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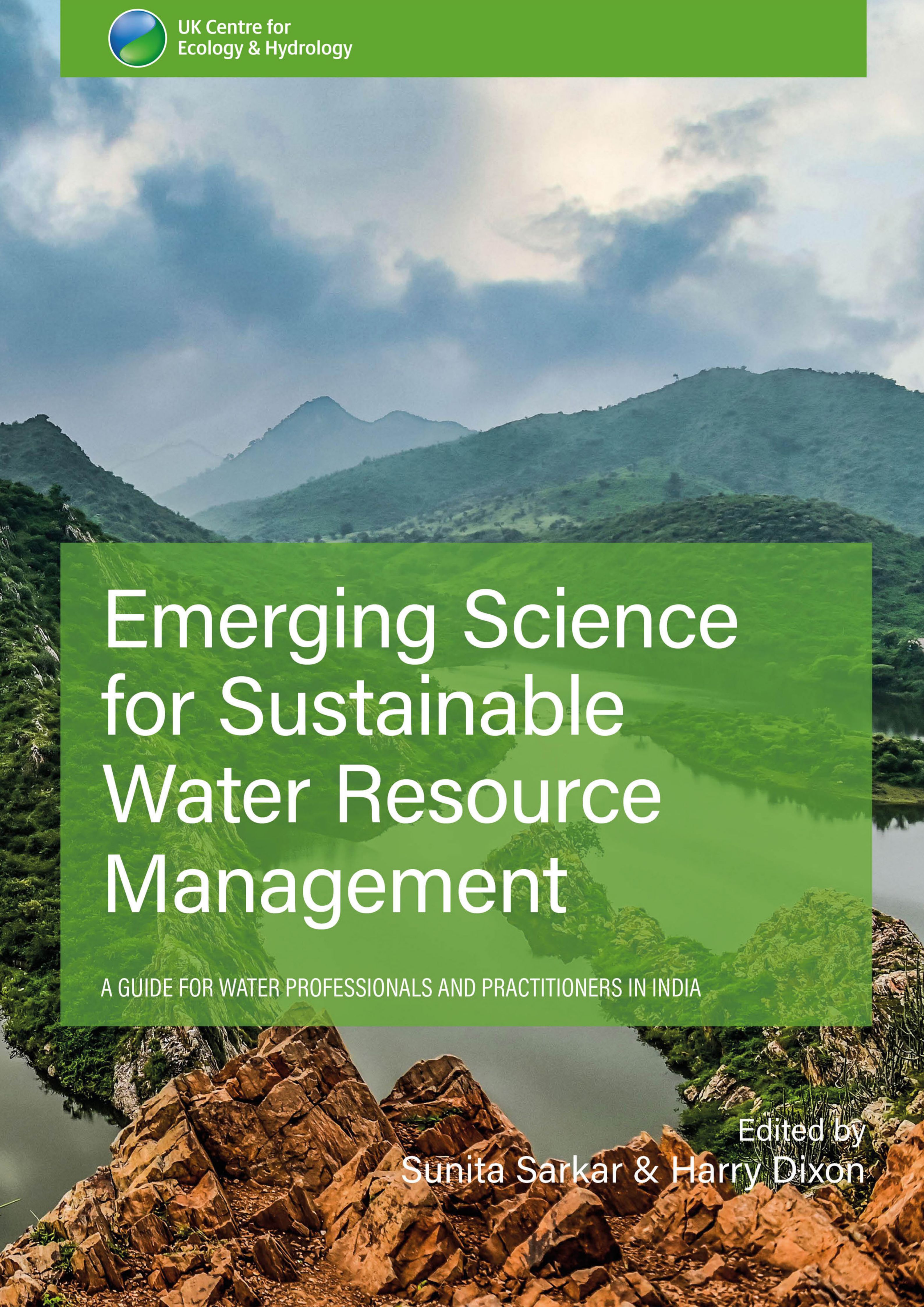

