APPLICATION OF ICTS FOR CLIMATE CHANGE ADAPTATION IN THE WATER SECTOR

Developing country experiences and emerging research priorities

Editors: Alan Finlay and Edith Adera

APC

IDRC | CRDI

APPLICATION OF ICTS FOR CLIMATE CHANGE ADAPTATION IN THE WATER SECTOR

Developing country experiences and emerging research priorities

APC

IDRC | CRDI

Canadä

Application of ICTs for Climate Change Adaptation in the Water Sector:
Developing country experiences and emerging research priorities

Editors

Alan Finlay and Edith Adera

Assistant editors

Shawna Finnegan, Lori Nordstrom and Valerie Dee

Reviewers

Himanshu Kulkarni and Tina James

Publication production

Mallory Knodel and Flavia Fascendini

Graphic design

MONOCROMO

info@monocromo.com.uy

Phone: +598 2 400 1685

Proofreading

Lori Nordstrom and Valerie Dee

The views expressed in this publication are those of the individual authors and not necessarily those of APC or IDRC.

Images courtesy of NASA's Earth Observatory

Printed in Goa, India
by Dog Ears Books & Printing

Application of ICTs for Climate Change Adaptation in the Water Sector: Developing country experiences and emerging research priorities

Published by the Association for Progressive Communications (APC)
and the International Development Research Centre (IDRC)
South Africa
2012

APC-201202-APC-R-EN-PDF-134

ISBN: 978-92-95096-43-1

Table of contents

Appendices

Lake Chad was once the sixth largest lake in the world, providing freshwater to millions of people living in Chad, Cameroon, Niger and Nigeria. However, persistent drought and unsustainable irrigation projects have shrunk Lake Chad to nearly a twentieth of its original size, threatening local ecosystems and livelihoods.

PREFACE

A changing and variable climate will have far-reaching consequences on water resources, particularly on water that governs the lives and livelihoods of many people in the developing world. Discussions on adaptation to climate change and variability usually focus on how people use water resources. However, the chapters published here show that adaptation to contexts of water stress is often a mix of climate-consequential responses and responses to social, economic, political and cultural fluxes, in many of these regions. Moreover, responses that we often term "adaptation" occur on a wide-ranging scale, and are not necessarily confined to a specific community or context. Despite its complexity, a changing and variable climate presents us the opportunity to view water management through an entirely different lens, a lens that is less "development oriented" and more "management based". Climate change also prompts us to take a more "holistic" view of water resources and look closely at linkages with many other aspects of our ecosystem, an approach that is often missing in conventional development paradigms on water resource planning.

Information and communications technologies (ICTs) have proven useful in tailoring responses to situations arising out of the climate-water nexus. ICTs have emerged as a strong way to understand water security challenges. They are increasingly being adopted as key decision support mechanisms for adapting to climate change effects in the developing world. However, ICTs must not be considered simply a panacea for water security. Rather, they are tools that can be smartly used in developing appropriate responses to problems in the water-climate change arena.

The overlap of the water, climate and ICT fields, interestingly, is *communities*. People take the centre stage of adaptation strategies and it is therefore important to realise the *meaning* of communities in today's context given that demographic shifts occur more rapidly than ever before. In the context of climate change, water security responses today are quite demanding as multiple disciplines become important in arriving at appropriate adaptation strategies. Research on climate change, water and ICTs now involves practitioners from diverse backgrounds such as science, engineering, sociology, technology and climatology, to name just a few. An approach that integrates various disciplines into the process of adaptation is emerging in many regions that deal with the compounded challenges in water and climate management.

With the need for increased and improved integration, adaptation to climate change and variability in contexts of water stress will need to be backed by an innovative research agenda. Research that straddles multiple disciplines will not only help identify appropriate adaptation strategies, but will also innovate the application of ICTs in areas such as data collection and decision support, and improved communication networks. This publication brought out by the International Development Research Centre (IDRC) and the Association for Progressive Communications (APC) discusses current trends, conceptual models and the need for an integrated research agenda in the domain of ICTs, climate change and water, with special reference to regions of high biophysical vulnerabilities to climate change and variability.

Dr. Himanshu Kulkarni
Executive Director
Advanced Centre for Water Resources Development and Management (ACWADAM)

01.

Introduction

Alan Finlay and Edith Adera

The focus of the reports gathered here is how information and communications technologies (ICTs) can be used to help communities in developing countries facing water stress to adapt to climate change. The role and potential of ICTs in helping communities employ innovative approaches to prepare for, respond and adapt to climate change are increasingly being recognised. Within the water sector, ICTs can contribute towards improvements in water resource management techniques; strengthen the voice of the most vulnerable within water governance processes; create greater accountability; provide access to locally relevant information needed to reduce risk and vulnerability; and improve networking and knowledge sharing to disseminate good practices and foster multi-stakeholder partnerships, among others. While drawing on current experiences in the field of water management and sustainability, the perspective of the authors is primarily from the ICT for development (ICT4D) sector. Because of this the reports should be considered exploratory, offering a fresh perspective to the field of water security in vulnerable contexts.

The reports are the result of work commissioned by the International Development Research Centre (IDRC) and the Association for Progressive Communications (APC), which had the key objective of informing the research support agenda of the IDRC in the field of ICTs, climate change and water. The collaboration between the IDRC and APC involved several activities, including regional research in Latin America and the Caribbean (LAC), Africa and Asia, a call for projects working in the field to share their experiences (see the Appendices) and a workshop held in Johannesburg on 7-10 July 2011. Participants at the workshop were from around the world and were invited to discuss the implications of using ICTs to help vulnerable communities facing water stress to adapt, and to begin shaping a research agenda in the field.

While water management and sustainability is a specialist concern with its own body of evidence that has emerged over time, the interface of ICTs, climate change and water arguably poses new theoretical challenges and practical gaps. For one, there are not enough projects practically demonstrating the positive potential and innovative impact ICTs can have at the grassroots level in managing water resources. While a number of projects do exist, they are not yet widespread enough to meet the adaptation needs of communities facing water crises given the impact climate change is already having at the local level.

At the same time, the ICT4D sector itself has only recently seen a wider consideration of how climate change will impact on its work – the interface between ICTs, climate change and water is a complex one, involving new policy dynamics and areas, as well as sciences, that may be unfamiliar to many practitioners. How the sector itself adapts to a relatively new field of enquiry remains to be seen, and part of the purpose of this publication is to catalyse that process.

The timeline of the authoring of these reports is important. For example, the regional studies as well as the project write-ups preceded the Johannesburg workshop, and fed into those discussions. Chapter 4, which discusses an emerging research agenda, drew directly on discussions that were held in the workshop. The conceptual framework, presented in Chapter 2, draws on all of the above, as well as the research and analysis that had already been done in the field of ICTs and climate change adaptation over recent years at the Centre for Development Informatics, University of Manchester. As a result, the conceptual framework offers a more refined theoretical entry point into the subject of ICTs, climate change and water security, while the reports that follow it can be considered as reflecting earlier thinking on the topic. They also consider a range of important issues and observations that are outside of the scope of the theoretical analysis. Similarly, in line with the sequence of project activities, we felt it best to preserve something of the "raw energy" of the research questions that emerged from the earlier workshop discussions in Chapter 4.

In Chapter 2, "The ICTs, Climate Change Adaptation and Water Project Chain: A conceptual tool for practitioners", Angelica Ospina, Richard Heeks and Edith Adera elaborate on a potential methodology for integrating ICTs into the design, operation and evaluation of projects in contexts of water stress. As the authors state, they offer a process-focused approach, which is intended to have practical application and testing in real-life contexts – what the authors call "concrete e-enabled adaptation actions" (p. 18).

The authors outline what they call the vulnerability dimensions of water resources, offering a systems perspective that calls for an assessment of the potential of any system – such as a household, a community, a city – to be exposed to external shock, and its ability to cope with the impacts of that shock. Critical dimensions of a system involve livelihoods and finance, food security, health, human settlement and displacement, socio-political issues and water. In this context, water becomes a resource of "transversal importance" (p. 19), since the availability, scarcity, or other negative impacts of water stress impact on other vulnerability dimensions.

Importantly, the authors argue that adaptation should not be considered as something new: individuals, communities, groups, cities adapt all the time, and it should be considered a constant articulation of change rather than an event (even though climate change could precipitate a single catastrophic event that leads to the sudden need to adapt). While climate change is "challenging the ability of vulnerable populations to withstand, recover from and adjust to change" (p. 21), the authors argue for adaptation strategies to be wide ranging in their approach, and to address development priorities holistically rather than with a single, frequently reactive approach that only considers climate-related impacts on communities.

Drawing on prior thinking in the area, the authors categorise adaptation priorities for water into five areas: supply, demand, availability, management and governance. It is here that the potential for ICTs to impact on water security is located, in particular in the ability of technology to catalyse "adaptive actions" of a community or group in a vulnerable context. (Conceptually, the authors make a distinction between the adaptive capacity of a community – the potential for adaptation – and what actually occurs, i.e. the adaptive actions). However, they stress that while ICTs can enhance the adaptation capacities of communities, how they are "adopted, used, sustained or scaled" can also, when ill considered, result in "maladaptive practices and enhanced vulnerabilities" (p. 28).

One of the key considerations of the model developed is that project processes respond to local realities, and that mechanisms are in place to ensure that it remains responsive to local needs. As the authors put it, "These considerations are key in order to ensure solid linkages between the use of ICTs, and the water adaptation needs that the projects are ultimately trying to tackle" (p. 27). Drawing on the ICT4D Value Chain, the Sustainable Livelihoods Approach, and the concept of digital capital, the model outlines the symbiotic relationship between institutional frameworks and specific resources at the local level – whether social, human or financial capital – that are needed for the implementation of a project. As the authors point out, the model is not an ICT-centric approach, even while it attempts to interface the potential of ICTs with local adaptation needs:

> The effective implementation and use of ICTs for adaptation is based on the recognition that the presence of digital capital within vulnerable livelihoods cannot be automatically equated with the contribution of these tools to adaptation. Instead, the analysis of ICTs' role and potential in regards to the adaptation of water resources should be conducted systemically, taking into account the presence of other livelihood determinants (e.g. enabling institutions, structures and assets in the climate change and ICT fields), as well as the influence of both enablers and constraints in the process of ICT implementation (p. 28).

The authors outline implications for practitioners in the different stages of project implementation, laying the ground for the testing of the model's conceptual linkages on the ground. As they put it, the "model suggests that ICT tools have the potential to strengthen the capacity of developing countries to withstand, recover from and adapt to the water-related challenges posed by climate change" (p. 28). However, it is its attention to local-level differentials that is critical to the model:

> The conceptual model presented suggests that the availability and even use of ICTs within a given context cannot be automatically equated with a contribution of these tools to climate change adaptation. Instead, a more holistic and systematic approach has to be taken in order to integrate their role, maximise their potential and evaluate their impacts within water adaptation processes (p. 29).

In their LAC regional analysis, Gilles Cliche and Miguel Saravia emphasise a point that is implicit to all of the texts gathered here: that the global poor and marginalised will be most severely affected by climate change. However, the purpose of their emphasis is to serve as a spur to the inaction perceived in global efforts to address climate change. Cliche and Saravia draw attention to the fact that there are not only practical challenges in meeting the adaptation needs for water security, but that governments, civil society, businesses – us – have a moral responsibility to *actively* address these challenges. This is particularly so given that the impact of climate change on water security for the poor can already be broadly predicted, and that the growing interest in the issue can be set in the context of addressing other development imperatives.

Taking this as a cross-cutting consideration in their analysis, the authors offer an overview of climate change and its challenges in the LAC region, drawing attention to several key issues. For instance, while the region is effectively a "superpower" when it comes to renewable water resources – accounting for more than 30% of the world's renewable water resources – this does not accurately convey the dramatically unequal distribution of those resources across the continent. This they call a "spatial variability" that is largely due to the concentration of the freshwater around the Amazon, Parana-Plata and Orinoco rivers. As the authors explain:

> [I]n Peru, two thirds of the population lives in the dry part of the Andes and coastal zone where less than 2% of the country's water flows. In Mexico, less than 10% of the land receives half of the annual rainwater [and] the Atacama Desert extending from northern Chile to southern Peru along the Pacific coast of South America is the driest region of the world (p. 35).

This extreme spatial variability has the potential to worsen already existing disparities in socioeconomic development in the region, and is likely to place pressure on regional negotiations on water distribution.

All of the regional reports point out that the impact of climate change on water security is only one of several multiplier effects impacting on water security generally. Here Cliche and Saravia show that water resources are already under strain due to the impact of "agriculture and mining, aquifer depletion, deforestation and deterioration of watersheds and replenishment areas" (p. 34). Related to these practical issues are inadequate country and regional development plans, where, as the authors put it, "a dominant economic development model is one that favours products, firms and regions with a comparative advantage, and social programmes and safety nets for the rest" (p. 34). Similarly, close to 90% of the agricultural output in the region is rain-fed, while irrigated crops are mostly set for the export market, which means that this production, as the authors point out, "is important in the national economies, but less so for local staple food supply" (p. 37). This status quo is held in place by a policy approach where it has generally been the norm to "view climate change as an environmental problem" and there are "significant weaknesses regarding the inclusion of adaptation strategies in sustainable development plans" (p. 34). Therefore the economic policy imperatives driving a region that already accounts for 12% of the world's greenhouse gas emissions lay fertile ground for the potential impacts of climate change to be felt severely.

In line with the e-resilience framework for the application of ICTs in contexts of climate change developed by Ospina and Heeks,[1] the authors categorise the use of ICTs for water security according to five key resilience variables: robustness, scale, redundancy, rapidity, flexibility, self-organisation and learning. The authors produce four categories:

1. Ospina, A. and Heeks, R. (2010) *Linking ICTs and Climate Change Adaptation: A Conceptual Framework for e-Resilience and e-Adaptation*, Centre for Development Informatics, Institute for Development Policy and Planning (IDPM), University of Manchester, UK. www.niccd.org/ConceptualPaper.pdf

climate modelling (which they relate to robustness and scale), early warning systems (rapidity, redundancy and self-organisation), decision-support systems (robustness and self-organisation), and knowledge management (learning and sharing).

Of particular interest, they argue that there is a significant information and knowledge gap at the grassroots level. For instance, when it comes to climate modelling, they argue that a tension exists between localisation of climate data and reliability:

> There is a huge challenge particularly for mountain and hillside rain-fed agriculture in Central America and the Andes, where local climates are very complex, and where reliable historical and current meteorological and hydrological data series are rarely available (p. 41).

Similarly, when considering early warning systems, key challenges remain at the local level, in particular when it comes to last-mile technology. Decision-support systems also need to combine traditional knowledge with modern scientific practice "in the context of intra-annual climate variability, for which weather forecasting is of limited use, and local knowledge is losing its traditional references" (p. 44). For the authors, e-access "does not seem to be a major impediment for [ICT] deployment in climate change or other applications" (p. 39). Mobile phones are the most widely used technology, with most of the countries enjoying a ratio of about 50 phones per 100 people. Yet while "[t]he LAC region has seen an explosion of internet-based platforms and networks for information exchange and knowledge sharing" the authors also find that, in practice, "few local actors engage in formal learning processes, which involve basic documentation and analysis of local practice and sharing it with others who are not their day-to-day partners and co-workers" (p. 46).

Based on this assessment, they identify four critical research areas in support of the application of ICTs in the field of climate change and water sustainability: ICTs in vulnerability mapping, ICTs in integrated water management research, ICTs in the "last mile" challenge of early warning systems, and ICTs in social learning and knowledge sharing. They argue that researchers "seldom integrate social considerations that play a key role in the capacity of communities to prepare, cope and adapt" (p. 47) and call for the inclusion of both socioeconomic and biophysical data in vulnerability assessments. At the same time, weak policy considerations means that "[e]xcept in some extreme cases, the planning and management of water resources do not take account of climate information" (p. 48). A further challenge is posed by the privatisation of water data, which cannot easily be accessed for public planning. These mean that the integrated management of water is reactive rather than proactive, inhibits innovation and is unable to cope with the increasing demands of urbanisation and the poor. This, the authors argue, necessitates a policy review to unlock the potential for ICTs to be used at the local level to address inequalities in access to water.

In their report on the African region, Washington Ochola and Samuel Ogada-Ochola emphasise that any impact of climate change will be compounded by basic developmental inequalities, such as illiteracy, poor governance, weak institutions and infrastructure, limited access to health facilities, armed conflicts, and limited access to technology. They support Cliche and Saravia's contention that the strategic use of ICTs should have a pro-poor bias, especially in a region where, similar to LAC, water resources are unevenly distributed: "More than 40% of Africans live in arid, semi-arid and dry sub-humid areas and about 60% live in rural areas and depend on farming for their livelihoods" (p. 58).

The authors highlight the impact of water scarcity on agriculture and domestic water security, pointing out that the water available per capita for domestic use is below the global average and that most countries in Africa have fallen behind in meeting their water and sanitation targets. In the agricultural sector, risk factors include crop damage and disease, and variability in rainfall, both in intensity and duration, which makes it difficult to predict how agricultural systems will perform over the long term. Their summation for a continent considered the most vulnerable for climate change is bleak:

> The hydrological effects of climate change as well as constraints on public water supply in especially the arid and semi-arid regions of Africa urgently require priority attention to forestall the already occurring inter-sectoral, inter-institutional and transboundary conflicts. Many river basins, lake basins and watersheds in Africa are stressed by population increase, intensive agriculture and changing hydrological regimes, making them highly vulnerable to climate change. Appropriate institutional and technological solutions must continue to be designed (p. 60).

While e-readiness is improving in many countries in Africa, and there are indications that the take-up of water-management technology is also increasing (including tools for "water prospecting, gauging and water withdrawal control, water source mapping, water service provision [and] water pollution tracking and control" (p. 61), critical challenges to upscaling the use of ICTs include limited awareness of technological choices, limited access to funds, a lack of clarity on appropriate technologies at the local level, risks facing the commercial viability of large investments, limited infrastructure, and a weak policy environment.

Presenting several examples of the application of ICTs in water management on the continent, the authors contend that both mobile technology (used at the local level), and the roll-out of broadband infrastructure in the region hold strong potential for water management – the first already applied in a number of grassroots projects (e.g. for data gathering and reporting, as well as for water vending). Yet significant work still needs to be done in unlocking innovation at the local level to improve the potential of communities to adapt in the context of water stress.

The authors argue that there are overarching themes that should determine the research agenda of ICTs in the context of water management and security. These include: an emphasis on devices and technologies for water systems management (considering issues such as platforms, sensor networks, security, efficiency, speed, survivability and reliability of such applications and systems); a focus on wireless networks; and the use of data for decision making. Within these considerations, specific research focus areas could include: the use of open source technology; online monitoring; topic-specific evaluations of enabling infrastructure; research into water resource governance systems; research into the application of traditional knowledge for water security; and using technologies for fairer water distribution in communities and between countries.

Despite the progress in human development in the Asia and Pacific region, Rajib Shaw reminds us in his report that the region is still home to two thirds of the world's poor, with strong gender inequalities and country-specific development divides. At the same time, there is a strong dependency on water resources for socioeconomic and cultural security among the region's poor, who are in effect frequently left excluded from the rapid development felt around them:

> While urban and industrial growth power the region's rapidly growing commercial economy, the rural poor remain dependent on the benefits provided by ecosystems. Land and water resources are the foundation for the agricultural production, fisheries and aquaculture that provide nutrition and income (p. 74).

According to Shaw, the negative impacts of climate change in the region are likely to be felt in hydropower outputs and surface water availability: "In North China, irrigation from surface and groundwater sources will meet only 70% of the water requirement for agricultural production, due to the effects of climate change and increasing demand" (p. 75). Key challenges include rising seawater levels, the increased salinity of water, the frequency and intensity of droughts and floods, and pressure placed on sanitation and urban water management: "Developed environments like cities generate higher surface runoff in excess of local drainage capacity, causing local floods. Many urban drainage facilities are in bad shape due to lack of cleaning and maintenance" (p. 76). Water-related threats include epidemics from vector-borne diseases, while "malaria, dysentery and diarrheal diseases have a significant statistical correlation with changes in climate parameters" (p. 77).

The sweeping take-up of mobile technology in the region – even while country differences exist – suggests that, as in other regions surveyed here, it will play a critical part in climate change adaptation strategies. Shaw also specifically points to the potential of mobile broadband internet access, which is arguably less likely to play a key role in the immediate future in poverty-wracked regions on continents like Africa, where there often is no access or access is expensive. However, the author tempers his assessment of the potential for technology generally to play a key role given that "the rural-urban digital divide in some developing countries and disparities between sub-regions remain a major development challenge in Asia and the Pacific" (p. 78). This, he argues, means that policy bottlenecks that inhibit the widespread take-up of ICTs should be addressed.

While Shaw also draws attention to the potential application of traditional ICTs for the purposes of adaptation, such as television and radio, he finds that digital gaps, even at this level, pose serious challenges for public service messaging in the event of emergency or local-level learning:

> Television is also the most powerful means for mobilising social resources to support disaster response and rehabilitation efforts. Although most of the population centres in the region are

> covered by television and radio through cable and satellite transmission systems and local broadcasting networks, many least-developed and low-population areas still remain out of reach of such services (p. 78).

The author highlights a number of examples of the application of ICTs in the water sector, including projects promoting livelihoods adaptation; sensor networks used to assist farmers in improved water management; using GIS tools for micro-level drought preparedness; using ICTs for regional flood information systems and glacial monitoring and for groundwater management at the local level; and using mobile technology in early warning systems, e.g. for extreme weather events and floods.

He identifies five areas that should assist any emerging research strategy in the field. First, he highlights the potential of the Climate and Disaster Resilience Index (CDRI) – which has five dimensions, physical, natural, institutional, social and economic – in shaping a research agenda. In line with Cliche and Saravia who argue for socioeconomic and biogeographic information to inform policy, Shaw argues that:

> The [CDRI] helps to find out the strength and weakness of different socioeconomic, institutional and physical dimensions for drought resilience. Because of this government and different organisations can prioritise the sector for policy considerations, provide inputs for policy formulation and help to minimise the drought risk (p. 86).

Shaw also suggests that multi-stakeholder cooperation is critical in setting the research agenda: "Often governments, NGOs and businesses accentuate what divides them rather than recognise their shared values. At the same time, research conducted in universities and other isolated forums often does not reach the intended beneficiaries" (p. 86). Third, the author points to the need for interconnectivity in order to address the digital divide in adaptation strategies. Regional cooperation, he says, should focus on developing appropriate solutions that address digital differences: "Any future research agenda needs to articulate the technological differences between countries, so that the capacity-building and technological limitations and possibilities can be properly understood" (p. 86). Similar to the other authors gathered here, Shaw points to the need to link modern and traditional approaches, and the need for ICTs to "consider the interface between traditional skills and knowledge" (p. 86). Finally, he argues for the importance of drawing on already established networks when formatting a research agenda in order to strengthen its impact.

In the final chapter to this book, Tina James outlines emerging research questions in the field of ICTs, climate change and water. As the author notes, these are drawn directly from the workshop held in Johannesburg in July 2011. They should therefore be considered preliminary considerations in the field that could inform future agendas – agendas which are in turn dependent on the theoretical approach of researchers, donors or research institutions (one approach being suggested by the framework in Chapter 2, developed by Ospina, Heeks and Adera).

James notes several factors to consider when developing a research agenda. These include a move away from an ICT-centric approach in favour of a needs-based focus to water security. Clarity on what should be considered a "community" is also necessary, as is scalability, drawing on past experience, and developing a shared vocabulary (including, for example, whether a project aims to address climate change or variability). She draws attention to one of the contributions the ICT4D sector can make to the field of water security: "The use of ICTs in creating new opportunities for communications and collaboration between stakeholders is [...] recent and in this area there may be room for innovation and taking on board the lessons learned from other ICT4D applications" (p. 92). The importance of the practical link between knowledge and practice is also highlighted by the author, as well as attention to the dynamics or needs implicit in "community-driven" or "community-owned" initiatives.

James then identifies five key emerging research areas in the field: improving the management of water resources; strengthening the capacity of vulnerable communities to deal with climate change-induced water stress; creating more effective governance mechanisms to manage scarce water resources; building partnerships, networks and stakeholder collaboration through the use of ICTs; and supporting knowledge sharing, improved communications and dissemination for awareness raising and decision making. Usefully, specific research questions are offered for each category, such as, "What are the potential socioeconomic barriers to be addressed to implement a successful community-based monitoring system?" (p. 94) or "What targeted communications strategies are needed to improve adaptability to climate change?" (p. 95) and "How can ICTs be used to develop and support the implementation of such strategies?" (p. 95).

As suggested in this introduction, there are several overlaps between the authors' conclusions in the chapters gathered here. The authors show that using ICTs for water management is not necessarily an emerging field, but rather one that has attracted fresh currency in the context of climate change. This has implications for developing a research agenda given that there is potential to draw on the body of existing theoretical thinking and practical experiences in the field, including the experience of ICT4D practitioners in implementing grassroots ICT projects in communities.

Water security is also not just a climate change issue. As has been pointed out, climate change is likely to exacerbate development problems that already exist. Issues such as poverty divides and population growth, which in itself will increase water stress in communities, will be magnified through the lens of climate change, even while climate change is likely to introduce new challenges due to impacts on water cycles and availability.

The application of ICTs for adaptation in contexts of water stress faces a central challenge: a lack of e-readiness in many communities, despite the proliferation of mobile phones, limits the scope of local ownership and the potential of using ICTs for adaptation. This calls for the simultaneous unlocking of policy bottlenecks that might inhibit the take-up of ICTs in vulnerable communities. At the same time, while there is a desire and some potential for scalability, generalised assumptions regarding the potential of ICTs to catalyse innovative adaptation at the local level cannot apply. Innovative models are conditional on the e-readiness of any one local community. Adaptation implies localisation, in format and language, amongst them. Asia shows that even traditional ICTs – such as TV and radio – pose a challenge for local-level learning. Similarly, mobile strategies will differ, for instance, in regions like Asia and Africa, and between countries in these continents. Given this, it is unlikely that anything but rudimentary one-size-fits-all technology applications at the local level – with local ownership and usage – is likely to be feasible.

While policies need to be unlocked at the national and regional levels to unblock bottlenecks that inhibit innovation, and while regional and national ICT initiatives – for instance for data sharing and mapping – hold potential, local-level application can best be served through methodological approaches that determine the appropriateness of local innovation strategies using ICTs. These should, as the ICT4D sector well knows, incorporate local practice and knowledge for buy-in into innovation and adaptation. Given this, there is a need to pay attention to local-level variables, even while this may pose challenges for scalability.

The chapters also point to the need to link to local knowledge, resources and practice when implementing ICT strategies. While the regional studies argue for a close analysis of the implications of ICTs at the local level, also supported by the research questions emerging from the Johannesburg workshop, Ospina, Heeks and Adera offer a meta-level conceptual approach that allows for variability and consideration of local-specific dynamics. Their model draws out the specific role of ICTs, but does not necessarily promote an ICT-centric approach.

All authors writing here emphasise the need for pro-poor strategies, and for research agendas to foreground the impact of climate change on water security in vulnerable communities. Cliche and Saravia state this as a moral imperative – that there is a need to act now, and that sufficient data exists to justify that action. It is hoped that this publication does its part in challenging and unlocking some of the inhibitors to action. ■

02.

The ICTs, Climate Change Adaptation and Water Project Value Chain: A conceptual tool for practitioners

Angelica V. Ospina, Richard Heeks and Edith Adera

Water resources are one of the cornerstones of socioeconomic development, and as such, they are central to understanding climate change impacts on vulnerable populations. Emerging research at the intersection of climate change, information and communications technologies (ICTs) and development indicates the existence of increasing linkages between use of ICT tools and developing country efforts to mitigate, adapt, monitor and strategise in the face of climate change. Critical resources such as water are at the forefront of developing countries' adaptation agendas.

This chapter maps conceptually the linkages between climate change adaptation, water and ICTs, drawing on various approaches from the development, ICTs and climate change fields.[1] It presents a conceptual tool that can be used by ICT and climate change practitioners and researchers seeking to analyse and plan field interventions in contexts facing water stress due to short- and long-term climate change.

