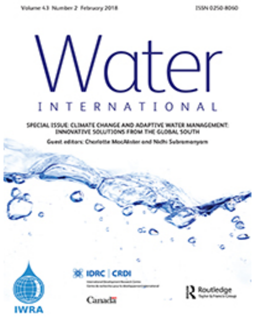

Water International

ISSN: 0250-8060 (Print) 1941-1707 (Online) Journal homepage: https://www.tandfonline.com/loi/rwin20

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To cite this article: Charlotte MacAlister & Nidhi Subramanyam (2018) Climate change and adaptive water management: innovative solutions from the global South, Water International, 43:2, 133-144, DOI: 10.1080/02508060.2018.1444307

To link to this article: https://doi.org/10.1080/02508060.2018.1444307

Published online: 19 Mar 2018.

WATER INTERNATIONAL, 2018
VOL. 43, NO. 2, 133–144
https://doi.org/10.1080/02508060.2018.1444307

Routledge
Taylor & Francis Group

EDITORS' INTRODUCTION TO THE SPECIAL ISSUE OPEN ACCESS Check for updates

Climate change and adaptive water management: innovative solutions from the global South

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Climate change is one of the most pressing threats to sustainable development across the globe. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) notes that 93% of the impacts associated with climate change will be felt in the water sector. Climate change is already altering precipitation patterns and snowmelt, impacting the frequency and magnitude of floods and droughts, and contributing to more extreme weather events and wildfires globally. Availability of renewable surface and groundwater resources is likely to decrease significantly in most arid and semi-arid subtropical regions, exacerbating competition for water between agriculture, ecosystems, industry and settlements (IPCC, 2014). Climate change is projected to lower raw and drinking water quality, due to interacting factors including increased sediment and pollutant loads due to heavy rainfall and breakdown of water treatment infrastructure during floods and extreme weather events, with flood hazards projected to increase across half the globe (IPCC, 2014).

The populations of developing countries, primarily in the global South, are particularly vulnerable to the impacts of climate change on water availability due to high levels of exposure to water-related risks, limited coping capacity, and limited ability to recover from loss, often arising from non-climatic factors.[1] The impacts of climate change are exacerbated by rapid population growth, rapid urbanization and chaotic economic development, particularly where water demands already exceed limited supplies. Climate change impacts destabilize development by affecting food security, health, infrastructure development and sustainable economic growth in developing countries. Simply put, climate change is not only a critical environmental concern but arguably the most urgent development challenge for the global South. Moreover, the voices of developing-country scientists – best placed to conduct research and present feasible local adaptation plans – are often silent in international public debate.

The International Development Research Centre is a Canadian Crown corporation, established by an act of parliament in 1970 with a mandate 'to initiate, encourage, support, and conduct research into the problems of the developing regions of the world and into the means for applying and adapting scientific, technical, and other knowledge to the economic and social advancement of those regions' (IDRC, 1970). This special issue of *Water International* represents a sample of IDRC-supported projects on water

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and climate change adaptation, implemented by researchers based in developing countries, and initiated as early as 2008. This sample of IDRC-supported research demonstrates the breadth and quality of water and climate adaptation research by researchers throughout the global South over the previous decade. The viewpoints expressed within this issue, including this introduction, are those of the article authors and do not represent the official position or policies of IDRC.

The evolution of water and climate change adaptation research supported by IDRC

IDRC has a long history of funding water and climate change adaptation research, which predates the current debate on what constitutes adaptation and adaptive capacity. Between 2005 and 2015, with support from development partners including the United Kingdom's Department for International Development (DfID) and the government of Canada, IDRC committed significant funds to adaptation research, of which a large proportion focused on water issues. As early as 2005, IDRC committed CA$ 18M of government of Canada funds to the Urban Poverty and Environment (UPE) programme, which supported climate change adaptation research projects and built adaptive capacity in the water sector in many communities in the global South. The UPE programme ran from 2005 to 2010 and sought to address the disproportionate suffering of the urban poor as a result of 'environmental burdens including lack of basic environmental services, environmental degradation caused by pollution or over-pumping of water, and vulnerability to natural disasters' (IDRC, 2005). UPE provided funding to 60 research and capacity-building projects focusing on urban agriculture, urban water and sanitation, waste management and vulnerability to natural disasters, with land tenure identified as a cross-cutting issue. The projects were distributed throughout Latin America and the Caribbean, Sub-Saharan Africa, Asia, the Middle East, and North Africa. Fifty percent of them were directly related to water. The programme focused on large conurbations, leaving a gap in the research on the water sector in small and medium-sized cities. This was later addressed by the IDRC's Cities and Climate Change initiative – launched in 2015 – which specifically considered adaptation deficits in small to medium-sized cities. In this special issue, Allan Cain's (2018) commentary arose from research funded by the UPE programme in 2009, with continuing support from the programme then called Climate Change and Water in 2012.

