on the rivers that flowed into Pakistan, staked its claim to the waters of the rivers that flowed through the territory in its control—including the disputed territory of Kashmir. From Pakistan's perspective, its claim to unrestricted flows of water was based on long-established use. As Haines has described, territorial Partition meant that both countries began to employ competing "hydrologics" to justify their claims to the Indus rivers (Haines, 2016; Sattar, 2017). Of the six main rivers of the Indus, the three Eastern rivers (to be clear: those located in the East, not those who flow east) were allocated to India, and the three western rivers allocated to Pakistan. India was allowed specified uses but without diminishing or changing the downstream flows. India's upstream position and growing energy demands since the IWT's adoption have meant that in the last two decades, the IWT's dispute settlement mechanism has been called upon to settle competing claims more than ever (Briscoe, 2010; Hill, 2013). Within the framework of the resolution that resulted in the sharing of the Indus waters between Pakistan and India, there is no mention of Kashmir—an omission that has caused much concern given the power projects India has been building there without consulting the local population, and which is even more concerning because of the troubling change to its constitutional status in India in 2019 (Dar, 2012). Further, within Pakistan the effects of the IWT have led to deeply contested interprovincial water relations, as we detail below.

Ashfaq Mahmood, a retired federal secretary from the then Ministry of Water and Power in Pakistan was involved with both the Baglihar and Kishanganga disputes about hydropower development in India. These were high profile and contentious cases that were contested under the IWT dispute resolution mechanism (DAWN, 2011; Aquapedia, 2015). Mahmood has published a deeply revealing practitioner's insight into the transboundary working relations of Pakistan and India (Mahmood, 2018). He identifies mutual distrust between the neighbors as the fundamental factor that hampers the work of the Permanent Indus Commission, which has one commissioner each from Pakistan and India. He explains that India has already been operating 43 run-of-the-river power plants on the western rivers and that after the decisions made in both cases, India and Pakistan should have enough clarity on the treaty to operate in goodwill.. For Mahmood, a treaty, as an instrument of international law, is an object of its time. As such, because the immediate impetus for the IWT was the stoppage of canal waters by Indian Punjab, it is entirely focused on structural mechanisms to prevent any changes to the flow regime by upstream India that would adversely affect downstream Pakistan. In the meantime, the treaty does not govern significant aspects such as groundwater quality and quantity, surface water quality, the impact of dams on sediment flows, environmental impacts, and overall considerations about the Indus' watershed. Given that demands are set to increase as supplies dwindle, these concerns need to be tackled urgently and with sincere commitment. And Mahmood thinks that they can be. For Cohen, the "Indus Waters Treaty is a model for future regional cooperation, especially on energy, environmental concerns, and even the management of the region's impressive water resources," especially as it "provides for technical consultations, experts meetings, and a system of appeal and grievance adjudication"(Cohen, 2004). The "Indus which rises in Tibet and flows some 2,800 km through India and Pakistan to its mouth in the Arabian Sea, has been the subject of controversy since the Partition of British India into the dominions of India and Pakistan" (Mohanty & Khan, 2005). Nevertheless, we believe that recent mistrust in the broader Indus region can be overcome, in the same way that the IWT was agreed upon.

14.4 Pakistan's National and Interprovincial Water-Sharing Framework

Pakistan is an arid country where water is a limited resource, and thus the irrigation sector is facing problems of water scarcity. Pakistan's population has grown exponentially during the last few decades, and the latest 2023 census with final figures yet to be finalized puts the country's population at a whopping figure of just shy of 250 million. This rapid population growth has also resulted in increased water demands. Per capita water availability has decreased (to 1080 m^3) by almost 5 times of what it was in 1947. One estimate suggests shortage of water to further increase from 28 Million Acre Foot (MAF) in 2015 to an estimated 41 MAF in 2025. Despite water scarcity issues, the agriculture sector, which includes crops, livestock, fisheries, and forestry, accounted for 19.8% of Gross Domestic Product

(GDP) in 2015–16 and is a source of livelihood for 42.3% of Pakistan's labor force (Government of Pakistan, 2016). Approximately 27% of Pakistan's land area is cultivated. In addition to economic development, water availability impacts food security and quality of life at all levels. With a scarce resource facing increasing demand, water management has turned into a strategic challenge for the government. With agriculture playing a significant role, both economically and in terms of food production, resolving water scarcity issues through better water management and utilization is both urgent and important.

In addition to its economic impact, this scarcity of water may also further exacerbate interprovincial disputes regarding water distribution. In a federation such as Pakistan, issues over water distribution between the different federating units may, in turn, trigger political and social crises. That is why it is critical that the different provinces appreciate the significance of water scarcity as a joint challenge and devise collaborative approaches to address this problem for the future of Pakistan. To do this, however, requires a sociopolitical environment of mutual trust and understanding. This is important because multiple projects such as the China Pakistan Economic Corridor (CPEC) have become bogged down by trust issues between Pakistan's different federating units.

14.4.1 History of Interprovincial Water Issues

Water related issues among provinces date back to the pre-independence period. Therefore, understanding the history of these disputes is important if we are going to resolve them. Interprovincial water disputes started before Partition, during British colonial rule, with the construction of the Sutlej valley canals project in 1932. Issues between Sindh and Punjab were further with the construction of Sukkur Barrage in 1935. The (British) government allocated specific water rights for both Punjab and Sindh (from the river Indus), giving priority to Sindh's claims on the river. This (British) arrangement remained intact until 1970 when the federal government decided to allocate water on an ad hoc yearly basis, a decision that Sindh viewed as favoring Punjab. The issue of interprovincial water distribution received attention again when the proposal to build Kalabagh dam was put forward in 1984. Punjab was the only province in favor of this proposal. Khyber Pakhtunkhwa (KPK) opposed it not because it feared a reduced water supply but because of environmental and physical effects. Balochistan and Sindh opposed the proposal because of the fear of diminishing water supply. The following committees and commissions were appointed by the governments to determine the distribution of surface water amongst the provinces:

1937 Anderson Committee
1945 Rao Commission
1968 Akhter Hussain Committee

1970 Fazal-e-Akbar Committee
1976 Indus Water Commission (Anwar Ul Haq Commission)
1983 Haleem Commission

While these commissions and committees submitted their reports and recommendations to resolve water distribution issues no agreement was reached until 1991, when all four provinces (through the facilitation of the federal government) agreed on a formula to distribute irrigation water. This is known as the Water Apportionment Accord (WAA) of 1991.

The WAA of 1991 is a consensus document between all the provinces of Pakistan. It is the world's largest interprovincial water allocation plan by volume, as it apportions 144.749 Gm^3/year (billion m^3/year), more than the Krishna River Basin (58.34 Gm^3/year) and the Yellow River Basin (58 Gm^3/year). The WAA of 1991 has proved to be a major milestone in the efforts to fairly distribute water in the IBIS as well as in deciding about canal water entitlements between provinces. The accord performs these three key functions:

(a) Distribution of water between provinces, based on historical water flows,
(b) Distribution of excess water (caused by floods), and distribution of water shortages,
(c) Provision of minimum flow of water to the sea, to protect the Indus river delta.

The importance of the WAA 1991 is evident from the fact that although there are differences between provinces about the interpretation and implementation of the accord, all of them agree that this accord must be upheld and used to resolve water disputes.

It was agreed in the WAA 1991 (Para 13) that an authority would be established to make sure that the water distribution between provinces takes place as per the accord. Hence, the Indus River System Authority (IRSA) was established in 1992 through an act of parliament. Its mandate is to regulate and monitor the distribution of the IBIS in accordance with the WAA 1991 (Rajput 2011). The authority has five members——one one from each province, plus one from the federal government—who rotate the chairmanship each year.—Decisions are made by majority vote. Two committees (advisory committee and technical committee) have been formed to facilitate IRSA's decision making process. In case a province is not satisfied with a decision that IRSA has made, it can appeal to the Council of Common Interest (CCI).

CCI is a constitutional body—formed under the 1973 constitution—mandated to resolve conflicts between the federation and a province, and between two (or more) provinces. It works under the Ministry of Inter-Provincial Coordination. CCI consists of eight members that include the Prime Minister of Pakistan, four provincial chief ministers, and three members—generally federal ministers—nominated by the prime minister. The provinces can make a reference to CCI if they feel an IRSA decision has violated their rights, but this has rarely happened.

14.4.2 *Key Features of the WAA 1991*

The WAA 1991 apportions the water among the four provinces as per Table 14.1. The figures have been converted to Gm^3/year (billion m^3/year) to conform to SI units and the proportions for each province are calculated. The total volume to be apportioned is the 144.749 Gm^3/year (baseline volume) as per clause 2 of the accord of which 3.7 Gm^3/year is top-sliced for the civil canals in the province of Khyber Pakhtunkhwa. The remaining water (141.049 Gm^3/year) is then distributed among the provinces over two seasons. In order to identify key issues in the implementation of the accord, there has been some literature/data available from secondary sources, but we preferred to directly contact the key stakeholders and gather primary data and synthesize it in a format that is easy to understand and propose the way forward.

14.4.2.1 Key Issues as Identified by Stakeholders at the Interprovincial Level

Given the contentious nature of water allocation and distribution issues in Pakistan, we interviewed multiple officers of irrigation departments from all four provinces. This was done to make sure that the perspective of all important stakeholders was included in this chapter. Our initial set of interviews in Punjab led us to an important conclusion: officers' responses were remarkably similar about other irrigation departments. In fact, hardly any new information was gleaned beyond the first couple of interviews. This pattern of responses was repeated in other provinces as well. Overall, we conducted a total of 17 interviews (5 in Punjab, 6 in Sindh, 4 in

Table 14.1 Apportioned Volumes (Gm^3/Year) from Clause 2 of the Accord

	Summer season (April–September)		Winter season (October–March)		Annual	
Province	Volume	Proportion (%)	Volume	Proportion (%)	Volume	Proportion (%)
Punjab	45.725	32.42	23.276	16.50	69.001	48.92
Sindh[a]	41.864	29.68	18.280	12.96	60.145	42.64
Khyber Pakhtunkhwa non-Civil Canals	4.293	3.04	2.837	2.01	7.130	5.05
Khyber Pakhtunkhwa Civil Canals[b]	2.220	–	1.480	–	3.700	–
Balochistan	3.515	2.49	1.258	0.89	4.774	3.38
Civil Canals top-sliced volume	2.220	–	1.480	–	3.700	–
Apportioned baseline volume	95.397	67.63	45.651	32.37	141.049	100.00
Baseline volume	97.618	–	47.131	–	144.749	–

[a]Including already sanctioned Urban and Industrial uses for Metropolitan Karachi
[b]Ungauged Civil Canals above the rim stations

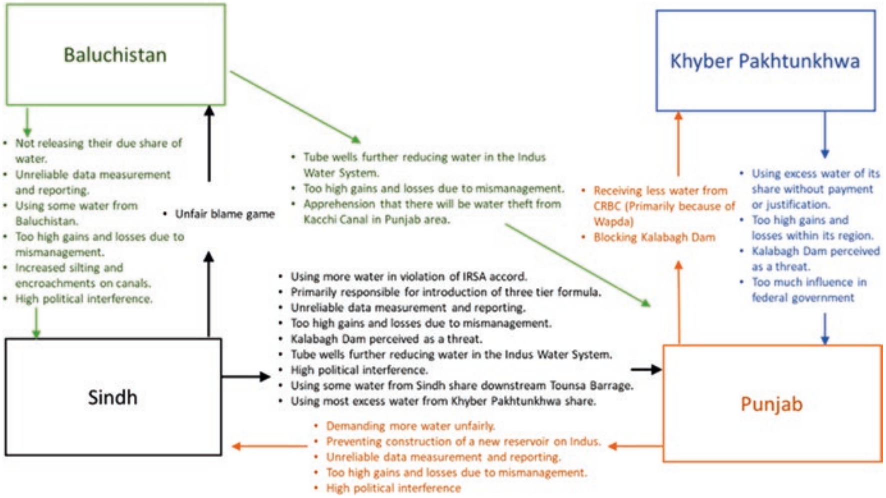

Fig. 14.1 A summary of key water related interprovincial trust issues. (Source: Authors' own interviews with officials)

Baluchistan and 3 in Khyber Pakhtunkhwa). To make sure we had captured the key interprovincial concerns of all four provinces, we also compared the key findings of our data with relevant research and gray literature on hydro-politics within Pakistan as an additional quality check. We summarize the key interprovincial issues that emerged from the data we gathered in the Fig. 14.1. It represents the views shared by irrigation professionals from each province about the other provinces and provides a comprehensive picture of the state of mistrust amongst the provinces. We have also presented the summary of the key issues that each province has with the federal government and IRSA in Fig. 14.2. We will now discuss these issues at each provincial level and then devise a way forward in tackling these issues in the subsequent section.

Perspective from Punjab

At the provincial level, Punjab is primarily concerned about Sindh and believes its demands of excess water are unfair. Punjab also think Sindh blocks the construction of new dams on Indus. Punjab contends it is open and transparent about sharing data on its canals and barrages while Sindh misreports and hides data. Sindh's water accounting shows too extreme gains and losses and use political pressure to resolve technical water distribution issues. Punjab also believes the KPK does not support the construction of the Kalabagh Dam just as Sindh doesn't.

At the federal level, while Punjab appreciates the role of IRSA, it also believes it lacks the capacity to effectively monitor the flows in the IBIS and that it needs

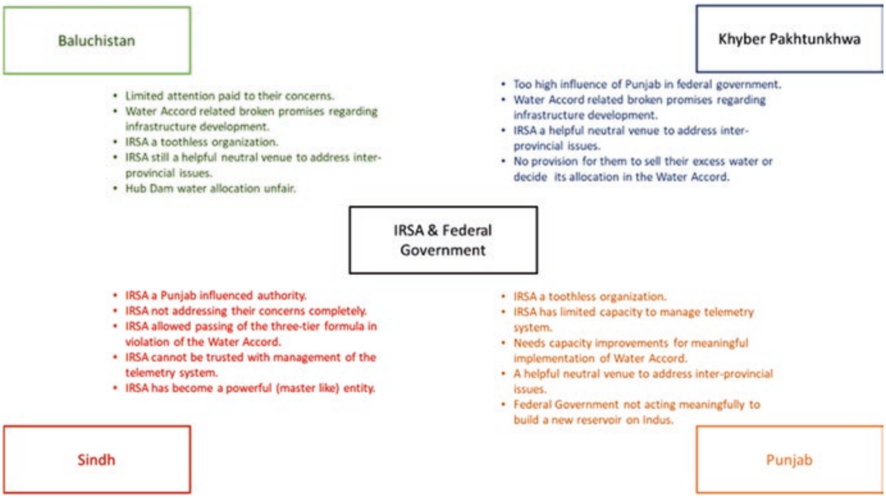

Fig. 14.2 A summary of key provincial issues with IRSA and Federal Government. (Source: Authors' own interviews)

significant capacity building. Punjab blames the federal government for not building enough storage to deal with water shortages.

Perspective from Sindh

At the provincial level, Sindh has major issues with Punjab. Sindh believes that Punjab solely responsible for the introduction of the IRSA operational rules of 2003 (Three Tier Formula) which it thinks is disadvantageous for Sindh. It also believes Punjab steals its water and misreports discharges, resulting in gains and losses that are too much. Sindh is particularly against the construction of any new reservoirs on the Indus. They are also against the excess use of groundwater in Punjab through tubewells. Sindh believes Balochistan's accusations are unfair and not grounded in reality.

At the federal level, Sindh believe IRSA to be a pro-Punjab authority which does not address their genuine concerns. It also believes IRSA accepted the three tier formula which favors Punjab. There is a severe lack of trust in IRSA particularly when it comes to the monitoring of discharges and telemetry system.

Perspective from Khyber Pakhtunkhwa

At the provincial level, KPK blames Punjab for benefitting from its unused share of water without providing it any compensation. It also acknowledges Punjab's disproportionate influence at the IRSA level are against the construction of the Kalabagh

Dam. It also believes Punjab is reporting gains and losses that are too high and questions the water accounting.

At the federal level, KPK trusts IRSA but at the same time it believes that IRSA's decisions are influenced by Punjab. It blames the federal government for not developing enough infrastructure in KPK so that it can fully utilize its share of water, which in turn benefits Punjab.

Perspective from Balochistan

At the provincial level, Balochistan has serious concerns regarding its share of water which it receive from the province of Sindh. It blames Sindh for not releasing its due share of water and misreporting actual discharges. It is also worried about the gains and losses reported by Sindh and the poor maintenance and high siltation of canals in Sindh. It believes that Punjab extracts a lot of water through tubewells and incur huge gains and losses in water accounting. It is also worried about receiving its due share from Punjab through the Kacchi canal.

At the federal level, it believes its concerns receive less attention. Like KPK, it blames the federal government for not fulfilling its promises on infrastructure development in Balochistan. It also claims that it does not receive its fair share from the Hub dam.

14.4.2.2 Interprovincial Water Issues of Pakistan—A Network of Distrust and Suspicion

In this section we present the common themes that emerge from the data of interviews we have analyzed so that we can devise a way forward in tackling these issues to see a more harmonized relationship between the provinces of Pakistan.

First of all, there are major issues of integrity. Integrity implies that organizations within a network believe that other organizations behave in an open, honest manner and will abide by the terms of any legal or moral contracts between them. We identified three primary sub-dimensions of integrity in our data; openness, credibility, and promise keeping. Provinces are not open in sharing the data on water use, water flows, and losses and gains incurred in their provinces. On this account, Punjab is suspicious of the lack of openness by Sindh's irrigation department about its water usage data. Almost all representatives of Punjab's irrigation department mentioned this as a critical factor for continuing lack of trust between Punjab and Sindh. Sindh on the other is unequivocal in its claim of Punjab using the Three Tier formula devised by IRSA against it. A critical dimension of trust within interorganizational networks and collaborative governance arrangements is the belief that other organizations are providing honest information about their conduct. This dimension is, however, mostly missing among the four provincial irrigation departments. Almost all representatives of irrigation departments were concerned about the reliability of other provinces when it comes to reporting correct data about water flow and discharge. Another important theme is what we call the lack of benevolence on the part of all provinces. All the provinces are working on maximizing their self-interest and nobody is willing to accept sub-optimal outcomes for the benefit of the overall IBIS. This overall lack of benevolence and perception of behavioral fairness is limiting the development of collaborative management of water and potential solutions to longstanding problems. There are also questions regarding the competence of IRSA in monitoring the flows of the four provinces. All the provinces question the capacity and capability of IRSA to undertake fair monitoring of flows and entrust a third party to carry out such a task.

Another critical theme identified during our research pertains to the significance of the larger political ecology for the perspectives of different provincial irrigation departments towards each other. It is critical to remember that the provincial irrigation departments operate within the larger political ecology of Pakistan, which is characterized by a low level of trust among the federating units. This larger ecology of distrust provides a readily available frame of reference whenever there is a conflict over water distribution within the different provinces. During our research we found that there is limited, if any, direct interaction between the employees of the different irrigation departments during their routine activities. In most cases, the irrigation department officers only interact with their peers from other provinces when there is a conflict over water distribution. It was interesting to note that in almost all interviews, the interactions remembered by irrigation department officers with their peers in other provinces were over conflicts. For example, a senior irrigation department officer from Punjab mentioned that in the last ten years, apart from IRSA related meetings, he had visited Sindh only once to meet his peers, and even that visit was for a water distribution conflict. In fact, independent of IRSA, there are hardly any fora for direct interaction between the different irrigation departments.