The "ICTs, Climate Change Adaptation and Water Project Value Chain" maps a process-focused approach for integration of ICT tools into the design, operation and evaluation of projects in the field of climate change adaptation and water resources.

It will be argued that, while ICTs have the potential to enable adaptive capacities and actions for water resources under climatic stress, their role needs to be integrated into ongoing and future initiatives from a holistic perspective; one that considers the complete "project value chain". Ultimately, projects in the field should ensure not only the availability, affordability and accessibility of ICT tools (all aspects of "digital capital"), but also

1. The chapter draws upon principles from the Sustainable Livelihoods Approach (SLA), the ICT4D Value Chain, and the concepts of digital poverty and adaptive capacity.

their actual uptake and use if adaptation goals and, ultimately, development outcomes are to be achieved.

The analysis will suggest that integrating this "hybrid" process-focused approach into the design, operation and evaluation of water-adaptation projects could help build the adaptive capacity of vulnerable communities to climate-induced shocks and chronic trends.

This chapter was prepared building on the findings of three regional reports commissioned by the International Development Research Centre (IDRC) and the Association for Progressive Communications (APC) on ICTs, Climate Change and Water; from discussions held by experts and practitioners at an international workshop on the subject (Johannesburg, 7-10 July 2011);[2] and on research conducted by the authors in the field of ICTs, climate change, water and development.

1. Introduction

The intersection of climate change, ICTs[3] and development is an emerging area of research where crucial developing country priorities converge. Within contexts affected by poverty and marginalisation, the impacts of climate change and climate variability on critical resources such as water are evidencing the need for innovative approaches to better withstand, recover from, and adjust to uncertainty. Building adaptive capacity for the management of water resources is among the most urgent areas for action in the climate change agenda of developing countries.

At the same time, one of the biggest challenges in the emerging climate change, ICTs and development field involves the provision of practical conceptual tools that can be applied to specific resources (e.g. water), and that can help practitioners with the design, implementation and evaluation of ICT initiatives aimed at strengthening adaptive capacities within vulnerable contexts.

In response to that need, this paper develops a conceptual model linking ICTs' role with water resource adaptation to climate change. By mapping the key factors that need to be considered in order to integrate ICTs into project design, operation and evaluation, the conceptual model is expected to provide guidance to practitioners and researchers, and to contribute to the transition from ICT availability to concrete e-enabled adaptation actions in the water sector.

The model is developed in three progressive stages. The first stage contextualises the analysis by identifying the main linkages that exist between climate change, vulnerability and water resources. This includes the vulnerability dimensions that are exacerbated by acute climatic shocks and slow-changing trends on water. The second stage of the analysis introduces the concept of adaptive capacity, identifying priority areas for adaptive actions in the water sector, and providing examples of ICTs' potential with regards to each of those areas. Having acknowledged the empirical role of ICTs in this field, the last stage of the analysis builds a conceptual model linking their role with the achievement of enhanced adaptation of water resources. It focuses on the key factors that need to be considered in order to effectively integrate ICTs into the design, operation and evaluation of projects in the field.

2. Further information about the workshop is available at: ccw.apc.org

3. ICTs are defined as technologies that process or communicate digital data (Heeks and Leon, 2009).

2. Climate change impacts on water resources

Water will be the resource most severely affected by climate change (Chavarro Pinzon et al., 2008). Scientific evidence suggests that climate change manifests itself in both slow-changing trends (long term) and in acute shocks (short-term events) that have profound effects on water resource sustainability. Changes in precipitation and runoff patterns, as well as in the intensity and frequency of hydro-meteorological events linked to climate change, including floods and droughts (RPD, 2010), exacerbate the development stressors that prevail within vulnerable contexts.

The magnitude of climate change-related effects upon vital water resources has been documented in a variety of areas, including sea level rise and melting glaciers, lower quantity and quality of water sources, and greater complexity of water management and governance, among others (IPCC, 2007a). Expected climatic impacts such as temperature increases in high mountain areas can accelerate the evaporation of water and contribute to the loss of glaciers and moorlands, adding new pressures to the water supply, and causing flooding and landslides due to an increase in river flow. Higher temperatures are also expected to increase demand for irrigation water, and to decrease natural sources such as lakes (ibid.).

While the extent of climate change impacts varies among and within geographical regions, studies conducted in Asia, Africa and Latin America (Shaw, 2011; Ochola and Ogada, 2011; Cliche and Saravia, 2011) suggest a number of critical areas where water resources are most severely affected by the impacts of changing climatic trends and acute events. The identification of these areas or "vulnerability dimensions" can help to map the impacts of climate change on water resources, particularly within developing countries.

Vulnerability dimensions of water resources

Vulnerability involves both the likelihood of exposure to external shocks, as well as the ability of a given system (household, community, region or nation) to cope with the impacts of that shock (Elbers and Gunning, 2003; Ospina and Heeks, 2010). Thus, a systems perspective suggests that the analysis of vulnerabilities – such as those related to the impacts of climate change – should consider both the external shocks and variations that impinge upon the system, as well as the ability of that system to cope with their impacts (ibid.). In the case of developing contexts, climate change impacts have been documented mainly in relation to a set of critical dimensions, namely livelihoods and finance, food security, health, human settlement and displacement, socio-political issues and water (IISD et al., 2003; IPCC, 2007b; Magrath, 2008; Oxfam, 2009).

Given the fact that this last resource is of transversal importance to all sectors, the impacts of climate change on water exacerbate prevailing development challenges across the other vulnerability dimensions, as illustrated in the (non-exhaustive) examples provided below.

Water, livelihoods and finance

More frequent and intense precipitation cycles (e.g. unexpected periods of extreme drought or strong rainfall) can affect vulnerable livelihoods in multiple ways. Unexpected changes in precipitation patterns can affect the productivity of the land, fostering erosion and nutrient loss and lowering production levels, negatively affecting the main livelihood of millions of agricultural producers.

Both excess and lack of water can make some plant species more susceptible to plagues and diseases, which can also have serious consequences on the quality and the volume of crops produced. In the longer term, changes in sea levels can affect local livelihoods that depend on tourism and fishing, while threatening the availability of fresh water sources for consumption and productive activities. Ultimately, these effects weaken the income level and the quality of life of those with resource-dependent livelihoods.

The availability of water resources is also closely linked to agricultural production costs. Heightened precipitation cycles can translate into mudslides or flooding, which affect the transportation and distribution of produce, raw materials and equipment, ultimately raising production costs and reducing availability of local finance. Water scarcity and fluctuations in river flows can also impact hydropower generation (RPD, 2010), which is an important source of energy in developing countries.

Water and socio-political conditions

Climate change is linked to potential tensions and conflicts around access to water by different user groups such as different farming groups, or farmers and industrialists (Pageler, 2009). At the same time, extreme hydro-meteorological events can weaken political structures and institutions, as their capacity can be overwhelmed by the effects of climatic shocks (WHO and DFID, 2009). They can also destabilise weak water governance structures that lack robustness, redundancy and flexibility to deal with intensified water stress (Bapna et al., 2009; Ludi, 2009). Additionally, in situations of water stress, the increased amount of time required to collect water, as well as the higher risk of water-related health hazards, can heighten the vulnerability of specific groups such as women and girls (Ludi, 2009; UNESCO, 2011b).

Water and health

Climate change can impair the quality and the quantity of water resources available for human consumption and sanitation, jeopardising the health of vulnerable populations such as elders and children (RPD, 2010). Heavy rainfall can lead to the rapid spread of pollutants (such as pesticides) and water-borne disease, and can affect traditional crops, thus altering local diets and nutrition, especially among low-income populations (UN-Water, 2010; Calow et al., 2011). Floods can also overwhelm the capacity of sewers, and water and wastewater treatment plants, with negative effects on human health (UNESCO, 2011a).

Water, human habitat and migration

Hydro-meteorological events can affect the stability of human habitats, particularly by damaging the already weak housing infrastructure that characterises low-income and informal settlements. The intensification of hydrological cycles can affect the coping capacity of water infrastructure, overwhelming storm water drainage systems and wastewater treatment facilities, and affecting the regulation and the distribution of water, particularly to densely populated urban centres (WHO and DFID, 2009). Extreme episodes of water excess (flooding) or deficit (drought), as well as changes in the use of productive land, have also been linked to human migrations and displacement (usually rural-to-urban), contributing to poverty and marginalisation (Brown, 2008; UNESCO, 2011b).

Water and food security

The impact of extreme climatic events and more intense variability on water resources poses multiple threats to food security. The loss of crops and productive assets that results from unexpected periods of water surplus or deficit constrains the ability of vulnerable populations to access sufficient and adequate food. More intense and frequent precipitation periods also contribute to food insecurity through fluctuations in crop yields and local food supplies, as well as a decline in nutritional intake (Ludi, 2009; FAO, 2008).

Water, biodiversity and ecosystems

Water plays a pivotal role in the stability of ecosystems and in the maintenance of biodiversity. Sea level rise can affect natural coastal habitats by decreasing beach areas and eroding mangrove formations, which play an important role as natural barriers against the force of hurricanes and storms. Reefs, coral formations and animal species can also be affected by changes in salinisation and currents, or by runoff from land areas, impacting biodiversity and coastal ecosystems. Likewise, changes in precipitation patterns in high mountain areas and moorlands can weaken native species to the detriment of biodiversity, wildlife and water supply (UN-Water, 2010; UNESCO, 2011a).

While the specific impacts of climate change on water resources are highly localised and dependent upon the spatial, temporal, socioeconomic and institutional conditions of each context, adaptation constitutes a shared and pressing priority among developing countries. Defined by the IPCC (2001) as a system's adjustment in response to observed or expected changes in climatic stimuli and their effects, in order to alleviate adverse impacts of change or take advantage of new opportunities, climate change adaptation is a complex process that is best approached from a systemic perspective. We therefore turn next to a systemic understanding of adaptation, and of how it relates to particular aspects of water resource management.

3. Climate change adaptation, water resources and ICTs

The ability of individuals, groups or organisations to adapt to change and uncertainty, as well as their ability to translate adaptation decisions into concrete actions, represent two important dimensions of adaptive capacity (Ospina and Heeks, 2010). Adaptation decisions occur continuously, and while they are not solely necessitated by climate change manifestations, the increased frequency and intensity of these manifestations are challenging the ability of vulnerable populations to withstand, recover from and adjust to change.

Studies of climate change impacts on water resources in different regions of the world (Cliche and Saravia, 2011; Shaw, 2011) have identified a number of adaptive measures that are being implemented in response to and in anticipation of climate change. From improvements in the storage, distribution, management and use of water, through the development of flood controls and drought monitoring, to water policy reforms, developing countries are starting to prioritise the adoption of measures to better withstand, recover from and adjust to climate-induced changes.

Sources in the field (Nicol and Kaur, 2009) suggest that adaptation priorities for water can be categorised in five key areas, which are closely linked to the vulnerability dimensions identified above:

- *Adaptation to changes in water supply* relates to changes in precipitation patterns, loss in snow caps, ice melt and moorlands, changes in evapotranspiration and soil moisture, changes in flooding and drought patterns, as well as in the intensity with which they will impact vulnerable systems (ibid.). Adaptive actions in this area include new investments in water reservoirs, irrigation systems, capacity expansions, levees and wastewater treatment facilities, among others.
- *Adaptation to changes in water demand* reacts to increased consumption from agricultural, domestic and industrial sources, that increase being prompted by population and economic growth, urban migration, warming, and changes in land use – some of which are exacerbated by climate change (ibid.). Adaptive actions in this area include awareness raising, monitoring, regulation, and support for technological change among water users, largely aimed at reducing their consumption levels (UN-Water, 2010).
- *Adaptation to changes in water availability* addresses water deficit at the national and subnational level, and changes in the quality and quantity of water resources available to users (linked to climatic and non-climatic factors of physical, social or economic scarcity, as well as to prevailing weaknesses in water models and assessment mechanisms) (ibid.). Adaptive actions in this area include the re-engineering of dams, irrigation and distribution systems, the adoption of desalination technologies and improved wastewater reuse, the construction of canals, and the implementation of community-based water pumps, among others.
- *Adaptation to changes in water management* may be taken in anticipation of or in response to the involvement of new stakeholders in the sector, to increasing competing uses of the resource (including urban development and industrialisation), and the increased uncertainty over patterns of supply and demand. Changes in water management may lead to new decision-making processes over water resources (including the coordination, planning and implementation of initiatives), and/or tensions and conflicts that may arise from unequal access to and restricted knowledge about the resource. Adaptive actions in this area include the implementation of multistakeholder approaches (i.e. public, private, civil society) for water conservation, including awareness raising and capacity building at the national and/or local levels, among others.
- *Adaptation to changes in water governance* involves the implementation of new climate policies, water policy frameworks, or national and sectoral regulations that impact the four areas mentioned before. Adaptive actions in this area can also be needed due to exacerbated tensions across transboundary river basins and sectors, requiring new governance mechanisms. Adaptive actions in this area include the adoption of new water pricing systems, funding mechanisms for the protection of ecosystems, or new legislation for river basin management, among others.

These five areas for adaptation reflect the complexity of hydrological changes that are linked to climate change. They also reflect the importance of building adaptive capacities that are not limited to climate-induced impacts, but that acknowledge the multiple vulnerability dimensions that play a role in the achievement of development outcomes. Ultimately, they suggest that adaptation efforts should address "change" in a broad sense, as a function of multiple climatic and non-climatic factors which are best understood from a systemic perspective.

While extreme events such as flooding capture significant public attention and help raise political support for the adaptation agenda, the areas of change identified above suggest that climate change challenges in the water sector will be closely linked to long-term patterns in hydrological systems, and that non-climatic factors such as demography and economic growth also have to be considered.

Within this context, the access and use of information and knowledge constitute a pivotal component of improved water sector responses to climate change (Nicol and Kaur, 2009). Widely diffused ICTs in the global South, particularly mobile phones, have been linked to improved access to development opportunities, employment and income generation, and broader access to health, education and government services (UNCTAD, 2009; UNCTAD, 2010; ITU, 2011).

Growth of ICT service availability and uptake is also contributing to the emergence of new approaches to the challenges posed by climate change, particularly in the adaptation field. Tools such as the internet, mobile phones, Web 2.0 and social media, participatory video and community radio are being integrated into both spontaneous and planned adaptation strategies, providing users from the national to the local levels with a new set of tools to address adaptation challenges. With that in mind, we move to look at what ICTs can offer water-related adaptation.

ICTs and water resources adaptation

While the impact of climate change and climate variability on water resources is well documented (IPCC, 2001; IPCC, 2007a; UN-Water 2010), less is known about the design and impact of innovative adaptation approaches that integrate the use of ICTs. Recent evidence (e.g. case studies supported by IDRC and APC) has started to provide a more systematic understanding of ICTs' role within adaptation processes in the water sector. Examples of this potential in regards to the priority areas identified before include:

- *Water supply and demand:* ICT-enabled meteorological information systems can support the monitoring of precipitation patterns, while the use of GIS/remote sensing applications can help to measure glacial and snow cap loss as well as flood patterns. ICTs such as the internet and community radio have been used to raise awareness about the impact of climate change on water resources, helping to influence perceptions and behaviour towards more efficient water use, conservation practices, water recycling and optimisation of consumption.
- *Water availability:* Remote and local ICT-based sensing technologies can enable the monitoring of surface and groundwater supply levels, and the degradation of water quality due to increased temperatures and pollutants, providing updated data that can inform decision-making processes (including those related to water pricing and irrigation) (Ospina and Heeks, 2010; UNESCO, 2011a). The use of new digital modelling techniques can help to manage and document scarce water resources (e.g. melting glaciers, salinisation and pollution of fresh water sources) (ibid.), as well as modelling and monitoring water distribution systems, thus contributing to water security. ICTs can support hydro-climatic information systems, enabling the identification and assessment of water resource availability. ICT applications can also map existing vulnerabilities and address information gaps (including data gathering and analysis) in regards to the use of water resources, and to develop improved systems to monitor and manage more efficiently water quality and quantity.
- *Water management:* Applications such as GIS and remote monitoring can strengthen in various ways water resource management techniques in the field. ICTs can help to address the informational gaps that affect lower-income sectors of the population, contributing to the adoption of water-efficient technologies, improved management practices to prevent erosion or water logging, or modifying the timing of cropping activities (Ludi, 2009). Internet-based applications can provide tools to improve forecasting and warning, as well as drought monitoring, all of which are central to water management decision making (UNESCO, 2011a). ICTs' potential in this area includes enabling cross-sectoral and interdisciplin-

ary dialogue and knowledge exchange on water issues, the effective communication of research findings (between sectors and scales), as well as the promotion of inter- and intra-regional learning processes on water security issues. Tools such as mobile phones and community video can foster knowledge sharing and dissemination among audiences with low literacy levels, contributing to more equitable access to water resources.

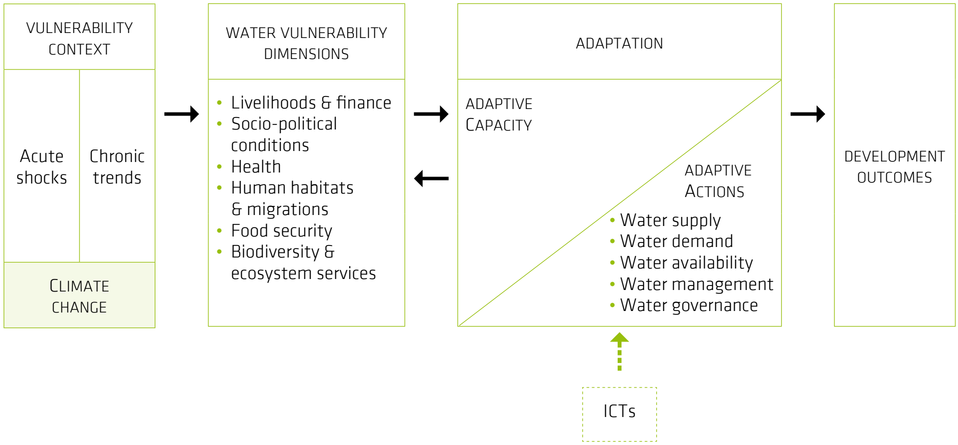
- *Water governance:* ICTs such as mobile phones can be used in participatory governance and monitoring systems, enabling users to provide near-real time data during the occurrence of floods or droughts, as well as providing updated data to inform decision-making systems on water resources. By enabling access to relevant water information (including issues of water quality and availability) at the local level, ICTs can support empowerment of community water users and hence more participative forms of water governance. Likewise, the use of internet and mobile-based tools, as well as more traditional technologies such as community radio, could support processes of water policy design by integrating voices and opinions from groups that have been traditionally excluded from decision-making processes (e.g. women, youth, ethnic minorities). Tools such as Web 2.0 and social media can support partnership building, networking and stakeholder collaboration in the water sector, again contributing to more open and democratic models of water governance.

As summarised in Figure 1, the analysis conducted thus far suggests a chain of linkages that exist, with short- and long-term climate change impacting the six water-related vulnerability dimensions of households, communities, regions, etc. These impacts demand adaptive actions which are shaped by the vulnerabilities, but which in turn reshape those vulnerabilities, ultimately leading to outcomes in terms of broader development goals.

As reflected in Figure 1, both adaptive capacity and adaptive actions are closely linked yet distinctive components of adaptation. This distinction is related to the notion that what a system (household, community, etc.) is free to do – its "capabilities" – should not be automatically equated with what it actually achieves – its "functionings" (Sen, 1999; Heeks and Molla, 2009). Thus, adaptive capacity refers to the system's ability to cope with, adjust to, and take advantage of the opportunities associated with a changing climate (Jones et al., 2010), while adaptive actions are the actual actions taken (Ospina and Heeks, 2010). Adaptive capacity relates to the availability of core livelihood factors such as assets, institutions and structures, knowledge and information, innovation and flexible forward-looking governance, among others (Jones et al., 2010). Adaptive actions are based on the ability of the system to implement and use, in practice, those precursors and inputs towards realised adaptations in one or more of the five fields of water resource adaptation.

FIGURE 1

Vulnerability to climate change and water resources adaptation



Source: Adapted from Ospina and Heeks, 2010

Figure 1 (via the dotted box) shows – as described above – the potential for ICTs to contribute to water-related adaptations. But this current model does not offer a conceptual foundation for those seeking to understand how ICTs make this contribution. Nor does it offer specific guidance for project practitioners. Further development of this model is therefore needed. On the one hand, this can help to identify the key factors, enablers and constraints that lie behind ICTs' impact on adaptive capacity. On the other, it can help to identify the stages that need to be considered in ICT-enabled interventions that seek to achieve such an adaptive impact; for example, in relation to water resources. The proposed conceptualisation can also help practitioners to distinguish between ICT interventions that merely build adaptive capacity, and those that go a step beyond to achieve actual adaptive actions.

The following section will explore these linkages, drawing from conceptual foundations within the climate change, ICTs and development fields.

4. An integrated conceptual approach: ICTs, climate change and water

The analysis conducted in the two previous sections suggests that any approach aimed at building adaptive capacity within developing contexts needs to consider a range of non-climatic factors and pre-existing vulnerabilities that are best understood from a systemic perspective. But which systemic perspective would be most suitable? Ludi (2009) argues that understanding water use within livelihood strategies "is key in the assessment of water stress and drought impacts, and, as such, will be key in the assessment of climate change impacts" (p. 5). We have already seen echoes of the livelihoods approach in Figure 1. Here the suggestion is to take this one step further, and understand the availability, access and use of water as being part of a livelihood system, and thus needing to relate to core livelihood concepts such as the assets, institutions and structures that enable livelihood strategies and the achievement of development outcomes.

Adaptive capacity within livelihood systems

The livelihood determinants (i.e. assets, institutions and structures), livelihood strategies and outcomes identified by the Sustainable Livelihoods Approach (SLA) (DFID, 1999) are thus seen to provide a useful systemic basis to explore the challenges and opportunities that developing countries face within the climate change adaptation field. As pointed out, the SLA encompasses a number of elements already identified in the analysis that supports Figure 1 (i.e. the vulnerability context of shocks and trends, the vulnerability dimensions that are present within the system, the livelihood strategies of adaptation – including the adaptive capacity and the adaptation actions aimed at withstanding, recovering from and adjusting to change – as well as the livelihood/development outcomes) (Ospina and Heeks, 2010).

Drawing from the principles of the SLA, the capacity of livelihood systems to adapt to climate change is connected to the set of assets or resources (i.e. human, natural, financial, social and physical capital), structures and processes that are available within a given system. A varied asset base is key for the sustainability and security of livelihoods, and thus for the ability of vulnerable populations to adapt to the impacts of acute and chronic climatic manifestations, forming the basis of both adaptive capacity and realised adaptation strategies (Chambers and Conway, 1991; IISD et al., 2003; Ospina and Heeks, 2010).

At the same time, institutions and structures play a key role in determining access to resources, mediating the effects of hazards, and enabling the decision-making frameworks required for adaptation processes to take place (Burton and Kates, 1993;

Ospina and Heeks, 2010). By blocking or enabling access to assets, what the SLA refers to as "processes" (laws, policies, culture and other institutions), and structures (formal, such as those belonging to the private or civil society sectors, or informal, such as family groupings) are pivotal in the implementation of livelihood strategies, and consequently, in the ability of systems to cope with and adapt to change.

But while the SLA provides the basis for a system-based approach to the linkages between vulnerability, adaptation capacity and development outcomes, it does not identify any specific role for ICTs. In particular, it does not recognise the role of "digital capital" as part of the asset base of livelihood systems. Defined by May et al. (2011) as the availability of ICT supply infrastructure, the resources necessary to afford ICT services, and the skills necessary to effectively access and use ICT tools, "digital capital" can play an important complementary and supportive role to other livelihood determinants. It comprises the specific set of assets that are required in order to deliver working ICT systems – such systems comprising digital capital if they are available, affordable and accessible to vulnerable populations.

The lack of explicit acknowledgement by the SLA of the role of digital capital, or that of information and knowledge mediated through ICTs within livelihood strategies, suggests that exploring the role of these tools within water resources adaptation requires a new, specific and more holistic conceptualisation. Towards that aim, the following subsection will build upon and develop further the linkages identified in Figure 1, in order to present a conceptual model that can help identify and operationalise the role of ICTs within climate change adaptation projects, in this case with specific reference to water resources.

Integrating ICTs into water resources adaptation

The analysis conducted thus far has established conceptual linkages between climate change impacts on water resources, livelihood components and processes, and the potential of ICTs to support adaptation capacity and development outcomes within vulnerable contexts. However, the aim of this paper is to develop a conceptual model that contributes to the implementation of ICT-enabled adaptation projects in the water sector, and thus, that helps practitioners to identify the key elements that need to be considered in such projects.

With this in mind, and drawing from the principles of the ICT for Development (ICT4D) Value Chain,[4] the SLA, and the concept of digital capital, the role of ICTs will be mapped, sequentially, throughout the main stages that characterise development projects: design, operation and evaluation.

Project design

This stage involves the identification of the systemic prerequisites for any ICT4D initiative. It includes two main components:

- The first is identification of the *contextual structures and institutions* that are present in the context of implementation. They constitute the foundational precursors that need to be in place, mainly at the macro and meso level, for the implementation of ICT4D projects (e.g. ICT policy and regulations, human and technological infrastructure, legal structures and institutions, plus the institutional driver of demand for intervention in the particular project area). They need to be considered in light of the specific context and dimensions of vulnerability, e.g. water vulnerabilities to climate change.
- The second is the identification of the *project inputs*, a specific *set of livelihood assets* that feed into ICT4D initiatives. As suggested by the SLA, these assets can be "hard", such as financial, physical or natural resources and technology, as well as "soft", such as social networks, human skills, values and motivations. They can be summarised by the SLA "pentagon" of asset types: financial, physical, natural, social (sometimes expanded to socio-political) and human.

Project operation

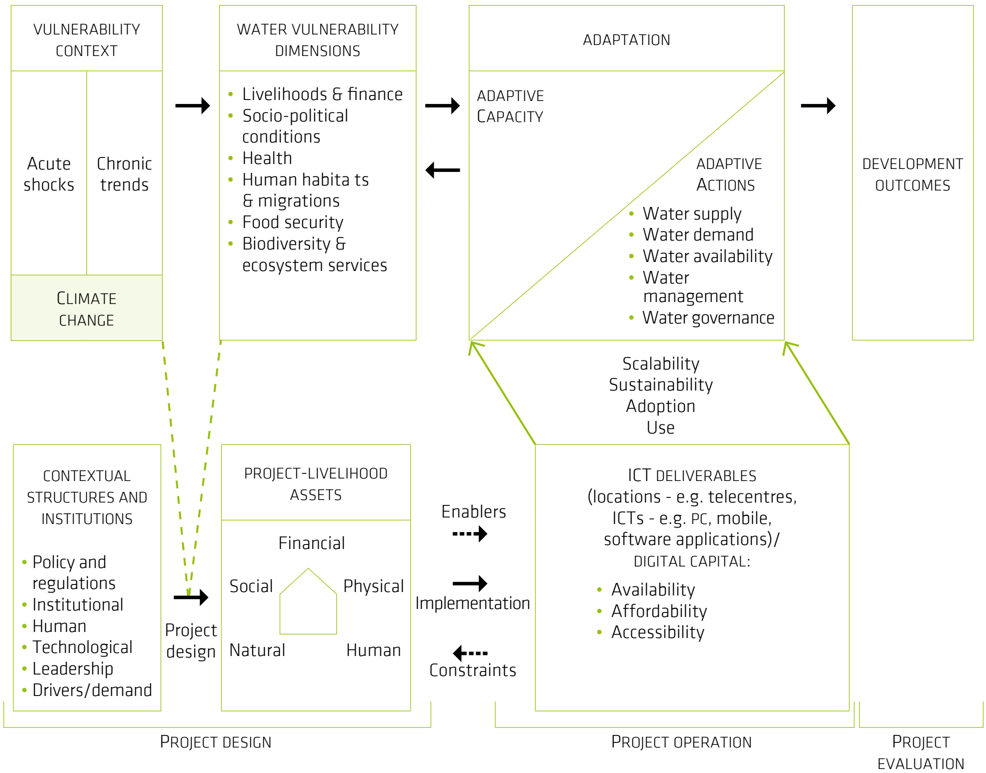
This stage is largely based on the implementation of the project design, and consists of two key components.