Emerging Science for Sustainable Water Resource Management

A GUIDE FOR WATER PROFESSIONALS AND PRACTITIONERS IN INDIA

Edited by
Sunita Sarkar & Harry Dixon

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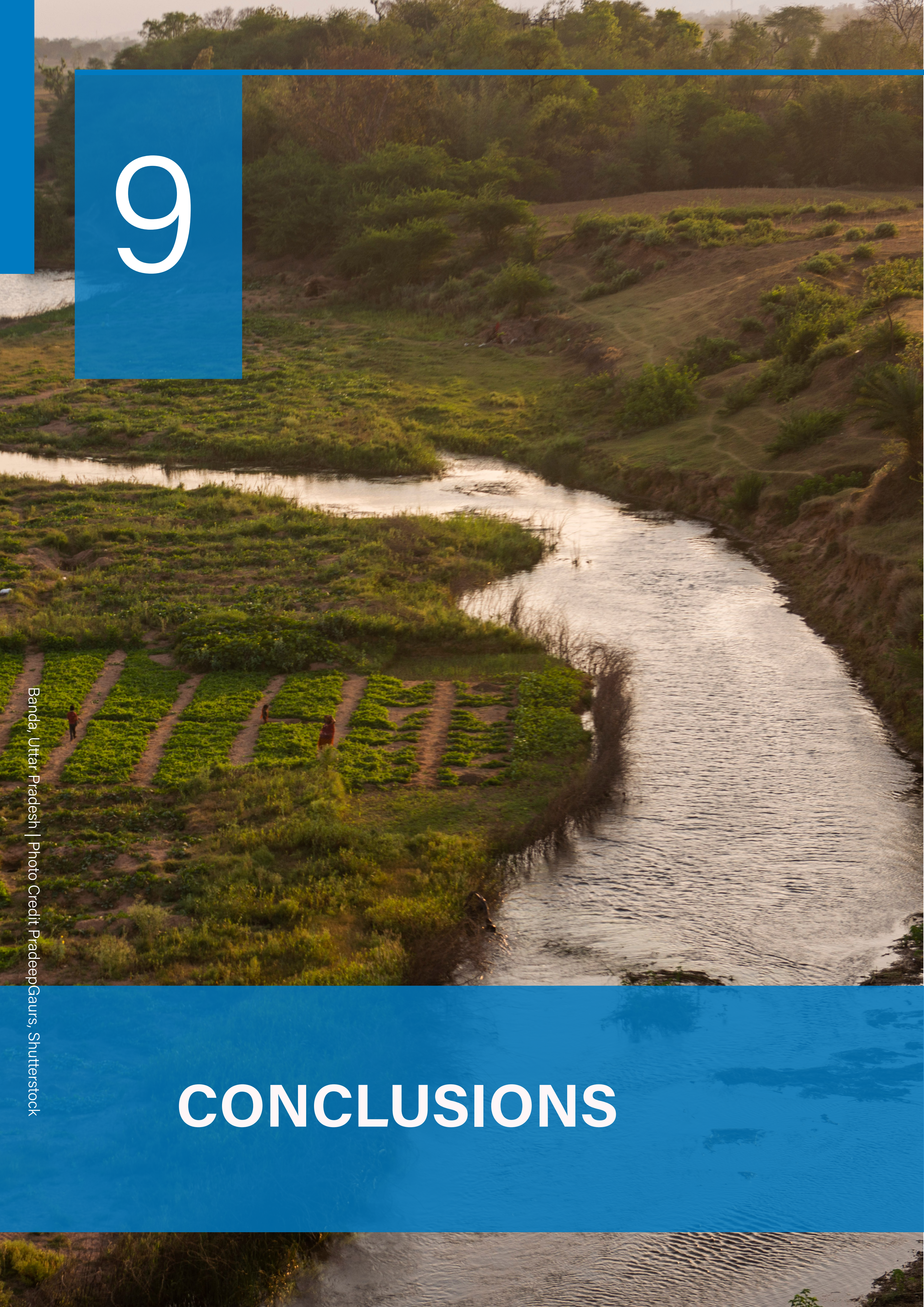
9 CONCLUSIONS



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THE INDIVIDUAL CHAPTERS of this book have covered a range of water related challenges with a common thread of exploring how emerging science can provide new solutions and support sustainable development. The problems we face in the management of our water resources are complex and diverse. The interconnected nature of the hydrological cycle means that water resources ought not to be looked at on an individual component basis in any particular catchment, basin or region but rather be considered as an integrated whole. Arguably, the need for such a holistic approach to water management is even more critical in countries like India, where hydrological extremes, climate-sensitive environments, rapid land-use change, burgeoning demands for water, and pollution growth are widespread and acute. Although this book has presented the research in separate chapters, it is hoped that, you, the reader, will be able to identify how this new knowledge can be combined and applied to address our shared water challenges.