14.4.2.3 The Way Forward

Our analysis indicates that trust among the different provincial irrigation departments is at a very low level. Moreover, the significance of structural and ecological factors is also critical to take into account before designing any measures to address the high level of distrust between provincial Irrigation departments. While we share below some thoughts about possible ways to improve interprovincial trust among the irrigation departments, our findings suggest that ultimately, development of trust is a complex long-term goal which is unlikely to be achieved through short-term ad-hoc measures.

Open, Reliable and Accurate Data Availability Needs to be Ensured

The availability of open, reliable and accurate data about water flow and discharge is a critical requirement for trust between the different provincial irrigation departments. In this regard, the following policy options may be explored:

- Installation of a reliable telemetry system is needed to provide objective and neutral measurement of water flow and discharge at all key sites on the Indus Water distribution system. This system should be state-of-the-art and not have the hardware limitations of the system installed previously.
- Almost all provincial irrigation departments think that, by itself, this new system will have limited impact on the trust level between different provinces. That is why, it is critical that this system is managed by an organization or authority which is trusted as neutral, fair, and competent by all provincial irrigation departments. Our findings suggest that IRSA and WAPDA are unlikely to be considered such authorities. That is why, it is critical to explore outsourcing or partnering with credible private organizations as legitimate policy options for managing this new system.
- The formulae and techniques for measuring water flow need to be interpedently verified to make sure water flow and discharge measurements are accurate and reliable.

Capacity Building and IRSA Reforms Are Needed

There is a serious need to rethink the role and mandate of IRSA. At present, IRSA is considered to be a partisan organization by Sindh and a toothless authority by others. There are also questions about the capacity of IRSA to address key issues related to the implementation of the Water Apportionment Accord 1991. The following measures may be considered in this regard:

- Improving the technical capacity of IRSA to manage, monitor, and evaluate implementation of the Water Apportionment Accord in its letter and spirit.
- Improve IRSA's implementation powers. As noted above, multiple provinces feel that IRSA has limited authority in cases where a province fails to cooperate with it. If this situation is not rectified, it will gradually result in a situation where every province will start looking towards the CCI as the only legitimate forum to resolve water disputes. This will not only increase distrust and further politicize these issues but will also result in IRSA becoming merely a symbolic forum.
- IRSA and CCI must make sure that all provisions of the Water Apportionment Accord 1991 are implemented in letter and spirit. Despite its limitations, the Accord enjoys almost unanimous support from all provincial irrigation departments. In fact, almost all major trust related problems emanate from perceived deviances from the accord.
- IRSA also needs to oversee a meaningful, objective annual water audit to increase transparency, accountability, and perceptions of fairness in the Indus water distribution system.

Educate for a more Harmonious Political Ecology of Water Distribution

One of the major reasons for a lack of trust between the provincial irrigation departments is the general lack of brotherhood and harmony among the federating units. Consequently, it would be naïve to expect these departments to develop a high level of trust within a larger socio-political ecology of distrust. While ultimately it is a pluralist endeavor, irrigation departments and the organizations working with them can take the following measures to do their part in addressing this concern:

- Awareness seminars for the public, academia, and press in which representatives of all four provincial irrigation departments participate can be helpful in dispelling some popular misconceptions about water distribution issues.
- It is critical to develop non-partisan, accessible booklets in local languages that present objective figures about water distribution and also include the perspective and legitimate concerns of all four provinces. These booklets, which should easily be available in print and electronic form, should be disseminated widely to make sure the larger public is aware about the different sides of this issue.
- Water distribution issues have been used to spread further vitriol in society against other provinces. Media, politicians, and irrigation department officers all have been complicit in this at various times. It is critical to use these forums for the discussion of technical matters, not to further divide an already acrimonious society. Provincial irrigation departments may consider developing a code of conduct in this regard which prevents officers, other than those officially sanctioned, to talk to the popular press about such conflicts.

Increase Overall Availability of Water

There is a dire need to increase water availability in the Indus Water Distribution System. Scarcity inevitably creates conflict over limited resources and that is why, in the long-term, that is the only way to address trust issues between different provinces. This can be done by pursuing one or both of the following policy options:

- Minimize gains and losses: A coordinated effort to minimize losses throughout the Indus Water distribution system is needed. While it might be unrealistic to hand out penalties to the provinces for reporting high gains and losses in the current political ecology, it can be explored as a viable option if the situation does not improve through other measures. These penalties, however, should be introduced only after a reliable telemetry system is installed and managed in a fair manner.
- Intraprovincial financial or job-related penalties should be introduced for regions within a province that fail to improve (or worsen) their losses.
- A regular, meaningful water audit done by a competent and reliable third party can also help in this regard.
- The option of lining key waterways may also be explored subject to financial feasibility.

- Build New Reservoirs: This option, while an obvious one, is not without its drawbacks, specifically in terms of building trust among different provinces. For example, while it might be technically feasible, establishing a reservoir at Kalabagh might be counterproductive for interprovincial trust given the current political climate of the country. If large reservoirs are to be established, they should be built through a consensus-based approach.
- Perhaps more importantly, the significance of medium and small size reservoirs needs to be recognized to allow better availability and management of water at the local level throughout the Indus Water Distribution System.

Improve Perception of Fairness Among All Provinces

The following measures may help in improving perceptions of behavioral and formal fairness among all four provincial irrigation departments.

- A consultative mutually agreed upon approach is needed for the allocation of excess water from Khyber Pakhtunkhwa. Following suggestions are made in this regard
  - Irrigation infrastructure improvements in Khyber Pakhtunkhwa promised at the time of signing the Water Apportionment Accord should be completed as a first priority so that the province is better equipped to use its allocated water share.
  - Until the province is able to do so, it should be given a preferred voice in deciding how its excess water is allocated among the other provinces.
  - A consultative process among key stakeholders may be initiated to find out whether a consensus can be developed to amend the Water Apportionment Accord to compensate or allow the trading of excess water to Khyber Pakhtunkhwa.
- To address the concerns of Baluchistan regarding formal fairness, the following measures may be considered:
  - Creation of a joint task force with representation from Sindh and Baluchistan, to be headed by a neutral party to resolve issues related to distribution of water from Hub Dam and about encroachments, decreased capacity, increased silting, and water theft in canals carrying water from Sindh to Baluchistan.
  - Rapid completion of irrigation infrastructure projects allowing Baluchistan to optimally use its water allocation.

Enable Collaborative Interactions Among Irrigation Departments

A key reason for lack of trust is the limited direct interaction among the different irrigation departments. The following measures can be helpful in improving this structural factor:

- Increased opportunities for interaction among different provincial irrigation departments in the form of capacity and/or trust building tours, seminars, and fora.
- Team building executive trainings where representatives of all four provincial irrigation department officers participate. These executive trainings must be organized for all major levels of management (SDOs, Executive Engineers, and Chief Engineers) to make sure there are opportunities for lateral peer interaction.

Learn from Others

Key personnel of different irrigation departments may benefit from trainings on negotiation and learning about case studies through which similar conflicts were resolved by other countries. There are multiple examples across the world of national and sub-national governing units amicably resolving water distribution issues. Both the technical and managerial nature of such solutions needs to be studied to help devise new solutions to familiar problems in the Indus Water Distribution system of Pakistan.

14.5 Conclusion

As we've detailed, the Indus River basin both ties together and is a source of conflict and division across a vast swathe of land and across four countries' territories. Pakistan's role in the further judicious and environmentally sustainable use and development of the Indus' waters will be a primary driver for the future: both as a user, and, we hope, as a forward-looking member of the group of nations that evolve more cooperative frameworks for co-managing an increasingly stressed resource. Within the realm of international water law and the development of the norms of customary international water law, Pakistan has, to date, not played an active role and has simply followed established norms rather than contributed to the designing of improved principles, laws, and institutions. We hope this changes and that it begins to see the vast advantages to such participation, especially as a country that has a proud tradition of managing one of the world's great river basins.

Specifically in relation to its bilateral water treaty with India, while we can agree that the IWT "solved" these problems to an extent, "The preamble of the treaty provides that the settlement of all such questions as may hereafter arise in regard to interpretation or application of the provisions of the treaty should be done in a cooperative spirit thus giving concession to political maturity and pragmatism" (Mohanty & Khan, 2005). Mustafa has shown how the treaty's division of the rivers meant that the ecological and social consequences that it created were pushed down to the subnational scale (Mustafa, 2010). We believe it is now time to tackle the challenge at the transboundary (both international and subnational) and regional scales. It has been suggested that the IWT can play a much larger role as a Confidence Building

Measure (CBM) in South Asia (Kraska, 2003) and even though there has been a downturn recently between the two major neighbors in the region there is no reason to think that this is necessarily a permanent feature, nor that relations will continue to deteriorate. As per Article XII (3) of the IWT, "this Treaty may from time to time be modified by a duly ratified treaty concluded for that purpose between the two Governments." Mahmood, as a thoughtful practitioner, suggests that, "a wide spectrum of knowledge in the realms of not only engineering and law but also social sciences, diplomacy, science, environment and climate change" must be added to the Treaty's processes (Mahmood, 2018)—and we concur. And while Akhter too suggests that it is time to expand the conversation beyond engineers and lawyers to, for instance, "sociologists, anthropologists, political geographers, fluvial ecologists," he also states that "it is only by dealing squarely with the thorny issue of Kashmiri sovereignty that a truly just sharing of the Indus rivers can begin" (Akhter, 2013). While India's recent abrogation of the special constitutional status of Kashmir may be an added obstacle that creates more complications in the region beyond the control of the Indus' waters (Rao, 2020), this challenge needs to be confronted nevertheless. As Jamir has shown, despite what the IWT helped resolve, it is undeniable that because of the increased development of hydropower potential upstream by India, stress on the Treaty is growing. Nevertheless, "researchers and policymakers, in order to achieve desired ends of maintaining cooperation on water sharing, must monitor and understand the social reality and thereby suggest the right mechanisms to address the challenges associated with sharing this vital resource. This process cannot be based on 'hyper-nationalism' and 'jingoistic' policy. In other words, without understanding the ground realities and the multiple and complex factors causing them, it will not be possible to prescribe valid and balanced policies to overcome the challenges that are surfacing on Indus water sharing" (Jamir, 2016). As may be clear throughout this chapter, we endorse the view that efforts to continue the development of international water law and the problems that it may help overcome must continue with renewed vigor (Meshel, 2019).

There is no doubt that Pakistan will have to continue to rely on and cooperate with the international community, and more specifically, its co-riparian neighbors to ensure that its water resources are protected and adequate for its (necessarily) evolving needs. In this regard, international water law will play an important role in Pakistan's cooperation with other states. As a deliberate construct, international water law is dexterous and adaptable. Looking to the future, Stephen McCaffrey aptly notes "[t]he facts and circumstances of each case, rather than any *a priori* rule, will ultimately be the key determinants of the rights and obligations of the parties. Difficult cases, of which there are bound to be more of in the future, will be solved by cooperation and compromise, not by rigid insistence on rules of law" (McCaffrey, 2019). To this end, the IWT is more than capable of withstanding the current barrage. As cooler heads prevail, the IWT can evolve and incorporate new concepts in international water law to build an even better instrument—specifically tailored to the facts and circumstances of the Indus River Basin. The same can also be said to apply to the Kabul River and Pakistan's need to reach a water-sharing accord with Afghanistan (Kerry et al., 2011)—more so than ever given the great turmoil the country is currently undergoing that is undoubtedly stressing already stretched water governance institutions. And with the lessons learnt, these processes may continue to feed the future evolution of an ever more just and virtuous international water law that can meet the challenges of the twenty-first century and beyond.

Also, we have offered a range of options that policymakers could begin to take to address the long-standing tensions accompanying subnational and transboundary water-sharing within Pakistan. These range from trust-building exercises such as staff exchanges between provincial irrigation departments, looking to and learning from the examples of other river basins with cooperative and data-sharing agreements and institutions in place, and including but not limited to educating the range of users and water managers in newer more ecologically sound norms developing around the world to manage water. Given our belief that if Pakistan begins to manage water within its territory in a more environmentally sound and judicious manner, that such positive experience and lesson building will serve it well when it aims to bring its learnings to the bilateral, regional and global scales, nothing could be more urgent than the task of putting its own house in order.

Global water stress is growing. Even river basins that have more collaborative instruments in place, such as the Colorado River Basin, which has a plan in place to cut water shares depending on the level of water availability and is suffering through a two-decade-long drought, are still instructive examples for South Asian countries (Sattar et al., 2018). Given the transboundary water-sharing challenges the basin faces at all scales, calls are growing to build a new cooperative encompassing framework that extends across the four countries that share the rivers: Pakistan, India, Afghanistan and China with a focus on including the voices of regions that are directly impacted by water-use decisions but thus far have been left out of the decision-making process (Adeel & Wirsing, 2017). The threats to the waters of the Indus mean that the time is now ripe for co-sharers to evolve improved cooperative frameworks and go from a severely stressed basin to a model for other large basins—let us call on hope and capacity to reset our imaginative visions.

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Part IV
From Management to Nexus to Governance and Wisdom

The water, food, and energy nexus has emerged as a new perspective in debates concerned with balancing potentially conflicting sectoral imperatives of large scale development investments concerned with energy, water, or food security. The nexus means that water, energy and food security are intimately linked. Food production requires water and energy; water extraction, treatment and redistribution requires energy; and energy production requires water. Optimizing this link is key since an action in any one area usually impacts one or both of the others. While this link has always existed, it has drawn more attention because the water-food-energy nexus is central to sustainable development and the complex linkages between these critical domains require a suitably integrated approach to ensure water and food security and sustainable agriculture and energy production. Both in Pakistan and in other countries, due to rapid population and economic growth in combination with accelerated urbanization and changing lifestyles, demand for food, water and energy is constantly increasing.

In summary, unprecedented rates of population growth in urban, peri-urban and rural areas of the Pakistan has severely impacted land, water, and energy provision and distribution, resulting in a disorganized extraction of natural resources, poor water and sanitation conditions, and an overall depletion in standards of living. Increasing pressure on resources for socio-economic development has resulted in growing and competing demand for water, food and energy. Not taking the nexus approac often results in sub-optimal investments. For example, the result of not having demand management policies is wasteful investment that could have been averted otherwise. Similarly, there is a tendency not to control pollution problems at the source. Policies and development strategies are very much sector-driven, with key sectors such as water and agriculture planning and executing projects in silos, resulting in large scale incoherence, often pushing policy actions on the ground with conflicting interest, further resulting in missed opportunities for enhanced synergies.

Further, the last chapter of the book elaborates on the cross-cutting role of knowledge capacity in Pakistan's Water Resources, a theme that can be found in all previous chapters of this book. As in the circle of justice, most of the policy issues facing Pakistan's water sector can only be addressed by developing the ability of all actors and stakeholders to adopt holistic thinking and bridge critical knowledge gaps. The authors have developed a philosophical view of basin-level water management at sub-continental and regional scales inspired by the irrigated garden metaphor. The work is further extended by exploring the role of knowledge production, technologies and capacity-building in this new framework. Most importantly, the policy implications of this approach are articulated.

Specific water knowledge production and products may come in the form of new scientific inquiry such as quantifying scenarios and impacts of climate change on environmental degradation, water resources, agriculture, and public health. New knowledge may need to emerge in indigenous and scalable technology solutions, ranging from ICT-driven precision irrigation delivery services to the refinement of sustainable agriculture techniques. Significant challenges exist in the adoption and scaling-up of solutions, which is what "knowledge capacity" often means in the water management and governance literature. Knowledge capacity investments are needed in farmers' skill development to adopt water efficiency solutions, often by enhancing the role of extension services, empowering them with information about using new digital technologies, and complementing the role of government regulation and support by private service providers. At the institutional level, the capacity of irrigation engineers and policymakers must be enhanced to absorb new integrated planning approaches. In particular, integrated modeling-based scenario generation and analysis is one way to understand complex interactions in the water-energy-food nexus; and to explore investment options, optimize tradeoffs, and anticipate any rebound effects. Additionally, actors at all levels must be equipped to appraise the social and ethical dimensions of various investment options and to undertake and learn from long-term ex-post evaluation of completed projects.

Addressing all of the above dimensions may require broad reforms in curricula and training, investments in new scientific infrastructures (such as earth observation networks) and strengthening of institutions. In some key areas, a complete re-imagination of water and environmental resources may be required such as a switch to demand-based surface water management, sustainable intensification of agriculture, and managing massive urban development along polluted riverfronts. Such imagination may spark controversies, invoke ethical dilemmas, and test the limits of knowledge capacity.

Chapter 15
Developing Knowledge Capacity and Wisdom for Water Resource Management and Service Delivery: New Conceptual Models and Tools

Abubakr Muhammad and James L. Wescoat Jr.

The world is a garden for the state to master….
Justice is that by which the rectitude of the world subsists

Circle of Justice text, translated in Thomas W. Lentz and Glenn D. Lowry (1989, p. 12).

Abstract Using the "Circle of Justice"—the guidance for princes that has ancient Mesopotamian origins, this chapter elaborates on the cross-cutting role of knowledge capacity in Pakistan's water resources. As in the Circle of Justice, most of the policy issues facing Pakistan's water sector can only be addressed by developing the ability of all actors and stakeholders to adopt holistic thinking and bridge critical knowledge gaps. These twin aspects of knowledge and capacity, holism and strategic innovation, and the need to balance them in ethical ways are addressed in this chapter through the rich metaphor of irrigated garden traditions and associated knowledge capacity in Pakistan. The chapter provides a historic perspective on knowledge capacity in the Indus Basin. Irrigated gardens provide powerful images and metaphors — positive and negative — for the land, water, and people of Pakistan. These can be used to reimagine and improve outcomes for water policy in Pakistan. There are three components that the irrigated gardens ideal might require: (a) focusing future knowledge capacity on the cultivation of wisdom in water use and stewardship; (b) pursuit of nature-inspired water science and technologies, especially those that benefit smallholders and landless workers; and (c) water and environmental education aimed at realizing irrigated garden ideals.

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Keywords Knowledge capacity · Adaptive resource management and service delivery · Principled pragmatism · Basin-level water management · Water gardeners · Indus River Basin · Capacity building

15.1 Introduction

So read the opening and closing verses of the "Circle of Justice"—the guidance for princes that has ancient Mesopotamian origins, and has subsequently been transmitted through every region and era of Islamic civilization (Darling, 2009, 2012, 2013; London, 2011). Incorrectly attributed to Aristotle, its origins are much older. It was incorporated in the Arabic text on governance, *Sirr-al Asrar*, translated into Latin as the *Secretum Secretorum*, Secret of Secrets. It was transmitted by luminaries from Ibn Khaldun in the west to Nizam-ul-Mulk in the east, and adopted in the three early modern Ottoman, Safavid, and Mughal empires (Quinn, 2010). Just rule was historically associated with rain and fertility (Darling, 2014), and far beyond that with the gardens of paradise (Darling, 2002). A break in any link of the circle of justice leads to a failure of the whole. Of course, no historical regime has been able to establish and maintain the circle of justice ideal, even when inspired by the image of the world as a garden. Why not? In addition to human failings, the Circle of Justice itself needs additional links devoted to the knowledge and values needed to sustain the world as a garden, as articulated below.