- The first is the conversion of the contextual structures, institutions and livelihood assets identified during the stage of project design into

4. The ICT for Development Value Chain (Heeks, 2010) offers a model to analyse, sequentially, the role of ICT4D resources and processes. It constitutes a useful tool to explore the historical progression of ICT-related projects, as well as to design, implement, assess and/or evaluate ICT interventions. The value chain is focused on four key domains, namely readiness, availability, uptake and impact, which are here modified to correspond to project lifecycle stages.

FIGURE 2

ICTs, Climate Change Adaptation and Water Project Value Chain



actual *ICT deliverables* (i.e. ICTs applied in the project, for example, a telecentre, a mobile application, a web-based software program, etc.). Activities within this component are aimed at the formation of *digital capital*, which encompasses three key dimensions: availability (e.g. the specific ICT deliverable is in place), affordability (e.g. sufficient income to afford ICT services), and accessibility (e.g. skills required to use ICT services).

- The second is the process of *ICT uptake*. This involves the conversion of the digital capital (ICT that is available, affordable and accessible) to *actual use* in development practice (e.g. as part of adaptation actions that specifically address water supply, demand, etc.). Thus, ICT uptake involves issues of actual adoption and use, as well as strategies for the sustainability and potential scaling up of successful ICT-based approaches if they are to achieve a meaningful level of impact.

Project evaluation

This stage constitutes the last of the project value chain, and involves the assessment of ICT's impact. This can be divided into three sub-elements: *outputs* (e.g. micro-level behavioural changes associated with technology use), *outcomes* (e.g. wider costs and benefits associated with ICTs, encompassing the particular adaptive actions that have been taken), and *development impacts* (e.g. the contribution of ICTs to broader development goals) (Ospina and Heeks, 2010).

The value of the "project value chain" model is seen as two-fold. It has a conceptual depth that enables it to be used for comprehensive analysis of initiatives at the intersection of climate change adaptation, water resources and ICTs. But it also has a practical value for project managers, enabling them to understand concrete decision factors and actions at each stage of their projects.

Figure 2 reflects the way in which the ICT4D project value chain can be linked to the conceptual elements that have been identified thus far.

The upper portion of the model represents the linkages discussed in Figure 1, namely those that exist between climate change manifestations (acute shocks and chronic trends), their impact on the set of vulnerability dimensions that characterise water resources, the adaptive capacity and actions required to respond, and the achievement of development outcomes. The lower portion of the model reflects the main livelihood components (i.e. the conversion of livelihood assets to digital capital within a specific structural and institutional context) and well as the stages (i.e. design, operation and evaluation) of the particular project.

ICTs are linked to climate change adaptation in the water sector through the stage of project operation (i.e. implementation), when available digital capital converts into actual ICT usage, contributing to enhanced adaptive capacities and actions. These links are realised through the uptake of ICT tools (the two upward-facing arrows), which reflect the conversion of digital capital into ICTs that are actually adopted, used, sustained and/or scaled up towards the achievement of water adaptation goals (i.e. supply, demand, availability, management and governance). The impact of ICTs on the achievement of adaptation and development outcomes is subsequently assessed as part of the project evaluation stage.

The model suggests a series of key process-based factors to be considered by practitioners and researchers working at the intersection of ICTs, climate change adaptation and water resources. First, in the stage of project design, the model reflects the need to understand the relation between broader structures and institutions (contextual/national-level precursors) and the specific inputs (livelihood assets of financial, physical, human, natural or social capital) that are required for the operation of a particular project in the field. The model also suggests that the project design needs to integrate local climate change impacts (i.e. acute shocks and chronic trends) and water sector priorities (i.e. vulnerability dimensions), in order to ensure that the subsequent stage of project operation responds to and is rooted in local realities (this is reflected by the two dotted lines linking the upper and the lower portions of the model). These considerations are key in order to ensure solid linkages between the use of ICTs and the water adaptation needs that the projects in the field are ultimately trying to tackle.

The model also reflects the need to acknowledge the presence of enablers and constraints that may either foster or hinder the implementation of project activities (reflected by the dotted lines facing right and left, in the lower portion of Figure 2). The *enablers* refer to the technical (e.g. end-user technologies, applications and networks), economic (e.g. markets, enterprises and regulatory frameworks) and social components (e.g. social actors, interactions and networks, content) (ibid.) that shape the functioning of ICT systems, and that ultimately determine the way in which ICT tools are implemented and used at the macro, meso and micro levels (May et al., 2011). The *constraints* are the substrates of "digital poverty", which is defined by Barrantes (2005) as "the lack of goods and services based on ICTs" (p. 30). Digital poverty limits the availability, affordability and accessibility of ICT tools at the individual, community and national levels, constraining their potential use in achievement of adaptation and development outcomes.

At the same time, the model distinguishes between the availability of ICT infrastructure, resources and skills (i.e. of digital capital and its dependent assets), and their actual adoption and use (i.e. uptake), which can enable the transformation of adaptive capacities into adaptive functionings[5] or actions. Strengthened adaptation capacity can, in turn, contribute to the effective implementation and use of ICT applications in response to the set of vulnerability dimensions identified earlier, which is reflected by the double-pointed arrows in the upper portion of Figure 2.

The stage of project design reflected in the conceptual model is closely linked to the foundations of the Sustainable Livelihoods Approach (SLA). While the "conceptual structures and institutions" refer to the macro-level generic foundations that need to be in place for the implementation of ICT initiatives, the "project-livelihood assets" reflect the specific resources, mainly at the meso and micro levels, that need to be present to feed into a particular project in the field. Thus, the stage of project design includes the role of the SLA's livelihood determinants.

The effective implementation and use of ICTs for adaptation is based on the recognition that the presence of digital capital within vulnerable livelihoods

5. Adaptive functionings can be defined as the ability of a system to transform adaptive capacity into action by implementing adaptive decisions (Nelson et al., 2007; Ospina and Heeks, 2010).

cannot be automatically equated with the contribution of these tools to adaptation. Instead, the analysis of ICTs' role and potential in regards to the adaptation of water resources should be conducted systemically, taking into account the presence of other livelihood determinants (e.g. enabling institutions, structures and assets in the climate change and ICT fields), as well as the influence of both enablers and constraints in the process of ICT implementation.

Within vulnerable developing contexts characterised by poverty and marginalisation, the way in which ICT tools are actually adopted, used, sustained or scaled will also determine the extent of their contribution to adaptation processes, or in turn, their potential role towards maladaptive practices and enhanced vulnerabilities.

Implications for practitioners and researchers

The ICTs, Climate Change Adaptation and Water Project Value Chain model has multiple implications for the way in which practitioners and researchers approach the integration of ICTs into climate change adaptation processes in the water sector. The following are some key aspects to be considered through the stages of project design, operation and evaluation of water adaptation initiatives:

- *The stage of project design* would involve: 1) the identification of the vulnerability context (specific climate change shocks and trends) that impinge upon existing development challenges; 2) the identification of the specific vulnerabilities, linked to water resources, that exist within a given context; and 3) the establishment of the presence or absence of structures, institutions and livelihood assets that could enable or constrain the project's implementation (including implementation of the ICT-specific components), as well as the strategy that converts contextual precursors into specific project inputs (e.g. climate change leadership into political support, institutions into enabling frameworks, etc.).
- *The stage of project operation* would include: 1) the conversion of available assets into ICT applications (i.e. deliverables) that can be used to tackle water adaptation issues in a given context; 2) the specific potentiality of those applications in terms of their availability, affordability and accessibility for the target user group; 3) the actual adoption and use of ICT tools with regards to water resources at the individual, community or national level; and 4) the identification of sustainability and scaling-up options for the applications implemented. This stage would also involve the identification of critical enablers and constraints that ultimately determine the role that ICTs can play towards the enactment of adaptation capacities into actions.
- *The stage of project evaluation* would involve analysis of the ICT-enabled adaptation actions in regards to areas of climate-induced change. The *outputs* would correspond to micro-level behavioural changes associated with the use of ICTs within adaptive actions, while the *outcomes* would relate to the costs and benefits associated with the use of ICTs within specific (water-related) adaptive actions. The assessment of impacts also involves the identification of *development outcomes* (broader adaptation and water management goals) that the initiative contributed to.

The sequential stages reflected in the model can help to integrate ICTs more systematically and rigorously into water and climate change adaptation initiatives. The model suggests that ICT tools have the potential to strengthen the capacity of developing countries to withstand, recover from and adapt to the water-related challenges posed by climate change (e.g. changes in water supply and demand, availability, management and governance), given the presence of key precursors and inputs, the uptake of digital capital, and the impact of ICT-enabled interventions.

5. Conclusions

The increasing linkages that exist between ICTs, climate change and development are posing new challenges and opportunities to practitioners working in these fields. This is particularly true of those that work within vulnerable developing environments where the growing rate of ICT adoption is redefining the ways in which development objectives are pursued and met. The urgency of adapting to the effects of climate change and climate variability demands innovative approaches, such as those enabled by ICTs. And evidence is growing of the role ICTs can play in enhancing the capacity of vulnerable systems to withstand, recover from and adapt to the effects of acute climatic events and chronic trends.

Water resources are at the core of climate change adaptation strategies. Experiences in the field suggest the potential of ICT tools to help countries and communities adapt to changes in water supply, demand, availability, management and governance, exacerbated by the effects of climate change. But there is a growing need for conceptual tools that can help practitioners to better understand, plan, implement and evaluate projects at the intersection of ICTs, water and climate change adaptation.

The ICTs, Climate Change Adaptation and Water Project Value Chain model constitutes a first step in that direction. Building on the principles of the SLA and the ICT4D Value Chain, the model provides a tool for practitioners to effectively integrate ICTs into water adaptation projects through a series of sequential stages. These could ultimately contribute to better design, implementation and evaluation of ICTs' contribution to adaptive capacity and adaptive actions.

The conceptual model presented suggests that the availability and even use of ICTs within a given context cannot be automatically equated with a contribution of these tools to climate change adaptation. Instead, a more holistic and systematic approach has to be taken in order to integrate their role, maximise their potential and evaluate their impacts within water adaptation processes.

The model suggests the importance of identifying the particular set of water-related vulnerabilities that affect a given context (at the community, regional and national level). It is also important to narrow down the key areas impacted by climate-induced change where ICTs could help to improve the system's ability to accommodate water shocks and stress, cope with the uncertain impacts of future climatic conditions, and take advantage of potential opportunities. Within vulnerable developing contexts characterised by asset scarcity and by the presence of inequality, marginalisation, weak institutions and centralised governance structures – among other development challenges – the timely identification of enablers and constraints to the implementation of ICT applications in the water adaptation field could also be crucial.

Further research in this field could explore in greater detail the practical and conceptual implications of utilising this model to strengthen adaptation projects in the field, particularly through its use and assessment within initiatives implemented in the adaptation of water resources of developing contexts. ■

References

Bapna, M., McGray, H., Mock, G. and Withey, L. (2009) *Enabling Adaptation: Priorities for Supporting the Rural Poor in Changing Climate*, World Resources Institute (WRI), Washington D.C. www.wri.org/publication/enabling-adaptation-climate-change

Barrantes, R. (2005) Analysis of ICT Demand: What is Digital Poverty and How to Measure it?, in Galperin, H. and Mariscal, J. (eds) *Digital Poverty: Latin American and Caribbean Perspectives,* Instituto de Estudios Peruanos, REDIS-DIRSI, Lima, Peru, pp. 29-54.

Brown, O. (2008) *Migration and Climate Change*, International Organization for Migration (IOM), Migration Research Series, No. 31, Geneva, Switzerland.

Burton, I. and Kates, R. W. (1993) *The Environment as Hazard*, 2nd edition, Guilford, New York.

Calow, R., Bonsor, H., Jones, L., O'Meally, S., MacDonald, A. and Kaur, N. (2011) *Climate Change, Water Resources and WASH: A Scoping Study*, Overseas Development Institute (ODI), Working Paper 337, London, UK. www.odi.org.uk/resources/download/5998.pdf

Chambers, R. and Conway, G. R. (1991) *Sustainable Rural Livelihoods: Practical Concepts for the 21st Century,* Institute for Development Studies (IDS), Brighton, UK. community.eldis.org/.59b4ab37/dp296.pdf

Chavarro Pinzon, M., Guerrero Garcia, A., Garcia Portilla, J., Pabon, J. D., Prieto Rozo, A. and Ulloa Cubillos, A. (2008) *Preparing for the Future: Threats, Risks, Vulnerability and Climate Change Adaptation* [Preparandose para el Futuro: Amenazas, Riesgos, Vulnerabilidad y Adaptacion frente al cambio Climatico], United Nations Office on Drugs and Crime (UNODC), Bogota, Colombia. www.minambiente.gov.co/documentos/cartilla_adaptacion.pdf

Cliche, G. and Saravia, M. (2011) Information and Communication Technologies, Water and Climate Change: Issues and Research Priorities in Latin America and the Caribbean, paper presented at the Association for Progressive Communications (APC) ICTs, Climate Change and Water Workshop, Johannesburg, South Africa, 7-10 July. ccw.apc.org/wp-content/uploads/2011/05/LAC_CCW-ICT_Scoping_vs2_22June.pdf

DFID (1999) *Sustainable Livelihoods Guidance Sheets,* Department for International Development (DFID), London, UK. www.eldis.org/vfile/upload/1/document/0901/section2.pdf

Elbers, C. and Gunning, J. W. (2003) Estimating Vulnerability, paper presented at the Staying Poor: Chronic Poverty and Development Conference, Chronic Poverty Research Centre (CPRC), Manchester, UK, 7-9 April 2003. www.dfid.gov.uk/r4d/PDF/Outputs/ChronicPoverty_RC/ElbersGunning.pdf

Heeks, R. and Leon, L. (2009) *Remoteness, Exclusion and Telecentres in Mountain Regions: Analysing ICT-Based "Information Chains" in Pazos, Peru*, IDPM Development Informatics Working Paper No. 38, University of Manchester, Manchester, UK. www.sed.manchester.ac.uk/idpm/research/publications/wp/di/documents/di_wp38.pdf

Heeks, R. and Molla, A. (2009) *Impact Assessment of ICT-for-Development Projects: A Compendium of Approaches*, IDPM Development Informatics Working Paper No. 36, University of Manchester, Manchester, UK. www.sed.manchester.ac.uk/idpm/research/publications/wp/di/di_wp36.htm

IISD, IUCN, SEI, SDC and Intercooperation (2003) *Livelihoods and Climate Change: Combining Risk Reduction, Natural Resource Management and Climate Change Adaptation in a New Approach to the Reduction of Vulnerability and Poverty,* International Institute for Sustainable Development (IISD), International Union for Conservation of Nature and Natural Resources (IUCN), Stockholm Environment Institute (SEI), Swiss Agency for Development and Cooperation (SDC) and Intercooperation, Winnipeg, Canada. www.iisd.org/pdf/2003/natres_livelihoods_cc.pdf

IPCC (2001) Climate Change 2001: Impacts, Adaptation, and Vulnerability, contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), McCarthy, J. J., Canziani, O., Leary, N., Dokken, D., and White K. (eds), Intergovernmental Panel on Climate Change, Geneva, Switzerland. www.ipcc.ch

IPCC (2007a) *Fourth Assessment Report (AR4)*, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland. www.ipcc.ch

IPCC (2007b) Climate Change 2007: Impacts, Adaptation and Vulnerability, contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M. L., Canziani, O. F., Palutikof, J. P., Linden, P. J. v. d. and Hanson, C. E. (eds), Cambridge University Press, Cambridge, UK. www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

ITU (2011) *Measuring the Information Society*, International Telecommunication Union (ITU), Geneva, Switzerland. www.itu.int/ITU-D/ict/publications/idi/2011/Material/MIS_2011_without_annex_5.pdf

Jones, L., Jaspars, S., Pavanello, S., Ludi, E., Rachel, S., Arnall, A., Grist, N. and Mtisi, S. (2010) *Responding to a Changing Climate: Exploring How Disaster Risk Reduction, Social Protection and Livelihoods Approaches Promote Features of Adaptive Capacity*, Overseas Development Institute (ODI), Working Paper 319, London, UK. www.odi.org.uk/resources/download/4790.pdf

Ludi, E. (2009) *Climate Change, Water and Food Security*, Overseas Development Institute (ODI), ODI Background Notes, London, UK. www.odi.org.uk/resources/download/3148.pdf

Magrath, J. (2008) *Turning Up the Heat: Climate Change and Poverty in Uganda,* Oxfam GB, Kampala, Uganda. www.oxfam.org.uk/resources/policy/climate_change/downloads/ugandan_climate_change.pdf

May, J., Dutton, V. and Munyakazi, L. (2011) *Poverty and Information and Communications Technology in Urban and Rural Eastern (PICTURE) Africa*, International Development Research Centre (IDRC), Kenya.

Nelson, D. R., Adger, N. W. and Brown, K. (2007) Adaptation to Environmental Change: Contributions of a Resilience Framework, *Annual Review of Environment and Resources,* Vol. 32, p. 395-419.

Nicol, A. and Kaur, N. (2009) *Adapting to Climate Change in the Water Sector*, Overseas Development Institute (ODI), ODI Background Notes, London, UK. www.odi.org.uk/resources/download/3149.pdf

Ochola, W. and Ogada, S. (2011) ICTs and Water under a Changing Climate: Key Issues and Research Priorities for Africa, paper presented at the Association for Progressive Communications (APC) ICTs, Climate Change and Water Workshop, Johannesburg, South Africa, 7-10 July. ccw.apc.org/wp-content/uploads/2011/05/CCW_Africa_Scoping-paper_draft.pdf

Ospina, A. V. and Heeks, R. (2010) *Linking ICTs and Climate Change Adaptation: A Conceptual Framework for e-Resilience and e-Adaptation*, Centre for Development Informatics, Institute for Development Policy and Planning (IDPM), University of Manchester, UK. www.niccd.org/ConceptualPaper.pdf

Oxfam (2009) *Suffering the Science: Climate Change, People and Poverty,* Oxford Briefing Paper 130, Oxfam International. www.oxfam.org.uk/resources/policy/climate_change/downloads/bp130_suffering_science.pdf

Pageler, M. (2009) *Local Government Perspective on Adapting Water Management to Climate Change*, International Council for Local Environmental Initiatives (ICLEI), Bonn, Germany. www.preventionweb.net/files/12912_PersPap07.LocalGovernment1.pdf

RPD (2010) *Regional Policy Dialog in Latin America and the Caribbean: Challenges and Opportunities for Water-Based Adaptation to Climate Change, Elements for a Regional Agenda*, Regional Policy Dialogue on Water and Climate Change in the Americas. idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=35806970

Sen, A. (1999) *Development as Freedom*, Oxford University Press, Oxford, UK.

Shaw, R. (2011) Information and Communications Technologies (ICTs) and Water in the Face of Climate Change, paper presented at the Association for Progressive Communications (APC) ICTs, Climate Change and Water Workshop, Johannesburg, South Africa, 7-10 July 2011. ccw.apc.org/wp-content/uploads/2011/05/CCW_Asic_Scoping-Study_draft.pdf

UN-Water (2010) *Climate Change Adaptation: The Pivotal Role of Water*, United Nations. www.unwater.org/downloads/unw_ccpol_web.pdf

UNCTAD (2009) *Information Economy Report 2009: Trends and Outlook in Turbulent Times*, United Nations Conference on Trade and Development (UNCTAD), Geneva, Switzerland. www.unctad.org/en/docs/ier2009_en.pdf

UNCTAD (2010) *Information Economy Report 2010: ICTs, Enterprises and Poverty Alleviation,* United Nations Conference on Trade and Development (UNCTAD), Geneva, Switzerland. www.unctad.org/en/docs/ier2010_en.pdf

UNESCO (2011a) *The Impact of Global Change on Water Resources: The Response of UNESCO's International Hydrological Programme*, United Nations Educational, Scientific and Cultural Organization (UNESCO), International Hydrological Programme (IHP), Paris, France. unesdoc.unesco.org/images/0019/001922/192216e.pdf

UNESCO (2011b) *Water and Climate Dialogue: Adapting to Climate Change, Why We Need Broader and 'Out of the Box' Approaches*, United Nations Educational, Scientific and Cultural Organization (UNESCO), Division of Water Sciences, Perugia, Italy. www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/WWAPCOP16_BN_PICA_WEB_090811.pdf

WHO and DFID (2009) *Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change*, World Health Organization (WHO) and Department for International Development (DFID), Geneva, Switzerland. www.who.int/water_sanitation_health/vision_2030_9789241598422.pdf

03.

ICTs, climate change and water: Issues and research priorities in Latin America and the Caribbean

Gilles Cliche RIMISP - Latin American Centre for Rural Development
Miguel Saravia Consortium for the Sustainable Development of the Andean Ecoregion (CONDESAN)

Latin America and the Caribbean (LAC) is a region with abundant water resources. However, it is exposed to significant risks associated with water quality and availability, many of which are due to climate change. Climate change is impacting on the evolution of the water system in terms of the quality, quantity and spatial distribution of the resource. This report draws on a literature review of recent studies and reports presenting the threats that the region faces, and the roles that information and communications technologies (ICTs) are playing in this growing area of concern. It provides an overview of the complex impacts of climate change in LAC, stressing the importance of climate change adaptation to address the goals of both poverty reduction and equitable development. Drawing on the e-resilience framework, it outlines the context of ICT adoption, providing examples of ICT applications using the framework's sub-properties (robustness, scale, redundancy, rapidity, flexibility, self-organisation and learning). It also discusses and presents research issues and priorities that could inform an ICT research agenda on climate change adaptation with an emphasis on water. Key research subject areas identified are vulnerability mapping, water management, early warning systems, and social learning and knowledge sharing.

1. Impacts of climate change on water security in LAC: The problem and its context

The Intergovernmental Panel on Climate Change (IPCC) Technical Paper on Climate Change and Water (Bates et al., 2008) identified climate-related impacts that have affected Latin Americans over the last three decades. Extreme weather events, including floods, droughts, landslides and hurricanes, are happening with increased intensity and devastation. Latin America is a region endowed with abundant water resources. It is however exposed to significant risks associated with water quality and availability. Water distribution is highly unequal in the region and water resources are affected by a number of factors, including excessive use for agriculture and mining, aquifer depletion, deforestation and deterioration of watersheds and replenishment areas. This is compounded by an increase in population, urbanisation and the shift in dietary regime toward more water-intensive food products. Climate change and variability are adding to the vulnerability of the region given the uncertainty of their effects on water resources for domestic uses and agricultural production.

Climate change vulnerability and adaptation have recently started to receive more attention from national governments in the region. The Fourth Assessment Report of the IPCC recognises that together with conservation of key ecosystems, countries in Latin America have made efforts to adapt to climate change through early warning systems, risk management in agriculture, strategies for flood, drought and coastal management, and disease surveillance systems (Magrin et al., 2007) – many of these initiatives involving ICT-based applications.

The region accounts for 12% of global greenhouse gas (GHG) emissions, which is high considering that the region has about 8.5% of the world's population and GDP. CO_2 emissions due to land use changes (such as from forest to rangeland and urban encroachment) are by far the main contributor, accounting for 46% to 48% of the region's GHG emissions (De la Torre et al., 2009). GHG reduction efforts are being financed predominantly by the Clean Development Mechanism (CDM), and a great majority of CDM projects are taking place in Brazil and Mexico.

The tendency in the LAC region has generally been to view climate change as an environmental problem. In most countries, environment ministries continue to be the government bodies concerned with climate change; their emphases tend to be on natural reserve conservation, biodiversity and endangered species, together with clean or greener technology – particularly in the energy sector.

The Fourth IPCC Assessment Report identifies significant weaknesses in Latin America regarding the inclusion of adaptation strategies in sustainable development plans, and more generally the lack of integration of climate change into development policies. Addressing these weaknesses is a major issue in the LAC region, where the dominant economic development model favours products, firms and regions with a comparative advantage, and social programmes and safety nets for the rest. This model has failed to overcome the region's problems of poverty and marginalisation. There is a significant opportunity to revert this situation if the growing interest in climate change investment and interventions includes a requirement to contribute to the goals of poverty and inequity reduction.

Challenges for domestic and agricultural water security

Latin America possesses more than 30% of the world's renewable water resources. In the LAC region, approximately 70% of water is used by agriculture, 10% by industry, and 20% by urban and domestic sectors. The world average for agricultural water use is 70%, similar to LAC, but for industry (20%) and domestic use (10%) the proportions are reversed. In continental Latin America, overall water use as a proportion of renewable water resources is, together with that of Oceania, the lowest of all the regions at 1.9% (see Table 1). This figure, however, hides huge geographical variability. For example, in Peru, two thirds of the population lives in the dry part of the Andes and coastal zone where less than 2% of the country's water flows. In Mexico, less than 10% of the land receives half of the annual rainwater. And while the Amazon, Parana-Plata and Orinoco rivers carry

TABLE 1

Water resources and usage, 2000 (in cubic kilometres per year)

Region	Renewable water resources	Renewable water usage	Water usage						Usage as a % of renewable resources
			Agriculture		Industry		Domestic (urban)		
			Amount	%	Amount	%	Amount	%	
Africa	3,936	217	186	86	9	4	22	10	5.5
Asia	11,594	2,378	1,936	81	270	11	172	7	20.5
Latin America	13,477	252	178	71	26	10	47	19	1.9
Caribbean	93	13	9	69	1	8	3	23	14.0
North America	6,253	525	203	39	252	48	70	13	8.4
Oceania	1,703	26	18	73	3	12	5	19	1.5
Europe	6,603	418	132	32	223	53	63	15	8.3
World	43,659	3,829	2,633	70	784	20	382	10	8.8

Source: UNESCO and Earthscan (2009) *World Water Development Report 3*

together into the Atlantic Ocean more than 30% of the renewable freshwater of the world, at the other extreme the Atacama Desert extending from northern Chile to southern Peru along the Pacific coast of South America is the driest region of the world. Brazil alone, with 5,645 billion m³ (double that of India with less than 20% of its population), enjoys 40% of LAC freshwater. However, of these abundant renewable water resources, Brazil has only 47 billion m³ that is considered a reliable water supply – less than 1% of the country's total. The Amazon basin accounts for about 20% of the annual global runoff, while its total population – from the nine countries sharing it – is less than 10 million inhabitants. Mexico has ten times less freshwater per capita than the regional LAC average. The Caribbean islands are also deficient in rivers, and their actual withdrawals already take a large share of their limited renewable resources (14%, which is closer to the Asia rate than that of any other region).