From 2006 to 2012, IDRC joined forces with DfID in committing CA$ 41.5 to the Climate Change Adaptation in Africa programme (Lafontaine, Oladipo, Dearden, & Quesne, 2012). This programme aimed to build research capacity for adaptation to climate change by strengthening the knowledge base of African scientists to address the needs of the most vulnerable, primarily through 'action research'.[2] The programme supported 41 research projects in 33 countries and made a lasting contribution to Africa's capacity to adapt to climate change by nurturing many of researchers and institutions now active in the sector. As of 31 March 2012, over 200 African organizations had carried out research on climate change adaptation as lead, collaborating, or participating institutions of the programme. A further 68 scholars and professionals deepened their expertise through the African Climate Change Fellowship programme.

Cyriaque-Rufin Nguimalet (2018) received such a fellowship, supporting his research published in this issue.

In 2008, the IPCC published a technical paper, 'Climate Change and Water', based primarily on the findings of the Fourth Assessment Report (AR4) and earlier IPCC publications (Bates, Kundzewicz, Wu, & Palutikof, 2008). This publication primarily addresses freshwater but also includes the impacts of sea-level rise on freshwater in coastal areas. It begins by stating that 'the relationship between climate change and freshwater resources is of primary concern to human society and also has implications for all living species' and that 'freshwater-related issues are critical in determining key regional and sectoral vulnerabilities' (p. 7). Six 'systems and sectors' were addressed, including ecosystems and biodiversity; agriculture and food security; land use and forestry; human health; settlements and infrastructure; and economy (insurance, tourism, industry, transportation). Eight geographic regions are considered: Africa, Asia, Australia and New Zealand, Europe, Latin America, North America, Polar Regions, and Small Islands. While all sectoral and regional reviews included analysis of water and adaptation, the content was limited.

In 2010, responding to the need for specific support for research on adaptation to climate change in the water sector, IDRC initiated the Climate Change and Water (CCW) programme in four of the world regions noted by the IPCC (Africa, Asia, and Latin America, including Small Island States). The programme ran from 2010 to 2015 and provided CA$ 75.3M of research support. This included CA$ 35.5M from 'Canada's commitment to fast-start financing for climate change action in developing countries', made during the 2009 Copenhagen Conference of the Parties (COP15) of the United Nations Framework Convention on Climate Change (Government of Canada, 2013). Cognizant of the critique that adaptation research is indistinguishable from classic 'development' research, this programme focused on providing support for research that clearly addressed novel ways to measure and build adaptive capacity across the water sector. It solicited interdisciplinary projects that were 'commensurate with the complexity of climate change, in response to growing demand for research that generates solutions for addressing the enormity of the challenge' (Adger, 2005). The overall objective of the programme was to improve the availability and quality of water for vulnerable populations across the developing world. It attempted to do this by funding research that addressed two key questions with water as the clear entry point:

(1) How can immediate short-term threats (i.e. impact of extreme climate events) be reduced within the context of longer-term climate change?
(2) What adaptation strategies are both socially and economically feasible, and make for wise longer-term investments?

The implementation of the programme assumed that 'adaptation policies, plans, and action [would] be strengthened with high quality and evidence-based interdisciplinary research, particularly when supported with early engagement of end-users and improved coordination between stakeholders' (Climate Change and Water, IDRC, 2014). The portfolio of supported projects aimed to achieve the following broad outcomes:

(1) Research funded through the program improves the quality and availability of water for vulnerable communities, reduces risk, and builds adaptive capacity;
(2) There is an improvement in the capacity of researchers to conduct vulnerability, social, gender, and economic analysis in the field of climate change and water; and
(3) Researchers are better able to work closely with policymakers as a matter of practice and communicate their research results to potential users.