This book has only been able to provide a small glimpse of current scientific research and technological development. Its intention has been to stimulate visions of a future where more, if not all, of our water-related decisions are underpinned by scientific evidence, and where innovative technologies facilitate improved management of the freshwater environment. Around the world, significant strides have been made towards such a future, but inevitably more remains to be done. As water scientists and practitioners, we must continue to integrate and expand our knowledge across boundaries, sectors, and disciplines. We must innovate together to co-design and co-develop new science-based solutions to enhance all aspects of river basin management.

9.1 Current opportunities for water practitioners

If one considers the case of any one of India's river basins, the scale of the challenges but also the opportunities for enhancing water management

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Shyok River meeting Siachan River, Ladakh valley (Photo credit: Zrin-mythsplash, Shutterstock)

through the new science outlined in the book, are clear. By harnessing the **hydro-meteorological skills** that exist within India and internationally, and leveraging **new information sources**, we could increase our knowledge of current and near future hydrological conditions, paving the way for forecast-based action at national, State and basin scales (Chapter 6).

At the same time, **new monitoring technologies** provide the potential to move to a situation where, at the local level, farmers have, literally at their fingertips through their smartphones, guidance on the most effective amount of water their crops need based on the latest soil moisture information (Chapter 2). The resulting savings in water- and energy-use could reduce bills, improve crop productivity, and enhance household income. Where droughts occur, more timely and accurate early warning conveyed using more meaningful drought indicators (Chapter 4), will provide irrigation engineers and local government officials with tailored information when they need it most. This will be vital in future, with the predicted increases in drought occurrence, extent and severity due to climate change.

Indeed, our future success in managing our water resources is going to depend, in no small part, on our ability to **adapt to the changing climate**. Our planning of water allocations and major decisions around water infrastructure require us to improve our modelling of availability and demand (Chapter 8), so that the wider implications upstream and downstream of developments and changes in socio-economic conditions can be properly taken into account. This will help to identify where specific actions need to take place, and the where trade-offs might be needed across the basin. Hydrological extremes are also likely to change in a warming world, requiring us to move beyond current methods of assessing risks to ones that take into account uncertainties (Chapter 3), thus ensuring that flood protection and policies that minimise future losses are in place for people and ecosystems.

Improving water harvesting, reducing water loss through unsustainable use, and other actions directed at increasing the amount of water available for humans and the ecosystem need to go hand-in-hand with efforts to protect and enhance water quality. As populations in urban areas and industrialisation continue to grow, so too does the need for a more **holistic understanding of water quality**. The improved and, in some cases, novel approaches to monitoring of water parameters that include both chemical and biological indicators, can provide managers with the information required to more accurately plan and locate green- and grey-infrastructure, such as artificial (treatment) wetlands and sewage treatment plants, respectively (Chapters 5 and 7). Ensuring that industrial effluent, sewage, and other waste water is treated prior to its entering water bodies, would help protect their biodiversity and the myriad ecosystem services they provide. Reliable and effective water quality monitoring should, therefore, underpin all mitigation policies and restoration approaches to ensure sustainable water management results in sufficient water of good quality for now and the future.

Of course, science and technology alone cannot provide all the answers. Many of the ways in which we use water and interact with the fresh-water environment are driven by **policy-instruments and education**. Whether it be the agricultural economics of irrigation, control of emerging contaminants, or transboundary allocations of water resources. As we improve our scientific understanding of catchment processes and develop new technologies to manage them, institutional arrangements, policies, and regulations, as well as societal behaviours and attitudes, would ideally keep step. As evidenced in Chapters 2 and 7, involving citizens in monitoring and managing their water resources is already occurring, and has great benefits towards expanding monitoring schemes and establishing new technologies. With political will and the establishment of an enabling governance environment, along with enhanced water education for the wider public, the benefits of citizen science could be attained.