The retreat of Andean glaciers that has been observed since the 1970s is a clear indication of global warming in South America, as is the melting of polar ice, rise of sea levels and the bleaching of coral reefs observed elsewhere. The tropical glaciers of Bolivia, Colombia, Ecuador, Peru and Venezuela have receded in the past decades and some of the smaller glaciers have already disappeared. In the short term, glacier melting has the effect of increasing water availability; however, it is not yet clear what impact it will have in the longer term.[1]

Parry et al. (2007) in their Working Group II contribution to the Fourth Assessment of the IPCC, have compared actual runoff data from 1980-1999 with SRES A1B climate change scenario projections to 2090-2099 (see Figure 1). While projections of localised precipitation changes are criticised by several researchers for exceeding the capacity of current scientific knowledge, the results predict that the greatest increases in rainfall (between 10% and 30%) will occur in eastern Argentina and southern Brazil, while the most significant decreases (between 10% and 30%) are forecast for Mexico, Central America and central Chile.[2]

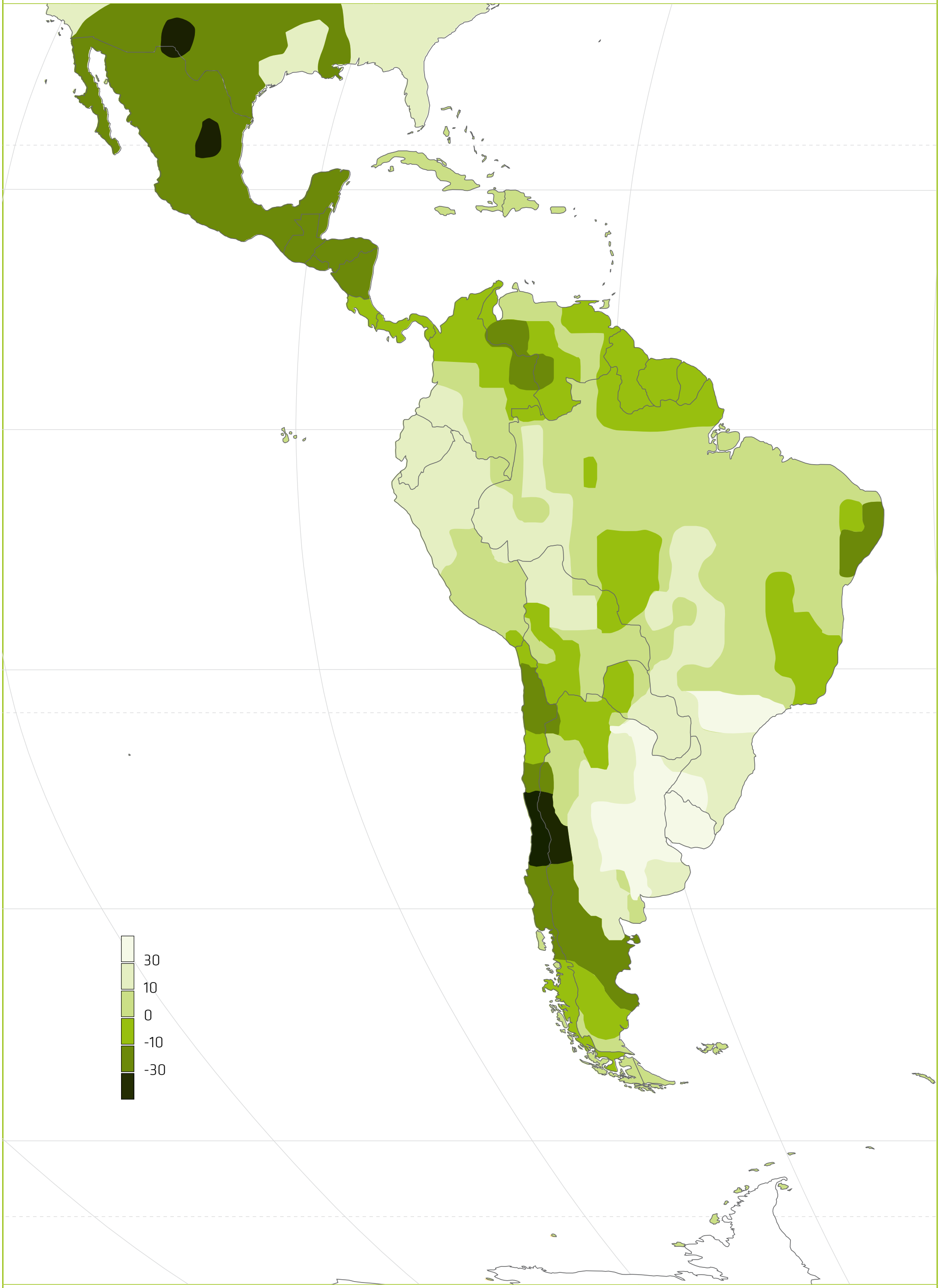
Other concerns are related to effects on the fragile Andean ecosystems, which play multiple roles and are very important for water-related environmental services. The *páramos* (high altitude wetlands or moorlands) and *bofedales* (high altitude peat lands) are providers, purifiers and regulators of water for domestic, agricultural and energy uses. Bogota, the capital city of Colombia with

1. According to Bernard Francou, glaciologist and research director at the French Institute for Development Research (IRD) (personal communication). The IRD predicts that if the trend continues most Andean glaciers will have disappeared in 30 years.

2. Graciela Magrin, lead author, LAC section of IPCC's Fourth Assessment Report, and agronomist at INTA, Argentina (personal communication).

FIGURE 1

Mean changes in runoff



Source: World Water Report 3 (based on Comprehensive Assessment of Water Management in Agriculture, 2007) close to seven million inhabitants, is relying almost exclusively on *páramos* for domestic water supply during the dry season.

Strzepek and Boehlert (2010) estimate that overall in Latin America, the effect of climate change on water supply will be less of a threat to agriculture than growing municipal and industrial demands and environmental flow ecologies. Food production is, however, critically dependent on local temperature and water availability, and climate change is therefore adding to the daunting challenges of increasing agricultural productivity to feed a growing population. Agriculture in Latin America is overwhelmingly rain-fed (close to 90% of the sector), irrespective of the size of farms. South America has about 10.5 million hectares under irrigated agriculture[3] concentrated in specific regions, mostly for high-value crops (fruits, vegetables) and the export market. This production is important in the national economies, but less so for local staple food supply.

Significant potential exists for increasing agricultural production in the region and thereby contributing to regional and global food security. It is estimated that an additional 416 million hectares of suitable land that is not part of forest ecosystems could be used for agricultural production (Echeverri and Sotomayor, 2010).

Access to safe drinking water

According to the Water and Sanitation Program[4] administered by the World Bank, for the Latin American region to meet the Millennium Development Goal (MDG) of halving by 2015 the number of people without access to safe drinking water and adequate sanitation, approximately 123 million additional people in urban areas and 23 million additional people in rural areas will require access to a water supply. For sanitation, 131 million additional urban dwellers and 32 million rural inhabitants will need access to services. A recent publication of the Water and Sanitation Initiative at the Inter-American Development Bank (IDB, 2010) shows that the MDG target of 93% for access to safe or improved sources of drinking water had been exceeded in 2008. However, as of 2008 there were six LAC countries that were not progressing at the required rate to reach the 2015 MDG target: Colombia, Haiti, Jamaica, Nicaragua, Peru and the Dominican Republic. In the case of sanitation, 79% regional coverage has been achieved while the target for 2015 is 85%. Only eight of the 25 countries studied had reached their 2008 target: Bahamas, Barbados, Uruguay, Chile, Ecuador, Belize, Mexico and Paraguay.

Many large cities in Latin America depend on aquifers for their water supply – which are being mined much faster than they are being replenished. For example, Mexico City depends on aquifers for 70% of its water supply (Barlow and Clarke, 2004). Infrastructure leakage is estimated to be on average over 50% in most large LAC cities. A number of cities have resorted to water rationing (Wilkinson, 2010). In other cases, increased levels of contamination are leading to more distant sourcing and higher costs, and declining confidence in the quality of tap drinking water. Soft drink markets have seen an explosion in both mineral (directly from the source) and mineralised (recycled) bottled water. Global players (Nestlé, Coca Cola and Pepsico) are buying up (and probably drying up) key mineral springs supplying local communities.[5] In Venezuela a litre of bottled water is more expensive than a litre of soft drink and costs 25 times more than a litre of gasoline![6]

Challenges facing the poor and marginalised

The Population Division of the Economic Commission for Latin America and the Caribbean (ECLAC) projects that the LAC population will reach 762 million inhabitants by 2050, from an estimated 582 million in 2010. Urbanisation in LAC is the highest in the developing world, with 77% of the population living in cities in 2005, a figure that is projected to be over 85% by 2050.[7] Water requirements for domestic and agricultural uses will therefore grow substantially at a time when climate change will also affect the current pattern of supply and distribution.

3. www.worldwater.org/data20062007/Table16.pdf

4. www.wsp.org

5. For an analysis on the subject, see the debate and results of the electronic conference "*Visión Social del Agua en los Andes: Agua, Comercio y Regulación*" (Social Vision of Water in the Andes: Water, Commerce and Regulation) organised in 2007 by CONDESAN and Aguas Sustentable, available at www.infoandina.org/node/8249/comments

6. ipsnoticias.net/nota.asp?idnews=90896 Note however that the price of gasoline in Venezuela is ridiculously low at approximately USD 0.04 a litre.

7. www.eclac.cl/celade/proyecciones/basedatos_BD.htm

Associated with the high level of inequality in Latin America, huge disparities exist in access to water, sanitation and adequate housing for the most vulnerable groups compared to the well-off, and the same is true of their exposure to the effects of environmental degradation. Of the 120 million urban poor (29% of the urban population), it is currently estimated that 100 million slum dwellers are living in unacceptable conditions in LAC cities, with an absence of basic utilities such as drinking water and sanitation. In turn, rural poverty affects about 52% of the rural population, or an estimated 63 million people (ECLAC, 2010).

Inadequate water supply and deficient sanitary services are higher among the indigenous population and Afro-descendent people, and directly linked to the higher levels of poverty prevailing among these population groups. In the case of gender inequalities, it is well known that the lack of access to water, sanitation and adequate housing bears more heavily on women than on men. When access to these services is deficient, women and girls spend more time seeking and transporting water, which carries a high opportunity cost by reducing both the time and energy women can devote to productive and paid activities, and the time girls can spend in education (ECLAC, 2010).

2. ICTs and their adoption in LAC

The Global Information Technology Report 2010-2011 (World Economic Forum and INSEAD, 2011) indicates that a number of countries in the LAC region posted notable improvements or consolidated their achievements in networked readiness.[8] However, the region as a whole continues to trail behind international best practices in leveraging ICT advances. Of the 138 countries covered, no regional economy appears in the top 20 and only a few feature in the top 50: Barbados (38th), Chile (39th), Puerto Rico (43rd), Uruguay (45th) and Costa Rica (46th). Compared to the previous report, Brazil has moved up five places to 56th, Mexico is stable at 78th, and Argentina has dropped five places to 96th. The average percentage of internet users in LAC in 2009 was 32.37 per 100 inhabitants (ITU, 2010), with Nicaragua having the lowest penetration (3.48), and Mexico the highest (58.16). Many LAC countries have a relatively high internet adoption rate with estimates above 40% of their population. There is, however, a major difference between access in urban and rural areas. Rural Chile, for example, has a penetration rate that is just above 10%.

The Information Society Index of the Centre for Enterprise in Latin America[9] shows a positive evolution in access. The mobile sector was the leading force in the ICT equipment variable in 2010 with an average of 980 mobile phones per 1,000 inhabitants. Social networks were the leading force in the ICT services variable with 134 social network users per 1,000 inhabitants (an increment of 89% over 2009 data), measured according to Facebook users (Pin et al., 2010). According to the International Telecommunication Union (ITU), the great majority of LAC countries have more than 50 mobile phones per 100 inhabitants, with Antigua, Argentina, Barbados, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Panama, Surinam, Trinidad and Tobago, and Uruguay with more than 100 mobile phones per 100 inhabitants (ITU, 2010). Cuba lies at one extreme (and is an exception) with 5.54, and Panama at the other with an incredible 164.37.

According to Miles (2009), the use of ICT-related applications for data analysis, management, information and knowledge sharing, as well as decision-support systems, appears to be logical and appropriate to assist in dealing with the issue of climate change. ICTs can be used to facilitate knowledge and information sharing, engagement and decision support, but, the author states, this is feasible only in countries that have affordable, widespread and accessible ICT infrastructure. The ITU (2009) has expressed the same opinion at a symposium on ICT and Climate Change in Quito in July 2009.

Overall, the regional data on ICT penetration presented above are relatively good. Even if the costs of services (internet, mobile telephony) in LAC are much higher than those in OECD countries, they show a steady growth that will continue at the national scale in most countries and should progressively expand to currently underserved rural areas. There is increasing recognition by governments, organisations, enterprises and individuals of the importance of ICTs, internet and mobile telephony, and it can be argued that access does not seem to be a major impediment for their deployment in climate change or other applications. The limitations reside elsewhere.

ICTs and climate change: An analytical framework

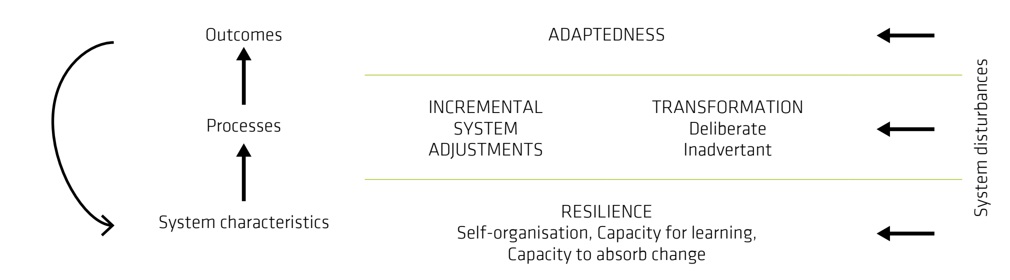
In climate change adaptation, vulnerability is defined as the degree to which a system or unit is likely to experience harm due to exposure to perturbations/disturbances or stress. The concept originated in research communities examining risks and hazards, climate impacts, and resilience. The vulnerability concept emerged from the recognition by these research communities that a focus on perturbations alone (environmental, socioeconomic,

8. The Networked Readiness Index is defined as a measure of the "capacity of countries to fully benefit from new technologies in their competitiveness strategies and their citizens' daily lives" (World Economic Forum and INSEAD, 2011, p. IX).

9. CELA of the IESE Business School at the University of Navarra and the EVERIS Group have created an Information Society Index (ISI) which determines the degree of progress made by Argentina, Brazil, Colombia, Chile, Mexico and Peru. The index has two basic components: (a) information and communications technologies and (b) information society regional environment.

FIGURE 2

Characteristics, processes and outcomes of adaptation actions



Source: Nelson et al. (2007)

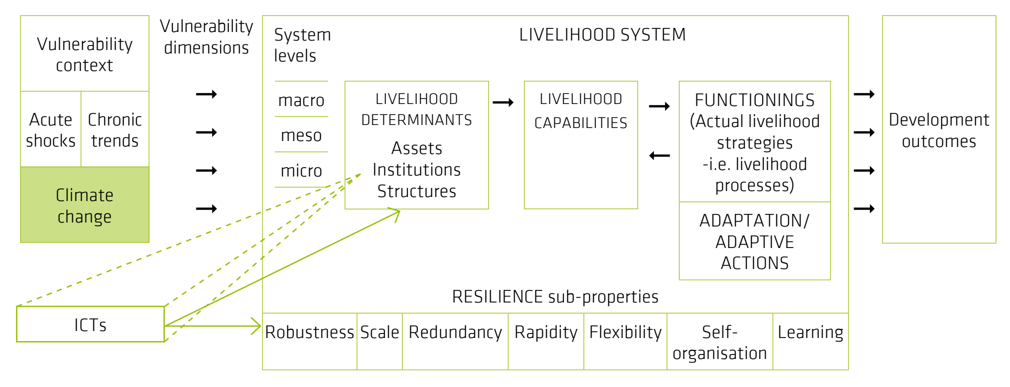
technological) was insufficient for understanding the responses of and impacts on systems (social groups, ecosystems, places) exposed to such perturbations (Liverman, 1990; Nelson et al., 2007). In this context, adaptation and adaptive capacity are used in the sense of ability to adjust.

In turn, and to simplify, resilience means an ability to withstand or a capacity to recover. Resilience is arguably a more complex concept to measure and evaluate in the face of multiple and both slow- and fast-moving stresses happening with climate change at different temporal and spatial scales, and with a high level of uncertainty. Nelson et al. (2007) elaborate on the characteristics, processes and outcomes of adaptation actions (see Figure 2) with a resilience framework that broadens the understanding and the types of analyses necessary to promote successful adaptation to environmental change with incremental systems adjustment. Among other aspects, their study summarises that there is an inherent tension between high adaptedness and system resilience, which results in trade-offs between current efficiency and future vulnerabilities.

In these framework discussions and conceptualisations, ICTs have been mostly absent, invisible or both. It is only very recently that Ospina and Heeks (2010) brought ICT for development (ICT4D) to the climate change adaptation and resilience framework discussion table. They make a solid conceptual contribution to analyse the role and potential of ICT as a sector and system component contributing to resilience and helping to allow adaptation in livelihood strategies. Their "e-Resilience" framework, adopted by our study, is schematised in Figure 3. Its "e" dimension develops ICT's potential contributions to strengthen a set of resilience sub-properties (robustness, scale, redun-

FIGURE 3

e-Resilience framework



Source: Ospina and Heeks, 2010

dancy, rapidity, flexibility, self-organisation and learning) interacting with livelihood determinants (assets, institutions, structures) exposed to vulnerable contexts induced by climate change.

ICT applications and the e-resilience framework

Climate modelling, projections and predictions: Robustness and scale

Science is producing convincing evidence of global warming. Climate change models include Global Circulation Models (GCM) and Integrated Assessment Models (IAM), but both have severe limitations concerning climate predictions. GCMs model the chemistry and physics of the atmosphere in interactions with oceans and land surface; IAMs simulate the interactions between humans and their surroundings to estimate GHG emissions that are in turn made available to the GCM models as inputs that alter atmospheric chemistry. The calibration of GCMs is made by comparing their prediction results with records of past climates. So far, the available past climate data are concentrated around the North Atlantic and East Asia, and errors can be caused by the very sparse coverage of records for the Southern Hemisphere and for the interior of the major continents.[10] Different emission scenarios integrating other future change parameters are tested. The end result is a set of estimates of temperature and precipitation values around the globe, normally at two-degree intervals (about 200 km at the equator) for different run-time periods. They provide an approximation and probably a fair measure of trends, and their prediction accuracy increases when a concordance exists among different models showing a same sign (+ or -) in their localised predictions of temperature or precipitation variations. The computing requirements for running these models are extreme, and only the most advanced computers are used. Most GCMs predict relatively significant precipitation anomalies (both positive and negative) in the tropical regions of Latin America, and smaller anomalies in the extra-tropical region of South America. Despite the high level of uncertainty regarding future precipitation patterns, there are strong indications that climate change could intensify the extreme weather already observed in the region. Because of this, many areas which are continuously exposed to drought and flooding may have to deal with drier conditions and increased precipitation, respectively. Landa et al. (2010) have made a useful compilation of GCM predictions to 2050 for LAC at a continental level (see Figure 4).

GCM models alone do not provide information at a scale that could be used in climate change adaptation. Their resolution is too coarse and they do not take account of physiographical parameters that have a strong influence on local climate (e.g. fronts, orographic features, topography, altitude, etc.). For this, researchers are working on statistical and dynamic spatial downscaling, temporal downscaling or simpler spatial disaggregation methods, with resolution outputs normally at 10-arc minutes (≈20 km at the equator). Some, such as WorldClim,[11] generate data at 30-arc seconds (≈1 km at the equator). However, the time is still far off when downscaled model outputs will be able to provide the degree of reliability that would make them usable in local climate projections of use in agriculture planning. There is a huge challenge particularly for mountain and hillside rain-fed agriculture in Central America and the Andes, where local climates are very complex, and where reliable historical and current meteorological and hydrological data series are rarely available.[12]

> The development of downscaled models is an integral part of a new CGIAR Challenge Programme on Climate Change, Agriculture and Food Security. This programme is led by the International Centre for Tropical Agriculture (CIAT) headquartered in Cali, Colombia, which makes significant research investments in this area in the LAC region. Key partners to CIAT in this undertaking are the International Livestock Research Institute (ILRI) and the International Food Policy Research Institute (IFPRI). The Programme operates the futureclim.info website which provides online access to data in GIS formats for different downscaled models. This opens the door for researchers in different areas to experiment with downscaled climate datasets for their regions of interest.

10. Martin Manning, New Zealand Climate Change Research Institute (personal communication).

11. www.worldclim.org

12. A recent effort addressing some of these aspects is the Iniciativa Regional de Monitoreo Hidrológico de Ecosistemas Andinos (Regional Andean Ecosystems Hydrological Monitoring Initiative) at sites.google.com/site/iniciativaregionalmhea (see also Appendix 1).

FIGURE 4

Main threats and expected impacts until 2050

Source: Landa et al. (2010)

A potentially promising ICT-related contribution (other than computing, GIS mapping and handling of meteorological stations) is the new remote sensing satellite SMOS (Soil Moisture and Ocean Salinity)[13] recently launched by the European Space Agency. This can provide good resolution (100 metre) data from which to extract complementary information on soil moisture and evapotranspiration to increase the reliability of downscaled model projections for their applications in agriculture and for hydrological modelling. All SMOS products will be available free of charge to scientific and non-commercial users. A global image of surface-soil moisture will be provided every three days, with an estimation of the water content in soil down to a depth of one to two metres ("root zone") that is important for improving short- and medium-term meteorological forecasting, hydrological modelling, monitoring photosynthesis and plant growth, and estimating the terrestrial carbon cycle.

Early warning systems: Rapidity, redundancy and self-organisation

Changes regarding extreme weather events are of particular concern in the Caribbean. Between 1950 and 2007, more people in that sub-region were affected by natural disasters such as floods, droughts and tropical cyclones (hurricanes) than anywhere else in the world. In 2008, for example, a tropical storm and three hurricanes cost the lives of 350 people and caused losses estimated at USD 2.8 million. In the past three decades, the Caribbean has recorded direct and indirect losses of the order of USD 700 million and USD 3.3 billion, respectively, owing to disasters caused by natural phenomena. Over the last 36 years, they have cost over 114,000 lives and afflicted some 46 million people, mostly in social groups whose living conditions were already insecure in terms of housing, income, education and other services (ECLAC, 2010). In the Caribbean, in addition to increased exposure to hurricanes and severe weather events, climate change will threaten coastal water supply and sanitation systems due to salt intrusion from the rise of sea water level; the Gulf of Mexico is also exposed to the same threats.

In Central America, devastating tropical storms and hurricanes have seriously affected the development of the sub-region. In 1998, for example, Hurricane Mitch devastated Honduras, Nicaragua and parts of Guatemala and El Salvador. In Honduras, Mitch caused such massive and widespread loss that then President Carlos Flores claimed that 50 years of progress in the country had been reversed. The hurricane destroyed about 70% of crops and an estimated 70% to 80% of transportation infrastructure, including nearly all bridges and secondary roads. Across the country, 33,000 houses were destroyed, an additional 50,000 damaged, some 5,000 people killed and 12,000 injured. Total losses were estimated at USD 3 billion.

In Central America and the Caribbean, with international cooperation assistance, the development of early warning systems (EWS) has flourished as a key to disaster preparedness and mitigation strategies. Among innovations in EWS in the region, the Central American Flash Flood Guidance System (CAFFG) is a fully automated EWS that was developed as a post-Mitch contribution by NOAA in partnership with national Central American meteorological and hydrological centres. CAFFG has been operational since 2004 and covers all the Central American countries (see Appendix 1 for a full description).

Another innovative EWS is the Aburrá Valley Natural Hazard Early Warning System (AVNHEWS). This system is developing "from the ground up" to reduce the impact of flash floods in Medellín and nine other neighbouring municipalities in the Aburrá Valley of the Colombian Andes (see Appendix 1). AVNHEWS has the capacity to expand its thematic coverage, initially centred on flash floods, to a range of other applications such as water pollution.

In the area of EWS related to disaster threats, the "last mile" component for reaching communities at risk is often a major weakness. The time it takes for response agencies to issue on-time warnings to the population (via loudspeakers, radio and/or television when operational) is a limitation that mobile phone applications and social networking systems (e.g. Twitter) could help to address. This is an area of research that could be inspired by mobile phone applications that are being developed in other EWS domains. It must be noted, however, that EWS should never rely on a single communication mechanism, due to the danger of failure that would make the system useless: multiple means of communication are a requirement.

Chile is in the process of implementing an innovation as a consequence of the major earthquake and subsequent tsunami of 27 February 2010 in the southern central region of the country. A project is underway for adapting a system initially developed for the Defence Department of Israel by eViglio and Ericsson. In its original application, the alert system

13. www.esa.int/SPECIALS/smos

Agua-Andes (Water in the Andes) is a web-based policy support system being developed as part of the CGIAR Challenge Programme on Water and Food. It is meant for use by analysts and decision makers to test potential on-site and off-site impacts of land and water management decisions in terms of their ability to sustain environmental services and human well-being. The system covers a series of features in climate and economic change, policy interventions and policy exercises for examining the intended and unintended consequences of particular decisions. Though the remote sensing, database and modeling systems are rather sophisticated, they require very modest local resources and expertise to use.

CentroAgua at the Universidad Mayor de San Simon in Bolivia is leading two related project initiatives in water and climate change aimed at decision-support system applications. SID-AGUA (2009-2012) is establishing a modelling laboratory in coordination with the Polytechnic University of Catalunya, as support for the development of information systems and the use of simulators for water management. The laboratory will integrate and process information on the main Bolivian watersheds and will serve the Ministry of Water and the Environment in the implementation of the Bolivian water legislation. In turn, the Climate Change and Water Management Project aims at a practical application by contributing to the understanding of local manifestations of climate variation and climate change, and their impacts on irrigated agriculture and water management in the Pucara watershed. (See Appendix 1 for more details.)

consisted of the automated sending of SMS text messages to mobile phone users in the eventuality of an approaching missile attack. In Chile, eViglio is part of a consortium (Global Systems Chile, S.A.) that includes local private firms, for adapting the technology to provide an application for the National Emergency Office (ONEMI) to send SMS messages at no cost to mobile phone users located in a geographically defined risk zone. This would be used in case of an approaching tsunami and other natural disasters – volcanic eruptions, flash floods, etc. – giving the potentially affected population enough lead time to react and save their lives.[14] The system will operate using a dedicated radio frequency so as not to be affected by the typical mobile phone congestion occurring in an emergency. Chile intends to expand this application to make use of free digital television signals that will take five years to cover 100% of the national territory (once digital television is legally approved in the country). The use of Twitter is also being explored through an interface with EWS systems for sending alert "tweets" or messages to users.

Given the level of mobile telephony coverage in the LAC region, the expectation of rapid deployment of digital television and the growing popularity of social networking, this kind of application could be expanded to other parts of the region and for different types of EWS.

Rapidity and redundancy (i.e. multiple transmission/communication systems) are key objectives in the use of ICTs in the design and operation of EWS. Less developed but equally important is the contribution that ICTs can make in the self-organisation of EWS, whereby community-level end users can also be protagonists for feeding the systems with on-the-ground observations in real time using mobile technologies. In this area, one of the complications concerns the matching of user-provided observations with instrument measurements before the release of alerts, to avoid "cry wolf" effects.[15]

ICTs in decision-support systems: Robustness and self-organisation

In the changing contexts for agriculture in the LAC region, decision-support systems (DSS) combining modern science and local knowledge from good practices and traditions become critical for both food security and the livelihoods of farmers and their families. Agrometeorological networks can help farmers to plan what and when they will plant. Their use is still modest but growing in LAC, with Brazil leading, having gone from 20 stations in 2002 to some 10,000 today covering all the country's municipalities. Second to Brazil, Chile has about 200 stations, all in the fruit-growing regions and with 80% coverage in those regions. Nevertheless, there is a huge gap in this area, and a real challenge in the context of intra-annual climate variability, for which weather forecasting is of limited use, and local knowledge is losing its traditional references.

14. tecno.americaeconomia.com/noticias/chile-empresa-israeli-se-adjudica-sistema-de-alerta-masiva-celulares

15. Repeated fake alarms that engender mistrust by the population who then do not react when a real danger is happening.

ICT applications can assist with the development of "precision agriculture". That is, the related applications need to respond to changing farming requirements, with an emphasis on the local context, including supporting decisions on specialised irrigation systems, input versus yield analyses, maintaining soil fertility, and the selection of frost- or heat-resistant, humidity-tolerant or pest-resistant crops. Such applications need to be packaged using a language appropriate to the farmer end users and involving good extension services. Together with research to expand the use and reduce the cost of DSS in this area, it would be useful to identify and systematise existing successful local experiences using tailor-made agrometeorological network applications for small and medium-size farming.

Water utility management is another area for DSS research. Data on leakages alone in most cities of LAC are appalling and forecasted increases in water demand will only worsen the situation. Priority should be given to using smart devices, water meters and sensors to assist private and public water utilities in identifying and acting on infrastructure repair requirements. Other areas for ICT integration in DSS research in climate change in LAC cities could be geared to coping with storm water, wastewater treatment, and demand management in general.

Watershed-based integrated water management (IWM) is a generic area of DSS that is the subject of multiple studies and applications in LAC. The Global Water Partnership is an important collaborator with LAC countries in this field. GIS systems are now in use in all the IWM undertakings in Latin America. An issue in this area is often the duplication of projects working in isolation from one another, often all struggling with the same problem of lacking the same data to operate.

ICTs for knowledge management: Learning and sharing

The LAC region has seen an explosion of internet-based platforms and networks for information exchange and knowledge sharing. Climate change topics have often been added to existing network initiatives dealing with environmental issues, natural resources management and other aspects of sustainable development; some are spin-offs from knowledge-sharing platforms and initiatives of the broader ICT4D community.