CCW made several interventions in shaping the direction of adaptation research in the water sector in the global South and building the capacity of researchers to address the impacts of climate change in partnership with affected communities and policy stakeholders using interdisciplinary approaches. It supported projects in Africa, Asia, and Latin America and the Caribbean, and to a lesser extent in the Middle East and North Africa. Early in the programme, regional strategies were developed to highlight issues of importance and enable discussions on the focus of investments. The articles included in this issue represent some of the broad thematic scope of the programme. CCW themes included disaster risk reduction and preparedness, water governance, urban and peri-urban water and sanitation, coastal impacts of climate change, and adaptation in mountainous areas. The programme noted that in 2010 there was an absence of detailed economic assessments of the costs of climate change, while a number of projects did include aspects of training and capacity-building or assessment. So, simultaneously, IDRC also supported a programme specifically targeting 'environmental economics', which complemented CCW by exploring sources of external finance, financial think tanks, and private-sector actors that could support and sustain adaptation interventions in the water sector. These institutions included but were not limited to the Development Bank of Southern Africa, Natural Resources Canada, the Private Finance Advisory Network, Frankfurt Business School, Business for Social Responsibility, and Ericsson.

The nine articles in this issue capture the geographic and thematic breadth of the research on water and climate change adaptation supported by IDRC over the last decade. A much larger sample of water and adaptation options for a changing climate arising from IDRC-supported research can be accessed through the website www.adaptationoptions.ca. Following the completion of the projects with research outputs included in this issue, IDRC has continued to support research in the water and adaptation sectors. In 2013, IDRC partnered with DfID once again to jointly provide support over seven years to the Collaborative Adaptation Research Initiative in Africa and Asia. This programme, which will be active until 2019, aims to build the resilience of vulnerable populations and their livelihoods in climate change hot spots in Asia and Africa: semi-arid regions, deltas, and glacier and snowpack-dependent river basins – all with significant adaptive water components.

Contributions to the special issue

This special issue of *Water International* features a small sample of the policy-relevant adaptation research that was funded by the IDRC Climate and Water programmes. In response to the initial call for papers, we received 22 papers from researchers working on a wide range of adaptation-related questions across the world. After several rounds of rigorous peer review, eight papers have been selected for inclusion in this issue. The article by Nguimalet (2018), which is also a part of this issue, was funded under an earlier awards programme intended to build research capacity in the global South, as noted earlier. Based on their main contributions, the articles in this issue address two broad themes, both of which correspond to the original objectives of CCW: measuring adaptive capacity under changing water availability; and innovative approaches to adaptive water management.

Measuring adaptive capacity under changing water availability

As the Fifth Assessment Report of the IPCC explains, the impacts of climate change on water availability and quality vary across the world regions. Research needs to address these impacts at scales that inform and enable appropriate adaptive policies, across all sectors, and in particular, in planning and decision-making on water use and allocation. Similarly, improved methods of measuring the vulnerability and adaptive capacity of affected households and communities are needed to support targeted policies and judicious allocation of limited financial, human and natural resources.

Discussions of vulnerability have typically underestimated the importance of underlying drivers associated with gender, poverty and socio-political exclusion (Adger, 2006; Hewitt, 1983). Traditional assessments of exposure and vulnerability to water-related disasters (e.g. flooding, drought and landslides) also fail to take into account future scenarios informed by climate science. Understanding how existing forms of vulnerability may be compounded by climate change under different scenarios is critical to assess what forms of adaptation are most suitable to reduce risks and improve local adaptive capacity. A number of articles in this special issue combine vulnerability analysis and climate modelling to develop targeted policy recommendations. Five consider how decision-making on water management and allocation by various formal and informal institutions influence the vulnerability and adaptive capacity of households and communities to climate-related water insecurity in the short and long run.