This chapter elaborates on the cross-cutting role of knowledge capacity in Pakistan's water resources, a theme that can be found in all previous chapters of this book. As in the Circle of Justice, most of the policy issues facing Pakistan's water sector can only be addressed by developing the ability of all actors and stakeholders to adopt holistic thinking and bridge critical knowledge gaps. These twin aspects of knowledge and capacity, holism and strategic innovation, and the need to balance them in ethical ways are addressed in this chapter through the rich metaphor of irrigated garden traditions and associated knowledge capacity in Pakistan. In previous works, the authors have developed a philosophical view of basin-level water management at sub-continental and regional scales inspired by the irrigated garden metaphor (Wescoat, 2012; Wescoat & Muhammad, 2021). In this chapter, we extend this theme by exploring the role of knowledge production, technologies, and capacity-building in this new framework. Most importantly, we articulate some policy implications of this approach.

By way of introduction to the theme of knowledge capacity, it is useful to consider that scholars often distinguish between data (perceived observations), information (that data contain), knowledge (created through various processes of inquiry and reason), intelligence (that seeks and applies knowledge in a domain), and wisdom (that balances practical and ethical considerations in human action). Wisdom is not always included in the knowledge hierarchy (Sternberg & Gluck, 2019). For example, it is not mentioned in Young et al. (2019) or any national water policy documents in Pakistan. However, it is emphasized in a later section of this chapter as a crucial guide for knowledge capacity building in Pakistan's water management.

Before proceeding, it is important to introduce the concept of capacity, which is often discussed in the water resources field under the rubric of capacity-building. In this chapter the relevant capacities are those of compiling, storing, analyzing, and learning from changing bodies of data, information, and knowledge. These are sometimes described in relation to capabilities, which help fulfill various aims of well-being or happiness (Robeyns & Byskov, 2021). Knowledge capacity is thus an inherently social and institutional, as well as individual, characteristic. It is contingent upon historical processes. The relationships among various demographic, political, and economic conditions of knowledge capacity that stimulate innovation are widely debated. In some contexts, population growth may drive agricultural innovation, while in other contexts population growth may follow or be independent from agricultural growth. Political instability may weaken water knowledge at one level while enabling its growth in others. In every context, it may be argued that societies should at least strive to *conserve* knowledge capacities, while building upon them in wise and strategic directions.

To be more specific, water knowledge production and products may come in the form of new scientific inquiry, such as quantifying scenarios and impacts of climate change on environmental degradation, water resources, agriculture, and public health. New knowledge may emerge in indigenous and scalable technology solutions, ranging from ICT-driven precision irrigation delivery services to the refinement of techniques for sustainable agriculture. Significant challenges exist in the adoption and scaling up of solutions, which is what "knowledge capacity" often means in the water management and governance literatures. Knowledge capacity investments are needed in farmer skill development to adopt water efficiency solutions, often by enhancing the role of extension services, empowering them with information about new digital technologies, and complementing the role of government regulation and support with private service providers. At the institutional level, the capacity of irrigation engineers and policymakers must be enhanced to contribute to integrated planning approaches. For example, integrated modeling-based scenario generation and analysis can help understand complex interactions in the water-energy-food nexus and thereby explore investment options, optimize tradeoffs, and anticipate any rebound effects. Actors at all levels must be equipped to appraise the social and ethical dimensions of various investment options, and learn from ex post evaluation of completed projects.

Addressing the above dimensions would require broad reforms in curricula and training, investments in new scientific infrastructures (such as earth observation networks), and strengthening of institutions. In some key areas, a complete reimagination of water and environmental resources may be required, such as a switch to demand-based surface water management, sustainable intensification of agriculture, and managing massive urban development along polluted riverfronts. Such imagination may spark controversies, invoke ethical dilemmas, and test the limits of current knowledge capacity.

This is where deeply rooted cultural models like the metaphor of irrigated gardens can prove useful in Pakistan. In other work, we have shown that every region and cultural group within Pakistan—from the upper Indus headwaters to the delta—has produced a rich heritage of irrigated gardens (LUMS Media Lab, 2017; Wescoat & Muhammad, 2021). In such gardens, knowledge producers and wise consumers of knowledge *ideally* share a vision that encompasses holistic thinking and that freely incorporates the ethical and social dimensions of the complex socio-hydrological issues that confront Pakistan and the entire Indus River basin. This vision stems from cultural and spiritual heritage, inspired by the Qur'anic description of "gardens, underneath which rivers flow." Significantly, this heritage warns against the hubris of irrigated gardens, water uses, and knowledge systems that lack humility, gratitude, and generosity.

The next section outlines the history and heritage of water knowledge in the Indus basin region to support the argument for conserving the knowledge capacity derived from every period and region—every irrigated garden—of Pakistan. Section three discusses the current situation and reviews recent studies that underscore the various types and levels of knowledge capacity that are currently needed. However, we conclude that section with a sense that several fundamental components are missing, including the importance of wisdom regarding the types of knowledge capacity to be cultivated, emerging technologies for nature-based solutions, and the vital role of educational reform in moving toward those ends. Throughout this chapter, we refer to case studies of ongoing work in Pakistan to support the key ideas listed above. We also refer to insights in other chapters of this volume.

15.2 An Historical Geographic Perspective on Knowledge Capacity

It is useful to consider that emerging forms of knowledge capacity both build upon and break with earlier ways of producing, applying, and adapting knowledge. Earlier modes of knowledge production remain relevant albeit in diminished ways. A brief macro-historical geographic survey helps to illustrate this point.

Little can be said about the water-related knowledge of Neolithic life in the Indus basin, though some inferences may be drawn from archaeological studies of material culture, and in particular from the mixed livelihoods of hunting and gathering that followed available water supplies and the sources of food associated with them (i.e., vegetation, fish, and animals) (Jarrige, 2013). That began to change with more extensive agricultural cultivation and larger urban settlements in the protohistoric Harappan period (Wright, 2010). Urban settlements had brick-lined wells, tanks, and drains while rural areas employed earthen dug wells, simple counterweight water-lifting devices (*dhenkli*), and inundation floodplain farming methods. In addition to archaeological evidence for expanded cultivation of horticultural as well as grain crops, the development of a script and standardized weights and measures reflected an advancing system of water-related knowledge production (Fuller & Madella, 2001; Weber, 1991). While Harappan civilization's socio-environmental and knowledge capacity remained resilient for over a thousand years, it was not sustained beyond the second millennium BC.

The early Vedic period (c. 1500 BCE onwards) marked major shifts in knowledge capacity. Hymns to the gods in the Rig Veda alone contained hundreds of references to water (Jamison & Brereton, 2014), as did later religio-legal texts like the Manava Dharmashastra (*Laws of Manu*, Olivelle, 2009). Their relevance to the evolution of knowledge capacity included: (a) extraordinary feats of memorization; (b) oral transmission of knowledge; and (c) perceived causal relations between ritual acts, punishments, and rewards. Cognitive practices of this sort may have extended in less formal and more pragmatic ways to knowledge production and transmission in early inundation canal agriculture. Farmers continued to rely largely on floodplain farming, wells, and check dams that were combined in increasingly sophisticated strategies of pastoral and agrarian production.

Classical periods of Indian philosophy and social thought in the first millennium CE developed formal texts on knowledge capacity as part of the larger fields of epistemology (*pramana*s) and avoidance of ignorance (*avidya*) (Perrett, 2016). Although they did not often focus on water, they rigorously explored the bases of knowledge in perception and inference, the meaning and criteria of truth, and their relevance for right action (*dharma*). In applied fields of knowledge, medieval Sanskrit texts described the ideal construction of tanks, regulation of water diversions, and responsibilities from the king to the cultivator (e.g. Wojtilla, 2010, pp. 111–12). Medieval states developed increasingly systematic methods of land survey, production, and record-keeping that helped guide land reclamation and revenue policies and practices, though states did not necessarily contribute as much to the knowledge capacity of cultivators.

The many regional bodies of knowledge and practice came into increasing contact with one another in the Indus basin with the expansion of early modern empires from the twelfth through eighteenth centuries (Habib, 2014; Huff, 2003; Pollack, 2011). Local knowledge was increasingly complemented by encounters with Arab, Persian, Turkic, and Chinese bodies of thought that included water management technologies and practices, e.g. geared water wheels (*noria, rahant*), *qanat* or *karez* technologies that involved sophisticated hydrogeological expertise imported into Balochistan, Sindh, and Gujarat; and surface canals commissioned by Firoz Shah Tughluq, repaired by Akbar (d. 1605), and extended by Shah Jahan (d. 1666) and others. By the 1580s, the Mughal empire encompassed all of the Indus basin provinces (Kashmir, Kabul, Punjab, Multan, and Thatta) as well as most of the northern subcontinent. The *Ain-i Akbari* compiled gazetteers for each of these provinces, noting their major rivers, crops, peoples, and revenue statistics. Although Mughal texts frequently mentioned the climate of a location, that classification referred to latitudinal zones rather than to any measurement or analysis of temperature and rainfall. Water withdrawals from canals, tanks, or wells were not recorded, although Babur (1996, d. 1530) did mention categories of watercourses, e.g., a "one-mill stream", and land revenue records distinguished irrigated from rainfed parcels.

Knowledge capacity was frequently exceeded by natural hazards and disasters, which the Mughal elite often avoided by moving to safer locations, leaving peasants to cope with limited relief (Agrawal, 1983; Wescoat, 2013). While Mughal imperial knowledge waned in the eighteenth century, some localities such as Kabul prospered for a time, at the expense of those that they plundered, such as Punjab. Gilmartin (2015) has drawn attention to the strong, and in some ways enduring, tribal structure of mixed pastoral and agrarian social formations, the knowledge basis and resilience of which are not well understood.

These decentralized political dynamics created a space for colonization by the British East India Company, which did not reach the Indus basin region until the mid-nineteenth century (1849). Soon after the revolt of 1857, the region came under the control of the British Crown. Colonial authorities introduced and imposed new modes of scientific water knowledge and capacity building for imperial purposes, which Gilmartin (1994) has jointly described as imperial science and the science of empire. While Gilmartin stressed the politics of irrigation science, Imran Ali (1988) analyzed revenue records to discern the economic logic of what he called "malign" growth in Punjab, i.e., the economic growth of landlords, the military, and bureaucracy without the social development of peasant agriculture. Imperial irrigation science ranged from daily weather data collection to river discharge measurement, physical hydraulic models, and eventually groundwater levels (Wescoat et al., 2018). Knowledge capacity assumed world class scientific status in the Punjab Irrigation Department, to a lesser extent in the Sindh Irrigation Department, and tragically, hardly at all in the dependent princely state of Jammu and Kashmir. As separate provinces, these territories were in a continuous state of competition and conflict over water resources with limited knowledge sharing throughout the colonial era. Urbanization aggravated water pollution problems that colonial public health systems addressed with scientific surveillance methods that were applied in socially inequitable ways (Halvorson & Wescoat, 2020).

The partition of India and creation of Pakistan in 1947 brought a new territorial configuration to the Indus basin, and a new national imperative for water-related knowledge capacity (Wescoat et al., 2021). The massive loss of life and refugee migration, followed by India's cutting off of several transboundary canals in 1948, disrupted many assumptions in the irrigation system, and led to a long period of international negotiation that yielded the Indus Waters Treaty of 1960 and the Indus Basin Development Fund to finance the massive reservoirs, barrages, and link canals that transfer water from the western rivers to eastern canal commands (Michel, 1967). In terms of knowledge capacity, however, this led to a shift from provincial irrigation departments to the federal Water Power and Development Authority (WAPDA), which became a major center of river basin development and management—a Tennessee Valley Authority on a national scale. WAPDA became the new data repository, modeling center, and planning organization for Pakistan. Provincial irrigation departments declined in expertise, funding, authority, and governance with limited ability to address the growing emphases on social, environmental, and natural hazard dimensions of water management (e.g., Mustafa, 2013, 2021).

However, that process of centralization in knowledge capacity reversed again with the 18th Amendment to the Constitution of Pakistan in 2010, which dissolved most federal agencies and devolved their responsibilities back to the provinces. As a semi-autonomous government authority, WAPDA continues, but with declining knowledge capacity vis-a-vis provincial irrigation departments. Concurrently, and with increasing access to government documents and data online, several universities and non-governmental agencies have shown significant initiative in creating research centers in collaboration with provincial and urban water agencies. This trend helps Pakistan move forward after a period when universities and water agencies were disconnected from one another. As these trends are discussed in greater detail in section three below, we conclude with a sense of the historically deep but largely untapped intellectual history of knowledge production in South Asia that is relevant for future water resources management in Pakistan.

15.3 Current Gaps and Bottlenecks

All of the chapters in this volume address practical gaps and bottlenecks in Pakistan's water resource management system. In this section we focus on gaps in knowledge that are inherent in several major water resources assessments. We begin with Briscoe and Qamar's (2005) *Pakistan's Water Economy: Running Dry*, which provides a succinct review of major gaps and recommendations. While many parts of that report require new knowledge, several sections focus specifically on knowledge capacity. For example, "an inadequate knowledge base" is one of 14 "sobering facts" flagged in the report. The authors boldly declare that:

> The past twenty years should have been ones of massive investment in knowledge about this ecosystem. But the reverse has happened, and even the once-renowned Pakistan water planning capability has fallen into disrepair. The country is literally flying blind into a very hazardous future (p. 8).

They argue that "Challenge #1 is to develop a world-class knowledge based capacity for adaptive resource management and service delivery" (ibid., p. 13). By this they mean developing indigenous capacity and institutions for science, technology, and policy—rather than relying on contracted consultants (ibid., p. 14). Two generations earlier, Aloys Michel (1967) contrasted Pakistan's international engagement of foreign experts with India's emphasis on indigenous expertise, noting the advantages and disadvantages of each, and concluding that a dual strategy was wisest.

Authors in the Briscoe volume emphasize gaps in knowledge surrounding groundwater, salinity, and drainage. But their recommendation in the section on "knowledge capacity" is more comprehensive:

> This is a capacity which requires a wide range of disciplines—those necessary for understanding climate, river geomorphology, hydraulic structures, surface and groundwater hydrology, limnology, water chemistry, sediment management, hydraulics, soil sciences, terrestrial and coastal ecosystems, agronomy, plant physiology, industrial organization, conflict management, politics, economics and financing. It will require an expansive and

> long-term human resource strategy which will update the skills of the formidable capacity which exists in Pakistan, but will also strengthen the capacity of universities and other scientific and training institutions to produce high-quality applied research and to train the next generation of water policy makers and managers. (ibid., p. 100).

Unfortunately, the arts and humanities, including history, philosophy, and religion are omitted.

While much good work by universities, NGOs, consulting firms, and government agencies has been done in the 18 years since this report, it falls far short of what was envisioned in this recommendation. The report itself concludes with a fallback strategy of "principled pragmatism" and "rules for reformers" that does not depend fundamentally upon new knowledge or ways of knowing (ibid., p. 106). We list them here not so much for their perspective on knowledge, as for their relationship to the wisdom of experience discussed further below.

Rule # 1: Water is different.
Rule # 2: Initiate reform where there is a powerful need and demonstrated demand for change.
Rule #3: Involve those affected, and address their concerns with understandable information.
Rule #4: Reform is dialectic, not mechanical.
Rule # 5: It's implementation, stupid.
Rule #6: Develop a sequenced, prioritized list of reforms.
Rule #7: Be patient and persistent.
Rule #8: Pick the low-hanging fruit first—nothing succeeds like success.
Rule #9: Keep your eye on the ball—don't allow the best to become the enemy of the good.
Rule #10: There are no silver bullets.
Rule #11: Don't throw the baby out with the bathwater.
Rule #12: Reforms must provide returns for the politicians who are willing to make changes.

These are useful rules, gained through decades of experience, but they seem a step backward from the number one challenge of developing a world-class knowledge system.

Improvements were made in the Indus Basin Model (Yu et al., 2013; Young et al., 2019). USAID funded a water center at Mehran University of Engineering and Technology for five years. And, as will be elaborated, the PIDs, IWMI and LUMS piloted advances in decision support systems. But the Friends of Democratic Pakistan (FoDP) envisioned a larger scale of investment in knowledge capacity.

In 2016, the Pakistan Council for Research in Water Resources (PCRWR) and U.S.-Pakistan Center for Advanced Studies in Water at Mehran University led wide consultations within the country to produce a National Research Agenda on Water for the decade of 2016–2025. Five research themes evolved during the consultation related to water resource planning and management, agricultural water productivity, water quality, climate change, and water governance. Within each theme, data and information needs were enumerated along with capacity and technological needs.

Some of the highlighted capacity needs were related to satellite remote sensing, flood forecasting and management, information management systems, innovative cultivation techniques, on-farm water efficiency, extension services, land reclamation, saline agriculture, virtual water trade, corporate agricultural models, water policy and law, laboratory testing, hazard mapping, numerical modeling, sensors and drones, and watershed and groundwater modeling. That research agenda mapped each theme to a water vision, identified key partners, and interfaces with Sustainable Development Goals. Until the approval of the National Water Policy in 2018, reports like the National Research Agenda of 2016 set their own targets and visions. In 2017, the Hisaar Foundation released its recommendations for a national water policy, which paved the way for wider consensus on the 2018 National Water Policy.

The inclusion of water governance in the PCRWR Research Agenda is commendable, as it is often mentioned but rarely treated as a research topic. Even in this context, it was addressed more as a field for "institutional analysis" following a top-down approach, rather than a direct engagement with water "politics" as pursued in political science, political sociology, and political history (e.g., Akhter, 2022; Ali, 1988; Gilmartin, 2015; Mustafa, 2013). Political research is shedding new light on Pakistan's water sector, but it remains to be seen what difference this new knowledge can make for social and environmental action and well-being. To its credit, the Research Agenda also established linkages with WAPDA's Vision 2025 policy and the U.N. 2030 SDG (Sustainable Development Goals). It frequently mentioned knowledge and capacity in close proximity to one another, and in relation to governance, but it did not focus directly on "knowledge capacity" in different socio-political or educational domains.

Approval and adoption of the National Water Policy in 2018 was a landmark event in Pakistan's history. While the document received criticism from many stakeholders, there is a wide consensus that this is a step in the right direction. The National Water Policy explicitly addresses capacity needs in four of its 33 goals: (Goal 5) *Promoting behavioral change to reduce wastage of water by raising public awareness through media campaigns and incorporating water conservation lessons in syllabi/curricula at primary, secondary and tertiary levels*; (Goal 9) *Upgrading water sector information systems for improved asset management and to derive evidence and data driven decision making*; (Goal 20) *Strengthening and Capacity building of water sector institutions,* and (Goal 28) *Promoting research on water resources related issues of national importance and building, capacity/delineating roles and responsibilities of Federal research institutions and promoting coordination among them.* The policy calls for setting up provincial water authorities, revitalizing and restructuring WAPDA, and establishment of a groundwater authority. The policy document ends with a strong commitment, "…*capacity building of Water Sector Institutions at the Federal and Provincial level for a period of 5 years keeping in view the relevant priority of each province*." It is interesting to note that the National Water Policy mentions the word "knowledge" only once, while it mentions data and information multiple times in the document.