Among the most used and known in the region, the Asocam platform is specialising in key areas of rural development. Asocam has regional coverage and water and climate change is occupying a major place in the interest of its users with a dedicated web portal[16] (see Appendix 1). Of particular relevance for learning and sharing in the sector, the Asocam portal is documenting a number of case studies and good practices and provides comparative studies and analysis as a basis for online multimedia reports and publications. Its intra-regional, South-South scope and approach have the potential for expansion to other regions, using relevant methodology for organising virtual communities of practice.

Another good example of a learning platform is that of Grupo Chorlaví. Grupo Chorlaví runs learning cycles of 18 to 24 months in duration on key rural development issues. Its eighth edition, initiated at the end of 2009, was on "climate change, use and management of water: the responses of the excluded in Latin America". Selected local projects and experiences on this topic are currently being systematised using a common methodology. The thematic learning cycle includes a study, meetings (face-to-face and e-conferences), newsletters, and a final e-conference to present and debate results before a synthesis report is produced (see Appendix 1). The methodology used by Grupo Chorlaví for social learning and knowledge sharing from grassroots experiences is readily available for adaptation in other regions.

Without being exhaustive, Appendix 1 includes other learning platforms using web-based tools that are of relevance to the area of water and climate change in LAC. In particular, WALIR (Water Law and Indigenous Rights) is an initiative that has made a strong contribution to the sector in the region, but that has unfortunately lost its impetus since 2003. It remains a reference in LAC on issues of water and indigenous rights, and reviving or building from it to incorporate climate change adaptation issues would be an interesting undertaking.

For a category of users, and particularly grassroots organisations and policy makers, there is the common issue of making better use of the information and knowledge in these initiatives via different languages and formats. Too often the information circulating is "technocentric", meaning that it makes use of scientific terminology and jargon without paying enough attention to a

16. www.aguaycambioclimatico.info

non-technical[17] local population and decision makers. Another challenge concerns the lack of participation of local community members in those virtual spaces. Where internet access is not *per se* a major impediment, and where jargon issues are properly taken into account,[18] we typically expect that with good facilitation, stakeholders can engage in an active learning process and build a knowledge base with specific solutions to practical problems. In practice, however, we find that few local actors engage in formal learning processes, which involve basic documentation and analysis of local practice and sharing it with others who are not their day-to-day partners and co-workers.

ICTs in advocacy and awareness raising: Self-organisation and learning

There are three categories in advocacy and awareness raising that we identify as relevant for a discussion on ICTs, water and climate change. First, the advocacy by the secretariats of sub-regional governmental entities for raising the profile of climate change on the agenda of their member states. Second, the vertical articulation of climate change preparedness through levels of government, and the related governance and shared responsibility issues in the context of decentralisation and the role of local governments. And third, civil society movements and coalitions that use ICTs in their campaign strategies for collective action in order to influence public policies. Some of the LAC cases in each category are briefly described in Appendix 1.

A case in the second category which has a particular appeal is the Municipal Water Governance project of the National Network of Rural Peruvian Municipalities (REMURPE). REMURPE operates from a strong central technical secretariat and sub-national chapters across Peru. Together they make extensive use of multimedia and the internet as part of a strategy for the formulation of proposals that the network brings to national-level spheres of decision making – in particular, the Peruvian National Commission on Climate Change. Their example could be replicated broadly given the common governance problems with water administrations that are often centralised in capital cities, but fragmented across institutions.

17. Even fascinating open source software tools such as those developed by Ushahidi (meaning "testimony" in Swahili) require a technical savvy level that is seldom available in poor rural settings (www.ushahidi.com).

18. There are initiatives, such as InfoAndina (see Appendix 1), that have made important accomplishments in the vulgarisation of knowledge and its sharing in formats appropriate to local stakeholders.

3. Towards defining a research agenda

Four critical topics for ICT-related research supporting applications in the field of climate change and water are recommended for Latin America and the Caribbean:

- ICTs in vulnerability mapping
- ICTs in integrated water management research
- ICTs in the "last mile" challenge of early warning systems
- ICTs in social learning and knowledge sharing.

ICTs in vulnerability mapping

Vulnerability mapping at an appropriate scale is a critical step for identifying territories to prioritise in a climate change adaptation agenda. Vulnerability mapping is needed to inform and guide resource allocation decisions of countries and donors. ICTs play a major role in support of this important requirement, given their applications in spatial data capture, analysis, results presentation and dissemination.

The scales at which researchers have currently generated their analysis of threats and exposure to climate change cannot serve at the operational level in a climate change adaptation programme. The analyses also seldom integrate social considerations that play a key role in the capacity of communities to prepare, cope and adapt.

Two key categories of vulnerability variables, socioeconomic and biophysical, must be assessed together, each one using different parameters, and this at an operational scale. From our perspective, a territory can be defined in terms of a watershed extension, a landscape, a space with cultural identity from tangible, intangible or natural patrimony, and where political-administrative boundaries and institutional arrangements co-exist.

Socioeconomic vulnerability can be mapped from national census and household survey data aggregated at the municipal level. Trends at that scale can be measured from inter-census series[19] using average per capita income to proxy economic development, and the Gini index of this indicator to proxy levels of equality and poverty. Hotspots of socioeconomic vulnerability can then be identified at the territorial scale where clusters of vulnerable municipalities are appearing (Cliche, 2011). For approximating a relationship to water in climate change, it could be interesting to use methods for mapping natural resources-dependent (or reliant)[20] communities, for example, by overlaying geo-referenced data on agriculture/water-reliant communities using household survey data on local employment at the municipal level. This method is used for place-based policy recommendations, but to our knowledge it has not been used in climate change adaptation-related research.

Biophysical vulnerability mapping can be approximated by climate model predictions (large scale) and by a careful use of downscaled model projections and, most importantly, records of localised historical extreme climate events. This latter is arguably the best source of information available on vulnerability hotspots, using the premise that territories which have been repeatedly affected by given categories of extreme weather events are likely to continue to be exposed to the same in the future.[21] Such data are readily available from DesInventar[22] and its online Disaster Information Management System covering a majority of LAC countries. Third-party organisations are generating GIS databases from these disaster records. For example, a 2009 Digital Atlas of Populations and Assets Exposed to Natural Threats in the countries of the Andean Community of Nations was developed by the OSSO Corporation, a Colombian NGO, and includes vulnerability maps and geo-referenced data on the extension of flood and drought constructed

19. On this, the Rural Territorial Dynamics programme at RIMISP has produced databases and maps for eleven LAC countries, covering over 10,000 municipalities and close to 400 million inhabitants representing 73% of the total LAC population (www.rimisp.org/dtr).

20. Based on the relative importance of or dependency on a resource sector in a particular community, such as a percentage of employment, typically 30% or more, or employment income from a primary sector.

21. For example, this premise and approach are used by the Economy and Environment Program for Southeast Asia (EEPSEA) in its "Climate Matters" vulnerability map of Southeast Asia published by IDRC in 2009.

22. www.desinventar.net

using DesInventar records.[23] OSSO's and similar vulnerability mapping and databases need to be constantly updated to remain relevant (for example, in several of its regions, the 2010/2011 winter floods in Colombia have had an unprecedented extension). This is difficult when they depend on project funding with a start and end date.

Examples of research questions related to ICT applications in vulnerability mapping could be phrased as followed:

- Where are the most critical locations to focus a research agenda concerned with optimising the outcomes of research in pro-poor climate change adaptation?
- How do you produce a sound spatial analysis of complex climate change vulnerability determinants and present it in scales and convincing formats for use by different stakeholders?
- In what way do ICT tools and methods compensate for the lack of or gaps in data required at an operational scale for adaptation actions?

ICTs in integrated water management research

Except in some exceptional cases, the planning and management of water resources do not take account of climate information. In addition, a lot of the information on water systems in the hands of private enterprises is not disclosed; private transnational water service operators and mining companies simply have no obligation to do so. These impediments mean that planning and management are approached in a reactive way, and this is currently in crisis.

Hydrometeorological systems in the region must be strengthened and public policies should be reviewed to facilitate the generation, implementation and communication of information, and to make mandatory the disclosure by private firms of their water data; to improve the technological human capacity for monitoring and analysis of climate information; and to "support a shift from a culture of attention and reaction to disasters, to a culture of preparation and prevention" (Miralles-Wilhelm, 2010). Along these lines, improving integrated water management research will involve a range of requirements, and when dealing with mid- to long-term objectives in climate change adaptation, they are likely to encounter additional obstacles for the engagement of governments in the process.

Investments in ICT applications could concentrate on investigating ways to compensate for the weaknesses in hydrometeorological data availability using new applications offered by remote sensing (such as SMOS applications) and building capacity in the area. This data can also make a contribution in the development of more reliable downscaled climate models. Additionally, ICT contributions can be beneficial in the area of finding alternatives for the transmission of climate data at a low cost between stations, central analysis centres and users.

Technology needs to be brought within the reach of small and medium-size family farmers, in ways that can reduce input requirements (water in particular) and help to address the challenges of climate variations, with changing seasonal patterns of rain, heat or frost. Finally, there is a need to encourage the use of smart devices, water meters and sensors, to assist private and public water utilities in identifying and acting on infrastructure repair requirements. ICT technology is a component of these challenges, and it would be very useful to identify, systematise and share knowledge on good practices in these under-explored areas.

Examples of research questions related to ICT applications in integrated water management could be phrased as followed:

- What ICT applications could respond to the research impediments caused by the weaknesses in hydrometeorological data availability in LAC?
- How can ICTs be integrated to modernise water monitoring systems so as to make their data more useful?
- How can ICT research serve small and medium-size family farms to help them access agrometeorological services to protect crop efficiency and lower input requirements?
- What norms can be designed and enforced to make water information freely available and to reduce water waste by institutionalising the use of ICT technologies for monitoring purposes?

23. www.osso.org.co/docu/proyectos/corpo/2009/atlas/web

ICT for the "last mile" challenge of EWS

Particularly in the Caribbean and Central America, where early warning systems have been developed in applications such as flash flood preparedness, the "last mile" challenge in the operation of the EWS could be addressed by the use of mobile telephony and SMS messaging for reaching the population at risk. Contributing to the design of EWSs with this feature could make a huge difference. Research into ICT applications would also be helpful for finding the best ways to integrate on-the-ground verified observations taken directly from local community members in EWSs and making use of local knowledge in their design.

Examples of research questions related to ICT applications in EWS could be phrased as followed:

- Can mobile telephony and SMS messaging be adequately incorporated as an add-on to the alert and risk management features of EWSs for fast-approaching disasters?
- What role can ICTs play in enabling bottom-up EWSs, integrating community observations and quality control?
- How can we improve the connection among different types of social communication networks in ICT-supported EWSs?

ICTs for social learning and knowledge sharing

A valuable resource for the region is the existence of networks on climate change and their use of internet portals and platforms for data sharing and communication. International organisations such as the ITU and the OECD are also among the important references on subjects of relevance to ICTs and climate change. There is, however, a gap in the information on local experiences directly related to ICTs and water in the context of climate change, or the information available is partial and not sufficiently documented. There have been attempts to collect case studies, but very limited results have been achieved.

There is a need and an opportunity to identify cases that are "out there", using demonstrated methodologies to assist with the systematisation of local experiences, in order to produce a knowledge base on the subject. From our experience, it would be worth exploring this avenue in a learning process that could serve different stakeholders involved in climate change and water and for whom practical information on ICT applications would make a positive difference in their work.

Examples of research questions related to ICT in social learning and knowledge sharing could be phrased as followed:

- How can we stimulate the documentation and sharing of good practices and innovative experiences in ICT usage in the context of climate change and water?
- What is required to successfully accompany different stakeholders in learning from and using knowledge generated by research in the field?

4. Conclusion

Latin America is currently favourably placed with regard to both land and water availability even though these resources are unevenly distributed. At the same time, it is perhaps the region that is most vulnerable to negative tendencies affecting these resources, since most aspects of its economy are organised in terms of the comparative advantage which these resources offer in energy, agriculture, forestry and mining. We should therefore be very alert to the danger of mutual degradation of land and water.

With the large and continuously growing urbanisation and population increase, water supply in cities will be even more at risk, particularly where ground water is increasingly becoming a decisive source of drinking water while water mining largely exceeds recharge; and in the Andean water systems dependent on glaciers and *páramos*, where their disturbance will have as yet unknown but probably devastating consequences. Feeding the growing population calls for intensive production in agricultural systems. Latin America is an important player in global food security and to continue as such it will require significant research investments to develop agricultural technologies adapted to the changing environmental conditions and for making the best possible use of water and other resources.

Finally, Latin America is home to many subregions exposed to intense and frequent extreme climate events that are likely to increase in number and/or intensity, and this is calling for serious and continuous efforts for robust systems of prevention, preparedness and risk management.

We can argue that ICT applications do not constitute "an emerging field" *per se* for addressing water-related impacts of climate change. They have been used in the sector for some time. This report has outlined examples of ICT uses and applications in water-related climate change issues that can be categorised as: (a) applications for monitoring and responding to extreme climate events and the changing distribution and availability of water resources; (b) applications for capturing, analysing and structuring data in meaningful ways for different audiences in support of decision making; and (c) applications for disseminating information and connecting people, experts and knowledge bases.

ICTs can be a companion to action. While many uncertainties on the impact of climate change in the region remain, these uncertainties should not imply inaction when we convincingly know that Latin America will be affected negatively, and can even pinpoint which sectors will be worst affected. Inaction will succeed only in worsening the conditions of the poor and the marginalised – and we can be certain this will happen if we do not engage our energies in their cause. ■

References

Barlow, M. and Clarke, T. (2004) The Struggle for Latin America's Water, *NACLA Report on the Americas*, July.

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. (eds) (2008) *Climate Change and Water*, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.

Cliche, G. (2011) Cambio Climático y Pobreza Rural en América Latina: Enfoque Territorial en la Agenda para la Adaptación, presentation at the Congreso Internacional Cambio Climático, Retos y Decisiones, Pereira, Colombia, 18-20 May.

De la Torre, A., Fajnzylber, P. and Nash, J. (2009) *Low Carbon, High Growth: Latin American Responses to Climate Change. An overview*, World Bank, Washington, D. C. go.worldbank.org/DHYKDZVRM0.

Echeverri, R. and Sotomayor, O. (2010) *Estrategias de gestión territorial rural en las políticas públicas en Iberoamérica*, Grupo Inter-Agencial de Desarrollo Rural, CEPAL Documento de Proyecto LC/W 376.

ECLAC (2010) *Millennium Development Goals: Advances in environmentally sustainable development in Latin America and the Caribbean*, Economic Commission for Latin America and the Caribbean, United Nations publication LC/G.2428-P.

Fundación Futuro Latinoamericano (2008) Consultation to assess regional priorities, capabilities and research gaps on climate change and poverty reduction in Latin America and the Caribbean, report to IDRC and DFID.

IDB (2011) *Integrated Strategy for Climate Change Adaptation and Mitigation, and Sustainable and Renewable Energy*, Inter-American Development Bank. idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=35987798

IDB Water and Sanitation Initiative (2010) *Drinking Water, Sanitation and the Millennium Development Goals in Latin America and the Caribbean*, Inter-American Development Bank. idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=35468495

International Water Management Institute (2007) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*, Earthscan, London and Colombo. www.iwmi.cgiar.org/assessment

ITU (2009) Background paper, International Telecommunication Union Symposium on ICTs and Climate Change, Quito, Ecuador, 8-10 July. www.itu.int/dms_pub/itu-t/oth/06/0F/T060F00600C0004PDFE.pdf

ITU (2010) *Technology Watch Report: ICT as an Enabler for Smart Water Management*, International Telecommunication Union.

Landa, R., Ávila, B. and Hernández, M. (2010) *Cambio Climático y Desarrollo Sustentable para América Latina y el Caribe: Conocer para Comunicar*, British Council, PNUD Mexico, Cátedra UNESCO-IMTA, FLACSO Mexico.

Liverman, D. (1990) Vulnerability to global environmental change, in Kasperson, R. E. et al. (eds) *Understanding Global Environmental Change: The Contributions of Risk Analysis and Management*, The Earth Transformed Program, Clark University, Worcester, p. 27-44.

Magrin, G., Gay García, C., Cruz Choque, D., Giménez, J. C., Moreno, A. R., Nagy, G. J., Nobre, C. and Villamizar, A. (2007) Latin America, in Parry, M. L. et al. (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, p. 581-615.

Miles, R. L. (2009) An Overview of ICT Applications for Sustainable Development Focusing on Climate Change Preparedness, discussion paper prepared for the United Nations Department of Economic and Social Affairs. unpan1.un.org/intradoc/groups/public/documents/undpadm/unpan037120.pdf

Miralles-Wilhelm, F. (2010) *Challenges and Opportunities in Climate Change Adaptation in the Water Sector: Elements for a Regional Agenda*, Regional Policy Dialog for Latin America, Stockholm.

Nelson, D. R., Adger, N. W. and Brown, K. (2007) Adaptation to Environmental Change: Contributions of a Resilience Framework, *Annual Review of Environment and Resources*, 32, p. 395-419.

Ospina, A. V. and Heeks, R. (2010) *Unveiling the Links between ICTs & Climate Change in Developing Countries: A Scoping Study*, University of Manchester, UK. www.niccd.org/ScopingStudy.pdf

Parry, M. L., Canziani, O. F., Palutikof, J. P. and co-authors (2007) Technical Summary, in Parry, M. L. et al. (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, 23-78.

Pin, J. R., Gallifa, A. M. and Bacerló, D. (2010) Indicador de la Sociedad de la Información, in *Situación de las Tecnologías de la Información en Argentina, Brasil, Chile, Colombia, México y Perú*, IESE-CELA, p. 55-57. www.iese.edu/es/files/ISI_edicion_2010-10_tcm5-60444.pdf

Strzepek, K. and Boehlert, B. (2010) Competition for water for the food system, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365 (1554), p. 2927-2940.

UNESCO and Earthscan (2009) *World Water Development Report 3: Water in a Changing World*.

Wilkinson, J. (2010) *Water and Land in Latin America: Global Strategies and Policies*, Plataforma Democratica - Project on Global Geopolitical Changes and their Impact on Latin American Democracies, Rio de Janeiro.

World Bank (2009) *World Development Report: Reshaping Economic Geography*, World Bank, Washington, D.C.

World Economic Forum and INSEAD (2011) *The Global Information Technology Report 2010-2011*. www3.weforum.org/docs/WEF_GITR_Report_2011.pdf

APPENDIX 1

Selected climate change and water-related ICT initiatives in LAC

1. ICT-based social learning and knowledge sharing in climate change

Asocam is a Latin American platform facilitating initiatives, exchanges and collective actions to promote knowledge management in key areas of rural development. The platform is operated by InterCooperation and supported by the Swiss Development Corporation (SDC). Water and Climate Change is one of its principal specialised areas and a dedicated portal was developed (www.aguaycambioclimatico.info) with a wealth of case studies, publications and other online resources such as a recent (2010) catalogue of publications on water and climate change and risk management (www.asocam.org/biblioteca/ASO_CAT_AGUA_CC.pdf).

IPROGA (Instituto de Promoción para la Gestión del Agua) is a specialised Peruvian organisation with a long tradition of programme activities in water governance, water conflicts prevention, and concerted actions in water-related issues. While its work is concentrated in specific water-stressed regions of Peru, IPROGA also works in alliances with like-minded institutions in other Andean countries, notably in Bolivia and Ecuador. An interesting example is the PA&S Andino programme which, with support from ICCO and GIZ, is aiming at strengthening national processes for improving water management at the inter-Andean level, with a focus on integrated water management and human rights. This programme is carried out with the participation of Bolivian, Ecuadorian and other Peruvian organisations (Agua Sustentable and LIDEMA in Bolivia, CAMAREN and SENDAS in Ecuador, and AGUA-C and COOPERACCIÓN in Peru). The Canadian International Development Agency (CIDA) is also currently financing a project on water conflicts monitoring and prevention at IPROGA.

www.iproga.org.pe

Grupo Chorlaví is an interactive network that aims at stimulating and facilitating decentralised social learning processes geared to enriching the quality and improving the efficiency of the transformative initiatives of Latin American rural societies. Grupo Chorlaví is coordinated by RIMISP and operates a competitive fund used to identify and select local innovative initiatives for their systematisation along a common methodology and on a specific yearly topic. Each round of the Grupo Chorlaví programme is two years in duration. The topical systemisation reports are the basis for a learning cycle that includes coordination workshops, open e-conferences, synthesis and broad dissemination (radio, web and other means, often including e-training in alliance with specialised organisations). In its eighth edition, which started in 2009, the topic concerns Climate Change and Water in Latin America. The related learning cycle is ongoing with local projects and experiences being systematised by the Institute of Political Ecology (IEP), Chile; Women's Support Programme A.C., Mexico; AGRORURAL, Ministry of Agriculture, Peru; Vox Terra, Bolivia; Intermon Oxfam (Ecuador and Peru offices); EkoRural, Ecuador; and the Peruvian Centre for Social Studies (CEPES).

www.grupochorlavi.org

Plataforma Climática Latinoamericana (PCL) (Latin American Platform on Climate) is a space of convergence, dialogue and articulation among diverse stakeholders committed to finding responses to the challenges of climate change. PCL was founded by civil society organisations of South America. It operates through a website and its executive secretariat is at the Fundación Futuro Latinoamericano (FFLA) in Quito, Ecuador.

www.plataformaclimaticalatinoamericana.org and www.intercambioclimatico.com/en

WALIR (Water Law and Indigenous Rights) is a joint initiative of ECLAC and Wageningen University in the Netherlands that was in active operation until 2003 and has accumulated a significant knowledge base, available at: www.eclac.cl/drni/proyectos/walir

Redes de Gestión de Riesgo y Adaptación al Cambio Climático (Climate Change Adaptation and Risk Management Networks) is an initiative funded by DIPECHO (the European Commission's Humanitarian Aid Department). The network was set up to inform about disasters related with climate change and to exchange information and knowledge about adaptation to climate change between different networks.

www.redesdegestionderiesgo.com

InfoAndina is CONDESAN's information and communication platform, with more than 2,000 subscribers, which has been providing updated information regarding sustainable development in the Andean ecoregion since 1993. InfoAndina is a regional knowledge base on issues like water management and climate change, and facilitates dialogue among different stakeholders on these topics through its e-Forum platform. Recently InfoAndina has been exploring different ways, such as micro radio programmes, to share its knowledge base with subscribers.

www.infoandina.org

2. ICT, awareness raising and advocacy

Sub-regional strategies and initiatives in climate change are being designed and developed by relevant secretariats, with the goal of raising the profile of the subject in the national agendas of member states. In LAC, there is the Central American and Dominican Republic Regional Strategy on Climate Change (CCAD-SICA, 2010); the Caribbean Regional Framework for Achieving Development Resilient to Climate Change (CCCCC-CARICOM, 2009); and the Andean Environmental Agenda (Andean Community of Nations, 2007). No equivalent MERCOSUR initiatives have been identified.

Gobernabilidad Municipal del Agua (Municipal Water Governance) is a project of the National Network of Rural Peruvian Municipalities (REMURPE) with support from the German GIZ. One component is the production of a manual to help local governments incorporate an integrated water management approach. In the area of water governance, among others, REMURPE makes use of multimedia and the internet as part of a strategy for the formulation of proposals that the network brings to national-level spheres of decision making, in this case the National Commission on Climate Change.

www.remurpe.org.pe

Digital Resources for Sustainable Economic Development (RED-DES) is a regional programme promoted by Hivos in Central America. Led by Cooperativa Sulá Batsú and Fundación Galileo, it seeks to foster the use of ICTs to change consumption habits and strengthen green entrepreneurship in the region. One of the most important strategies of this programme is the use of ICT campaigns for a citizen awareness and discussion process about climate change, energy efficiency and sustainable energy. The regional coverage includes the following countries: Guatemala, Honduras, El Salvador, Nicaragua and Costa Rica.

www.red-des.org/el-programa

La Red VIDA (Vigilancia Interamericana para la Defensa y Derecho al Agua) (Inter-American Water Defence and Water Rights Surveillance Network) was created in 2003 with 54 member organisations from 16 countries advocating for the defence of water as a public good and a basic human right. It involves associations and organisations of consumers, women, environmentalists, trade unions, human rights activists, and religious, indigenous and social movements. The network is expanding its web presence and operations from: www.laredvida.org

3. Decision-support systems and risk management

AGUA-ANDES (Water in the Andes) Policy Support System is a web-based policy support system combining an extensive spatial database with process-based models for hydrology, crop production and socioeconomic processes. As part of a CGIAR Challenge Programme on Water and Food, it is intended to allow analysts and decision makers to test the potential on-site and off-site impacts of land and water management decisions in terms of their ability to sustain environmental services and human well-being. The system is provided in English and Spanish with a series of defined features for (climate and economic) change, policy interventions and policy exercises for examining the intended and unintended consequences of particular decisions. Though the remote sensing, database and modelling system are rather sophisticated, the system requires very modest local resources and expertise to use.

www.ambiotek.com/website/content/view/17/39

SID-AGUA Project (2009-2012) at the **Andean Centre for Water Management and Use (CentroAgua-Bolivia), Universidad Mayor de San Simon, Cochabamba, Bolivia.** Financed by the Spanish Agency for International Development Cooperation (AECID) in coordination with the Polytechnic University of Catalunya, this project is establishing a modelling laboratory as support for the development of information systems and the use of simulators for water management. The laboratory will integrate and process information on the main Bolivian watersheds; it will serve the Ministry of Water and the Environment in the implementation of the Bolivian water legislation.