In many regions, climate change is causing sea-level rise in coastal zones, leading to saline water intrusion in many coastal aquifers, while at the same time changing precipitation patterns are causing water shortages and increased groundwater abstraction, aggravating the intrusion. The difficulty of downscaling climate change impacts and modelling coastal aquifer hydrodynamics as well as future water demand under various development scenarios makes it particularly difficult for coastal aquifer managers to predict and quantify saline water intrusion rates in a context-specific manner. Safi, Rachid, El-Fadel, Doummar, Abou Najim, & Alameddine (2018) apply simulated sea-level rise under various near-future (2012–2032) climate and water abstraction scenarios, with a multi-objective 3D variable-density flow and soluble transport model. They consider various climatic and non-climatic causes of saline intrusion in the urban coastal aquifer that supplies water to Beirut, Lebanon, to inform adaptation strategies for sustainable aquifer management. A key contribution of the article is its discussion of alternative scenarios that may arise if the following adaptation strategies are adopted to guard against saltwater intrusion in Beirut's aquifer: (1) water conservation practices to prevent network losses; (2) the injection of treated wastewater for aquifer recharge; (3) the importing of water from inland areas or the use of desalinized seawater, requiring construction of large infrastructure projects; and (4) water demand and consumption management using smart metering and/or tariff restructuring. The analysis indicates that sea-level rise due to climate change will likely have a lower impact on the salinity of the aquifer than anthropogenic abstraction, and hence, the authors advocate adaptation strategies that focus on reducing groundwater dependence. They note that even in the ideal case where all groundwater abstraction ceases, aquifer recharge with freshwater will take several decades to reduce the salinity. This study points to the importance of considering the interactions between various drivers of saline intrusion so that context-appropriate adaptation strategies may be implemented. These strategies also need to include a groundwater monitoring programme to assess their effectiveness.

In addition to downscaling and quantifying the impacts of climate change in specific contexts, it is essential to understand the vulnerability of households and communities to these impacts and their adaptive capacity to cope with them. Households vary in their exposure to (and therefore risk from) climate–water hazards. Sujakhu, Ranjitkar, Niraula, Salim, Nizami, & Schmidt-Vogt (2018) apply a composite livelihood vulnerability index developed by Hahn, Riederer, and Foster (2009) and Islam, Sallu, Hubacek, & Paavola (2014) to investigate the determinants of vulnerability among farming households in the Asian highlands, which form part of the Hindu Kush Himalayas in Pakistan and Nepal. Farming communities in the Asian highlands face water hazards such as changing rain and snowfall, flash floods, soil erosion, mudflows and landslides. The authors argue that to implement policies that build households' adaptive capacity at the local level, policy-makers need to understand how access to various forms of capital, sensitivity and adaptive capacity shape households' vulnerability.

They find that education of the household head, the household's diversification of income sources away from agriculture, dependence on irrigation and technology for cultivation, and degree of influence on decision-making at the local level all affect its vulnerability to water hazards. Thus, this study not only reveals the various forms of capital essential at the household level in the Asian highlands, but also discusses how interlinkages between these forms of capital might produce vulnerability on the ground. For example, in order for a household to build adaptive capacity by diversifying its income sources beyond agriculture and adopting new forms of technology for farming, it needs skills and education (human capital), as well as land and livestock (natural capital).

Nguimalet (2018) presents a community-level perspective of adaptation to changing precipitation patterns in two watersheds impacted by climate change in the Central African Republic and Kenya. Using a mixed-methods approach combining analysis of historical and contemporary precipitation data with surveys of affected communities' autonomous adaptation strategies, this study discusses how autonomous adaptation strategies have evolved over time in response to increasing spatiotemporal variability of precipitation and river flows, and the availability of resources in these under-studied contexts. Kenya and the Central African Republic have suffered prolonged and recurrent droughts in the past. Nguimalet finds that the study communities' adaptation strategies are largely reactionary, in part due to the absence of investments in forecasting and prediction tools or in capacity-building for disaster preparedness by the governments or the international donor community. In a context of weak institutional capacity, communities are left to cope on their own. This article recommends concerted efforts by national governments and international actors to build institutional capacity for decentralized decision-making and disaster risk reduction in both Kenya and the Central African Republic.

The vulnerability of many urban communities to climate impacts is also exacerbated by poor water quality and quantity, and weak or absent institutions that fail to provide and regulate adequate water supply and sanitation. Rapid urban population growth in Asia, the Middle East, and North and Sub-Saharan Africa is outpacing the ability of governments to extend the existing piped water infrastructure (where it exists) to all residents. Residents who do not have access to the formal piped network, particularly those living in informal settlements, rely on a variety of alternative sources, such as informal private water suppliers or unlicensed private borewells, to meet their water needs (Alameddine, Tarhini, & El-Fadel, 2018),[3] leading to unsustainable practices at larger scales if not properly regulated or managed. Therefore, working with informal water providers and/or households that rely on private water sources to improve and guarantee water availability for all will be an important adaptation challenge for governments in these developing contexts.