Knowledge management was reiterated as one of five main aims in a 2012 report by Friends of Democratic Pakistan (FoDP). In 2019, the World Bank commissioned another comprehensive assessment titled *Pakistan: Getting More from Water* (Young et al., 2019). It highlighted five recommendations in Table 15.1 that, with the exception of Indus basin modeling, have not been implemented at scale.

It also assessed Pakistan's investment in knowledge management (Fig. 15.1). Interestingly, they found that investment in knowledge management exceeded other subsector items but was still less than what was recommended (Young et al., 2019, 68). Some of the bolder knowledge-related proposals included those for citizen science: "Pakistan does not promote the role of citizens in collecting and analyzing water data. Citizen involvement in the planning, installation, and management of hydrometeorological or water quality monitoring networks could help improve water data and community knowledge…" (ibid., p. 59).

Disturbingly, Young et al. (2019) report that only a third of the funds allocated for the Water Sector Capacity Project (W-CAP) were spent, which they inferred reflected limited government capacity to create new programs, as well as a risk averse attitude toward new program development. If correct, this reflects a constraint that their report should have explained more fully or called for research on this limitation.

Table 15.1 List of knowledge management recommendations, contributions, and implementing organizations (Young et al., 2019, p. 155)

Partnership with an institution (e.g. eWater) to develop the architecture and culture which produces integrated, demand driven knowledge product	Consistent knowledge base for operations at different levels	MOWP, FFC, IRSA, WAPDA, PIDs	2012–16	30
An operational simulation model for the Indus Basin	Management and investment decisions	WAPDA with PIDs	2012–16	20
Knowledge base for groundwater management	Sustainability and productivity	MOWP, PIDs, FATA, Space and Upper Atmosphere Research Commission (SUPARCO)	2012–16	20
Other decision support systems for data sharing, canal, assets management, and managing climate change	Operation of the 1991 Indus Water Accord and infrastructure, improved water productivity	PMD, IRSA, WAPDA, SUPARCO, PIDAs (provincial irrigation and drainage authorities), and PIDs	2012–16	30
Capacity building for management and research	Developing capacity	Higher Education Commission (HEC), MOWP, Ministry of Science and Technology, standing committees of the National Assembly and Senate on water and energy, universities and research institutions	2012–16	15

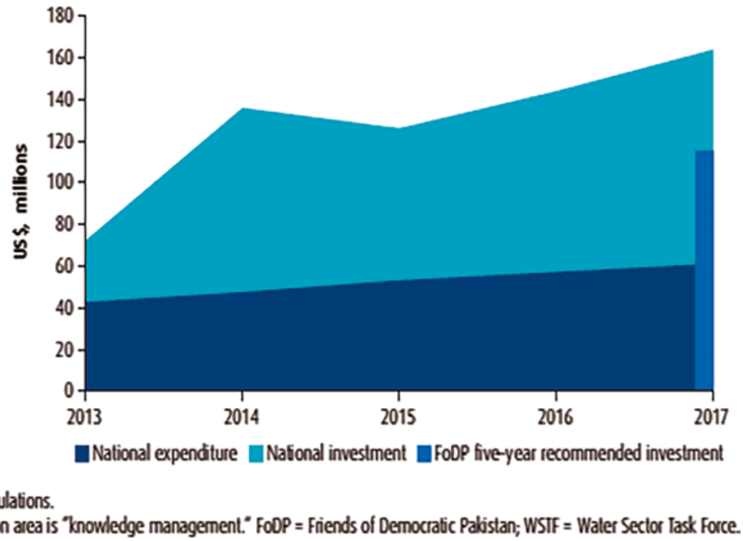

Fig. 15.1 National investment in Knowledge management, 2013–17 (Young et al., 2019, 70)

The Young et al. (2019) report identified fourteen major recommendations. In reviewing them, we find that they emphasize the data, information, and monitoring levels of knowledge production. In several cases data analysis and modeling are also highlighted. Many recommendations stress the need for clarifying and strengthening various federal and provincial legal frameworks, policies, and institutions for water management. Other substantive recommendations are based on research and professional experience, but do not call for further research to support them. Radical proposals to "replace" the historical *warabandi* irrigation allocation system with more demand-driven approaches of the sort being explored in the Lower Bari Doab Canal command in Punjab require basic socio-economic and mathematical research to develop workable innovations. Emerging conceptual frameworks like the Water-Energy-Food nexus also require rigorous research and testing. In other words, this report, like that of Briscoe and Qamar (2005), may suffer from low expectations, perhaps as a result of the limited expenditure and performance in relation to previous knowledge management recommendations. It seems to us that those deficiencies need to be more deeply analyzed, explained, and understood to provide a basis for innovative approaches.

Interestingly, in 2018, Pakistan had just passed the new 41-page National Water Policy mentioned above, which covers all major sectors and issues of water management in an approach that is informed by international standards. The Government of Punjab also passed a new 50-page *Punjab Water Policy 2018,* followed rapidly by the *Punjab Water Act of 2019,* which parallels the national water policy and is forward-looking. The Punjab Policy and Act propose new institutions such as a Punjab Water Council. It aims to change the province's emphasis on canal irrigation to a more comprehensive water resources development and management vision that includes groundwater management, environmental, and social processes. Interestingly, the Punjab policy groups knowledge and information together under the banners of "Knowledge database and water informatics" and "Harnessing information technology and creating knowledge." In the national policy document, capacity building is addressed more in institutional and organizational terms, and less in relation to education, research, or knowledge capacity while the Punjab policy document refers to capacity enhancement of other stakeholders such as laboratories, universities, and research institutions.

Development of these major water assessment and policy documents suggests that there may not be a further need to clarify laws, policies, and institutions. New strategies for implementation and enforcement of current progressive policies is arguably a more pressing need. However, we also need to understand what "knowledge capacity" means at a deeper level. Calls for more data, monitoring, modeling, and social research are commendable, but they do not raise fundamental questions about the new types of knowledge and new ways of knowing that are needed.

Some basic research questions have not received adequate attention. We highlight four here. First, there is a fundamental "spatial misalignment" between data collection for irrigation systems based on canal commands and all other aspects of water management, including crop yields, fertilizer use, and land use, which are based on the administrative hierarchy of districts, *tehsil*s, *mouza*s, and union councils. Future models depend upon a standardized way of closely aligning these two spatial systems. Second, toxicity of irrigation and drinking water is a rapidly escalating, and poorly monitored, health risk. Increasing fractions of the urban population are consuming water and food with unknown levels of contamination, though basic research on *nallah* water contamination raises grave concerns. Third, human health and nutrition depend upon safe and secure water for domestic use, sanitation, and hygiene. The recent Pakistan National Nutrition survey (2018) revealed that 40.2% of children under five years old are stunted. Coupled with the crisis in public education, and the large proportion of school-age children in Pakistan, water-related malnutrition raises profound questions about future knowledge capacity at a societal level. Fourth, there is a profound shift in infrastructure design and development from western collaborative arrangements to the China-Pakistan Economic Cooperation (CPEC) alignment. This is not mentioned in most water sector documents, as many CPEC projects are transportation infrastructure, but dams of various sizes and other technologies are also pending. Domestically, large land development proposals of housing schemes, "smart forests," and whole new cities along the Ravi River floodplain near Lahore, as well as the Bundle Island development project near Karachi, would have important implications for both natural hydrologic processes and regional water resources access, vulnerability, and sustainability.

These emerging issues, when compared with the more familiar water resources management priorities in recent studies, raise questions about the types of knowledge and ways of knowing that will be needed in the twenty-first century. We turn to that question in the final section of the chapter.

15.4 Toward a New Philosophy of Knowledge Capacity for Pakistan's Water Resources

The preceding section and many studies of the water sector in Pakistan identify important gaps in water knowledge, along with constraints on improving knowledge capacity in the current situation. Most of their policy recommendations focus on extensions of the "water management revolution" initiated in the 1980s. Eschewing both radical political reforms and economic optimization of the water system, Briscoe and Qamar (2005) argue for a "principled pragmatism" that focuses on implementing the easiest and least controversial "low hanging fruit," after which more difficult challenges and choices may become practicable. Several studies have proposed systemic innovations, for example, shifting from the "green revolution" of the twentieth century to a "gene revolution" in the twenty-first century, which would usher in genetically engineered drought and salinity tolerant crops, buying time for other socio-environmental adjustments. These proposals are variations on the theme of "more crop per drop."

These are worthy aims, but do they go far enough? Some argue that they do not. Mustafa (2013) and others have argued that Pakistan has produced a "hydro-hazardscape," characterized by converging vulnerabilities to flood, drought, and climate change. The roots of these crises lie in a globalizing capitalist political economy coupled with rent-seeking structures of social and environmental exploitation in Pakistan. David Gilmartin and Imran Ali trace the roots and impacts of exploitation to the colonial irrigation system designed for political control, military recruitment, and revenue generation. Even some of those who have spent their careers in water management have offered critical historical perspectives on Pakistan's irrigated agrarian system (Naqvi, 2013).

We too argue in this section for a fundamental transformation of the water sector, inspired by a vision of the Indus Basin as an irrigated garden and of its stewards as wise gardeners. Our previous research has shed light on the rich heritage of productive irrigated gardens in every region of the basin (Wescoat & Muhammad, 2021). Here we elaborate and build upon that ideal in greater detail, beginning with the vision; proceeding to emerging scientific, technological, and institutional innovations; and concluding with its deeper societal and educational implications.

Beyond the vision of the world as a garden in the Circle of Justice theory, there is a deep and widespread vision in Muslim societies like Pakistan of paradise (*jannat*) as a garden underneath which rivers flow. Verses of the Qur'an describe the creation of the world and the ultimate reward for those who have had faith and done good works as an abundantly watered paradise garden. Countless commentaries elaborate and underscore various aspects of this paradise garden vision. To our knowledge, there has been very little exploration of leveraging these widely invoked religious concepts of the irrigated gardens of creation and paradise as inspirations for thinking about water and environmental issues of *this* world in modern times. What do our basin managers, policy makers, irrigation engineers, and ordinary water users believe, and what they believe they know—we think that such knowledge is needed.

In between the gardens of creation and paradise are the irrigated gardens of this world, including those of the Indus Basin of Pakistan and of neighboring riparians. These gardens provide a mixed range of signs, some cautioning against human failings—including hubris, arrogance, and greed—while other irrigated gardens provide clear signs of divine beneficence and guidance for human action.

Irrigated gardens thus provide powerful images and metaphors—positive and negative—for the land, water, and people of Pakistan. What do these irrigated garden ideals require? We do not presume to know, but we highlight what we think are three important components:

First, focusing future knowledge capacity on the cultivation of wisdom in water use and stewardship.

Second, pursuit of nature-inspired water science and technologies, especially those that benefit smallholders and landless workers.

Third, water and environmental education aimed at realizing irrigated garden ideals.

15.4.1 From Knowledge to Wisdom

We begin by offering some thoughts about the progression from knowledge to wisdom. There is renewed scholarly emphasis on the importance of cultivating wisdom in modern life. Some scholars focus on the psychology of advanced practical judgement, especially in the context of conflicting values (Sternberg & Gluck, 2019). Others pursue the history of ideas about wisdom or *hikmah* in Islamicate contexts, and still others re-examine the virtues associated with those who are thought to be wise. The irrigated garden metaphor invites questions about how water wisdom can be cultivated.

Recent water research suggests growing interest in this question. Agarwal and Narain (1997) sought to revive the "dying wisdom" of rainwater harvesting in what has become a widespread movement with projects and policy adoption across India. Former Indian water secretary Ramaswamy Iyer (2007) authored a set of essays titled *Water Wisdom* based on his experience in government. These examples write of wisdom in qualitative ways guided by implicit notions of wisdom. What would an explicit theory of water wisdom involve?

At least three enduring approaches come to mind. The first approach cultivates the wisdom inherent in all creatures, as exemplified in the allegory of Hayy ibn Yakzan, whose observations of the natural world from infancy to adulthood drew out innate knowledge and wisdom in his character, his relations with other creatures, and the world around him (Ibn Tufayl & Goodman, 2009). This story has inspired centuries of educators, some affiliated with progressive and experiential education internationally, including the spiritual aspects of learning envisioned here. A second approach argues that wisdom can and must be taught. This tradition holds that principles, standards, and learning outcomes can help accelerate and guide processes of learning that might otherwise not develop in sufficient depth or timeliness. It is important to distinguish teaching wisdom from pedagogies that convey content about wisdom, filling students with maxims, laws, and cases as if they are receptacles for knowledge. That approach may appear to increase knowledge content, but it does not enhance the capacity for wise judgment. A third perennial approach to wisdom involves following those whose example imparts wisdom, and *learning* from those mentors. In many cultures and disciplines, this mode of learning is most commonly manifested in master-apprentice relations. The master challenges the disciple with what seems like paradoxical propositions. The wisdom of the master, much like the mythical guide Khwaja Khizr, is not always initially obvious to followers, even followers as illustrious as Moses or Alexander, but rather, as al Hujwiri wrote, it involves a progressive unveiling of the veiled (Halman, 2013; Hujwiri, 1982). The universal capacity needed by disciples to resolve these paradoxes is unbounded love, a perennial approach from Buddha to Jesus and Muhammad, and across Sufi and Bhakti traditions. These three approaches to wisdom—the innate, taught, and learned—can help cultivate human love of and in the irrigated gardens of this world. We know of no study of wisdom and love along the lines described above anywhere in the world, but think it has enormous promise in Pakistan, especially if coupled with innovations in science as illustrated in the section that follows.

15.4.2 Science, Technology, Knowledge, and Intelligence

The role of science and technology is widely recognized among the many desirable goals of water governance, e.g., efficiency, equity, devolution, transparency, and justice. The role of scientific knowledge in reaching those other goals is generally considered to be important in three fundamental ways: first, in understanding *complexity and organization*, whether it stems from the interplay of physical elements (Bras, 2015) or in the various manifestations of human-water interactions; second, in developing methods and solutions to cope with *uncertainty* and *variability* (Hall et al., 2014); and third, in generating and evaluating alternative courses of action worthy of societal consideration. The late twentieth century witnessed the development of systems analysis tools like the Indus Basin Model to guide infrastructure investment, scenario analysis, and management reform (e.g., Yu et al., 2013). While impressive analytically, some social scientists described its seemingly insatiable data and programming needs as a form of "secular mysticism" (sociologist David Freeman, pers. comm.). They had no idea what was coming.

In the twenty-first century, the pillars of scientific method are no longer thought to be only *theory* and *experiment*. *Data* and *computation* feature as equally important (Peters-Lidard et al., 2017). For example, computation informs the design of experiments, experiments generate data, and theory is explored via computation. The impact of this radical shift in scientific thinking on water-related disciplines is such that subjects such as hydrology have flipped from being data-poor to data-deluged in a single generation (Blöschl et al., 2019). The drivers of this transformation are various advances in information and communication technologies, such as earth observation satellites, internet-of-things (IoT), and citizen-science social networks. Today, many major advances in science and engineering are related to generating new data, and subsequently to managing the resultant data-deluge by devising ways to convert data into information using so-called intelligent algorithms (Reichstein et al., 2019).

In water-related disciplines, these advances have been welcomed and enthusiastically incorporated in the creation of smart infrastructures, closed-loop irrigation control systems, hydrometeorological monitoring networks, hazard-warning systems, climate-smart agricultural systems, smart water distribution and sewer collection networks, and still others under the emerging epistemological labels of hydroinformatics, precision agriculture, etc. (e.g. Gourbesville, 2009). The end goal of these advances in knowledge production, accumulation, and analysis is the creation of greater situational awareness and intelligence. Despite the fact that even the most advanced artificially intelligent systems, whether existing today or conceivable in the future using current approaches, have no hope of developing consciousness, the proponents of these technologies aspire for the emergence of sentience or self-awareness.

For our twin considerations of knowledge and capacity, these developments pose two major questions. First, if knowledge can and should lead to wisdom, as we have argued in the previous section, can the road to technology-led intelligence contribute to that aim, and if so, how? Secondly, if the emerging methods and aims of science and technology involve the *accumulation of knowledge* to generate intelligence, where is the seat of knowledge capacity? In other words, whose capacity are these developments building?

Comparison with the three modes of acquiring wisdom from knowledge (innate, taught and learned) can be instructive for understanding the road to intelligence from knowledge. In a landmark paper on machine intelligence, Alan Turing (1950) proposed that the road to artificial superintelligence should not aim at engineering an entity that is comparable to the full abilities of a human adult. Rather, it should strive to create an intelligence which is comparable to that of a child only. The innate capability of the machine's evolutionary algorithms would propel itself towards full intelligence, much as a child learns about the world. This argument is not unlike the innate wisdom-acquiring approach of Ibn Tufayl mentioned in the previous section. The sudden awakenings in Hayy ibn Yazqan have the familiar connotations of being-to-becoming, analogous to AI researchers' hope for a singularity when computing hardware and algorithmic complexity reach certain tipping points. In the past decade, the field of machine learning has witnessed such awakenings, when decades-old algorithms have suddenly been found to be highly effective with the availability of big data, enabled by the emergence of internet and social media. In the hydrological sciences, the deep learning revolution hit the community only a few years ago. Already, it has started to demonstrate startling advances in tasks related to prediction (e.g. of precipitation to stream flow), classification, and parametric learning (see Nearing et al. (2021) for a recent review). Deeply shocked by their success, many scientific researchers have expressed a lack of satisfaction over how unexplainable these evolutionary algorithms are. Although some claim that rapid progress in theoretical advances can explain the workings of complex black-box mechanisms (e.g., artificial neural networks), these purportedly innate approaches to intelligence defy transparency, explainability, and fairness at a fundamental level. The way these mechanisms are designed invariably injects the prejudices of the creator and overfits the learning episodes (training data) during generalization. Due to the rapid wide-scale disruption of such solutions via viral IT technologies, some have termed such machine learning systems as weapons of math destruction—a pun on weapons of mass destruction (O'Neil, 2016). What is the wisdom, if any, learned on this highway to intelligence? If the Indus Basin Model of the late-twentieth century is any guide, deeper insights may come from parallel processes of water inquiry, interpretation, and (mis)uses of new tools. The tradition of acquiring taught knowledge is also common to the approaches of wisdom and intelligence. The art of conveying knowledge to students through content delivery is one of the most familiar forms of contemporary education. Knowledge creation is, in this sense, content creation within various epistemological boundaries. In the scientific path that starts with data, rule-based models are the most profound generators of knowledge. The "unreasonable effectiveness of mathematics" (Wigner, 1990) in describing analytical models is also the reason for their suitability for educational content. Academics and practitioners spend years and decades perfecting the generation of models that carry the full power of explanation, in contrast with experiential learning. In water-related disciplines, the hydrological sciences are the prime example of such knowledge generation. It is no accident that the discipline of hydrology presented itself initially as a physical science in the early twentieth century. The mathematization of knowledge generation in the hydrologic sciences carried over to related areas of the social sciences, particularly economics, in the mid-twentieth century. In contrast to the humanities and qualitative social research, economics attempts to extend the mathematical explainability of physical laws to human behavior. Other emerging water-related disciplines, such as areas of socio-ecological systems (Ostrom, 2009), socio-hydrology (Sivapalan et al., 2012), and environmental economics deploy mathematical tools in game theory, system dynamics, and mathematical optimization, which assume that agents in society manifest various forms of rational behavior. In the next step, the knowledge acquired feeds into decision support systems, integrated assessment models, or scenario generation tools, thereby generating other forms of intelligence. However, this time the intelligence only appears to carry the power of explainability and transparency. Wise generators of such knowledge always acknowledge their limitations and admit that *all models are wrong (*e.g., Box, 1976) but such caveats do not go far enough. Decision support models purport to describe system behavior when run in a simulation mode; but, when run in an optimization mode, they also claim to identify normative solutions, i.e., what society ought to do if it is rational. The gap between such *optima* and human actions are often attributed to "politics," "culture", and other types of humanistic and qualitative social knowledge, which are explicitly omitted from the model. One response to these gaps has been to pursue multiple lines of modelled and unmodelled water knowledge in parallel and in dialogue with one another (Wescoat & Leichenko, 1992). Another response is to try to quantify previously unquantified variables, which is increasingly common in sociology and political science. But we also need to think and learn differently, as outlined below.