Climate Change and Water Management Project (2009-2011) at **CentroAgua-Bolivia**. Within the framework of a joint agreement between the Swedish Agency for International Development and the UMSS, this project is implemented by CentroAgua with the participation of Bolivia's National Meteorological and Hydrological Service (SENAMHI), together with the collaboration of the National Council for Scientific and Technical Research (CONICET) of Argentina. The project aims at contributing to the understanding of local manifestations of climate variation and climate change, and their impacts on irrigated agriculture and water management in the Pucara watershed

www.centro-agua.org

Centro del Agua del Trópico Húmedo para América Latina y El Caribe (CATHALAC) (LAC Water Centre of the Humid Tropics) is an international organisation established in 1992 at the service of the humid tropics of Latin America and the Caribbean. Its objective is to promote sustainable development through applied research and development, education and technology transfer on water resources and the environment. Operated from the City of Knowledge located in Clayton, Panama, the objective of its education programme is to form a community of professionals from multidisciplinary backgrounds who are capable of responding to both the challenges and opportunities related to integrated watershed management, climate change, environmental modelling and analysis, and risk management. CATHALAC offers postgraduate education programmes in these areas, including a Master's programme in climate change delivered jointly with the Ibero-American University Foundation (FUNIBER).

www.cathalac.org/home

Risk management and insurance scheme to promote climate resilience in Bolivia. An insurance scheme has been developed in four provinces in the north and central Altiplano regions of Bolivia that combines incentives for proactive risk reduction and an insurance index mechanism. In this scheme the index is based on the production levels of reference plots of farmland in areas which are geographically similar in terms of temperature, precipitation, humidity and type of soil. A group of farmers identify a peer (or "Yapuchiri" in the local language) who is considered to use the best available methods. That Yapuchiri serves as a reference farmer and technical assistance agent to help other farmers reduce their risks and improve their yields. The system encourages other farmers to match the reference farmer in implementing risk reduction efforts to reduce the effects of drought, excess rains, hailstorms and frost. The reference farmer's land becomes the reference plot, the yields from which serve as an indicator of whether production levels have been adversely affected by environmental factors (triggering an insurance payout) or by other factors within the farmer's control. The objective becomes to perform or outperform the reference plot by improving agricultural practices and reducing risk of damage from weather hazards. The NGO Fundación PROFIN, the Suka Kollus Programme (PROSUKO) and the Union of Altipano Productive Associations (Unión de Asociaciones Productivas del Altiplano - UNAPA) have formed a strategic alliance to create this system within the framework of a project called "Insurance as a financial instrument for agriculture production risk management", a component of the Swiss Development Cooperation (SDC) programme on disaster risk reduction. The insurance system is administered by Fundación PROFIN, with a fund (Fondo de Mitigación del Riesgo Agrícola) created with contributions from UNAPA.

www.fundacion-profin.org/fmra.html

4. Early warning systems and monitoring networks

Central American Flash Flood Guidance System (CAFFG) is based primarily on satellite data. Following the catastrophic flooding of Hurricane Mitch in 1998 in Central America, the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) provided technology transfer, training and technical assistance to the meteorological and hydrological services in the countries hardest hit (Honduras, Nicaragua, El Salvador and Guatemala). It later added Belize, Costa Rica and Panama to implement CAFFG with fully automated real-time operation for data acquisition, ingest, quality control, model processing, output publication, and data management, and flash flood warnings for both regional and small river basins. Operational since August 2004, all products (graphical and text rainfall, soil moisture, flash flood guidance and flash flood threat) are disseminated via the internet from the regional centre at the National Meteorological Institute in Costa Rica, to national meteorological/hydrological centres and response agencies. The flash flood warning system uses the NOAA/NESDIS HydroEstimator for estimating precipitation. Online training courses on CAFFG are available at: www.hrc-lab.org/caffg_training/en/index.html

Aburrá Valley Natural Hazard Early Warning System (AVNHEWS) is a system developing "from the ground up" to reduce the impact of flash floods in Medellín and nine other neighbouring municipalities in the Aburrá Valley of the Colombian Andes. It is being developed from a systems engineering approach with an iterative, mission-driven design and construction process that breaks a complex system into a series of seven simpler subsystems. It is designed to be able to grow thematically and support applications beyond hydrological, flash flood and debris flow forecasting. For example, Red Aire and Red Río could use it to issue public health warnings whenever Medellín experiences an unsafe level of air or water pollution. Debris flow forecasting could be expanded to include other forms of mass movement, including landslides. It is also worth noting that AVNHEWS is open to any type of data that may be available. Observations derived from traffic camera feeds, emergency reports and visual observations could be integrated to improve the situational awareness of AVNHEWS forecasters.

www.redriesgos.gov.co/index.php?option=com_content&view=article&id=35&Itemid=27

Sistema de Información y Alerta Temprana para Ciclones Tropicales (SIAT-CT) (EWS on Tropical Cyclones) is an automated EWS operated by the Mexican National Civil Protection Authorities as a simple, fast and efficient methodology to locate the regions which will possibly suffer the effects of a tropical cyclone or hurricane approaching Mexico. This tool is very useful for the implementation of actions oriented towards protecting the population against this type of storm. The system considers different stages of warning to different areas, depending on the characteristics of the cyclone. It works like a traffic light with an alert time scale that has proved to be very useful in translating the forecasts of scientific and monitoring teams into actions to be taken by the Civil Protection authorities and the population.

huracanesyucatan.com/explicando/siatct

GLORIA is an Andean monitoring network which aims to support a regional monitoring system to assess the impact of climate change on biodiversity in the high Andes. The system is producing information for mitigation and adaptation actions to reduce the vulnerability of ecosystems. With ten monitoring sites all over the Andes and with more in the process of being installed, this initiative articulates more than eight organisations of the Andes, under the technical leadership of CONDESAN and the General Secretary of the Andean Community and with the financial support of the Spanish Agency for International Development Cooperation (AECID).

www.condesan.org/gloria

MHEA (Monitoreo Hidrológico de Ecosistemas Andinos) (Regional Andean Ecosystems Hydrological Monitoring Initiative) is installing several hydrological monitoring stations in different Andean basins to produce information that can help local stakeholders in taking informed decisions regarding water and land management. This initiative is led by CONDESAN, with the technical direction of the University of Cuenca.

sites.google.com/site/iniciativaregionalmhea

04.

ICTs, climate change and water: Issues and research priorities in Africa

Washington O. Ochola Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)
Samuel Ogada-Ochola Department of Environmental Studies and Community Development, Kenyatta University

Africa is arguably the continent most vulnerable to climate change. The water sector is amongst the first to be affected, with water security being an urgent concern, especially regarding domestic and agricultural water supply. ICTs have the potential to address water security, but their application in the sector remains largely in its infancy on the continent. This report outlines challenges posed by climate change in Africa, and existing ICT initiatives that aim to address water vulnerability. It discusses how domestic and agricultural water security can be achieved through ICT-driven integrated water management taking a systems perspective. Based on examples and cases from different parts of the continent, the report points to the role of ICTs in observation, measurement, implementation, networking, communication, prediction, monitoring and evaluation. Existing research gaps in this emerging field are also presented. The report concludes that there is potential for ICTs to narrow the gap between local water resource management priorities and higher scale (organisational, national and regional) goals. There is also evidence that ICTs offer complementary support to integrated approaches to adaptation, including use in monitoring and early warning to ensure water security and equity for vulnerable people and water systems.

1. Impacts of climate change on water security in Africa: The problem and context

According to the United Nations Framework Convention on Climate Change (UNFCCC) (2007), many areas in Africa have climates that are among the most variable in the world on seasonal and decadal time scales. Frequencies of floods and droughts are increasing, with many episodes reported in the same area within months of each other. Reports indicate that one third of African people already live in drought-prone areas and many more are exposed to drought each year (UNEP, 2010; Lobell et al., 2008). A number of factors contribute to and compound the impacts of current climate variability in Africa. The IPCC (2007) projects that these factors will have negative effects on the continent's ability to cope with climate change. These factors include poverty, illiteracy and lack of skills, weak institutions, limited infrastructure, lack of technology and information, low levels of literacy and health care, poor access to resources, low management capabilities and armed conflicts (UNFCCC, 2007).

Water is a critical element in ensuring livelihoods, since more than 40% of Africans live in arid, semi-arid and dry sub-humid areas and about 60% live in rural areas and depend on farming for their livelihoods (UNEP, 2010). In terms of dryness, Africa is second only to Australia. The continent's water resources are unevenly distributed, with central Africa holding nearly half of the total inland water reserves (UNEP, 2006).

Significant changes in runoff fluctuations are predicted for Africa (IPCC, 2007). Many climate models project constrained hydrological cycles for many regions and a decrease in annual mean rainfall. Over the past decade observed trends have reflected extended and more frequent droughts as well as an increase in frequency of floods (UNEP, 2007). The mean annual runoff in the main river basins could decline by as much as 32% by 2050 (IPCC, 2007). Climate change is expected to exacerbate the current stress on water resources from population growth, development and land-use change, including agricultural expansion. The changes in precipitation and temperature already are affecting runoff and water available for different uses, including domestic and agricultural demand.

The projected decreases in runoff by 25% (IPCC, 2007) in many parts of the continent will be largely

TABLE 1

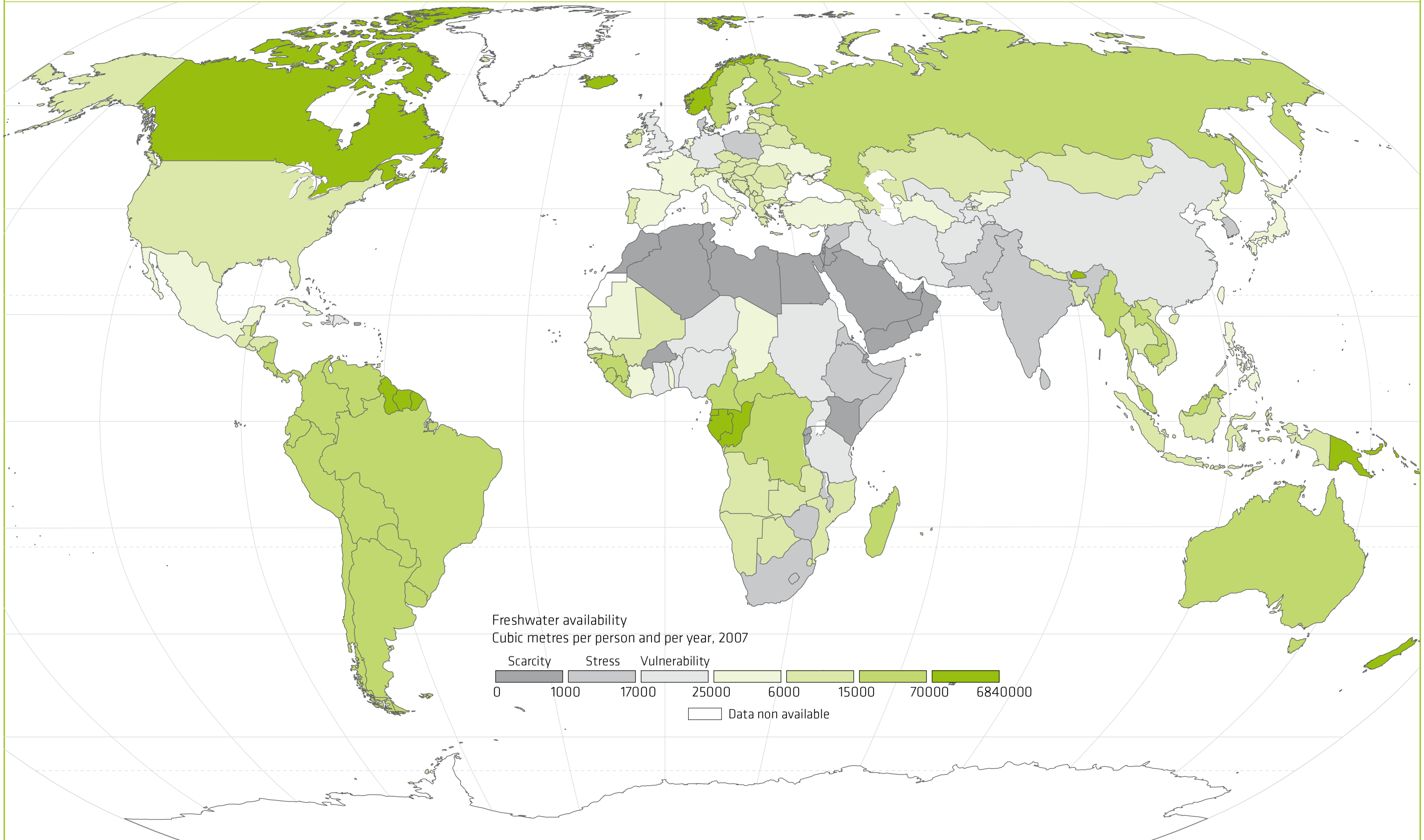
Africa's renewable water resources

Sub-region	Population (millions)	Area (1,000 km²)	Average precipitation		Inland renewable resources	
			mm/yr	km³/yr	km³/yr	Percentage
North Africa	174	9,259	195	161	99	<1
Western Africa	224	6,139	629	3,860	1,059	27
Central Africa	82	5,366	1,251	6,746	1,743	44
Eastern Africa	144	2,758	696	1,919	187	5
Southern Africa	150	6,930	778	5,395	539	14
Western Indian Ocean Islands	19	594	1,518	2,821	345	9
TOTAL	793	30,045	744	22,352	3,949	

Source: UNEP (2006) Africa Environment Outlook 2

FIGURE 1

Global water stress



Source: UN-Water www.un.org/waterforlifedecade/scarcity.html due to decreases in rainfall and higher rates of evapotranspiration. More regions are bound to be drought stricken, adversely impacting on multiple sectors such as agriculture, water supply, energy production and health. Irrigation demands on the continent are also expected to escalate (UNEP, 2006). In Southern Africa, in particular, there is a high likelihood that up to 25% of the population in lowlands will be affected by the projected increase in flood frequency and severity. Even in the coastal regions water resources are constrained due to sea level rise, which exacerbates salinisation of groundwater supplies (IPCC, 2007).

The impact on agriculture and domestic water security

Climate change is said to pose the greatest threat to agriculture and food security in the 21st century, particularly in many of the poor, agriculture-based countries of sub-Saharan Africa, with their low capacity to effectively cope (Lobell et al., 2008; Shah et al., 2008; Nellemann et al., 2009). In Africa both rain-fed and irrigated agriculture are affected by the spatial and temporal variation of precipitation (Schmidhuber and Tubiello, 2007). The short-term variability of rainfall is a major risk factor, while soil moisture deficits, crop damage and crop disease are all driven by rainfall and associated humidity. The variability in rainfall intensity and duration makes the performance of agricultural systems in relation to long-term climate trends very difficult to anticipate even with existing downscaling models. More water-efficient agricultural production technologies are needed to service the continent's food production and water use systems (FAO, 2008).

Domestic water security is crucial for Africa and may be one of the key indicators of the achievement of the Millennium Development Goals (MDGs) towards 2015. For domestic use alone, the amount of water available per person (approximately 4,008 m^3) is below the global average (UNEP, 2010). This amount has been reported to be declining due to climate change and the failure of current adaptation and mitigation measures. Access to quality water is also skewed by socioeconomic and geographical placement of households. This creates challenges of equity across population segments and exacerbates the already greater vulnerability to climate-induced water stress. According to the United Nations Environment Programme (UNEP), few countries are on track to meeting water and sanitation sector targets (UNEP, 2007).

Many governments are attempting to develop reliable water systems for the rural and urban poor. These attempts, however, are beset with falling aquifer levels, declining and unreliable rainfall, an inadequate water resource base and distorted prices, as well as inefficient water provisioning institutions. Although the groundwater system supplies over 75% of Africa's population, it represents only 15% of total renewable water resources on the continent. According to UNEP (2010), only 26 of the 53 countries are on track to realising the MDG water provision target of reducing by half the proportion of the population without sustainable access to drinking water by 2015.

The hydrological effects of climate change as well as constraints on public water supply in especially the arid and semi-arid regions of Africa urgently require priority attention to forestall the already occurring inter-sectoral, inter-institutional and transboundary conflicts. Many river basins, lake basins and watersheds in Africa are stressed by population increase, intensive agriculture and changing hydrological regimes (Bates et al., 2008), making them highly vulnerable to climate change. Appropriate institutional and technological solutions must continue to be designed.

A number of recent studies and reports provide clarity on this. Goulden et al. (2009) have reviewed current knowledge of the potential impacts of climate change on water resources in Africa, presenting critical thresholds, barriers or opportunities for adaptation to climate change. They single out capacity, partnerships, institutional frameworks and research focus as important entry points. Mukheibir (2008) developed a framework for strategy considerations for water resources management in South Africa to meet the development goals in the municipal and agricultural sectors, incorporating stressors, projections and water supply balance. Taken on a continental and annual basis Africa has abundant water resources (Schuol et al., 2009) but many people and large areas suffer from insufficient water supply due to large spatial and temporal variation now worsened by climate change. Nevertheless, the likely impacts of climate change on water resources in Africa are varied (Strzepek and McCluskey, 2007). This is linked to varying infrastructural development and vulnerabilities of social, economic and ecological systems. The variation in impact of climate is also being witnessed in increasing water stress for many countries. Between 75 and 220 million people are expected to face more severe water shortages by 2020 (UNEP, 2010) with the dry and semi-humid regions most affected.

2. ICTs and their adoption in Africa

ICT access is increasing in urban and rural parts of Africa. While this includes mobile phones, PCs and community radio, other water sector-relevant information tools are also becoming increasingly available. These water sector applications include tools for water prospecting, gauging and water withdrawal control, water source mapping, water service provision, water pollution tracking and control, as well as an array of applications in water systems management.

However, crucial barriers prevail in Africa constraining the wider deployment of ICT-based climate change-related solutions to water resource problems. The barriers vary from country to country and even within countries (e.g. between urban and rural areas and also between different ecosystems). They may take the following forms:

- Inability to identify suitable technologies, adapt them for specific local water systems application, and instal and maintain them due to skills, resources and capacity limitations.
- Limited awareness of ICT developments and their potential for sustainable water resource management.
- Limited capital base and access to capital, reducing investment options.
- Prohibitive and uncertain costs of new ICTs and lack of information on commercial viability of big investments such as smart grids and smart water servicing.
- Uncertainty in suitability of ICTs for certain local conditions relating to technology compatibility between areas, institutions, communities, countries and sub-sectors.
- Unfavourable regulatory and political environment, including markets and policies.
- A lack of focused research and organisational coordination on the adaptation and application of ICTs.
- Limited access to electricity.
- Social challenges such as illiteracy and skills shortages.

Despite these limitations, the use of computers, the internet, geographical information systems (GIS), mobile phones, Web 2.0 technologies as well as traditional media such as radio or TV for observation, production, communication, monitoring and linkages to markets and other knowledge networks is critical in the context of sustainable water security. Mobile phones are continuing to shape development in ways that were not anticipated a few years ago, including in the water sector (Heimbuch, 2009; Houghton, 2009). Examples include the Android application of Field Level Operations Watch (FLOW) for data gathering, analysis and reporting, as well as use of mobile phones for water vending.

Moreover, over the last few years a new wave of ICT development has impacted on the continent in the form of modernised infrastructures like broadband fibre optic cables and data centres, added value services and IT innovations. With these developments, prices are falling while demand for equipment, expenditure on ICTs and local content are burgeoning. ICT expenditure was expected to grow by 10% across Africa in 2011, reaching a total of USD 25 billion (IDC, 2011).

Emerging experiences from vulnerable communities in Asia, Africa, Latin America and the Caribbean point to the increasing use of community radio, mobile phones, the internet and other ICTs in climate change responses. They also indicate the value of an e-resilience approach, since this moves beyond shallow surface effects to understanding the way in which ICTs can – but often fail to – have a deeper and systemic effect that will help communities and nations sustain water resources management (Ospina and Heeks, 2010a).

As research at the intersection of ICTs, climate change and development continues to evolve, African and other developing country priorities and perspectives must become a central part of the debate, if the technology is to contribute to more holistic and inclusive responses to the challenges posed by climate change (Ospina and Heeks, 2010b). The Athi Water Services Board in Kenya, for instance, uses ICT systems in designing, installing, operating and maintaining water provision operations and in handling collection, manipulation and distribution of data for both internal and external client engagement. There is scope, however, for improving the system to include intelligent water metering in order to optimise operation and energy, quality control and manage crises. But these technologies can be expensive to deploy on a large scale in water distribution networks. Intelligent water metering should provide additional reliable real-time data at affordable cost to both consumers and water services providers.

In order for ICT applications to be meaningful, data and information about water systems must be fully integrated with the broader socioeconomic and biophysical processes. The rationale is for the ICT tools, platforms and protocols to facilitate the collection, storage, analysis, distribution and utilisation of data via interaction and feedback among various water actors. Such ICT tools may range from simple mobile telephony to the more advanced robust field sensors, telemetric data transmission and satellite-driven remote sensing of hydrological conditions. The scale and complexity depend on geographical coverage and volume of digital data to be moved. Such tools will allow water users and system managers to understand current water systems conditions and make informed forecasts.

Box 1: Environmental Information Circulation and Monitoring System on the Internet

The ITU, in collaboration with UNITAR and the Observatory for the Sahel and the Sahara (OSS), is implementing the Information System on Desertification (ISD)-Environmental Information Circulation and Monitoring System on the Internet (EISI) in Africa. The programme aims at developing information heritage relating to the environment, improving access to and exchange of environmental information, creating synergies and coordinating environmental operators. The first phase, already implemented, has permitted partners to organise sub-regional training seminars and implement pilot projects in seven African countries (Benin, Burkina Faso, Mali, Morocco, Uganda, Senegal, Tunisia) and three regions (West Africa, North Africa and East Africa). The project focuses on extending the field of application of EISI to the whole of the African continent, in order to respond to the numerous requests by African countries and sub-regions wishing to equip themselves with capabilities to build their own ISD-EISI.

ICTs for climate change adaptation: Unpacking the process

The following key steps are critical in ensuring that ICTs facilitate adaptation in the context of climate change:

- *Observation:* At specified scales (regional, national or local), the application of ICTs in observation ensures our understanding of how climate change and variability occur and affect water quantity, quality and processes. ICT applications facilitate data collection through tools and systems, remote sensing techniques and sensor-based networks. Further, the collected data is stored in digital repositories for access and sharing among water and agricultural user institutions to inform adaptation. Examples of ICT application in water systems observation include the Information System on Desertification (ISD) and the Google Water Maps (see Boxes 1 and 2).

- *Analysis and planning*: ICTs enable the analysis of data for use by water and agricultural water use scientists and policy makers. This helps ensure the planning and design of sound adaptation strategies and practices. Applications may include the analysis of climate change scenarios using software-based modelling systems, especially embedding Decision Support Systems (DSS) and based on GIS platforms. Adaptation plans emanating from such systems are capable of integrating what-if analysis for different sectors and by several actors.

- *Implementation and management:* The goal of adaptation for sustainable water management depends on the institutions and stakeholders involved as well as the scale of ICT application. The application of ICTs in supporting the implementation and management of water systems adaptation strategies occurs in, *inter alia*, forecasting, early warning systems and water resource management systems.

- *Training and capacity building:* ICTs are employed in raising awareness, advocacy and training to enhance skills and competencies of water users to anticipate climate change-induced water stress and apply the various adaptation strategies.

- *Collaboration, partnerships and networking:* In the water sector in Africa, as on other continents, ICTs are already playing an important role in producing, storing, analysing, retrieving, sharing and comparing information related to climate change issues that impact on the water sector. This allows cross-community, cross-institutional and multi-country knowledge management and collaboration. The emerging partnerships are crucial in co-management and addressing broader climate change challenges in the region. The increasing use of social networking media and other web-based platforms is a case in point.

- *Monitoring and evaluation*: As a final stage in the classical adaptation process, monitoring and evaluation (M&E) is important in enhancing learning for improved water systems management. The relevance, quality, effectiveness, efficiency, sustainability and overall performance of any climate change adaptation initiative ought to be constantly tracked. This is done against benchmarked indicators and goals set at the planning phase. ICT tools provide a quick and effective way to collect, analyse and store M&E data and communicate the impact of an adaptation strategy. Even more compelling are those ICT tools based on GIS platforms that support geo-referenced monitoring and evaluation of climate change adaptation strategies for water systems. Due to their layer-based nature, GIS platforms allow the inclusion of large geo-referenced information and the related water systems parameters in a coupled management system.

Examples of ICT applications used for water security

The application of ICTs in adaptation, mitigation and disaster risk management as a result of climate change in Africa is driven by some key antecedent factors, notably the growing national and regional political impetus and demand for information for efficient water systems management across scales and institutions. ICT applications are growing in priority among national governments and institutions concerned with water issues in Africa. The African Ministerial Conference on the Environment (AMCEN) and African Ministerial Conference on Water (AMCOW) have put more emphasis on tools for improved awareness and management as well as the positioning of the African Water Facility

Box 2: h2.0 Monitoring Services to Inform and Empower*

To address the weakness of an absence of reliable data for improving the understanding of service provision in the water and sanitation sector, especially for the poor in urban areas, UN-Habitat, with support from Google, has started the h2.0 Monitoring Services to Inform and Empower Initiative, which tests innovations in sector monitoring and seeks to help put in place powerful and effective monitoring systems of the urban environment. The system also provides information for decisive action by water consumers, service providers, policy makers and donors. The initiative aims at effectiveness of investment planning and transparency of decision making in the water and sanitation sector. The system also facilitates collaboration through the evolution of a community for sharing data through an open platform as opposed to the regular data repository in "closed", siloed systems. Building on the ongoing work by UN-Habitat's Monitoring and Research Division and Water, Sanitation and Infrastructure Branch in the Lake Victoria region, the initiative uses tools and approaches developed by Google for geo-referencing. The data is therefore made universally accessible. There is scope for cost-cutting and cost-effective replication of the initiative to regional levels. This would be achieved through building on existing monitoring strategies such as those from Water Point Mapping for surveys like the Urban Inequity Survey (UIS).

h2.0 provides data for measurement of service quality and service access as well as benchmarking data with other initiatives. It is particularly useful for water governance through the development of pilot citizen report cards. In Kenya h2.0 draws on the MajiData initiative, a pro-poor mapping exercise for collecting data on water and sanitation coverage in low-income urban areas, and Human Sensor Webs, a project aimed at assessing mobile communications systems to improve public access to water services information. The h2.0 initiative uses Google's visualisation and data management tools to display information relating to water and sanitation services. The project has designed a beta tool called GRUBS which displays information on urban water and sanitation services in parts of Kenya. Google Earth API, Fusion Tables and Google Charts are deployed together on a single interface. Piloting using mobile telephone-based updating mechanisms is currently underway in Zanzibar.

* For more information see Welle (2010).

FIGURE 2

Major areas of ICT application in water resources management

Mapping of water resources and weather forecasting Remote sensing from satellites In-situ terrestrial sensing systems Geographical information systems Sensor networks and internet	**Asset management for the water distribution network** Buried asset identification and electronic tagging Smart pipes Just in time repairs/Real time risk assessment
Setting up early warning systems and meeting water demand in cities of the future Rain/Storm water harvesting Flood management Managed aquifer recharge Smart metering Process knowledge systems	**Just in time irrigation in agriculture and landscaping** Geographical information system Sensor networks and internet

Source: ITU (2011)

(AWF) of the African Development Bank (AfDB) in supporting such initiatives. An example of such an initiative includes the formulation of Burundi's Integrated Water Resources Management (IWRM) Plan whose objective is to achieve a sustainable water resource management regime contributing to social equity, economic efficiency and environmental sustainability in the country. The project is facilitated by the Global Water Partnership (GWP). Mongi (2007) discusses the use of ICTs for disaster management. Likewise, the interest by institutions and communities around Africa to manage their water resources in the wake of climate change is another driver. ICTs have significant potential in supporting these aims.

Existing literature points to an increasing role of ICTs in climate change-related water systems management. In Africa, such literature stems from global perspectives and theoretical underpinnings with less stemming from field experiences. A lot therefore remains to be studied, implemented, done, documented and analysed, particularly with regard to the role of ICTs in enhancing water security in marginal ecosystems and among vulnerable communities. The ITU-T Technology Watch Report (ITU, 2011) provides an overview of how ICTs can be a strategic enabler for smart water management policies and surveys upcoming standards that will act as a catalyst for successful implementation of smart water management initiatives. The African global environmental change research agenda and science plan (Odada et al., 2008) enumerates exciting questions which would unravel these, more so when integrated with ICT functionality.

Recent studies show a concentration of efforts in application of ICT to solve climate-induced water management challenges in prediction, mitigation, monitoring, and now increasingly, adaptation and national or institutional strategy formulation (Heeks and Ospina, 2009; Houghton, 2009; Maumbe and Okello, 2010; Schuol et al., 2009; SEI, 2009). Ospina and Heeks (2010b) as well as Kalas and Finlay (2009) specifically mention ICT's role in mitigation, monitoring, adaptation and strategy. The overview model by Ospina and Heeks identifies current gaps and emerging topics that further analysis should focus on. These are arguably relevant for Africa where there are ongoing shifts in priorities and perspectives and close linkages between ICTs, climate change and vulnerability of water systems and communities. Institutions, governments and communities are increasingly acknowledging the challenges of ICTs within climate change as it relates to other sectors including water. There is a growing need to foster knowledge sharing and collaboration. There is also a need to ensure that resilience takes centre stage in the analysis of ICTs and climate change. In South Africa, for instance, the Water Research Commission (WRC) has developed an array of computer-driven systems for a variety of water management utilities, including for:

- Asset management for the water services sector
- Benchmarking of leakage for water suppliers

- Leakage management for water suppliers
- Cost and tariff model for rural water supply scheme
- Database on wetland plants with economic potential
- Management and reduction of levels of unaccounted for water
- Object-Oriented Toolkit for improved functionality such as modelling of water distribution systems
- Regional water supply services model for designing, modelling and controlling water treatment processes
- Stochastic analysis software package for water quality management for small communities
- Water supply services model/sanitation services model.

More examples exist in Africa from literature on ICT for development (ICT4D) rather than ICT for climate change adaptation in water. Existing systems also span different aspects of rural well-being with one single ICT tool able to address household and community energy, food security, health and water security. It is therefore difficult to come across an exclusively water resources-related ICT system with climate change adaptation goals. This highlights the need for the development of ICT tools and projects specific to climate change adaptation for domestic and agricultural water systems, which should be informed by research to direct analysis, conceptualisation and policy.