Enhanced water education must go hand-in-hand with improved learning around the **importance of natural ecosystems and biodiversity** to help change societal behaviours. By raising awareness in this way, we can increase public 'ownership' of water problems amongst the plethora of environmental challenges we currently face. These steps can, collectively, lead to improved water stewardship, where the aim is to ensure socially and culturally equitable, environmentally sustainable, and economically beneficial use of the resource. Every person who has a vested interest in the sustainable management of the water resource, including scientists, should be actively involved in the discussions and plans for its management. However, in order for any of this to work and actually make a difference, co-design and co-development of solutions should be the norm and not an exception.

The importance of **co-design and co-development** of research objectives and the planned outputs has been highlighted throughout this book. Moving forward, engagement across sectors and disciplines needs to be one of the first steps when applied science projects are initiated so that the end results can feed into practical solutions on the ground. This requires that both researchers and practitioners extend themselves to engage with the other. Such engagement can take the shape of one-to-one discussions, workshops, brainstorming sessions, or proactively seeking out networks and utilising existing networks.

One recent example of an Indo-UK collaborative network that promoted both scientific enquiry, but also engagement with stakeholders in water management and practice, was the India-UK Water Centre[1]. Aside from fostering collaborative research between the UK and India, the Centre hosted a series of events that took scientists to various field sites across India to engage with users of water, in particular farmers. The Centre held scientific workshops with those managing water, where representatives from government departments were involved in exploring how recent research could be tailored to their needs. These engagement events showed how enthusiastic farmers and local water managers are to finding science based solutions for their problems, but also highlighted some of the challenges in developing collaborative research projects. Some of these challenges surround data sharing between practitioners and researchers, but more significantly, the need for researchers to fully consider the current capacity and multifaceted requirements of practitioners on the ground.

There is, therefore, both a necessity and an opportunity for earlier, more routine and more in-depth two way knowledge exchange between researchers developing state-of-the-art technologies, methodologies, and applications, and those who would implement them on the ground, to help ensure the rapid translation of emerging science to practical solutions for the population.

9.2 The future of water research

As described in the chapters of this book, significant progress in water research is already being

1 https://www.iukwc.org

made in India, the UK, and globally that can be translated to practice. Given the complexity of the water challenges we face, however, we must continue to seek out new knowledge and new technological solutions. Research needs to continually progress to enable us to sustainably manage our water resources in the face of future problems. While not seeking to outline the full range of future avenues water scientists might explore over the coming years, some of relevance to the issues covered in the book are introduced here.

In the area of **sub-seasonal to seasonal forecasting** for example, the World Meteorological Organisation's Hydrological Status and Outlooks System (introduced in Chapter 6) will provide a global framework by which the latest in observational and modelling science could be levered to support informed decision-making by national hydro-meteorological services (Jenkins et al 2020). It will provide an opportunity to compare national water assessments and forecasts with global products, generating a tapestry of multi-scale, multi-source information for a range of water stakeholders. The implementation of such a global system is not only dependent on translating current science into operational practice, but also on advancing our hydro-meteorological forecasting of future hydrological conditions and developing new methods to integrate model outputs. If successful, however, such combinations of data and knowledge, with aligned enhancements of local scientific capacity, could have far-reaching consequences for water resources management. This is just one example of an area of research that presents many future opportunities in an Indian context (Dixon et al 2017).

Research on **hazard risk estimation, impact, and mitigatio**n is also continuing as both floods and droughts are expected to increase in frequency and/or intensity. Within the research community, long-standing approaches for estimating the likelihood and magnitude of hydro-climatic extremes are being revised to accommodate our changing climate, and the indicators we use to monitor such extremes are being updated (Chapter 3 and 4). Looking forward, due to the variability in drought impacts across sectors, the future of drought research has to include sector-based assessments of drought scenarios in order to develop tailored indicators (Bachmair et al 2016). When co-developed with local decision-makers, research to develop and apply such drought indicators in the design of drought monitoring systems, could significantly enhance their utility to practitioners and policy makers (Collins et al 2016).