The wisdom in such knowledge products comes at another level. *Models may serve roles similar to those of fables in traditional learning*. Much as the wisdom found in Aesop's fables and Sadi's *Gulistan* (Gladwin & Ross, 1865) served as training manuals for kings and princes of antiquity, conceptual models sometimes serve as frameworks for addressing social dilemmas, conflict resolution, legal thinking, or the administration of justice. In the physical sciences, the objective knowledge gained from the study of physical processes becomes an extremely powerful source of insights for policy, governance, and awareness. In economics and other social sciences, models such as the *prisoner's dilemma* have served as prototypes for studying complex socio-ecological problems, such as the management of common pool resources (groundwater, irrigation networks, cattle-pastures, etc.; see Ostrom [1990] for a review). They shed light on how societies choose to think about themselves, e.g., as zero-sum or non-zero-sum entities; as competitive, conflicting, or cooperative groups; as engaged in trade-offs or value creation; and so on. When made explicit, these alternatives may cause some models to be rejected, and others to be created.

Perhaps the deepest wisdom arises when the models present paradoxes or dilemmas rather than solutions. The resolution of a paradox is akin to the emergence of a moral in a fable. In water-related disciplines, a strong emergence of such wisdom can be found in the socio-hydrology literature (Di Baldassarre et al., 2019, Sivapalan et al., 2012). The common theme in many social dilemmas related to water is the occurrence of unintended consequences. See Table 15.2 for a list of such

Table 15.2 A list of socio-hydrological phenomena and paradoxes

Socio-hydrologic Phenomenon	Characteristics	Paradoxes
Safe development policies	Risk control measures that increase vulnerability	Levee effect Reservoir effect
Supply-demand feedback	Increased supply increases demand	Capacity expansion effect
Adaptation effect	Adaptation to drought that increases flood risk	Sequence effect
Pendulum swing	Local policy changes displace risk to other areas	Peak water effect
Rebound effect	Increased efficiency leads to increased consumption	Jevons paradox
Aggregation effect	Local optima have undesirable system effects	Collective action and equity impacts
Institutional Complexity	Trade-off between resilience and efficiency	Robustness-fragility trade-off

Adapted from Di Baldassarre et al. (2019, p. 6331) socio-hydrological phenomenon from a recent review in which unintended consequences feature prominently. In one of the most enlightening examples of social impacts, well-meaning investments to increase irrigation efficiency (such as drip & sprinkler irrigation, smart soil moisture sensing, etc.) at the farm level may lead to increased basin-wide consumption of recoverable water. In this so-called irrigation efficiency (or Jevons) paradox, farmers engage in undesirable rent-seeking behavior by which they divert local gains in water efficiency towards other locally desirable measures, such as increasing irrigated area or switching to water-consuming crop varieties that then diminish rather than increase water available for other uses and users. In the flood hazards domain, another apparent paradox occurs when increased public expenditure on physical flood control structures, like dams and levees, is positively correlated with increasing flood losses. This phenomenon, known as the "levee effect," was discovered through close study of increases in floodplain investment, and losses, that followed levee construction. It is only resolved by changing (and generally reducing) floodplain investment and development. A host of such social dilemmas explore the so-called *tyranny of small decisions* in these well-studied problems of human-flood interactions, irrigated land development, river channelization, and reservoir effects that contribute to water shortages.

The wisdom learned from these modern science-policy paradoxes is strikingly familiar to that gained from old traditions. However, unlike the wide dissemination of traditional wisdom via fables, parables, and myths, any wisdom found in the taught knowledge of modern disciplines remains notoriously exclusive and elitist. Farmers, practitioners, and ordinary consumers of water complain that the wisdom of modern taught knowledge remains locked and inaccessible in academic ivory towers. In other words, taught forms of knowledge have often failed to raise the capacity of its intended societal users. Compare this problem to the experiential learning of a farmer of many generations or a field-hardened irrigation engineer. They may initially dismiss the assumptions or veracity of new analytical methods as uninformed about ground realities, but over time they may accept and use them. Conversely, the upholders of taught scientific and engineering knowledge often express mistrust of such experiential learning, much in the way that today's empirical black-box machine learning methods are suspected of being opaque and incomprehensible. They suspect that experiential lessons learned in the field do not explore the entire problem space. Only solutions arising from peer-reviewed experiments that are carefully prototyped, tested in laboratories, and based on quantitative scientific methods are deemed to be *provably correct*. In addition, what seems to scale easily for these taught forms of knowledge is *intelligence*, and not wisdom, if the latter is taught at all.

Today's ICT technologies can bring the power of weather prediction and market information to millions of farmers. However, they do not critically address the operation of markets or the deep science of meteorology to less-educated but highly-experienced farmers. The dilemma of taught knowledge is *accumulation,* and its product is a highly centralized *intelligence*. It is generated from surplus disposable wealth accumulated at a few centers of learning, and it aspires to the accumulation of knowledge by a small number of agents, be they individuals, organizations, or machines. Even in traditional circles, the wise have protested against the methods and outcomes of this mode of learning, as echoed in the Punjabi Sufi poet Bulleh Shah's chant: *Ilm-o bas kari O yar*! (Enough with knowledge, my friend). What are the alternatives?

15.4.3 Education, Environment, and Social Change: Capacity Building for Everyone

The gaps between theory and practice, education and experience, academia and industry, the taught and the learned, manifest in the divergence between industrial and indigenous practices of farming and irrigation. The former can lead to short-term gains but unsustainable (unwise) long-term choices, while the latter can result in economically suboptimal (unintelligent) approaches. The negative impacts of industrial agriculture via excessive chemicalization, mechanization, and genetic modification—all products of taught forms of knowledge and hailed as revolutions—have prompted even the strongest proponents to pause and reconsider. One naive response would be to follow the previous revolutions with yet another one. A wave of blind digitalization via the precision agriculture and hydroinformatics revolutions might seem to salvage or at least make corrections to industrial agriculture and simultaneously promote sustainability (Basso & Antle, 2020). Although promising on many fronts, digital and precision agriculture solutions suffer from the shortcomings of accumulated intelligence at the highest levels, i.e., overwhelming data processing and non-transparency.

Perhaps a third way is required that aspires to combine the advantages of experiential learning with the strong points of taught knowledge in a new approach that aims towards wisdom, building socio-economic capacity, and filling knowledge gaps for all. Having addressed the first question raised at the start of the previous section about the limits of technology led-intelligence, we now elaborate on our second question. Whose capacity? The key to locating the appropriate seat of knowledge-capacity in irrigation agriculture may be found by focusing on societal needs, and thinking in particular about the plight of smallholder agriculture, for which water conservation is a major a challenge.

Smallholder farms produce 80% of the food in developing countries, yet their future is uncertain. Some prominent water engineers argue that the transition away from smallholder agriculture is rational, inevitable, and perhaps promising for all concerned. The late Peter Rogers (2010) of Harvard University wrote:

> … solution does not lie in the water sector: The hard reality is that [even with] the application of all the good practices of appropriate technology, community based development, capacity building, private sector engagement, demand responsive approaches, etc., small holder irrigated farming is unlikely to be sustainable in the long term. The only alternative is to encourage mass migration out of the rural areas.

However, even if small farmers are provided a productive exit from agriculture, industrial-era agricultural technologies do not lead to a sustainable or societally meaningful future. By contrast, the repetitive seasonal subsistence tasks such as those practiced in traditional agriculture can lead ideally to self-sufficiency, occupation, and a way of life, which in turn shape values, virtues, identity, and community (Thompson, 2009). Sustaining smallholder farming is not merely a question of financial profitability but a value-laden socio-economic choice (Fan et al., 2013).

The second agricultural revolution of modern times based on extractive mechanical and chemical industries resulted in 100-fold gains in productivity (Mazoyer & Roudart, 2006) but at the cost of resource depletion, increased input costs, loss of biodiversity and degradation of air, land, and water. The so-called Green Revolution, a term reportedly coined by USAID director William Gaud in 1968 to counter the Red revolution of communist states, pushed small peasantry aside in the developed world. This revolution advanced the reductionist scientific philosophy of great nineteenth century chemists such as Justus Liebig and the economic theories of Thomas Malthus and Garrett Hardin (Thompson, 2009). Disillusionment with the impacts of the Green Revolution coincided with the inclusion of agriculture in the climate and sustainable development agenda (Fischer et al., 2007, Beddington et al., 2012) and also with the food crisis of 2007–11 (Struik et al., 2014).

Response to this disillusionment came with new scientific revolutions under the titles of ecological intensification (Cassman, 1999), adaptation science (Meinke et al., 2009), eco-efficient agriculture (Keating et al., 2010), agroecological systems (Brussard et al., 2010), conservation agriculture (Hobbs et al., 2008), system of rice intensification (SRI) (Uphoff, 2021), and others. These approaches have much in common with, and are most powerfully articulated under the banner of, *sustainable intensification* (Pretty et al., 2018; Cassman & Grassini, 2020). They share the principles of minimum mechanical soil disturbance (e.g., no-tillage and direct seeding), permanent soil organic cover (through mulching with crop residues or through cover crops), and species diversification, for which special crop rotations are introduced. In some cases, such as the system of rice intensification, farmer expertise and labor in selecting and transplanting seedlings are substituted for land, water, and other costly agricultural inputs (cf. Christiaensen et al., 2020). The promise of sustainable intensification (SI) is that by adopting the above principles, even small-scale farmers will become profitable because of the significant reduction in the input cost coupled with the increase in yields. This new type of agriculture is sustainable because it improves soil quality and biodiversity in the environment, reduces the emission of greenhouse gasses, reduces water pollution by minimizing the use of synthetic fertilizers and pesticides, and slows down the impact of climate change (Kassam et al., 2009). Therefore, SI provides a constructive approach to sustaining small farming and making it profitable.

As a result of these positive economic and environmental impacts, nature-inspired practices have been making their way throughout the world. Although SI has been shown to work successfully in various parts of the world (Friedrich et al., 2012), the spread of these practices is still limited because they are fundamentally different from modern industrial agriculture. Initial adoption has significant financial overhead. A switch to sustainable intensification may also require a radical transformation in the social and economic organization of Pakistan's agriculture. Such changes are notoriously difficult to orchestrate (Waddock, 2013) because of rebound effects (Paul et al., 2019), technology treadmills (Levins & Cochrane, 1996), existing lobbies, infrastructures, subsidies, and institutional inertia. Intensification is not a value-neutral technical activity but may be associated with deliberate or unintended reconfiguration of society (Struik et al., 2014) and technology-induced environmental changes (Foray & Grübler, 1996). One may be required to think of unfamiliar tradeoffs in the energy-water-food nexus. It should be based on an all-inclusive assessment and cost-benefit analysis, including non-market benefit estimates.

In the context of Pakistan, these innovations have sometimes been called "paradoxical agriculture" because it appears that *fewer* inputs result in *higher* yields (Asif Sharif, pers. comm.). Paradoxical agriculture suggests that after initial seedbed preparation and mulching costs, some input elasticities become negative. If correct, many crop models and irrigation systems analysis in the Indus Basin Model would have to be radically revised. Already in this chapter, we have discussed the importance of resolving paradoxes for gaining wisdom. For the economic and environmental dimensions of the paradox, the resolution lies in knowledge itself. As a corollary to the *No Free Lunch Theorem* from economics and mathematical folklore, fewer inputs would result in higher yields only when the farmer resorts to advanced processes whose implementation requires the investment of both physical and mental energies guided by new forms of knowledge. The preparation of raised beds; optimal spacing of seeds during plantation; choosing the best crop combinations in a particular agro-ecological zone; and precise movement of light machinery for the tasks of sowing, weeding, inspecting, and harvesting, all require advances in mechanization, electrification, field sensing, and automation. Above all, they require the invention, optimization and replication of robust farm production processes that need to be adopted by farmers. SI or paradoxical agriculture is by no means a step back towards traditional pre-industrial age agriculture, but a step forward towards post-industrial era sustainable farming requiring new forms of digital data, scientific knowledge and machine intelligence. In purely economic and environmental terms, this future may or may not promote smallholder farming, as even large-scale farming requires an exit from its current unsustainable trajectory. As we will see in the following section, it is the road to wisdom (vis-a-vis intelligence) that can lead us to resolving the paradox of SI for the benefit of small farmers.

We come back to the issue of *whose* capacity-building would be required for such a radical transformation? It is clear that knowledge would need to be created, preserved, and communicated in multiple modes. Experiential and immersive learning would perhaps be the most effective path to discovering new farming techniques. Many sustainable agriculture practices have emerged as inspirations from close observations of nature, much the same ways that Ibn Tufayl or Alan Turing envisioned for their respective subjects. In Pakistan, pioneers of SI openly admit to receiving inspiration for their techniques during visits to the distant places like the Amazon rainforest, and not from any taught discipline of agriculture (Sharif, pers.

comm.). Cornell University credits the origins of SRI to the small agricultural field school of a Jesuit priest and Malagazy smallholding farmers in Madagascar in the 1960s through 1980s. These initial breakthroughs and pilot studies often hit the familiar issues of opaqueness, replication, and lack of explainability. These in turn have limited the diffusion and adoption of the SI techniques at wider scales.

Proponents of SI techniques call for farmer training schools and farm management education that are not modeled after traditional university education or driven by the experiential learning of individuals. They also call for reform in university education to incorporate lessons from SI into the traditional curriculum (Cornell University, 2023). A curriculum based on the physical and chemical reductionist philosophies of soil and the Green Revolution has to be revised and blended with a holistic biological philosophy of these newer approaches towards sustainable agriculture.

The roots of some of these approaches can be found in part in the controversial mystical works of Rudolf Steiner (d. 1925) who invented organic farming, and Sir Albert Howard (d. 1947) who pioneered composting techniques while in India (Thompson, 2009). For long, their techniques were dismissed as pseudo-science by the scientific establishment of industrial agriculture, until advances in the understanding of biogeochemical cycles, soil biology, and integrated systems thinking have proved the effectiveness of some of their methods conclusively. Other aspects have been correctly set aside.

In short, the seat of capacity spans the full spectrum of knowledge creators and consumers, ranging from field practitioners to university academics and government agencies. A similar synthesis of taught knowledge and experiential learning is being experimented at other places. In many new courses in engineering sciences, students are being exposed to both forms of learning from the very beginning, with the objective of creating respect for all modes of learning and exploring advanced topics related to complexity, sustainability, wisdom, and intelligence in coherent ways. Most importantly, the knowledge, wisdom, and intelligence acquired during the course of such explorations also increases appreciation and choice of an expanded range of worthy values. To balance sustainability (conservation) with intensification (growth) our water and agricultural sectors would need to realize that nature-inspired solutions extend from environmental and economic dimensions to encompass social and ethical concerns. This challenge is addressed in the final section of this chapter below.

15.5 Wise Indus Basin Gardeners of the Twenty-First Century

Throughout this chapter, we have tried to look at the dual dimensions of knowledge and capacity in the water sector of Pakistan through historical and philosophical lenses. Despite the immense importance of empowerment by knowledge, especially in the scientific disciplines, we have repeatedly cautioned the reader about knowledge capacity's ultimate destination. The socio-hydrology literature provides fascinating examples of learning from paradoxes and dealing with the unintended consequences of well-meaning actions. Similarly, the paradox of growing more food with less inputs through sustainable intensification provides clues for economic growth in agriculture, with water resources and smallholding farmers as major beneficiaries. Reflecting on paradoxes is therefore an important way to acquire knowledge *and* wisdom, whether the mode of reflection is the taught learning of model-driven science (e.g. socio-hydrology) or inferential learning from experience-in-nature (e.g. sustainable intensification).

We argue now that the examples given thus far only touch upon the acquisition of wisdom that is related to the *truths* of the world, be they scientific facts, mathematical constructs, laws of economics, or other aspects of reality. They do not, as yet, encompass the equally important dimensions of wisdom related to *beauty* and *goodness*.[1] One of the most effective methods of acquiring knowledge and subsequently discovering the wisdom related to the beautiful (e.g. aesthetically pleasing landscapes) and the good (e.g. the uplift of millions of smallholder farmers) is the third perennial approach to wisdom, which involves following those whose example imparts wisdom and *learning* from them.

In the Quran, the Prophet Muhammad (SAW) is introduced to believers as someone who will purify (*tazkia*), teach from the book (*kitab*), transfer wisdom (*hikma*), and whose life serves as a guide (*sunnah*). The prophetic way of learning wisdom from a master continues until today in many forms. Other Abrahamic traditions such as Christianity and Judaism deploy this method with various intensities, and almost all Eastern traditions rely on this mode of learning heavily. The master challenges the disciple with what seems like paradoxical propositions. The wisdom of the master, like that of the mythical guide Khwaja Khizr is not always initially obvious to followers, even followers as illustrious as Moses or Alexander, but rather, as al Hujwiri wrote, there is a progressive unveiling of the veiled (Halman, 2013; Hujwiri, 1982).

Setting aesthetics (beauty) and morals (goodness) aside for a moment, learning about puzzling religious truths such as *Tawheed* (the oneness of God) is an exercise in resolving paradoxes. The paradox imposed in knowing intimately about who is simultaneously the First and the Last, the Hidden and the Manifest, cannot be resolved by the rational mind alone, by believing in the dictates of a teacher, or solely by reflection on nature. The Quran advises all three modes of learning simultaneously. While hydrological truths do not, to our knowledge, impose paradoxes of such high intensity—some of the better known empirical examples like the Jevons and levee effect paradoxes have been noted above—in other sciences we do encounter high obstacles, and surmounting them has paid fantastic dividends. Prominent examples include Quantum Mechanics (e.g. the famous Einstein-Bohr dialogues led to various schools of QM interpretation and innumerable discoveries) and computer

[1] The classical trinity of Truth, Good and Beauty is mentioned in almost every tradition. (حق، خير، جمال)

theory (in which the pioneering mathematical works of Bertrand Russell, Kurt Godel, and Alan Turing on incompleteness theorems led to the discovery of universal computing and the entire computer revolution).