In many parts of Africa, community radio practitioners and community media have been using ICTs, mainly the internet and mobile phones, to confront the effects of climate change in local communities (Boulahya et al., 2005). In southern Madagascar, for instance (BCO, 2010), environmental change is pushing the poor even closer to the margins of survival. A project called Survival Strategies is providing communities in southern Madagascar with a platform to share their experiences, knowledge and coping strategies and to voice their concerns and priorities for the future, ensuring development plans like the Madagascar Action Plan are informed by indigenous people's experience and priorities. The initiative uses video to generate new channels of communication between individuals, groups and communities and the development partners. This is implemented in the context of technology for community development (t4cd, 2006).

Nevertheless, the number of cases of ICT application in African water and climate change initiatives is growing. As suggested, Google continues to innovate and support climate change and environment projects on the continent. Google applications that support such water-related initiatives include Google Earth, which facilitates remote sensing analysis now in use for water systems. Google Data Kit[1] and Google Data Explorer[2] are potential tools for exploring, visualising and communicating the large datasets of water resources.

The GTZ has successfully supported the implementation of a digital monitoring system for water regulation authorities in Zambia, Tanzania and Kenya. Long-term technical support in combination with a strong focus on human and organisational factors has enabled the regulators to own the process and make it sustainable. In Zambia, for instance, after the software developed with GTZ was installed, the regulator NWASCO revealed that coverage rates for water in urban areas had to be revised downwards from 90% to 47% (GTZ, 2009). The GTZ also provides Lake Chad Basin Commission (LCBC) and Commission Internationale du Bassin Congo-Oubangui-Sangha (CICOS) authorities with technical and methodological advice on establishing a sound knowledge management system that improves cooperation in resource management between riparian states.

To effectively implement Ethiopia's IWRM Plan, the African Development Bank supported its Water Information and Knowledge Systems Project (AfDB, 2006). The project aimed to achieve five goals:

- Support the establishment of a National Water Information System
- Strengthen water quality data generation and management
- Reinforce water research and knowledge management
- Support the establishment of a groundwater database
- Upgrade and expand ICT infrastructure capacity.

Other applications include:

- *The Africa Water Atlas:* Produced by UNEP, the Africa Water Atlas is a visual account of Africa's

1. opendatakit.org
2. www.google.com/publicdata/home

endowment and use of water resources. It is presented via ICT-designed maps and satellite images. It captures Africa's water issues and cases. The atlas is written in a policy-interesting fashion since it was commissioned and requested by the African Ministers' Conference on Water (AMCOW). Key in the presentation is a "contrasting story of a continent with adequate renewable water resources, but unequal access because water is either abundant or scarce depending on the season or the place." The initiative has taken advantage of space technology and earth observation science and shows how satellite imagery data can be used in monitoring changes in ecosystems and natural resources including continental and local water systems. Through this, ICT application has provided hard, evidence-based data to support policy making and water systems management at basins and aquifer levels.

- *FLOW (Field Level Operations Watch)*: A smartphone application that incorporates a mobile tool to identify broken pumps. It is an open source Android application used for data gathering and monitoring in water projects by capturing and sending data back to a central hub through integration of GPS tagging and imagery for automatic map generation (using Google Maps' or Google Earth's API). It has been applied in Malawi by UNICEF in a survey of over 54,000 water points.
- *Water Point Mapper:* This is a tool developed by WaterAid[3] for producing maps showing the status of water supply services. It targets water, sanitation and hygiene practitioners as well as local governments working at the district and sub-district levels in sub-Saharan Africa, even in locations with no internet connectivity (see an example application in Ethiopia in MacDonald et al., 2009). It adopts the Household Water Economy Assessment (HWEA) approach (Coulter, 2008). The tool displays district- or village-level water coverage, including system functionality, as well as access levels, financing and planning needs, water quality, and project and programme performance data. The tool is based on a Microsoft Excel spreadsheet and instantly converts water point data into Google Earth-compatible maps for offline access.

3. www.wateraid.org/uk/default.asp

3. Towards defining a research agenda

Research gaps and key research priorities

There is some degree of overlap between the effects of climate change on water systems and poverty linkages with environmental degradation. The latter often causes vulnerabilities which are difficult to distinguish from climate change impacts. It is only after clarifying these antecedent drivers that we are able to specify a role for ICTs. ICTs, for instance, can be used in planning, implementing, monitoring and evaluating cleaner water distribution and use systems that constitute smart water services for mitigation. Ospina and Heeks (2010b) report a range of research topics pertinent to ICTs and climate change, including the role of current and emerging technologies in adaptation, mitigation, disaster management and strategy formulation. An eminent challenge remains to clarify the role climate change plays within the broader socio-economic and environmental context that African domestic and agricultural water supplies operate in. This necessitates a holistic, integrated and systemic treatment of the analysis of ICT perspectives for climate change solutions in water resources. The specific areas of focus must however remain the relationship between ICT and adaptation, water resource sustainability, resilience of communities and water systems in an integrated manner.

Ospina and Heeks (2010b) enumerate six broad emerging research areas in the field of ICTs and climate change:

- Monitoring
  - ICTs, climate change monitoring and local empowerment
- Mitigation
  - ICTs and community-level mitigation
  - ICTs, climate change and global value and supply chains
  - ICTs, climate change and emerging consumer trends
  - ICTs, climate change and emerging business practices
- Disaster management and response
  - ICTs, disaster management and response
- Technologies: Impacts and issues
  - Low-cost and emerging technologies
- Adaptation
  - ICTs, climate change and localisation
  - ICTs and local livelihoods
  - ICTs, local voices and awareness raising
  - ICTs and emerging social aspects of climate change
- Strategy
  - ICTs, climate change and inclusion
  - ICTs, climate change and governance challenges
  - ICTs and climate change decision-making processes.

These are generally broad research themes from which specific topics and research questions can be drawn in the context of water security. For example:

- Research in emerging opportunities for innovation in the development of devices and technologies for water systems management, taking into account relevant platforms for communications and sensor networks, security, efficiency, speed, survivability and reliability of such applications and systems.
- Research in advanced communication networks focusing on how such networks will support ubiquitous wireless coverage in a sensor-rich, sustainable, lightweight infrastructure environment that is a requirement for managing the diverse and geographically distributed water systems.
- Research to simplify the migration from data into knowledge that institutions, communities, governments and individuals can use to improve their decision making and achieve water security.

Research in ICT application in water resource management must also aim at achieving water balance on the continent with respect to domestic, agricultural and industrial water withdrawal. Such studies must consider water saving as a means of security. Innovative technologies and projects that increase efficiency in water (re)use and closing water cycles, including development of online monitoring techniques and robust sensors, should form components of such studies coupled with investigations into ICT application in climate-induced water hazard assessment and water quality tailoring to specific needs for human, industrial and agricultural consumption.

Investment in research and development of open source data collection and use is a significant entry point. This would inform climate-smart and more water-efficient allocation of resources. Examples of specific topics in this regard are:

- Advanced ICT-driven water-saving concepts, technologies, production methods and processes.
- Comprehensive evaluation of the use, value and cost of enabling infrastructure such as ICT platforms (including access, maintenance, upgrades and the necessary skill sets and support systems) at different scales.
- Development of water resource-based climate change models at ecosystem, national and regional levels to refine planning and adaptation strategies for managing domestic and agriculture resources.
- Effective water resource governance systems and strategies to cope effectively with the stresses and impacts of climate change.
- ICTs for better knowledge management on quality of water supplies and water demands.
- ICTs for innovative water reuse methods.
- Indigenous knowledge and how water user groups and communities can best adapt to climate change using traditional knowledge and water management practices.
- Innovative tools and methods to detect, control and repair leakages, reduce waste and account for water supplies.
- Integrated water management tools to reach more equitable distribution and access.
- Models for economically efficient water allocation and distribution.
- Use of ICTs for prospecting and developing new and alternative water sources.

It is apparent that future research should also focus on ICT approaches for the quantification of natural aquifer storage and recovery. The reserves have hitherto not been fully utilised in Africa but remain vulnerable to climate change impacts. The ICT-based approaches could unravel our understanding of the dynamic input-output relationships within the hydrological regimes and along the seasons, followed by ICT platforms for water resources management that take into account, among other factors, the underlying recharge mechanisms, underground storage and turnover time of fresh and brackish water components respectively as communicated by relevant remote sensors or other ICT tools. Advanced ICT tools could also be tried out as means of integrating artificial aquifer recharge depending on geological and hydrological boundary conditions.

Research is also needed in the field of Decision Support Systems (DSS) for the allocation and use/reuse of domestic and agricultural water resources. This is because the complexity of water supply and sanitation poses severe challenges to decision makers at all levels (water utilities, industry, agriculture, municipalities and environmental authorities). Investigations in DSS could include:

- Development of integrated water management models to simulate the complex interactions in water basins and to forecast the impacts of new solutions and climate change.
- Spatial planning of water infrastructure and agricultural water use that incorporates the changing context of African communities and countries (impact of climate change, increasing and more affluent population).
- Supporting transparent and sustainable allocation and use of water resources given the conflicts between sectors, people and organisations that come with climate change-induced water stress.
- Use in the assessment and quantification of the impact of innovative concepts for water services (such as smart water, water footprint, etc.).

Breakthroughs are needed in hardware, software and systems research for climate change-focused water resources development and management. Specifically, research is needed to strengthen the quality and capacity of Africa's computing and communications infrastructure through understanding optimal ICT use. This, in turn, will open up research areas and innovations in the development of new products and services to ensure water security. With careful support for science and technology and innovation, such breakthroughs are possible in Africa in the quest for sustainable environmental growth (Webersik and Wilson, 2009). The effectiveness of these ICT-driven services and products in ensuring access, equity, quality and overall water sector development also forms a rich research niche. In Africa the interface between the ICT sector and the water sector is a fertile setting for innovation, especially when approached from a systems perspective.

4. Conclusion

There is a disconnect between local solutions and higher-level development plans. This may continue to jeopardise adaptation efforts in water systems and the achievement of development outcomes. In broader development contexts in general and water systems in particular, ICTs offer complementary support to integrated approaches to adaptation, including use in monitoring and early warning and other measures to ensure water security for the vulnerable. This report has analysed the existence of positive, valuable linkages between ICTs and the resilience of domestic and agricultural water systems in Africa, with the aim of advancing lessons and research gaps that would ensure quality water access and equity among Africa's peoples and countries.

The report shows that although African water systems are characterised by complex interlinkages between a set of stressors, including socio-political inequalities and public policies, innovative ICT approaches have the potential to promote water security. However, any analysis of the potential of ICTs for water resources management must be accompanied by careful consideration of the underlying socioeconomic factors of vulnerability. ■

References

AfDB (2006) *Support to the Development of Water Information and Knowledge Management Systems in Ethiopia*, African Water Facility, African Development Bank.

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. (eds) (2008) *Climate Change and Water*, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.

BCO (2010) *Madagascar: Survival Strategies, Participatory Video Project*, Building Communication Opportunities (BCO). www.bcoalliance.org/node/460

Boulahya, M., Cerda, M. S., Pratt, M. and Sponberg, K. (2005) Climate, Communications, and Innovative Technologies: Potential Impacts and Sustainability of New Radio and Internet Linkages in Rural African Communities, *Climatic Change*, Vol. 70, p. 299-310.

Coulter, L. (2008) *Long-term Action Research (LARS) on Growth and Water: Household Water Economy Assessment (HWEA)*, RiPPLE Concept Note (unpublished).

FAO (2008) *Water for Agriculture in Africa: Resources and Challenges in the Context of Climate Change*, Ministerial Conference on Water for Agriculture and Energy in Africa: The Challenges of Climate Change, Sirte, Libya, 15-17 December.

Goulden, M., Conway, D. and Persechino, A. (2009) Adaptation to climate change in international river basins in Africa: A review, *Hydrological Sciences Journal*, (54) 5, p. 805-828.

GTZ (2009) *The use of ICT in the Water Sector: Management Information Systems to support regulators and resource management*, Deutsche Gesellschaft fuer Technische Zusammenarbeit (GTZ), Eschborn, Germany.

Heeks, R. and Ospina, A. V. (2009) *ICTs, Climate Change and Development Overview Model*, Nexus for ICTs, Climate Change and Development (NICCD). niccd.wordpress.com/2009/12/14/overviewmodelofictsclimatechange-anddevelopment

Heimbuch, J. (2009) How Cell Phones are Changing the Face of Green Activism, *TreeHugger*, 20 July. www.treehugger.com/clean-technology/how-cell-phones-are-changing-the-face-of-green-activism.html

Houghton, J. (2009) *ICT and the Environment in Developing Countries: Opportunities and Developments*, Centre for Strategic Economic Studies, Victoria University, Australia. www.oecd.org/dataoecd/40/25/43631894.pdf

IDC (2011) *Rising IT sales in sub-Sahara*, International Data Corporation. www.biztechafrica.com/section/computing/article/rising-it-sales-sub-sahara/554

IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability, contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M. L., Canziani, O. F., Palutikof, J. P., Linden, P. J. v. d. and Hanson, C. E. (eds), Cambridge University Press, Cambridge, UK. www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

ITU (2011) *ICT as an Enabler for Smart Water Management*, ITU-T Technology Watch Report, International Telecommunications Union.

Kalas, P. and Finlay, A. (eds) (2009) *Planting the Knowledge Seed: Adapting to climate change using ICTs*, Building Communication Opportunities (BCO) Alliance. www.apc.org/es/system/files/BCO_ClimateChange.pdf

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P. and Naylor, R. L. (2008) Prioritizing Climate Change Adaptation Needs for Food Security in 2030, *Science*, (319) 5863, p. 607-610.

MacDonald, A., Dochartaigh, B. O. and Welle, K. (2009) *Mapping for Water Supply and Sanitation (WSS) in Ethiopia*, RiPPLE Working Paper 11, Addis Ababa. www.rippleethiopia.org/documents/stream/permalink/20100310-working-paper-11

Maumbe, B. M. and Okello, J. (2010) Uses of Information and Communication Technology (ICT) in Agriculture and Rural Development in Sub-Saharan Africa: Experiences from South Africa and Kenya, *International Journal of ICT Research and Development in Africa (IJICTRDA)*, 1 (1), p. 1-22.

Mongi, A. (2007) Using ICT for Effective Disaster Management African Forum: Event Report, Using ICT for Effective Disaster Management African Forum, Commonwealth Telecommunications Organization (CTO), Dar es Salaam, Tanzania, 12-14 November.

Mukheibir, P. (2008) Water resources management strategies for adaptation to climate-induced impacts in South Africa, *Water Resources Management,* 22 (9).

Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A. and Kaltenborn, B. (eds) (2009) *The Environmental Food Crisis: The environment's role in averting future food crises*, UNEP/GRID-Arendal.

Odada, E. O., Scholes, R. J., Noone, K. J., Mbow, C. and Ochola, W. O. (eds) (2008) *A Strategy for Global Environmental Change Research in Africa: Science Plan and Implementation Strategy*, IGBP Secretariat, Stockholm, Sweden.

Ospina, A. V. and Heeks, R. (2010a) *Linking ICTs and Climate Change Adaptation: A Conceptual Framework for eResilience and eAdaptation*, Centre for Development Informatics, Institute for Development Policy and Planning (IDPM), University of Manchester, UK. www.niccd.org/ConceptualPaper.pdf

Ospina, A.V. and Heeks, R. (2010b) *Unveiling the Links between ICTs & Climate Change in Developing Countries: A Scoping Study*, Centre for Development Informatics, Institute for Development Policy and Planning (IDPM), University of Manchester, UK. www.niccd.org/ScopingStudy.pdf

Schmidhuber, J. and Tubiello, F. N. (2007) Global food security under climate change, *Proceedings of the National Academy of Science*, Vol. 104, p. 19703-19708.

Schuol, J., Abbaspour, K. C. and Yang, H. (2009) Modelling freshwater availability in Africa: Projected changes in groundwater recharge, *Groundwater and Climate in Africa: Proceedings of the Kampala Conference, Uganda, 24-28 June 2008*, IAHS Press, Wallingford, p. 88-93

SEI (2009) *Economics of Climate Change in Kenya: COP 15 Report*, Stockholm Environment Institute (SEI).

Shah, M., Fischer, G. and van Velthuizen, H. (2008) *Food Security and Sustainable Agriculture. The Challenges of Climate Change in Sub-Saharan Africa*, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Strzepek, K. and McCluskey, A. (2007) *The Impacts of Climate Change on Regional Water Resources and Agriculture in Africa*, Policy Research Working Paper No. WPS 4290, World Bank, Washington D.C.

t4cd (2006) *Early Warning System Using Radio Broadcast for Southern Madagascar (AKA Project Radio)*. www.t4cd.org/Resources/ICT_Resources/Projects/Pages/ICTProject_306.aspx

UNEP (2006) *Africa Environment Outlook 2: Our Environment, Our Wealth*, United Nations Environment Programme (UNEP), Nairobi, Kenya. www.unep.org/DEWA/Africa/docs/en/AEO2_Our_Environ_Our_Wealth.pdf

UNEP (2007) *Global Environment Outlook 4: Environment for Development*, United Nations Environment Programme (UNEP).

UNEP (2010) *Africa Water Atlas*, Division of Early Warning and Assessment (DEWA), United Nations Environment Programme, Nairobi, Kenya.

UNFCCC (2006) *Technologies for Adaptation to Climate Change,* United Nations Framework Convention on Climate Change, Bonn, Germany.

UNFCCC (2007) *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries,* United Nations Framework Convention on Climate Change, Bonn, Germany.

UN-Water (2010) *UN-Water Climate Change Policy Brief*. www.unwater.org/downloads/unw_ccpol_web.pdf

Webersik, C. and Wilson, C. (2009) Achieving Environmental Sustainability and Growth in Africa: The Role of Science, Technology and Innovation, *Sustainable Development,* 17 (6), p.400-413.

Welle, K. (2010) *Water point mapping in East Africa: Strategic review of Ethiopia, Tanzania, Kenya and Uganda*, WaterAid. www.wateraid.org/.../East%20Africa%20WPM%20final%20for%20web.pdf

05.

ICTs, climate change and water: Issues and research priorities in Asia

Rajib Shaw Graduate School of Global Environmental Studies, Kyoto University, Japan

Rain-fed agriculture is practised in large regions of Asia, and variations in rainfall patterns have important consequences for the yield and quality of agricultural products. However, the impacts of climate change on water resources in Asia will be positive in some areas and negative in others. Challenges to water security largely relate to the management of available water resources, meaning that coherent strategies for integrated water resource management need urgent attention. This report provides an overview of the complexity of the impacts of climate change in a region that is topographically, socioeconomically and culturally diverse. It considers the potential for ICTs to impact positively on water security in Asia, given the different e-readiness levels of countries. It argues that future research into ICTs in the context of climate change and water security needs to focus more on technology application and outreach. To undertake this type of research, several strategies need to be incorporated, which include the need for multi-stakeholder collaboration, attention to the constraints and possibilities of interconnectivity between countries, the need to link modern and traditional approaches, and leveraging the potential of already established networks.

1. Impacts of climate change on water security in Asia: The problem and context

The need to adapt to the effects of climate change has become increasingly evident throughout Asia. The work of the Intergovernmental Panel on Climate Change (IPCC), research institutes, governments and development organisations has also raised awareness of the challenges that climate change poses, particularly for poor developing countries. Some developing countries, such as Vietnam, have started taking specific policy measures, in addition to the United Nations Framework Convention on Climate Change (UNFCCC) negotiations. While this report's key focus is on climate change, water and ICTs, it is important to note and acknowledge the complexity of the problem in Asia, where a number of factors or drivers put pressure on water resources and affect the options and requirements for water management.

Asia is considered one of the fastest developing continents. According to the 2010 UNDP Human Development Report, Asian countries like China, Nepal, Indonesia, Laos and South Korea are among the top ten fastest growing countries (UNDP, 2010). Significant progress in human development was found for most of the nine South Asian countries in the trends analysis: Afghanistan, Bangladesh, India, Iran, Nepal and Pakistan. However, despite the progress in the past three decades, the Asia and Pacific region is still home to two thirds of the world's poor (ADB, 2001). Inequality for women also remains a major barrier to human development throughout the region. The new Gender Inequality Index – which captures gender gaps in reproductive health, empowerment and workforce participation in 138 countries – shows that six countries of East Asia and the Pacific fall in the lower half on gender inequality, with Papua New Guinea among the bottom ten.

Across Asia, the fate of the rural poor is closely tied to the land and water resources that they rely on for food, water and economic security. Cultural practices are also deeply intertwined with water resources. While urban and industrial growth power the region's rapidly growing commercial economy, the rural poor remain dependent on the benefits provided by ecosystems. Land and water resources are the foundation for agriculture, fisheries and aquaculture that provide nutrition and income. These resources also support the production of livestock and forest products that provide food, fuel, fodder and building material crucial for the livelihoods of impoverished families (Tyler and Fajber, 2009).

In the UN World Water Development Report 3 (UNESCO, 2009), integrated water resource management (IWRM) has been re-emphasised as a governance and policy-making tool and approach for the water sector. Population growth is a very important driver, creating demands for more water and producing additional wastewater and pollution. In urban areas, the situation is compounded by the expected continued migration from rural to urban areas, which increases the current level of difficulty in securing and protecting water resources, especially for the urban poor. The strong and sustained economic growth in many developing or middle-income countries with large populations (such as China, India and Indonesia) has itself contributed to increased pressure on water resources.

Rice is Asia's staple food and pivotal to the Asian way of life, culture, customs, traditions and spirituality (Shrivastava, 2009). Some 3.7 billion Asians live on rice. The main meal in the Philippines, Japan, Indonesia, Malaysia, Thailand, Cambodia, China and Korea is rice and fish. In Bangladesh, India, Nepal and Sri Lanka, typical meals include rice, pulses and vegetables with some meat. Rice is also used to produce wine, liqueur and beer. Therefore the impact of climate change on water resources could have strong implications for Asian food and cultural security.

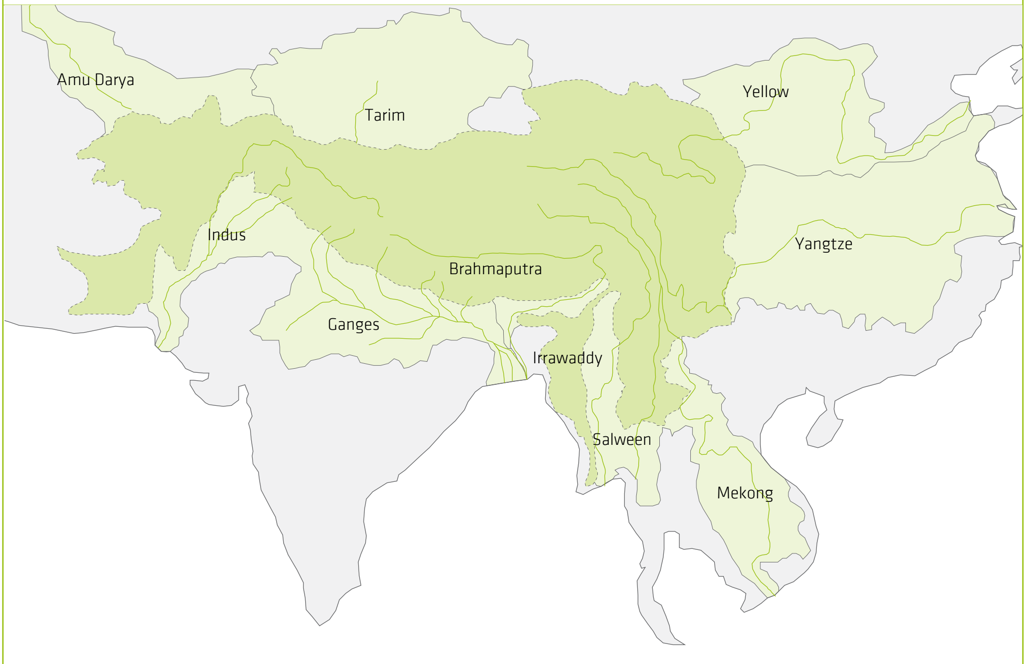
Overview of impacts of climate change on water resources in Asia[1]

The impacts of climate change on water resources in Asia will be positive in some areas and negative in others. Changes in seasonality and amount of water flows from river systems are likely to occur due to climate change. Changes in runoff of river basins could have a significant effect on the power output of hydropower-generating countries like

1. Based on Parry et al. (2007)

FIGURE 1

Major river basins in the Hindu-Kush-Himalayan region, where the impacts of climate change are critical



Source: Asia Foundation (asiafoundation.org)

Tajikistan, which is the third highest producer in the world (Granit, et al., 2010). Likewise, surface water availability from major rivers like the Euphrates and Tigris may also be affected by alteration of river flows. In North China, irrigation from surface and groundwater sources will meet only 70% of the water requirement for agricultural production, due to the effects of climate change and increasing demand (Liu, 2002). The maximum monthly flow of the Mekong is expected to increase by an estimated 35% to 41% in the basin and by 16% to 19% in the delta, with lower values estimated for the years 2010 to 2038 and higher values for the years 2070 to 2099, compared with 1961 to 1990 levels. In contrast, the minimum monthly flows are expected to decline by 17% to 24% in the basin and 26% to 29% in the delta (Hoanh et al., 2003), suggesting that there could be increased flooding risks during the wet season and an increased possibility of water shortage in the dry season. Flooding could increase the habitat of brackish water fisheries but could also seriously affect the aquaculture industry and infrastructure, particularly in heavily populated mega deltas. A decrease in dry season flows may reduce recruitment of some species.

India had become the largest groundwater user in the world by the mid-1980s; by the turn of the century, South Asia alone had more area under groundwater irrigation than all the rest of the world combined (Shah, 2009). In many ways, groundwater overuse has led to a reduced potential of groundwater resources acting as "drought buffers" in areas where groundwater extraction far exceeds the potential annual recharge to aquifers. Overexploitation of groundwater in many countries of Asia has resulted in a drop in its level, leading to impacts on drinking water, agricultural productivity and intrusion of seawater in coastal aquifers. India, China and Bangladesh are especially susceptible to increasing salinity of their groundwater as well as surface water resources, especially along the coast, due to increases in sea level as a direct impact of global warming. A sea level rise of 0.4 to 1.0 metre can induce saltwater intrusion one to three kilometres further inland in the Zhujiang estuary, for instance. Increasing frequency and intensity of droughts in the catchment area are likely to lead to more serious and frequent saltwater intrusion in the estuary and deteriorate surface and groundwater quality.

Floods and drought

A projected increase in surface air temperature in northwest China will result in a 27% decline in glacier area (equivalent to an ice volume of 16,184 km^3),a 10% to 15% decline in frozen soil area, an increase in flood and debris flow, and more severe water shortages. The duration of seasonal snow cover in alpine areas of China, namely the Tibetan Plateau, Xinjiang and Inner Mongolia, will shorten, and snow cover will thaw out in advance of the spring season, leading to a decline in volume and resulting in severe spring droughts. Between 20% and 40% reduction of runoff per capita in Ningxia, Xinjiang and Qinghai provinces is likely by the end of the 21st century (Tao et al., 2005). At the same time, the pressure on water resources due to increasing population and socioeconomic development is likely to grow.

The gross per capita water availability in India will decline from about 1,820 m^3/year in 2001 to as low as about 1,140 m^3/year in 2050 (Gupta and Deshpande, 2004). However, some expect India to reach a state of water stress before 2025. The projected decrease in winter precipitation over the Indian subcontinent would reduce the total seasonal precipitation during December, January and February implying lesser storage and greater water stress during the lean monsoon period. Intense rain occurring over fewer days, which implies increased frequency of floods during the monsoon, will also result in loss of the rainwater as direct runoff, resulting in reduced groundwater recharging potential.

Expansion of areas under severe water stress will be one of the most pressing environmental problems in South and South-East Asia in the foreseeable future as the number of people living under severe water stress is likely to increase substantially in absolute terms. It is estimated that under the full range of SRES scenarios, 120 million to 1.2 billion and 185 to 981 million people will experience increased water stress by the 2020s and the 2050s, respectively. The decline in annual flow of the Red River by 13% to 19% and that of the Mekong River by 16% to 24% by the end of the 21st century will contribute to increasing water stress.