Yamuna River, Agra (Photo credit: Mikadun, Shutterstock)

The potential applications of **water quality monitoring** programmes continues to expand as we develop effective methods to detect more pollutants at different scales. Ongoing Indo-UK collaborative research on the Ganga, involving the authors of Chapter 5 for example, has surveyed a suite of metals to provide information on geological sources, weathering processes, and industrial pollution sources; used in situ fluorimetry to characterise the dissolved organic matter, for source tracking and indicating underpinning ecosystem health; and conducted a microplastics survey of water and marginal bed sediments. At the same time, researchers in India, including the authors of Chapter 5, are also exploring the use of satellite and drone-based remote sensing to map water quality and identify pollution sources. Hyperspectral and thermal sensors mounted on a drone can provide much higher resolution data, which may be easier to relate to specific pollutants.

The research around these technologies is still advancing, and India has the potential to be at the forefront of many of these technological advances. Taken together, such science should provide exciting new insights into pollution sources, processes and ecological impacts, and could provide a blueprint for future multidisciplinary river studies in India and worldwide.

In urban areas, the use of **Nature-based Solutions**, such as green walls or constructed wetlands, have been proven to remove nutrients, toxic metals and organic matter from wastewater, as highlighted in Chapter 7. The future of research in this area includes understanding the scale of such solutions that is required to transform urban wastewater management, as well as the financing and governance plans needed for scaling up (Fowdar et al 2017). Furthermore, research on phosphorus removal in constructed wetlands, and the effect of regular harvesting of plants has on maintaining phosphorus uptake, for example, needs to continue in order to optimize treatment performance of constructed wetlands (Colares et al 2020). As most studies have taken place in low nutrient temperate systems, it is particularly important we build understanding of uptake potential in tropical urban hydrological systems.

Across these and many other areas of water science, significant strides are currently being made to push forward the boundaries of our knowledge in ways that will underpin our management of freshwater systems. At the global level, efforts are being made to support such research and promote the **integrated use of science** in tackling water problems. For example, the United Nations Educational, Scientific & Cultural Organization (UNESCO) recently approved a Strategic Plan for it's coming 9th Phase of the Intergovernmental Hydrological Programme. Entitled "Science for a Water Secure World in a Changing Environment", and due to run from 2022-2029, a specific focus will be placed on activities that build scientific capacity and knowledge to directly inform decision-making (UNESCO 2021).

Whether tackled through large-scale global initiatives, bilateral research partnerships between countries with complementary skills (such as the UK-India research outlined in this book), national science programmes or individual projects, the opportunities to further our understanding of freshwater environments in ways that provide practical answers for practitioners are plentiful.

9.3 Reflections

While the water related problems facing the world may be considerable, our ability to find solutions through the use of technological innovation and new scientific understanding arguably has never been greater. It is hoped that this book has given some insights into the opportunities that now lie before us and that you, the reader, will find ways of working across traditional boundaries to co-develop new science-based solutions to your own water management problems.

As this book has outlined, in India, the UK and elsewhere, we are making rapid scientific progress around water. The challenge now is to enhance the pull-through of research outputs into day-to-day use, ensuring that the tools, practices and policies by which we manage the freshwater environment, are based on the latest science can offer. Of course, we must do so at the same time as we co-design the research projects and programmes that will provide the emerging science we need in future.

The recent joint efforts of the SUNRISE programme has further expanded on a long history of collaboration in the water field that capitalises on the complementary expertise that exists between Indian and UK hydrologists, freshwater ecologists, water quality scientists, and others. Looking to the future, the continued international sharing of knowledge and co-generation of new understanding will be central to solving today's water problems and adapting to tomorrow's changing world. Together India and the UK are well poised to meet these shared challenges and develop solutions that will aid water management around the world.

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Endangered Ganges Dolphin, Brahmaputra River. Photo credit: Ranjan Barthakur, Shutterstock