Cain's commentary in this issue presents a participatory action research study conducted by Development Workshop with low-income communities and their informal water providers in the peri-urban *musseques* (slums) of Luanda, Angola, one of Africa's fast-growing megacities. In contrast to the government's view of the informal water suppliers as exploiters of the poor, Development Workshop's research reveals that the informal water sector fills a large gap in the public utility's supply – it serves nearly a third of Luanda's residents. However, the informal water supply is expensive relative to the public utility and is often untreated, increasing health hazards. Development Workshop argues that the formal utility should work with, and regulate, the informal, community-based providers until the utility can supply all residents. They find that community-based water management committees and associations are an effective transitional solution that can help residents access water, collect payments, maintain standpipes, and ensure that the water providers remain accountable to citizens.

In a second study focusing on Beirut, Lebanon, Alameddine et al. (2018) examine the costs to and impacts on households of saltwater intrusion, in addition to the costs to utility suppliers. Salinization of groundwater increases economic burden at the household level, including the cost of purchasing freshwater, degradation and damage of household appliances, and in some cases, the installation of desalination units. The authors develop a model to quantify the economic burdens due to seawater intrusion and measure households' willingness to participate, and to pay for a government programme to tackle groundwater salinity. They find that nearly two-thirds of the surveyed households were willing to participate in and pay for a government-instituted or building-level plan to manage the salinity of water, if it ensured adequate good water supply. In addition to making a case for building-level and city-wide interventions for desalination, their study also highlights the importance of regulating excessive groundwater extraction through water demand management, to avoid falling into the trap of further salinizing groundwater, a process accelerated by climate change–induced sea-level rise.

These studies note the importance of water demand management through formal or informal institutions, regulations, community capacity-building, and other approaches to adapt to the impacts of climate change.

Innovative approaches to adaptive water management

Water supply or demand management under climate change involves decision-making under high levels of uncertainty regarding projected impacts. To avoid risk-averse decisions that might prove inefficient and costly, such as large-scale infrastructural investments, Vicuna, Gil, Melo, Donoso, and Merino (2018) propose and evaluate 'water option contracts' as a flexible adaptation measure. Option contracts are risk-sharing instruments that allow less vulnerable water consumers to trade their water rights with more vulnerable consumers during extreme events. They can help avoid complex, ex ante decisions on expensive infrastructure, or large-scale regulatory reform in the water sector. However, their success depends on their cost-effectiveness, and the availability of a clearly defined water rights regime that allows trading of water rights between different user groups. The authors recommend and test the triggering conditions for two types of option contracts as adaptation measures in the case of the Maipo basin in Santiago de Chile. They conclude that option contracts could reduce transaction costs between various users and improve water management practices in the basin.

Lebel, Lebel, Chitmanat, Uppanunchai, and Apirumanekul (2018) address the issue of decision-making under climate, fish and water-demand-related uncertainties in Northern Thailand's aquaculture industry. They argue that fish farmers adopt a range of short-term or long-term adaptation strategies, depending on the type of aquaculture, for decision-making. But the relative costs and benefits of each of these measures remain unknown in the face of climate change, variable fish demand, and growing water demand from other sectors. They use a rule-based assessment model to evaluate the robustness of various adaptation strategies for aquaculture under different climate risk and water-demand scenarios at multiple spatial and temporal scales. Here, a robust strategy is one that performs satisfactorily, if not ideally, and increases net profits for aquaculture under a range of scenarios. The authors find that while short- and medium-term adaptation strategies are important, long-term adaptation poses several challenges depending on the timing of investments and the actual onset and duration of the impacts. They find that adaptation in the sector needs to be diverse enough to cater to different aquaculture systems and flexible enough to change with time by incorporating new knowledge and technologies. The study raises important questions regarding changes in policy culture, institutions and knowledge creation that need to occur for those robust adaptation decisions to be made.