Historical transformations of beauty in water experience also deserve close study. Ancient stone-lined tanks were eulogized in inscriptions that compared them to oceans, their sluices to doors, and steps down to the water as places for ritual ablutions and prayers. A century ago, large dams were celebrated as structures of sublime beauty, as "modern temples" in Nehru's words, to the extent that famous international architects like Le Corbusier were commissioned for their ornamentation. A generation later, however, their aesthetics were radically reversed by increasing awareness of their social and environmental impacts. Wetlands and deltas formerly perceived to be revolting wastelands are now renowned for their biodiverse beauties and bounties. What are the emerging water aesthetics in and of the Indus basin? Surely, satellite images of the brilliantly green irrigated Indus Basin convey the beauty more effectively than many maps or any wiring diagram ever can. Will part of that beauty include the visual and agro-ecological connectivity across disputed provincial and international boundaries? The aesthetic *rasa* theories of medieval Kashmir still shape the performing arts across South Asia; and they remind us that aesthetic emotions include disgust and anger as well as love (Pollack, 2018). Can such aesthetic emotions help transform *ganda nallahs* back into freshwater streams? Such questions remind us of the important connections between aesthetics and ethics, the beautiful and the good.

Resolving paradoxes related to desired values has a major role in knowledge capacity for water management in the Indus Basin, and in all hydrological societies. Coming back to our case of sustainable agriculture in the Indus, the paradox associated with the continuity of smallholder farming is only broken when the goal is simultaneously reframed as the resolution of economic-environmental challenges as well as the attainment of wisdom for these caretakers of the basin—caretakers who tend the basin much as gardeners.

The role of the garden as a model and practice for breaking the smallholder paradox brings us back to the Circle of Justice formulations at the beginning of this chapter, which begin with the verse, "The world is a garden…." Historically, the verses that follow are known as "mirrors for princes," that is, guidance for persons who would be kings. They describe the chain of political and economic linkages necessary for a successful dynasty or state. The chain of justice probably inspired Mughal places like Shalimar Garden in Lahore and others throughout the basin (Wescoat & Muhammad, 2021). But it was a chain that was often and ultimately unheeded. Surely analogous linkages are important at the transnational scale of Pakistan and its neighboring riparians.

But we have also argued that classical circle of justice formulations are incomplete, and they have broken down precisely because of their missing and unheeded values. Focusing on smallholders invites us to consider circles of justice that feature and support those most in need, beginning at the household level. Recent water research has focused attention on the role of women in water management, and on the ethics of gender equity from the household to community and societal scales (e.g., Zwarteveen & Ahmed, 2014). How might a household circle of justice read? It might begin with "The home is a garden…." Research at the community and irrigation distributary levels has long drawn attention to the injustices faced by tail-end and socially marginal water users (Mustafa, 2013), and it has underscored the importance of dignity and respect for all irrigating gardeners. In this approach, "service delivery" for all water users becomes a moral duty as well as a functional institutional task. How might a community-level smallholder circle of justice read, and how might that be articulated with larger scales of regionally irrigated gardens? We are not yet able to provide these reformulations, but we can offer some thoughts about the values that can guide further development of the garden metaphor.

Using the gardens of the Quran as a metaphor, we are reminded that people who reach the garden (*Jannah*)—small and big, women and men, poor and rich—are the ones who have been purified and taught the book and wisdom by the Prophet (SAW) (key verses in the Quran include 2:151 and 62:2). They learn the moral lessons and signs of gardens in this world, positive and negative, for those of the next. In that respect, they may be regarded as wise gardeners in a well-watered landscape, and they reach that state via a combination of innate, taught, and learned approaches to wisdom. At a larger scale, part of their wisdom may involve regard for our river basins as living mosaics of *gardens underneath which rivers flow*. This in turn may involve the use of intelligent machines inspired by new technologies that enable them to become wise in ways that help preserve and enhance the quality of all life (fauna and flora) in line with their cultural and spiritual aspirations (Wescoat & Muhammad, 2021).

In reaching a vision of this sort—others may wish to develop the garden metaphor differently—one key to resolving the paradoxes of truth, beauty and goodness is unbounded love, and the related garden ideals of *sacrifice, compassion, altruism, generosity,* and *selflessness*. These are values that cannot be realized in unconscious algorithms or mechanizations. Machine intelligence may exceed human capabilities in narrow tasks such as predicting streamflows or crop yields. It may even reach general artificial intelligence one day. When that happens, who and what ultimately does the machine learn from? More importantly, machines are unable to learn from paradoxes, the ultimate source of wisdom. This is the Achilles heel for the road to intelligence, as compared to the road to wisdom, since an unconscious algorithm is unable to deploy the seemingly irrational virtue of love.

As a demonstration, consider the quintessential problem of water rights and water allocation in irrigated agriculture. Many frameworks exist for dealing with water resource scarcity, which aim to be equitable, just, compliant, reliable, and consistent. In all frameworks, stakeholders are assumed to act selfishly in order to protect their self-interest, and any lack of compliance leads to conflict. In many settings, scarcity is shared equally among users in rotational programs, known as *warabandi* in the Indus Basin. Where the authority to impose a rotation program is absent, conflict may be resolved by negotiated bargaining, e.g. inter-provincial agreements among river riparians. Situations of absolute scarcity lead to the dissatisfaction of all stakeholders, even when the allocation is facilitated by an honest broker or imposed by a benevolent authority. There can be ways to incrementally improve supply side allocations, or *intelligent* interventions to manage demand, but absolute scarcity is a hard social dilemma that has no satisfactory solution for self-interested rational actors, even with assumptions of bounded rationality. Now compare this problematic situation with the story below from Hadith literature. A companion of the Prophet (SAW) narrates:

> During the battle of Yarmuk, I went out in search of my cousin, who was in the forefront of the fight. I also took some water with me for him. I found him in the very thick of battle in the last throes of death. I advanced to help him with the little water I had. But, soon, another sorely wounded soldier beside him gave a groan, and my cousin averted his face, and beckoned me to take the water to that person first. I went to this other person with the water. He turned out to be Hishaam bin Abil Aas. But I had hardly reached him, when there was heard the groan of yet another person lying not very far off. Hisham too motioned me in his direction. Alas, before I could approach him, he had breathed his last. I made all haste back to Hishaam and found him dead as well. Thereupon, I hurried as fast as I could to my cousin, and, lo! in the meantime he had also joined the other two.

We find wisdom in "Those who … find in their breasts no need for that which hath been given them but prefer (others) above themselves though poverty become their lot. And whoso is saved from his own avarice—such are they who are successful" (Quran 59:9).

Social scientists have studied the nature of altruism in human behavior (Batson, 2014). For example, economists Fehr and Fischbacher (2003, 785) state that, "Contemporary scholarship recognizes that the most fundamental questions concerning our evolutionary origins, our social relations, and the organization of society are centered around issues of altruism and selfishness. Experimental evidence indicates that human altruism is a powerful force and is unique in the animal world." The uniqueness to human beings has been debated by animal ecologists who observe cooperative and caring behavior in other species. "They form communities like you" (Quran 6:38). The answer to how interactions between altruists and selfish individuals can be organized in ways that incentivize cooperation over water resources may be found in the development of knowledge capacity that cultivates wisdom in addition to enhancing intelligence. We have suggested in this paper that a powerful way to operationalize knowledge capacity in pursuit of wisdom can be envisioned through cultural and spiritual ideals associated with irrigated gardens.

What might such an operationalization entail? Of course, education is the vehicle, enriched through all of the dimensions of taught, innate, and experiential forms of knowledge and wisdom, and with an aim of building capacity from the personal to the global scales. We end this chapter by wondering what a twenty-first century manual of wisdom might look like for water managers and water users of the Indus? Might it take the form of a compendium of modern fables along the lines of Aesop's stories derived from the *Panchatantra* and circulated in many forms through space and time? Or might it be a modern day *Gulistan* that links the traditional wisdom of religious and cultural values with insights from modern scholarship and new practices using beautiful prose and poetry? Or could it reimagine the apparent paradoxes of socio-hydrology (Table 15.2) through completely new genres of fiction and media? Perhaps, deep polysyllogistic insights such as those expressed in the circle of justice formulations could be refined and circulated in social media texts arranged in dynamic topological arrangements? Perhaps these innovations could appear in a MOOC offered to every student regardless of background, major, and location worldwide. We do not know which of these possibilities might resonate with different social groups, and in other ideas that readers imagine. Whatever it might be, it will be very different from the knowledge capacity products and processes that we are used to prescribing in modern water resources management. It would lead us to a very different path and hopefully very different—better and more beautiful—outcomes for our Indus Basin. Perhaps, a sentient river garden with the stewardship of wise water gardeners.

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Chapter 16
A Transformative Framework for the Water Sector

Mahmood Ahmad

Abstract Pakistan finds itself in a moment of reckoning, in which it must address a growing set of issues facing water and agriculture. These issues encompass the negative impact of climate change, the faltering green revolution, COVID-19, floods, droughts, and conflicts. We must learn from past mistakes and forge a new strategy to make our large water endowments more productive. This chapter summarizes the previous chapters, which have detailed the forces that shape the past, current, and future of Pakistan's water policy, described supply and demand options, and explained how agriculture (the primary user of water) can produce more and better quality food with less water. After a detailed description of the water economy, we propose a transformative agenda for the twenty-first century. Two guiding principles need to be understood before we propose a transformative agenda. The first principle is that we build our water management strategies by learning from the past. While both the issues and solutions have been well-documented in government-approved policies and strategies, it is implementation that has been the weak link because of the lack of political will. The second principle is that most water problems and solutions are outside the domain of any individual sector (population growth, agriculture, environmental flows, etc.) to fix. An integrated approach and cooperation within and between organizations is essential.

Keywords Low-cost supply and demand options · Water economy · Transformative agenda · Water policy in Pakistan · Water resource management in Pakistan · Indus River Basin · Regenerative agriculture

This chapter draws heavily on work presented by authors of key messages in some of the chapters.

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16.1 Introduction

In the past 60 years, a large number of policies and studies have been prepared to determine the water resources problems in Pakistan, with the World Bank's report *Pakistan's Water Economy: Running Dry* as the most recent document clearly highlighting the issues, challenges, and possible solutions, with a balanced approach on both the supply and demand side of water management in Pakistan. Prior to this, in 1995, the World Bank supported significant water policy reforms by the Government of Pakistan to decentralize operation and maintenance of the irrigation and drainage systems. Consequently, a program of institutional reforms was initiated for the purpose of establishing autonomous organizations at the level of the provincial, canal system, distributary, and minor canal levels. These institutional reforms envisaged the formation of autonomous, self-accounting and self-financing Provincial Irrigation and Drainage Authorities (PIDAs); Area Water Boards (AWBs) along canal commands; and Water User Associations (WUAs) at the watercourse level. However, the implementation has been characterised by varying degree of progress among different provinces. Some organizations, such as AWBs, worked well for some years, but then their efficacy deteriorated with time, mainly due to a lack of political, financial, and technical support.

Following the failure of these water policy reforms, no significant efforts were made to address key issues and the well-publicized National Water Policy (NWP) took 10 years to be formulated and was adopted in 2018. The new National Water Policy attempted to provide a much-needed framework for addressing the country's water woes. However, it still falls short on certain critical issues. A rational water policy should be based on (1) well-defined goals and guidance with the least expensive solutions that are sustainable in the long term. It is not easy to chart such policy goals since different interest groups view solutions differently and the key reforms needed to trigger change are not implemented.

This book provides a unique lens to the reader interested in knowing more about the forces that shape the past, current, and future of Pakistan's water policy. The various chapters have tried to balance low cost supply and demand options, and more importantly, explain how agriculture (the prime user of water) can produce more and better quality food with less water, in meeting growing demand from competing sectors. In this book, we hope the reader will be more familiar with the water economy, from the socio-economic perspective, to its history and stock taking that has brought Pakistan to where it is today as well as with proposals for a transformative agenda that can take it where it should be in the twenty-first century.

16.1.1 Twentieth Century Water Resource Management in Pakistan

During the pre-Indus Basin era, three major factors resulted in a large expansion of water resource infrastructure in the subcontinent driven by (1) population growth (2) changing standards of living (3) expansion of agriculture. The population in Pakistan has increased from 37 million in 1950 to 236 million in 2022 (World Population Prospects), which resulted in a per capita drop in water from 5222 Cubic meters/year in 1958–1962 to 1163 cubic meters/year in 2021, moving from excess supply to excess demand, or from a water-rich nation to a water-scarce country. At the end of the century, the development paradigm started shifting: from plenty of water to perceived scarcity. For the last three decades, the narrative has been that Pakistan is a water scarce country, but this narrative is largely misleading and hides the real problem: that among other factors, misguided policies were adopted. Pakistan is, in fact, rich in water resources, but has had to deal with bad governance, explosive population growth, and a lack of willingness to use economic instruments, all of which resulted in less water availability.

The anticipated impacts of climate change, such as uncertain rainfall and water availability, further exacerbate the situation. Consequently, the annual amount of available freshwater resources per person has declined by more than 20% in the past two decades.

16.1.2 A New Century Needs New Thinking, New Actions, and a Transformative Agenda

A new challenge in this century is the direct impact of climate change on water. As Simi Kamal writes in Chap. 1, "there are new emerging realities as the water regime of Pakistan is affected—the growing frequency of floods, the shifting of the seasons, natural region ecosystems, and agro-ecological zones. These old and new challenges often get set aside in the obsession to bringing more areas under agriculture and more infrastructure development."

Kamal goes on to say:

> A transformative framework for water in Pakistan must look at the intersection of water, agriculture, poverty, access, and use, while considering the devastating impacts of climate change on water. Many of water's economic outcomes are closely linked to social outcomes, given strong connections between the water regime, agricultural economies, and social trends. These include rural to urban migration, human health, and well-being, water-related conflicts, environmental degradation, severe threats to freshwater ecosystems, loss of biodiversity, increasing pollution, and the loss of productive areas due to waterlogging and salinity.

Without local government, it has become "increasingly difficult to reach the poorest people."

16.2 Lessons Learnt on Water Management in Pakistan

Studying Pakistan's water management can provide unique lessons as highlighted by Simi Kamal (Chap. 1) and Erum Sattar (Chap. 2) that can be used in forging new development paths. Several success stories have been summarized in Fig. 16.1 below. Indeed, Pakistan is one of the few countries where water has been allocated

Fig. 16.1 Indus Basin: positive outcomes. (Source: Author's work and analysis)

at all levels with well-established and agreed-upon mechanisms, such as the *warabandi* system, where water is allocated at the water course level. A number of researchers (Perry, 2011) have argued that despite the accurate criticisms that there is a mismatch between supply and demand, it is nonetheless an exceptionally stable and productive system for sharing scarce water supplies with minimum administrative input over vast areas.

In spite of being the largest contiguous irrigation system in the world, it is also one of the most mismanaged, as shown in Fig. 16.2. Institutional failure in delivering water at different levels is inefficient, inadequate, inequitable, full of corruption, and low public participation. There are too many organizations serving the water sector and often a lack of coordination among agencies responsible for supplying water to end users. Poor water governance, lack of an implementable regulatory

Fig. 16.2 Indus Basin: negative outcomes. (Source: Author's work and analysis)

framework, and unaccounted environmental costs are some other unresolved issues covered.

Again, as Kamal says in Chap. 1 of this book:

> Pakistan needs a different conversation around water and different ways of developing the transformative narrative that will lead clearly to the actions required in the twenty-first century." Pakistan's water woes and solutions lie largely outside of the domain of any individual sector (such as population growth and agricultural policies). This transformative narrative needs to rest on global trends and be anchored in the ground realities of each province. Maintaining and enhancing the integrity of the Indus Basin is a serious and important responsibility of the Federation, the provinces, and other administrative units. This means concentrating on repairs and replacement, instead of building new infrastructure with a leaky downstream. Kamal points out that, "funds invested in this way would save almost 50 percent of the water losses in the system—much more than the 'new' water that would supposedly be 'produced' by new dams.

16.3 New Factors

16.3.1 Climate Change

Most chapters highlight the fact that within a short span Pakistan has gone from being a water rich country in the 1950s to a water stressed country in 2020, and which is projected to be water scarce by 2035 (IISD) largely due to growing population, rising income and urbanization, and poor management practices. It warns that climate change will bring additional challenges to this finite supply.

Pakistan has seven thousand glaciers, more than any place other than the north or south poles. But with global increases in temperature, snow is melting faster in these glaciers, which has already led to 3000 outbursts, with 33 more ready to burst (Pakistan's Worst Floods, 2022). Adding to these abnormalities, monsoon rains have an erratic pattern—this year rainfall started early and poured in record amounts. Sindh's rainfall was eight times higher than usual and Baluchistan's was five times higher. On top of this, exceptional temperature were recorded in Nawabshah, a town in Sindh, where it was recorded to be 122.4 degrees (50.2 Celsius)(Washington Post, 2018) (Fig. 16.3).

In fact, 2022 has been a wakeup call, showing us what lies ahead: climate change caused at least three extreme weather events just in one year—two heat waves, with April as the hottest month in 61 years, and epic floods in the fall. The 2022 floods are much worse than they were in 2010, with much more devastation downstream in Sindh and Balochistan than Khyber Pakhtunkhwa to the north. According to NASA (Devastating Floods in Pakistan, 2022), the effect of the monsoon rains has been compounded by the continued melting of Pakistan's 7000 glaciers with widespread floods as shown in Fig. 16.3. Upwards of 1200 people have been killed and nearly 1.5 million homes have been damaged or destroyed, with 30 million Pakistanis affected. Planning Minister Ahsan Iqbal estimates that Pakistan would need US$10 billion to repair and rebuild infrastructure, which could take up to 5 years (Sheikh, 2022). Climate change has emerged as Pakistan's foremost existential threat. It is now at the heart of our national security paradigm. As we have seen, floods are triggered by climatic changes and they cannot be brushed aside simply as one-off events.

The debate surrounding climate change is moving in a new direction. Because of the sheer size of the catastrophe, the damage could not have been prevented. At best, it could only have been minimized. Adil Najam, who penned the foreword of this book, has called climate change "a threat multiplier — where the threat itself is poor governance and 2022 floods are evidence that the script has flipped. Climate change is now the threat, and Pakistan's weak governance is the footnote — a multiplier of the threat, but not the primary threat. Everything unjust and broken in Pakistan is going to get dramatically worse because of climate change, and the poor and vulnerable in Pakistan will carry a disproportionate share of the burden"(Zaidi, 2022).

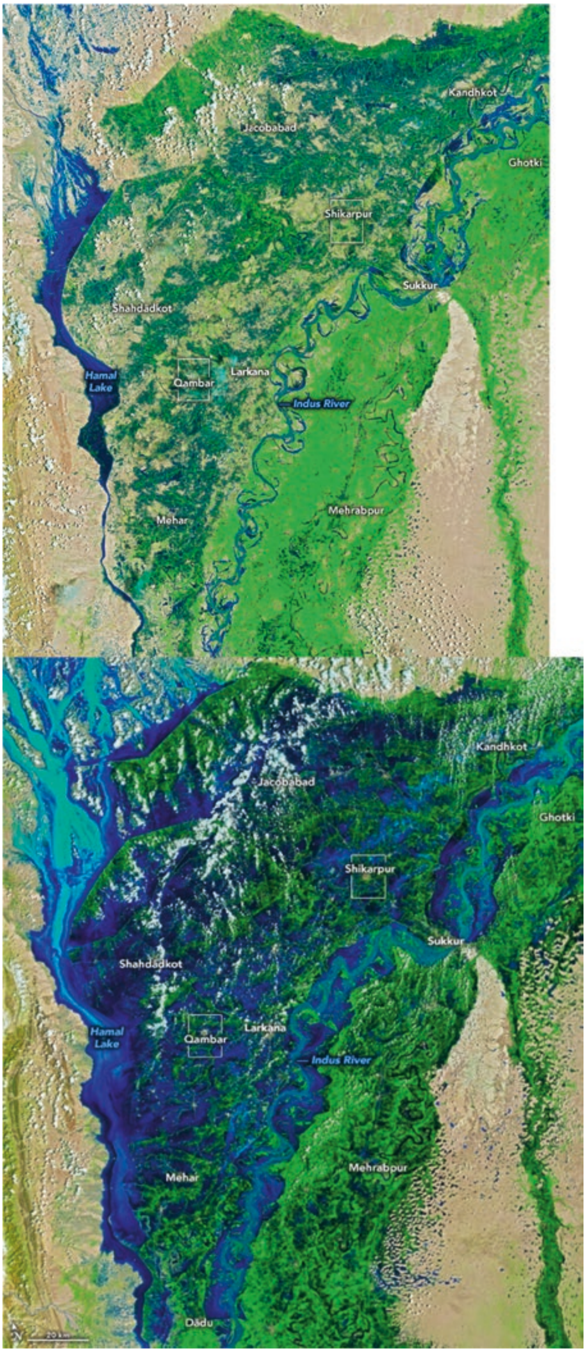

Fig. 16.3 Before and after the 2022 floods. (Source: NASA, Devastating Floods in Pakistan, 2022, public domain.)

But there are others who are of the view that we did not learn from 2010's huge floods and that we are just waiting for the next flood to come. Still others believe that the country didn't prepare or fortify its infrastructure for the floods and other disasters that would come with increased frequency and intensity (Sheikh, 2022). Floodproofing was not discussed widely even among academics, let alone among policy makers. Instead, the lakes became a tourist attraction and investors made the most of it by—legally and illegally—building hotels and other attractions without ensuring that these structures could withstand extreme floods.

Now, finally, a few voices have articulated clearly that Pakistan is the ground zero of climate change, since its carbon footprint is less than one percent of global emissions. A good case can be made to support financially bankrupt Pakistan with both short- and long-term financing to rebuild infrastructure for sustainability and resilience. But the immediate response from rich countries has been pathetic. Indeed, richer countries have their backs on developing countries and on cash-starved Pakistan. The EU, the UK, and the United States have contributed a shockingly low Rs 7.6, Rs 39 and Rs 24 *crore* (ten million) respectively, in contrast to Imran Khan (the former prime minister of Pakistan), who raised Rs 520 *crore* in three hours as donations for flood victims. This exposes how little richer countries support climate justice. Instead, they are more interested in supporting measures such as carbon offsetting, which does little to actually reduce carbon emissions.

Pakistan, with CO_2 emissions of 0.98% per capita, which contributes less than 0.5% to the climate crisis, is being handed crumbs and told to be grateful for them. Pakistan is not responsible for climate change in the way that developed countries such as the United States, China, Russia, and Europe are. The situation in Pakistan today may look like a distant reality for more developed countries, but what is happening on its soil is the future of the rest of the world if we don't stop burning fossil fuels.

What Pakistan needs to do is to address water-related climate change issues that have only become more pressing. Pakistan should start preparing itself for future climate change and its impact on each sector. Better water management would probably be the best strategy to deal with these challenges. This approach is characterized as working out the tradeoffs between adaptation, mitigation, and realizing productivity gains all along the water and commodity supply chains. Below are some priority area:

1. Drainage: Though we have a wonderful contiguous irrigation system, that system is very poorly designed. It is analogous to building an upscale washroom with state-of-the-art showers but without a proper outlet to dispose of dirty water. This problem has only been magnified with climate change.
2. Glaciers are melting: When the glaciers melt, there are serious food security implications, since less water will flow downstream. To deal with this, we propose more emphasis on nature-based solutions, climate smart agriculture, and to focus on improving water productivity, adaptation and mitigation.
3. This book describes an innovative way to finance climate change. This is the right time to seek funding opportunities

4. IISD has collaborated in the past with Pakistan's Ministry of Climate Change and has the following analysis:

In the near term, climate change is more likely to impact timing of peak flow and river flow volume and due to variability in precipitation, rather than annual overall flow volume from glacial and nival (snow melt) sources.

Further existing knowledge regarding the complex hydrological regime of the Upper Indus Basin is limited, which impedes development of clear projections of long-term water availability.

Priorities for action to address identified gaps in knowledge and capacity include accelerating uptake of sustainable irrigation practices by smallholder farmers, strengthening post-secondary education in climate change, establishing a repository of water data and analysis, and modernizing Pakistan's streamflow monitoring network.

16.3.2 The Food-Energy and Irrigation Nexus

What is this food-irrigation-energy nexus in Pakistan's water management? Agriculture and the water sector increasingly depend on energy and—more worryingly—on costly imported fossil fuel, making agriculture unprofitable and non-competitive. In addition, Pakistan's irrigation sector is increasingly relying on groundwater, much of which is pumped using ever expensive imported energy. Groundwater is being used faster than it is being recharged in most provinces, leading to overexploitation, and thus leading to depletion and a higher cost for using each additional unit of water. Electricity is subsidized in most provinces (especially in Baluchistan), thus encouraging it to be used wastefully. Climate-smart policies offers the possibility to delink strategic crop prices from global energy prices to improve farmer incentive structures while making production more sustainable.

16.3.3 Benefitting from Unconventional Water Use

The world is moving towards developing circular economies, meaning to reuse as much as possible. Our entry point is reuse of drainage and waste water. To protect the quality of limited freshwater resources, investing in wastewater treatment infrastructure and other non-conventional water resources development is necessary. It is especially important that the wastewater generated by municipalities, cities, and industries be treated before being discharged into water bodies. At present, only Islamabad, Karachi, and Faisalabad have wastewater treatment facilities, which are limited and only partly functional for various reasons, including a lack of financial resources to meet operation and maintenance costs and a lack of technical capacity. Therefore, in order to maintain the quality of the receiving water bodies, massive investment is required to install and operate sustainable wastewater treatment facilities. Further, a mechanism needs to be developed that can recover the operational and management cost from beneficiaries.

16.4 Framework for Actions—Implementing a Transformative Agenda

Two guiding principles need to be understood before we chart any new path or propose a transformative agenda.

The first principle is that we build our water management strategies by learning from past lessons—both the good and the not-so-good, as highlighted in the two figures outlining constraints and opportunities. Past policy discourse lacked the political will and trust among provinces that was needed to implement those policies. Both the issues and solutions have been well-documented in government-approved policies and strategies; it is implementation that has been the weak link. The second principle is that most water problems and solutions are outside the domain of any individual sector (population growth, agriculture, environmental flows, etc.). An integrated approach and cooperation within and between organizations is essential.

A large body of literature that provides a framework based on quantifying the cost of inaction can be used as a lever to raise awareness among governments and policymakers about the need for climate action sooner rather than later. Identifying the risk component of investments while highlighting how they can be compatible with strong economic performance, however, will shift the climate story from a threat to an opportunity.

Section 16.4.1 outlines key interventions that would benefit from better implementation.

16.4.1 Developing an Inclusive Water Economy

16.4.1.1 Better Access to Water for the Poor

As Kamal elaborates in the first chapter of this book, “Pakistan has always been a ‘water economy,’ with 60 percent of the population directly engaged in agriculture and livestock and 80 percent of Pakistan’s exports based on these sectors. Approximately 95 percent of surface water and almost all fresh groundwater in Pakistan is currently used in agriculture. But who benefits? We know that 39.2 percent of Pakistan’s total population—88 million people—live below the national poverty line. They are largely out of the domain of water subsidies, projects, and programs.

A paradigm shift is required to recognize the role of the actual farmer (not absentee landowners) as fundamental in the irrigation and agricultural production process, and the cornerstone of the water economy. As Kamal notes at the beginning of this book, "the poor health and sanitation conditions of the urban poor have to be recognized when we discuss the circular economy of water in urban areas."

16.4.1.2 The Equity Issue

As Sanval Nasim points out in Chap. 9 of this book, initially, *warabandi* worked well "as it ensured fair access to surface water." The system had enough water from the head-end to the tail-end — everyone "received roughly equal amounts of water, more than enough to adequately irrigate their crops. However, as the population increased and agriculture expanded, the demand for irrigation significantly increased," so that by the time the water reached the tail-end, it was "barely a trickle. This forced tail-end farmers to overwhelmingly rely on groundwater to irrigate their crops. The original spirit of *warabandi* — to ensure equitable access to surface water — faltered as head-end farmers benefited considerably more relative to tail-end farmers." However, the opportunities created by groundwater have steadily diminished. Nasim explains, "Most head-end farmers receive enough surface water to irrigate crops, so they have no need to rely on groundwater to meet irrigation deficits. Thus, head-end farmers do not extract too much groundwater. Without an adequate alternative source, these farmers compete to extract groundwater to meet their irrigation requirements. At the tail-end of a watercourse, not enough surface water flows through the irrigation infrastructure, leading to low natural recharge of the aquifer. High extraction and low recharge — with extraction well exceeding the recharge — means that the water table level at the tail-end has gradually fallen, increasing extraction costs over time."

16.4.1.3 The Role of Women

As Kamal notes in the introduction to this book,

> Pakistan's water sector's sensibilities about women's leadership and involvement are archaic. Fetching, carrying and managing domestic water, community-based sanitation work and water-related hygiene continue to be seen as the 'women's domain,' while national discussions, debates, decisions, infrastructure and initiatives on water are still seen as 'men's domain.'"

It is time to break the glass ceiling in the water sector and bring in Pakistan's talented women and girls.

Again, as Kamal points out, "women remain largely invisible in the country's water institutions, water-related ministries and department, water NGOs, and water businesses. They are seen mostly as 'affectees' of the water crises and climate change and therefore, are bracketed as part of the problem. Now they must be made part of the solution."

16.4.1.4 Improving the Integrity and Sustainability of the Indus Basin Irrigation System

As well documented in first two chapters, maintaining and enhancing the integrity of the Indus Basin is a serious and important responsibility of the federation, the provinces, and all other administrative units. This means concentrating on repairs and replacement, instead of building new infrastructure. The funds invested would save almost 50 percent of the water losses in the system, surpassing the amount that would be generated from building new dams.

Further, understanding "the fast-changing surface water and groundwater 'nexus' is also a challenge," and that does not mean the conjunctive use of water for irrigation is not important. We might have poor water use efficiency at the farm level, but efficiency at the global basin level is quite high. We need to assess how seepage from the irrigation system has fed the growth of groundwater reserves for decades, and whether these now need to be regulated under water sharing arrangements among the provinces."

16.5 Key Components of Transformative Process—The Strategic Options

16.5.1 Supply Side Options

While the supply-side focus continues on building large dams, which have been planned for the next decade and beyond, the main obstacles are the relocation of existing population, poor environmental records, and the crowding out of investments in low-cost solutions to generate an extra or save a unit of water. The unprecedented floods of 2022 have revived the debate on the need to build large dams, and the cost the nation is paying for forgone opportunities, especially by not building the Kalabagh Dam.

Each of these types of floods have their own causes (which need to be investigated) and with different remedial actions. Without proper investigations of causes, remedial actions cannot be specified. As Rasheed and Ahmad point out in Chap. 7, "there is the common perception that if Kalabagh dam had been built, the damage could have been avoided." Unfortunately, they write, this is not true since it would not have prevented either urban flooding and flash flooding from hill torrents. It would only have reduced flooding in the Indus downstream of Kalabagh if it had been properly operated. Several small dams in Balochistan did not prevent flood damage; indeed, the dams made things worse when they failed. Apparently, these dams had inadequate spillway capacities. Storage at farm levels and water harvesting at all levels is an option that is currently only being discussed but which has great potential both inside and outside the Indus basin.

Finally, Pakistan is extraordinarily dependent on its water infrastructure and has invested heavily in it. Opting against the construction of new dams is a lost opportunity but neglect has also led much of the existing infrastructure to deteriorate. There is no modern asset management plan to repair or replace irrigation infrastructure. Only 5–10% of what is needed to repair and maintain this infrastructure is budgeted. The cumulative effect on the river barrages and head works has left these strategic structures very vulnerable to unforeseen damage, with enormous consequences. Therefore, immediate investments are needed to maintain past water supplies option and in meeting future food and other competing demands. The reuse of irrigation and wastewater has also been untapped in Pakistan, a potential need to be harnessed.

Policy Actions:

- Supply side options should create water storage at all levels.
- Various floods have their own causes which need to be investigated and remedial actions proposed. Without proper investigations of causes, remedial actions cannot be specified.
- Implement a modern asset management plan to repair and replace irrigation infrastructure.
- Irrigation and drainage schemes need to be sustainable.
- Water harvesting is a policy option for cities and rural areas alike.
- Promote wastewater reuse.

16.5.2 Demand Management Options

As highlighted in Chap. 11, the agricultural sector uses a whopping 96% of water, wastes a large part of it, and pays less than the other sectors for water, while contributing only 20% to the GDP. Furthermore, the rigid and supply-driven nature of the world's largest contiguous irrigation network provides an in-built incentive to waste water and adopt low-value cropping patterns. Pakistan has underinvested in water demand management, which would offer some policy options that could enhance water productivity. Policy options aim to improve productive and allocative efficiency of water use in agriculture while also addressing issues related to the environment and climate change. In layman's terms, improving productive efficiency means getting more crop per drop while improving allocative efficiency often refers to extracting more value per drop of water. In the context of water, climate change leads to either "too much (floods) or too little water (droughts)" and a rise in global temperature.

In the future, the agricultural sector needs to produce not just more, but also more diversified and better-quality food using less water to meet the growing demand from competing sectors (including environmental flows). We have enough water; it is now time to correct water productivity policies and improve governance. Pakistan has invested more in improving productive efficiency rather than allocative efficiency since the former is politically less controversial. Even programs and projects to improve water use efficiency have been done in a piecemeal fashion—from canal lining to laser land leveling to high irrigation efficiency—with very mixed results.

The following three policies need to be promoted to enhance water productivity, which is key to sustainable water management at the field, farm, and basin levels: (i) increase the marketable yield of the crop for each unit of water transpired by it; (ii) reduce all outflows (e.g., drainage, seepage, and percolation), including evaporative outflows other than the crop stomatal transpiration; and (iii) increase the effective use of rainfall, stored water, and water of marginal quality (Hemdy, 2008).

Policy Actions:

- Implementing water demand management policies requiring structural incentives, regulations, and restrictions to help, guide, influence, and coordinate farmers' efforts in making efficient use of water.
- Rationalize water use in agriculture, starting with rice and sugarcane.
- Encourage the adoption of innovative water-saving technologies, water costs and values rationalized.
- For canal water incrementally move towards full cost pricing using appropriate tools.
- Groundwater needs both price control or regulations to sustainably pump, taking account of environmental externalities.
- Unbundle water rights from land rights as a starting point in developing a prudent water allocation policy.

16.5.3 Regenerative or Climate Resilient Agriculture

Presently, agricultural water usage in Pakistan is not sustainable because of its poor management at the farm level—a running theme in most chapters. This section explains how Regenerative Agriculture (RA)[1] is so important for water issues, especially given climate change challenges. Hence, we need to change our water consumption practices, especially in the agriculture sector. The past practice of inundating the soil using flood irrigation not only wastes too much water, it also

[1] Regenerative agriculture is a holistic land-management practice that uses the power of photosynthesis in plants to sequester carbon in the soil while improving soil health, crop yields, water resilience, and nutrient density.

It draws down atmospheric carbon dioxide and, at scale, can reverse the climate crisis. We are about to run out of topsoil to grow food worldwide. Regenerative agriculture rebuilds top soil and, can provide global food security. We are about to lose adequate water to sustain human societies. Regenerative agriculture recharges water cycles and restores water quality, and, at scale, can provide both drought and flood resilience.

(https://www.greenamerica.org/healthy-soil-cool-climate/regenerative-agriculture-101).

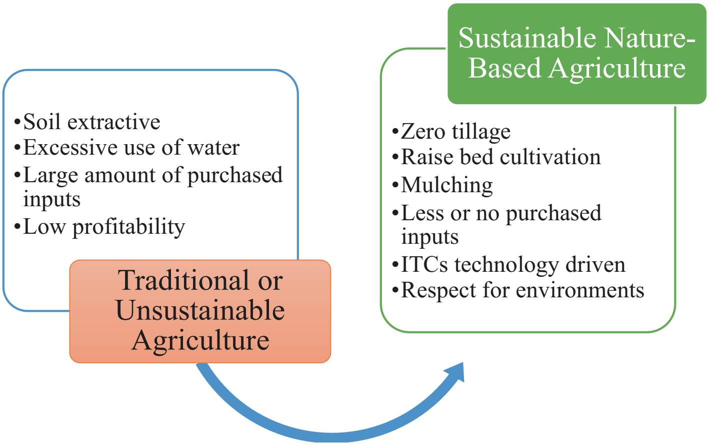

Fig. 16.4 Proposed transformative process in agriculture

harms the natural ecosystem. In RA, it is possible to grow food with far less water than we currently do, and make agriculture profitable, competitive, sustainable and inclusive. It is necessary to create an enabling policy environment for greater productivity and export competitiveness as outlined below (Fig. 16.4).

A comprehensive policy shift would entail:

- RA with the goals of growing, marketing, and saving in developing competitive agriculture.
- Market linkages—promoting village business centers, warehouses, etc.
- Providing digital options—service providers, financial services, retail and home delivery.
- Green growth policies in agriculture in line with present government policies.

The concept is based on FAO's work that has spanned four decades, starting with conservation agriculture (no tillage), and leading to more recent work on "Grow and Save" and also on "Climate Smart Agriculture (CSA)" (CIAT, 2017) which has been supported by additional donors. At a broader level, a climate-smart crop system requires farmers to (i) use quality seeds, adapted to the local climate and pests; (ii) diversify crop systems; (iii) use sustainable mechanization; (iv) apply soil and water conservation practices; (v) improve water management; and (vi) invest in agricultural knowledge transfer. In the context of water, three technologies and practices need to be promoted: (1) laser leveling and permanent raised bed cultivation (2) mulching (3) diversified crops and intercropping. Farmers using these technologies and methods have reported a decrease in input cost and an increase in crop yields and net farm incomes. Approximately 54% and 96% of those who have adopted Zero Tillage (ZT) and laser land leveling, respectively, have reported increases in yield (Qureshi, 2011). PEDAVER (the farmer's organization in Pakistan) reports water savings of up to 65%.