Lele, Srinivasan, Thomas, and Jamwal (2018) argue that while climate change is an important stressor affecting water availability, other stressors such as rapid urbanization, migration and land-use change also affect water demand, though their impacts are largely ignored in many adaptive water management plans. They also argue that the normative focus of adaptive water management should include not only the goals of adaptation and resilience but also important general developmental goals such as adequacy, sustainability, justice and democratic governance. According to Lele et al., acknowledging a multiplicity of goals helps to analyze the synergies and trade-offs between these goals while designing responses, just as the study by Lebel et al. (2018) demonstrates in the case of Northern Thailand's aquaculture industry. They note that the literature gives primacy to the city as the spatial unit of analysis and assumes climate change to be the main stressor, even as cities continue to source water from and dispose wastewater in distant areas, outside the city. In this article, they propose and apply a multiple-stressors, multiple-concerns, multi-scalar approach to analyze the impacts of climate change on two rapidly urbanizing sub-basins within the Cauvery River basin in southern India in the context of other dynamic changes underway in the basins. Based on observations of practice at the household, city and watershed levels, the authors argue for a relational, linked sectors and scales approach to policies and infrastructural interventions for water allocation, distribution and management under a changing climate so that adaptations at one scale, or in one sector, do not result in maladaptations in another domain. Although the mechanisms that enable us to acknowledge and act on this complex, interlinked approach to climate impacts and adaptation are beyond the scope of this article, the approach nevertheless calls for a radical reorganization of institutions and their interrelationships through organizational learning and capacity-building, funding for research and development, improved research, and its dissemination for public education.

The final study, by Vatta et al. (2018), presents a simple, low-cost technological solution that can be easily implemented at the individual farm level to improve water management in a context where regulations impacting agricultural water use are slow and costly to change, as in the case of Indian Punjab. To prevent farmers from over-extracting dangerously low levels of groundwater, the authors test the impacts of using a low-cost soil-moisture-sensing tensiometer on groundwater and electricity consumption for irrigation, and subsequent crop yields. They find that the tensiometer saves over a tenth of the water and electricity used for irrigation, with no reduction in crop yield. Scaled up, the tensiometer could reduce the overexploitation of groundwater and the concomitant energy used to pump groundwater in Indian Punjab. However, for widespread adoption of tensiometers, the authors find that farmers need to be aware of the pitfalls of the over-extraction of groundwater and the possible benefits of water-saving technologies. Thus, this article shows that technological solutions need to be complemented with institutional and regulatory changes that raise awareness and change the incentive structures for farmers to encourage water-saving behaviour.

Concluding remarks

This issue showcases a small sample of the work IDRC has supported over almost a decade, encompassing a broad range of water and climate adaptation research across the global South. This includes an expansive range of water entry points, such as private water suppliers in post-conflict Luanda and saline aquifers in Beruit, basin-scale decision-making from Chile to India, testing technologies and strategies ranging from low-cost tensiometers to smart metering, and from reduced fish-stocking densities to downscaled application of general circulation models. The funding and research support provided by IDRC and its partners has supported hundreds of researchers, many of whom are now leaders in their fields of expertise. It is notable that a number of them are now contributors to the IPCC's assessment reports. This body of work (and many other outcomes not included in this issue) represent a significant step towards IDRCs aim to invest in knowledge, innovation and solutions to improve the lives of people in the developing world. What all the articles in this issue have in common is the clear conclusion that climate impacts on water and essential adaptation cannot be considered without addressing all development impacts comprehensively – all adaptation strategies must be integrated with broader development strategies. The outcomes from the research presented here also highlight gaps in our knowledge and the needs of future research, such as: how to engage with and combine the effectiveness of formal and informal institutions, including private actors; analyses of how to build institutional capacity for demand management; land-use planning to prevent floods; water resources assessment, effective monitoring, integrated water/wastewater planning, and intersectoral approaches; and not least, how to increase participation and buy-in from the public in adaptation decisions. We hope that future research on adaptive water management in the face of climate change will contribute to these debates and influence policy positions on them.

Notes

1. We use the term 'global South' as a shorthand to refer to all nations classified by the World Bank as low- and middle-income in Asia, Africa, the Middle East, and Latin America and the Caribbean (Mitlin & Satterthwaite, 2013).
2. For an overview of the definition of action research, see Brydon-Miller, Greenwood, and Miller (2003).
3. For a discussion of the different types of formal and informal water services used by residents of peri-urban settlements in South Asia, see Narain, Khan, Sada, Singh, and Prakash (2013).

Acknowledgments

The guest editors would like to express their appreciation for the patience and support of the *Water International* editorial team, especially James Nickum and Philippus Wester. Thanks are due to all of the IDRC staff and awardees who have contributed their blood, sweat and tears to support the research in this issue and beyond, especially Mark Redwood, formerly the leader of the Climate Change and Water programme, who initiated this special issue several years ago and passed it on to us; and last but not least, all of the communities and individuals who gave their time to provide data and input, without which this research would not be possible.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Department for International Development, UK Government; the Government of Canada; and the International Development Research Centre.

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