It is still necessary to assess RA's potential to raise farmer incomes and enhance equity, while at the same time building climate resilience. RA can also address the impact of shifts in food security, water demand, and water quality. A key part of the work will require an assessment of current farmer experiences moving from traditional practices to RA practices. This will include an identification of the constraints to adoption as well as the policy environment needed for scaling up such practices. Farmers' key challenges in transitioning to RA will include access to information, agricultural extension support, availability and quality of requisite machinery, seed quality, pest attacks, labor needs, and the marketing of produce, including making buyers aware of quality differences and product value chains, etc.

Policy Actions:

- Minimize repeated crisis in food, water, and energy security during this transformative process to minimize investment risks.
- Promote and support policies that shift agriculture towards a more regenerative and sustainable production process, yielding true win-win solutions for agriculture, water, and climate change. Treat this as an entry point.
- Act to incentivize technologies and practices that are climate resilient. Invest in research, extension, and value chains to support or create enabling environments.
- Create a policy environment that enables greater productivity, reduced costs, increased incomes, and export competitiveness. This will make the transition to CSA/RA feasible especially for small farmers.

16.5.4 Reinvest in Ecosystem-Based Adaptation in Water Sector

Ecosystem-based Adaptation (EbA) measures are helpful in managing erratic precipitation and the expected increases in temperatures that exacerbate water security concerns. The environmental benefits of ecosystem-based measures are reflected in, for example, increased net volume of water in lakes or ponds, improved quality of water, improved hydrological flows around ponds or lakes, and improved ecosystem services. Benefits can also include reducing flood risk to lives and assets, strengthening local and provincial institutions, and building local knowledge while being sensitive to gender concerns. Finally, the economic benefits of ecosystem-based water could also be reflected in less flood damage and fewer costs, green/grey infrastructure being made more resilient to flooding, livelihoods sustained through improved aquaculture, and agriculture development where site interventions have been made. The 2022 floods are a lesson for us: that we need to not just respond when there is an emergency, but also prepare for future emergencies and rebuild infrastructure to be better than before.

Policy Actions:

- Enable a paradigm shift towards EbA for selected prioritized sites.
- Restore and manage wetlands. Implement site-specific restoration techniques, including desilting and excavation, reconnecting wetlands to river channels, afforestation initiatives, degraded wetlands (especially those with natural blocked flow paths to river channels), enhancing floodwater storage and groundwater recharge, diverting water to wetlands for excess floodwater storage.
- Planting trees in order to provide ecoservices at watersheds, to create shelters or wind breaks to regulate micro-climates at the farm level and plant forests and trees on farms that are naturally renewable and carbon-neutral, such as the moringa.

16.5.5 Addressing Climate Change and Disaster: Impact and Coping Mechanism

Meanwhile, climate threats and risks are also increasing globally at an accelerated rate, as seen in the increasing frequency of floods, fires, droughts, heatwaves and tropical storms in many Asian and African countries, but also in developed economies such as Australia, Canada, Germany, the United Kingdom and the US.

Pakistan ranks eighth in the world in terms of how much it is impacted by extreme weather events and climate change (2000–2019) by the Climate Risk Index. Between 1992–2021, climate- and weather-related disasters in Pakistan resulted in a total of $29.3 billion of economic losses.

Climate change is projected to push millions into extreme poverty and cause internal displacement and migration because of falling agricultural yields, food insecurity, and water stress. The lack of investment in climate resilience could have large adverse impacts on poverty, productivity, and future growth. A superflood, caused by the 2022 monsoons, in turn caused other types of floods. Hill torrents have been reported in various districts of KPK, Punjab and Balochistan. Riverine floods occurred throughout Pakistan, particularly in Swat, Kabul, and the Upper Indus river basins. Urban floods have also been observed and reported throughout Pakistan.

What can we learn from 2022 floods? Tauqeer Sheikh (2022) has provided a framework, noting that the 2022 floods are unusual and a fundamental departure from typical riverine floods. Given this, he states, there are three possible scenarios:

The Optimistic Scenario: This may well be a freak event year, and we may not have similarly serious non-riverine floods for several years or decades. We were not anticipating these floods but, in future, we will be better prepared. We will, therefore, have better management in the future.

The Pessimistic Scenario: Such floods will become more frequent but we will not draw any practical lessons — as we did not from the 2010 superfloods. We will live with the changes in the monsoon pattern as a New Normal, but continue with Business As Usual practices.

The Worst-case Scenario: These non-riverine floods will occur more regularly but they will also be accompanied by high riverine floods in the Indus and its tributaries. This will make the floods deadlier and costlier, because there will not be any fundamental changes in our approaches and preparedness.

In addition to implementing adaptation and mitigation policies, it is very critical to monitor land and water productivity when shaping climate change policies. Measuring productivity leads to a broad range of interventions that can improve it (crop varieties/patterns/governance/digital tools and information, etc.). Sustainable intensification uses ecosystem approaches to conserve water. Such approaches include knowledge-based precision irrigation, which provides reliable and flexible water use, along with deficit irrigation and wastewater reuse. However, these kinds of measures will have limited benefits if misguided subsidies, such as those to farmers which encourage them waste canal water, continue.

Policy Actions:

- Provide better drainage for urban areas; require new development projects to have planned drainage infrastructure.
- New irrigation infrastructure should be constructed better and designed to be flood proof.
- We need to identify vulnerable ecosystems, people, and biodiversity and explore how to shore up their coping mechanisms.
- Promote sound policies, information flow, early warning system, cross border agreements, cost sharing arrangements, and greater use of economic tools.
- Strategies be developed to move from emotional responses, as are often the case, to those that are need -oriented and assess the risks. In addition, larger dependence on emergency technical assistance be transformed to short- and long-term policies and programs.
- Measures need to be introduced to reduce flood risk through flood plains and hill torrent management, groundwater recharge, wetlands restoration, and community-based natural resource management.
- Sustainable groundwater management is a prudent policy option to mitigate droughts, with well-documented evidence from Jordan and Israel showcasing how managing groundwater effectively and sustainably can help to cope with the medium- and long-term impacts of droughts.
- The key to solving issues related to the environment is decentralized resource management at the local level. Recurring environmental disasters cannot be reduced unless local government institutions are developed, built and strengthened, trusted, and resourced (Sheikh, 2022).Manage risks in water/agriculture, promote crop insurance and develop early warning systems at the community levels.

- Propose low-cost mitigation options to meet drought and flood challenges.
- Implement methods to reliably measure carbon sequestration to soon allow smallholder farmers in developing countries (including Pakistan) to benefit from eco-system payment services, including potential transfers to support transition costs.

16.5.6 Food-Water-Energy Nexus—More Research needed to find real Tradeoff

The food, water, and energy nexus has emerged as a new perspective in debates about balancing potentially conflicting sectoral imperatives of large scale development investments concerned with energy, water, or food security. As Rabi Mohtar and Bassel Dahr explain, the nexus means that "water, energy, and food security are intimately linked. In simple terms, food production demands water and energy; water extraction, treatment, and redistribution demand energy; and energy production requires water" (Mohtar & Dahr, n.d.). Optimizing this link is key, since an action in any one area usually impacts one or both of the other areas. These links have always existed, but their importance has recently been highlighted, given how central this nexus is to sustainable development.

As agriculture has become more energy intensive, largely because of mechanization and water pumping, farmers complain that the cost of production has gone up. In addition, the cost of production has become more and more linked with global energy prices. Right now energy and wheat prices are at record highs, with significant food security implications not only for Pakistan, but also for other import-dependent countries. Countries must adapt their energy pathways, because after 2040, it will be impossible to maintain "business as usual" since there will be a clear conflict between other uses of water such as for food production and urban uses and the water needed in high-carbon energy production processes (Chap. 2).

As Dr. Erum Sattar writes in Chap. 2:

> As Pakistan races to provide electricity coverage to a greater percentage of its population amidst the rising energy demands of more affluent countries, it must think about the sheer scale of the water consumed in power plants for their cooling requirements, with coal and nuclear being particularly water intensive sources of energy. Given this, Pakistan must begin to explicitly take account of the impact of its energy production strategy and overall energy mix on stressed and dwindling water resources. This means that the political economy of water is inextricably linked with the political economy of energy production.

Policy Actions:

- Actions in the agri-food, water, and energy nexus can yield triple wins: equitable development, resilience to climate damage, and mitigation.

- Importantly, explicit accounting of water used in energy production is missing from current frameworks. Further, carbon emissions from the water-energy-nexus are often not taken into account.
- We need to raise awareness, both among policy makers and the general public, about how much water is actually used to generate energy and how those costs need to be taken into account when making public policy.
- Move agriculture towards less fossil fuel dependent water and energy use.

16.5.7 Mobilizing Unconventional Water Use

> In Chapter 2, Erum Sattar elaborates on the importance of reusing water: One aspect that has increased in importance over the years in countries around the world is the recognition that available water must be captured after use, recycled, and reused in sectors across the economy. Despite a growing climate of water stress in Pakistan's policy discourse, direct use of treated municipal wastewater as well as direct use of agricultural drainage water is yet to be tapped as a source of additional water supplies (FAO, 2011). The prevailing discourse to add water to the country's water supplies remains centered on building dams to capture 'new' water instead of creating more water through capture, recycling and reuse. This lack of focus on recycling and reuse is unfortunate, especially as it is an important way to tap into the innovative capacities of the private sector and companies who are keen to deploy the latest technology to the problems of water scarcity particularly as it plays out in large urban centers (Ferdinand, et al., 2021).

Water recycling, wastewater management, water treatment, water conservation, greening, water harvesting from rain and atmosphere, and other innovation are being adopted in both cities and towns. But these innovations are still haphazard, unregulated, and inequitable.

However, some voluntary interventions exist that are serving as a glimmer of hope for a sustainable future in Pakistan, such as the NUST MBR plant, which has successfully operated as a model site for MBR plants in Pakistan.

Policy Actions:

- Wastewater treatment systems, whether centralized or decentralized, advanced or basic, need to be put in place for municipal, industrial, and hospital wastewater.
- Provide adequate mechanisms for solid waste management and wastewater treatment as the extensive use of plastic contributes to urban flooding as it clogs the canal and drainage systems identify and implement simple nature-based solutions such as wetlands and low-cost technologies to address the problems.
- Policy actions need to be defined for short, medium, and long-term and sustainability of Water, Sanitation and Hygiene (WASH) projects.

16.5.8 Institutions and Governance

Pakistan's water sector is a classical case of policy, institutional, and market failure.

Policy failure is reflected in the low pricing for water, which does not cover the operations and maintenance cost nor the marginal cost of allocating resources. This low price also takes into account the limited utilisation of new irrigation technology.

In Pakistan, there are challenges to expanding modern irrigation technology—farmers may well be aware of technological options, but they will not invest in them unless they are pushed by (1) cost incentives (rising water prices); (2) pulled by profitable market opportunities; or (3) water is scarce. Both technology transfer and market development and incentive questions need to be addressed.

Institutional and market failures are reflected in poor water governance. There are 18 agencies serving the water sector yet there is no single organization responsible for the integrity of water resources in the Indus River Basin. Institutional reform needs a change in mindset, to move from a business-as-usual scenario to benefit-sharing mechanisms between provinces so that the needs and priorities of all provinces are met by the new water management legislative and institutional frameworks. Arrangements to deliver water at different levels of distribution are inefficient, inadequate, inequitable, and full of corruption, with low public participation.

Market failures in the water sector are prevalent because of three aspects: (1) water is treated as a public good; (2) there are a lack of policy reforms in creating water rights and markets and; (3) environmental externalities that are overlooked. At the heart of the water problem for policy makers and institutions is the challenge of allocating water among competing users with feasible regulatory and pricing mechanisms.

Policy Actions:

- Rethink policies that have created new water assets or built huge irrigation projects in the past without a sound financial plan that can recoup the cost from end users.
- The culture of build-neglect-rebuild should be replaced with investments in low-cost local solutions which users can pay collectively.
- Water pricing or other appropriate economic tools should be implemented now instead of being postponed to a later time. There should be a gradual move towards pricing that covers costs, but these reforms are not possible with distorted farm incentive structures.
- We need to deal with institutional failure—regulation, responsibilities, and building back better. Bottom-up consultation processes should be encouraged, and climate action should be incorporated into the mandates of implementing agencies to improve alignment and coherence between the national and local levels.
- Dealign with market failures: we suggest a detailed study be carried out on rights and externalities, looking at the possibilities of using taxes or other instruments.

16.5.9 From Management to Nexus to Governance and Wisdom

The water-food-energy nexus approach is also an important one to consider. In terms of the nexus, as Mahmood Ahmad and Tabeer Riaz write in Chap. 13:

> “unprecedented rates of population growth in urban, peri-urban, and rural areas of Pakistan have severely impacted land, water, and energy provision and distribution, resulting in a disorganized extraction of natural resources, poor water and sanitation conditions, and an overall depletion in standards of living. Increasing pressure on resources for socio-economic development has resulted in growing and competing demand for energy, food, and water.”

Thus, not using the nexus approach often results in sub-optimal investments.

Chapter 15 looks at water policy from a different and interesting lens and provides a good analysis of where we have been, where we are, and the possibility of turning the Indus Basin into the irrigated garden. As James Wescoat and Abu Bakr Muhammad write:

> “As in the Circle of Justice, most of the policy issues facing Pakistan’s water sector can only be addressed by developing the ability of all actors and stakeholders to adopt holistic thinking and bridge critical knowledge gaps. These twin aspects of knowledge and capacity, holism and strategic innovation, and the need to balance them in ethical ways are addressed in this chapter through the rich metaphor of irrigated garden traditions and associated knowledge capacity in Pakistan. Water knowledge production and products may come in the form of new scientific inquiry, such as quantifying scenarios and impacts of climate change on environmental degradation, water resources, agriculture, and public health. New knowledge may need to emerge in indigenous and scalable technology solutions, ranging from ICT-driven precision irrigation delivery services to refinement of techniques for sustainable agriculture. Significant challenges exist in the adoption and scaling up of solutions, which is what ‘knowledge capacity’ often means in the water management and governance literatures. Knowledge capacity investments are needed in farmer skill development to adopt water efficiency solutions, often by enhancing the role of extension services, empowering them with information about using new digital technologies, and complementing the role of government regulation and support by private service providers. At the institutional level, the capacity of irrigation engineers and policymakers must be enhanced to absorb new integrated planning approaches. In particular, integrated modeling-based scenario generation and analysis is one way to understand complex interactions in the water-energy-food nexus; and to explore investment options, optimize tradeoffs, and anticipate any rebound effects. Actors at all levels must be equipped to appraise the social and ethical dimensions of various investment options and to undertake and learn from long-term ex-post evaluation of completed projects.”

Policy Actions:
Wescoat and Muhammad suggest the following:

- Broad reforms in curricula and training, investments in new scientific infrastructures (such as earth observation networks) and strengthening of institutions.
- Complete reimagination of water and environmental resources may be required, such as a switch to demand-based surface water management, sustainable intensification of agriculture, and managing massive urban development along

polluted riverfronts. Such imagination may spark controversies, invoke ethical dilemmas, and test the limits of knowledge capacity.

16.5.10 Creating Enabling Environments, Capacity Building to Meet Future Challenges

As Sattar writes in Chap. 2:

> "Pakistan's fundamental challenges of water governance arise from a complex interplay of historically contingent factors. While these were adequate to meet the needs of the moment, they have also raised significant challenges to sustainable development, particularly in the context of rising demands and climate change. For the country, laying the foundation for a robust and progressive political economy of water such that it meets the challenges identified here will make the fundamental difference between long-term societal and environmental well-being and a less integrated response that will fail the aspirations and potential of its people."

The important question is whether our three key ministries: Water, Agriculture, and WASA and Environments are prepared or have the capacity to address these old and new challenges.

Sattar concludes:

> "Given the vast human reliance on the importance of getting water policy, incentives, and governance right, Pakistan must rise to the challenge and recognize that in doing so it will unleash a host of beneficial outcomes across sectors ranging from irrigation and agricultural water use, drinking water supply, and incentivizing the private sector amongst others, all within the context of climate change. Importantly, through virtuous and experimental internal policy innovations, it will be able to share its knowledge and experience of fundamental political economy reforms with the world in a way that sets it apart as a leader in global water policy innovation. As the fertile rivers and plains of the ancient Indus Valley civilization gave birth to a sophisticated and regionally integrated and food secure urban culture, so too must modern-day Pakistan seek to tap into its vaunted history of water management and update it for the 21st century."

There is also a disconnect between academia and the ministries that actually implement policy. As Kamal points out,

> "Linkages are essential between science, research and practice, and between the sociology and psychology of water use and water behavior to bring water studies into the modern era and prepare the water professionals of the future' (Hisaar Foundation, 2016). Young women and men need to be trained in emerging water technologies, management skills and knowledge base, to manage water in Pakistan in all its manifestations: the hydrology and geography, the engineering, economics and sociology of water working together, the psychology and behavioral sciences around water use, the conservation and stewardship of water bodies, new methods and models, managing the effects of climate change on water availability, and making water knowledge accessible to all."

With water, agriculture planning, and policy formulation all decentralized at provincial levels, provincial governments have little capacity to conceive, develop, and implement projects and supporting policies. Kamal notes:

> "The link of academia with government, business sector and civil society to reflect the principle of water being everyone's business, with each group playing its rightful role. Cutting edge specialized water research from primary sources is essential, as is re-packaging academic research, science and knowledge of water for general public, media and water user groups. All citizens need to understand what they have to do to conserve and better use water, so that we can continue to use our water resources as best as possible and avoid the catastrophe that awaits us."

The government must provide clear leadership and take responsibility.

Policy Action:

- A misalignment persists in translating national policies and plans into local implementation as a result of the lack of integration and harmonization at multiple levels—national, regional and local.
- The Hisaar Foundation report highlights the need for action at the federal level, such as "protecting the integrity of the not only of Indus basin but all other basins" and other water resources with a focus on conservation, better regulatory framework, financing mechanisms, and building infrastructure.
- Water policy implementation is under provincial jurisdiction; and management needs vary from province to province. But the provinces need to be managing and maintaining infrastructure, and running irrigation and drainage systems in sustainable and equitable manner. This requires making the provincial irrigation and drainage departments financially autonomous, and responsible for getting water to each district as per allocation.
- With floods increasingly affecting cities, and water for domestic needs becoming expensive, managing municipal and industrial water in sustainable and equitable manner is needed.
- There are success stories where communities are relying on local solutions, managing local water, for all its uses, in sustainable and equitable manner. According to the Hisaar Foundation, "it is essential that a well-resourced, autonomous, empowered and functioning local government is in place to deliver the intent of this policy."

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