Climate change is resulting in changes in rainfall patterns, and the frequency of sudden downpours of short duration is increasing in recent times. Saturated and impervious soil is exacerbated by seasonal storms and depressions during the rainy season with very high rainfall intensity and long duration. Developed environments like cities generate higher surface runoff in excess of local drainage capacity, causing local floods. Many urban drainage facilities are in bad shape due to lack of cleaning and maintenance. Depending on the local hydrogeological situation, groundwater rising or subsurface flows can cause local floods. They are generally confined to rather small geographical areas and are normally not of long duration. However, in regions of extended rainy seasons (monsoon climate), local floods may last for weeks, resulting in widespread destruction (Mulyasari et al., 2011).

Changing patterns of rainfall also impact on agriculture sectors. A recent case study in certain parts of Bangladesh has shown that farmers have a strong perception of a decrease in rainfall, while the average annual rainfall is found to be increasing (Shaw and Takahashi, 2008). However, this perception relates to rainfall required for agriculture, which due to changes in the precipitation pattern, is often delayed. This uncertainty and change in rainfall patterns are affecting the planning of crops, making the role of ICTs in delivering accurate rainfall information quite important.

The monsoon Asian countries are mostly characterised by floods and typhoons, which result from the interplay between the ocean, atmosphere and land. Many factors affect the strength of monsoons, including sea surface temperatures in the Indian and Pacific Oceans; variations in solar output; land snow cover and soil moisture over the Asian continent; and the position and strength of prevailing winds (Shaw et al., 2011). However, due to changes in climatic conditions, drought is becoming more prominent in the monsoon Asian regions, thereby resulting in depletion of stream and river flow and in the depletion of groundwater reserves.

Sanitation issues in urban areas: Water-borne diseases

In regions where low temperature, low rainfall or lack of vector habitat limit vector-borne disease (including malaria) transmission, climate changes may alter the ecological balance and trigger epidemics. Epidemics can also result from climate-related migration of reservoir hosts or human populations. According to a study in Vietnam (Kien et al., 2010), spatial analysis of influenza showed that northern mountainous provinces and the Central Highland have the highest rates of the disease, while in the South it was not significant. Most of the endemic areas for influenza have a lower mean temperature and higher humidity, while the disease has clear seasonality with the highest rates during the period August to October, or the interchange between summer and winter times. There is also an obvious trend of expansion of influenza from the mountainous and highland provinces to the transition areas at the Red River Delta and the central coast provinces. The study also showed that the inter-annual change of several important infectious diseases in Vietnam, including malaria, dysentery and diarrheal diseases, have a significant statistical correlation with changes in climate parameters (monthly rainfall, temperature) and the ENSO[2] phenomenon.

2. El Niño/La Niña-Southern Oscillation, or ENSO, is a quasiperiodic climate pattern that occurs across the tropical Pacific Ocean roughly every five years. The extremes of this climate pattern's oscillations, El Niño and La Niña, cause extreme weather (such as floods and droughts) in many regions of the world.

2. ICTs and their adoption in Asia

During the past decade, the Asia-Pacific region has experienced tremendous growth in the use of ICTs, including related infrastructure and services. Access to mobile and fixed telephone lines and the internet has expanded rapidly. At the end of 2008, in Asia and the Pacific, there were about 676 million fixed telephone lines, as opposed to 1.3 billion worldwide, and 2.1 billion mobile cellular subscriptions, as opposed to 4.0 billion worldwide. The proportion of mobile cellular subscriptions in Asia and the Pacific increased from about 32.9% of the world total in 2000 to more than 47.0% in 2006 and 51.6% in 2008 (ESCAP, 2009).

Mobile broadband infrastructures are also being increasingly rolled out in Asia and the Pacific. By the end of 2008, there were about 158 million subscriptions to third generation (3G) services in Asia and the Pacific, mostly in high-income economies. China and India, the world's two largest mobile markets, led growth in the Asia-Pacific region. 3G services are also deployed in other developing countries, although with limited coverage. Another emerging technology that may play an important role in both fixed and mobile broadband internet access, especially in providing broadband services for underdeveloped, rural and remote regions, is Worldwide Interoperability for Microwave Access (WiMAX). The Asia-Pacific region is expected to take a leading role in its deployment. However, the technology requires considerable investment in new infrastructure (ITU, 2009).

Despite rapid growth in mobile and broadband networks, the rural-urban digital divide in some developing countries and disparities between subregions remain a major development challenge in Asia and the Pacific. ICT penetration in the region remains relatively low, below the world average. Given the catalytic role that high-speed internet connections play in making the benefits of ICTs available to people, bridging the broadband divide in the Asia-Pacific region remains a major task for national and regional policy makers.

Television and radio broadcasts are the most popular form of mass media for delivering early disaster warning messages to the public and for educating people on building disaster-resilient communities. Television is also the most powerful means for mobilising social resources to support disaster response and rehabilitation efforts. Although most of the population centres in the region are covered by television and radio through cable and satellite transmission systems and local broadcasting networks, many least-developed and low-population areas still remain out of reach of such services. The radio community provides services for disaster preparation and post-disaster communications. Citizens' band (CB) radio is used widely in many countries, particularly in island countries, such as Indonesia, and is also used by many disaster response teams for their internal voice communications.

ICTs and water in Asia

In Central Asia, a diagnostic study on water resources and a concept strategy on rational and efficient use of water have been prepared and submitted for approval by governments. Training workshops have been held in the region on the promotion of public awareness of water resources and a regulatory framework for water conservation, in close collaboration with the International Fund for Saving the Aral Sea and several international and subregional organisations. Advisory services have been provided to Central Asia on legislation on transboundary water agreements. An Asian ministerial roundtable dialogue on water sector challenges, policies and institution development in Asia was held in Bangkok in May 2002. It was organised by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) and the International Water Management Institute, and was sponsored by the Asian Development Bank (ADB); it provided input to the regional preparations for the World Summit on Sustainable Development. An ad hoc expert group meeting on policy options and planning in sustainable development of water resources in Asia was held in Bangkok in November 2002 to review key issues, policies and strategies in the planning and sustainable development of water resources. Several new project initiatives have been taken to improve water services to the poor.

Part of China's water resource management planning that also responds to climate change, the South-to-North Water Diversion Project, is the largest construction project in China's modern history (Chinese Academy of Sciences, 2008). If all goes as planned, this massive construction scheme will be completed by 2050. It is planned to eventually divert 44.8 billion m^3 of water annually to the densely populated and drier north. When finished, the project will link China's four main rivers – the Yangtze, Huaihe, Yellow River and Haihe – and require the construction of three diversion routes, stretching south-to-north across the eastern, central and western parts of the country.

Studies of climate change impacts in the vulnerable North China plain suggest that if successful, the magnitude of the water transfers involved will far exceed potential climate impacts in drought years. Satellite image analysis and climate modelling played an important role in this aspect. In Guangdong province, for the past few years, many investments have been implemented in coastal areas to cope with the water-related hazards.

The application of ICTs is also found in the water sectors in Korea. First, the three-month standardised precipitation index (SPI) data from 59 rain gauge stations over the Korean Peninsula were analysed by deriving and spatially characterising the empirical orthogonal function (EOFs). The shapes of major estimated EOFs were found to reflect the observed spatial pattern of droughts. Second, the coefficient time series of estimated EOFs were then fitted by a multivariate time series model to generate the SPI data for 10,000 years, which were used to derive the annual maxima series of areal average drought severity over the Korean Peninsula. These annual maxima series were then analysed to determine the mean drought severity for given return periods. Four typical spatial patterns of drought severity could also be selected for those return periods considered. This result shows that the southern part of the Korean Peninsula is more vulnerable to drought than the other parts. Finally, the agricultural drought vulnerability was evaluated by considering the potential water supply from dams. In an ideal case, when all the maximum dam storage was assumed to be assigned to agriculture, all river basins in Korea were found to have the potential to overcome a 30-year drought. However, under more realistic conditions considering average dam storage and water allocation priorities, most of the river basins could not overcome a 30-year drought (Kim et al., 2011).

An analysis of water, climate change and ICTs in Vietnam states that annual rice production may be reduced by 2.7 million tons by 2050 due to climate change (Yu et al., 2010). However, proper agronomical practice and investment in rural infrastructure and human capital can mitigate the negative impact of climate change and help farmers adapt.

In Pakistan, ICTs were put to use extensively during responses to the devastating floods in mid-2010. Mobile phones were helpful in the dissemination of early warning messages in the long stretches of the Indus flood plain basin from north to south, encompassing a geographical area of about 13 million hectares. The emergency telecommunications cluster was put in place to enhance the response capacity of the government of Pakistan, the United Nations response team and non-governmental organisations. In order to address the most immediate humanitarian concerns, the World Food Programme (WFP) provided ICT support to United Nations agencies. The IT Emergency Preparedness and Response team of WFP helped the government of Pakistan in evacuation and search and rescue efforts. The Fast Information Technology and Telecommunications Emergency and Support Team (FITTEST) backed up WFP operations effectively. These ICT-enabled efforts allowed the government and the international community to rapidly scale up emergency assistance in the vast geographical area affected by the floods.

At a regional level, the ESCAP secretariat has incorporated the Regional Space Applications Programme (RESAP) in the environment and natural resources development sub-programme of the biennial work programmes. The secretariat established the information, communication and space technology sub-programme in 2002 and the work on space technology applications was transferred accordingly. Major activities recommended in the Strategy and Action Plan were consequently incorporated in the revised medium-term plan, 2002-2005, the revised biennial programme of work, 2002-2003, and the proposed biennial programme of work, 2004-2005. The medium-term plan and the biennial programmes of work were endorsed by the Commission. However, the incorporation of climate change issues came late in the process (ESCAP, 2003).

ICT plays a fundamental role in supporting the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters, which is the main outcome of the World Conference on Disaster Reduction held in Kobe, Japan in January 2005. The Framework is a recognised global guide for facilitating the effective implementation of disaster risk reduction at the international, regional, national and local levels to substantially reduce loss of life and of the social, economic and environmental assets of communities and countries. Governments committed to implementing the Framework allocate necessary resources and set up the appropriate institutional and legislative frameworks to facilitate its implementation.

Case examples of ICT application in the context of climate change and water

Communication for Development (ComDev): A project dealing with livelihood adaptation to climate change in Bangladesh[3]

ComDev combines participatory communication methods and processes with a variety of media and tools ranging from rural radio to more advanced ICTs. In the context of community-based adaptation to climate change, ComDev involves the systematic design and use of participatory communication processes, strategies and media to share knowledge and information among all stakeholders in a particular agro-ecological context. It aims to enhance people's resilience and capacity to cope through diverse livelihood options.

In Bangladesh, the project covers ten pilot sites, four of which are located in the northwestern drought-prone areas and six others in the highly saline coastal areas in the southwestern region. It aims to improve the adaptive capacity to climate change for sustainable livelihoods in the agriculture sector among farmers in drought-prone and saline coastal areas of Bangladesh where water management issues are critical. ComDev is integrated into the Climate/Farmer Field School (C/FFS) designed to train farmers towards more effective adaptation. The ComDev Approach in C/FFS uses a variety of appropriate communication methods and tools (e.g. photo and video cameras, audio recorders, mobile phones and folk media such as folk songs and drama) to enrich learning. It starts from local knowledge, is decentralised but coordinated and guided, enables farmers to make evidence-based decisions, and focuses on collective learning. Among the lessons learned were that planned use of ComDev enhances collective learning; the use and benefits of ICTs can provide new and better learning experiences in a local setting as well as help capture and record local knowledge; farmers are able to engage in critical and analytical thinking leading to more informed decisions because of ComDev integration into C/CFFS; and validation of local adaptation practices by the farmers themselves with the merging of local and scientific knowledge yields long-term adaptation options.

COMMON-Sense Net: Improved water management for resource-poor farmers using sensor networks[4]

In semi-arid regions, the amount of rainfall and its distribution influence most aspects of farming: crop yields, disease and pest incidence, farming operations, level of inputs, etc. Faced with climatic variability, resource-poor farmers are most vulnerable because they lack the resources to adapt to adverse conditions. The Common-Sense Net project implemented in rural Karnataka, India is an integrated sensor network system aimed at improving farming strategies in the face of highly variable conditions, in particular for risk management strategies (e.g. choice of crop varieties, sowing and harvest, prevention of pests and diseases, efficient use of irrigation water, etc.).

In situations of uncertain output, the use of a decision-support system able to give information on the benefits and risks of all the available options will help resource-poor farmers to make an informed choice for the best strategy. It is in this area that a sensor network can help, primarily by making it a tool in the hands of agricultural scientists who work on more sustainable practices and strategies. Simulation models of crops, pests, diseases and farming operations are important tools to answer several of the farmers' information requirements. The environment monitoring data provided over time and space by sensors can be used to validate and calibrate existing models (see Table 1). Finally, it can help to assess the efficiency of simple water conservation measures, such as planting trees or mulching. Secondly, when used directly in the field, sensors can improve farm-level decision making by providing important benchmarks for the impact of moisture deficits, and monitor in real time the field conditions with regard to these benchmarks, providing the farmers with a decision-support system adapted to their needs, and encouraging them

3. Adapted from FAO (2010)

4. Adapted from Panchard (2008) and Panchard et al. (2006)

TABLE 1

Environmental data required for marginal agriculture

Information needs	Specific questions of marginal farmers	Strategy to provide information	Role of sensors
Crop yield prediction	1. Assess appropriateness of crop choices 2. Assess appropriateness of farming operations	1. Use existing scenario-based models 2. Validate these models with local data	Soil moisture measurements to validate groundnut crop model
Pest and disease prevention	Provide forecasts of occurrences during weeding	Determine environmental parameters that have an influence, and their respective values	Gather soil moisture, air temperature and relative humidity data
Water conservation measures	Cost/benefit analysis of using bunds and trees	Compare effectiveness of different measures	Gather soil moisture measurements in different conditions
Deficit irrigation	Increase yield with minimal water use	1. Define critical thresholds in soil water content at different stages in crop growth 2. Issue warnings when water is needed (if possible,indicate amount of water needed)	Gather soil moisture information in each homogenous parcel

to invest in order to get higher profits from their farms. In particular, resource-poor farmers resort to rain-fed farming not out of choice, but out of necessity. Irrigation practices in the semi-arid areas of developing countries are usually inefficient and require large quantities of water. This necessitates drilling wells, which is either too risky or unaffordable for them. A reliable decision-support system is a component of a deficit irrigation system that seeks to maximise the impact of irrigation on crop yields while minimising the intake of water. For poor farmers, this could mean applying new strategies of partial irrigation, such as transporting water from community tanks on carts, or renting rich farmers' wells, among others.

ICT and GIS-derived tools for micro-level drought preparedness[5]

Addakal, located in Mahabubnagar district of Andhra Pradesh state in India, is a low rainfall region whose economy revolves around semi-arid agriculture and livestock. There has been a lack of drought coping and support systems in the locality and thus, to enhance drought preparedness among rural families, the International Crops Research Institute for the Semi-arid Tropics (ICRISAT), with support from the State Government, set up an internet-connected hub in Adakkal using a low-cost connectivity arrangement and supplied a small number of personal computers (PCs) to support local operations. Further, ICRISAT has set up Village Knowledge Centres (VKCs) in eight villages, each with its own set of PCs and internet facilities. The VKCs were a result of a participatory communication appraisal which revealed that macro- and meso-level knowledge-based development organisations had limited reach within the village communities. A realisation was reached that a spectrum of information services needs to be provided, especially market, climate, employment and wage information other than rural production aspects. The ICT-based hub as well as the VKCs are operated by women volunteers from the Adarsha Mahila Samaikhya (Adarsha Women's Welfare Organisation), a federation of all-women microcredit groups in Adakkal. Capacity strengthening support and technical advice are provided by ICRISAT and the Virtual Academy for the Semi-Arid Tropics (VASAT).

VASAT, as the ICT partner, uses a combination of innovative methodologies embedded with ICT-based approaches, including GIS-based techniques to produce micro-level drought vulnerability maps and videoconference trainings on new technologies in agriculture, to foster drought preparedness. Findings on the use of the micro-level drought vulnerability maps in the 2007 season show that the maps have been useful in drought preparedness and the rural families were able to understand their

5. Adapted from Ganapuram et al. (2009)

TABLE 2

HKH Initiative opportunities, challenges and expected outcomes

Challenges	Opportunities	Expected outcomes
Lack of regional river basin approach for integrated flood risk management	Enhanced understanding of the flow regimes in the context of changing climate	Strengthened framework for cooperation on sharing regional flood data and information among participating member countries
Lack of technical and human capacity and resources	Generation of reliable data for integrated water resources management for poverty alleviation and sustainable development	Establishment of a flood observation network in selected river basins in the participating countries
Lack of public participation and awareness	Establishing an end-to-end flood forecasting system and people-centred early warning system to vulnerable communities	Establishment of regional and national flood information systems to share real-time data and information and increase lead time
Gap in improved understanding of the present and expected climate change impacts	Reducing scientific uncertainties through collaborative research and sound scientific basis	Enhanced technical capacity of partners on flood forecasting and communication to the end users
Harmonisation of data, methods and techniques	Sharing of data and information, knowledge and technology	Full-scale regional project planned and agreed among participating countries
Political will and regional cooperation	Using new technology and advanced scientific knowledge for monitoring, assessing, forecasting and communicating information	
	Transboundary collaboration to improve flood management policies and broaden the available options for integrated flood management	

vulnerability with little training. Further, there is evidence that these have helped to make informed decisions in relation to crop cultivation as well as in the cleaning up of local water bodies to facilitate greater water retention. In terms of the videoconferencing facility, information exchanges between experts from ICRISAT and VASAT, especially on cropping patterns and water and soil management, have promoted drought preparedness.

Regional flood information system in the Hindu Kush Himalayan region (HKH-HYCOS)[6]

Water-induced disasters, particularly floods (e.g. riverine floods, flash floods, glacier lake outburst floods and landslide dam burst floods) in the Himalayas are on the rise. The initiative is based on the results of a series of consultative meetings with representatives from Bangladesh, Bhutan, China, India, Nepal and Pakistan held between 2001 and 2005, during which the project was recommended for implementation. The overall objective of the initiative is to minimise loss of lives and livelihoods by reducing flood vulnerability in the Hindu Kush Himalayan (HKH) region with specific reference to the Ganges-Brahmaputra-Meghna and Indus river basins. In addition, its purpose is to provide timely exchange of flood data and information within and among participating countries through an established and agreed platform which is accessible and user friendly. Table 2 presents the initiative's challenges, opportunities and expected outcomes.

The GlobGlacier Project[7]

Since glaciers are among the most reliable indicators of climate change and because they can have a major influence on water availability, knowledge of recent changes and future behaviour is of great interest for climate scientists and governing bod-

6. Adapted from www.icimod.org/?q=264 and Shrestha (2011)

7. Adapted from www.esa.int/esaEO/SEMY4HUJ15G_index_0.html and globglacier.ch/index.html

ies. A key to assess these changes or to model their future evolution is the existence of a detailed glacier inventory. In 2007, the European Space Agency (ESA) started the GlobGlacier Project as a major effort to develop and apply existing methodologies to monitor glaciers and contribute to a global glacier inventory using satellite observations. Kashmir, part of the Indian Himalayas, is one of the selected regions where little information is available on overall glacier extent or changes. GlobGlacier is creating inventory data for more than 1,000 glaciers in this region. The inventory combines information on glacier outlines based on archived satellite data from the Landsat Thematic Mapper (TM) and the Enhanced Thematic Mapper Plus (ETM+) instruments with topographic information from the Shuttle Radar Topography Mission and the Global Digital Elevation Model (GDEM) from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). When a time series of suitable images is available for a certain region, changes in glacier length and extent can be calculated to allow scientists to assess the overall pattern of changes in a larger region for a better determination of climatic change impacts.

ICT for water management in the arid zone: Jal-Chitra[8]

A considerable portion of western India lies in the arid zone, comprising the Great Indian or Thar Desert and the regions surrounding it, which lie in the semi-arid zone. This belt is perennially drought prone and water here is precious. In Rajasthan, India's largest state, there has been an alarming fall in the water table across the board in almost all the districts of the state. Given this scenario and the predicted climate change impacts in the region, ICT, in the form of a piece of software called Jal-Chitra (Water Map/Picture), is utilised to provide an integrated view of all the water sources available to the rural community and allow the community to prepare for future eventualities based on past records. It is aimed at helping villagers to take advantage of information and communication technologies to exercise their right to manage their own water sources. The project is being piloted in two villages in Rajasthan, one near Tilonia in collaboration with the Social Work and Research Centre and in Todgarh with a group of labourers and farmers called the Mazdoor Kissan Shakti Sangathan.

Jal-Chitra works in the Windows environment and consists of Map-Objects, an ActiveX component for GIS support. The software makes it possible to (i) create an interactive water map of the village and thus help villagers to be better equipped to cope with drought, (ii) estimate monthly water demand and create a water budget by allocating available water resources, (iii) keep a record of water quality testing, maintenance work required and maintenance work that has been done, (iv) inform the community about how much of its annual water need is being met from underground water and the approximate amount of recharging that is taking place, and (v) show the amount of the community's need that is being met through rainwater harvesting systems and how it compares with total potentiality of rainwater harvesting in the given village.

Neerjaal[9]

Managing and safeguarding groundwater has become a critical challenge for sustainable development in India. There are reports that Indians are tapping their groundwater faster than nature can replenish it. Of the 5,723 groundwater blocks in the country, more than 1,000 are considered either overexploited (more water is drawn on average than is replenished by rain) or critical. Across Rajasthan state, up to 80% of the groundwater blocks are in danger of running out. The reasons cited for water resource depletion are commercial harvesting of groundwater as well as rising demand for water for irrigation.

Neerjaal is an ICT-enabled water resource management system for grassroots communities. It is about collation of groundwater-related content and information and management of water resources with the available information. The Neerjal software facilitates generating, storing and making public water-related information in a village. Specifically, it facilitates groundwater preservation and sustainable use by (i) allowing the community to keep a record of the amount of water available from each of the water resource bases, (ii) keeping a record of water quality testing as well as informing about the quality of water (if it is potable or not), (iii) recording the maintenance required in groundwater management and listing activity priorities

8. Adapted from www.zlw-ima.rwth-aachen.de/mitarbeiter/dokumente/shaping_information_and communication_technologies.pdf

9. Adapted from www.defindia.net/section_full_story.asp?id=427

in the management process regarding what has to be done, (iv) providing an estimate of the demand and supply of water available for domestic and livestock use, (v) generating a monthly water resource budget based on the monthly records, (vi) providing information to the users about the demand-supply chain of water resources and how much the water demand is met from various water resource bases and (vii) facilitating water resource management and planning through usage of available data. The core objective of Neerjaal is to contribute towards managing scarce water resources across communities in India.

The Digital Yellow River Project[10]

Frequent devastating floods on the Yellow River account for some of the deadliest natural disasters ever recorded in China. For centuries, the Chinese have tried to prevent flooding but the river almost always seems to have its way. As China's population grew, increased settlement on the Loess Plateau began a cycle of deforestation, over-cultivation, soil erosion and increased silt runoff that has accelerated flooding and land use problems in the Yellow River basin. In 2002, the Chinese government began implementation of the Digital Yellow River Project to address the ongoing challenges of the Yellow River including flood threats, water distribution, water pollution and soil erosion. To study the natural phenomena occurring in the river, the project collects data via remote sensing and GPS verification. Data storage and processing, mathematical modelling and support for scientific decision making are other components of the system. Powered with ArcGIS technology, Digital Yellow River is focused on forecasting rainfall and monitoring rising water levels and sources of pollution while seeking new strategies for flood prevention. These efforts will help realise the project's goals of promoting economic stability in the region, securing an efficient management plan for the physical river and advancing a fundamental change in the traditional concepts and approaches to controlling the Yellow River.

Mobile phones for improved flood warnings[11]

The 2008 flood season in the Lower Mekong Basin saw rivers reach their highest levels since 1966 between the Chinese border and Vientiane, Laos and Nong Khai, Thailand. Extensive flooding occurred in Laos and Thailand, mainly in rural agricultural areas but also within urban areas. Parts of the city centre of Luang Prabang were flooded as well as areas on the outskirts of Vientiane and Nong Khai. More than USD 135 million worth of damage was caused, with Thailand and Laos bearing the brunt of this loss. Following this disaster, Lao villagers are being provided with mobile phones and trained to use them to report the likelihood of localised flooding to the Department of Meteorology and Hydrology – the national agency responsible for flood forecasting – to increase the detail and accuracy of flood forecasting. The information is entered into a computer and a flood forecast is fed back to villagers. The villagers then publicise the information on billboards at central locations in the flood plains, and advertise any imminent flood threat via loudspeakers. The information gathered by observers can also be used by the Department of Meteorology and Hydrology to develop maps and other computer simulation models for predicting when flash floods will be most likely to occur in remote areas, how people can adapt to these floods, and how they can better plan land use. Furthermore, the village-based flood monitoring on the flood plains will complement and contribute to the regional flood forecast that the Mekong River Commission (MRC) produces daily in the wet season, based on information collected at stations on the mainstream of the Mekong. Flood plains villagers in the trial districts will now get up to two days notice of any impending floods, enabling local populations to prepare themselves for severe flooding and evacuation, as well as take measures to protect cattle and other livestock. The broader picture that develops over the long term of flood patterns in specific areas will help villagers design better irrigation systems as well as plan what types of crops they should plant.

This MRC-supported scheme is part of a regional trial to increase the level of involvement in the flood forecasting process for communities living on vulnerable flood plains and to boost the capacity of

10. Adapted from www.esri.com/news/arcnews/spring10articles/the-digital-yellow.html

11. Adapted from www.mrcmekong.org/news-and-events/news/laos-villagers-provided-with-cell-phones-to-help-improve-accuracy-of-flood-warnings

national flood forecasting agencies. In dealing with these challenges, the MRC looks across all sectors including sustaining fisheries, identifying opportunities for agriculture, maintaining the freedom of navigation, flood management and preserving important ecosystems. Superimposed on these are the future effects of more extreme floods, prolonged drought and sea level rise associated with climate change.

Early warning mechanism: Mobile phone alerts in disaster-prone Bangladesh[12]

Bangladesh is highly vulnerable to natural disasters including cyclones, storm surges, droughts, floods and earthquakes. To mitigate the impacts caused by natural disasters, primarily floods, an initiative to improve capacity for forecasting floods through early mobile phone and flag alerts is being tried in Bangladesh. This initiative has piloted a community-based mobile phone early warning system in five Union Parishads (the smallest institution of local government) on the major river banks of Bangladesh. The early warning system is triggered whenever there is a regional flood warning. After the regional warning, the government immediately produces flood forecasts for the major rivers in Bangladesh and sends alerts through emails and websites to the national disaster management committees, government and non-government organisations and development partners. Next, the flood forecast is converted into + and – symbols (one + referring to an increase of around ten inches of water level and vice versa). The information is relayed via text message to the Union Disaster Management Committee members, volunteers and communities in the five pilot areas, who are trained in reading these symbols. Once the volunteers receive the flood forecast, they raise flags and update bulletin boards in their areas to caution the local people.

There are a total of 1,411 households in the five pilot areas that receive early mobile phone and flag alerts on a daily basis during the usual flood season in Bangladesh, from the beginning of May to the end of October. Since the launch of the mobile phone early warning system, disaster-related fatalities and losses of private and public assets have decreased significantly in the five pilot areas. The 2008 post-flood survey in these flood-affected areas showed that through early warnings, local people were able to save $1,499,893 in livestock, capital savings, agriculture and fisheries as compared to past experiences. This initiative ensures that disaster-prone communities receive alerts of possible flooding and/or cyclones in advance, enabling them to evacuate their homes and seek shelter in assigned locations, preventing the devastating effects of natural disasters.

12. Adapted from www.trust.org/alertnet/news/disaster-prone-bangladesh-trials-early-warning-cell-phone-alerts

3. Towards defining a research agenda

While each example of ICT use is very specific to the local context, by analysing the key messages emerging from the cases outlined above, it can be concluded that the following five areas are likely to improve the use of ICTs in water management in the Asian region, and therefore should inform any research agenda going forward.

Using the climate resilience framework

Kyoto University has developed a Climate and Disaster Resilience Index (CDRI) with five dimensions: physical, natural, institutional, social and economic (Shaw and Sharma, 2011). The five dimensions are related to 25 parameters and 125 variables. This framework can be used to understand climate change impacts on the water sector, since water issues in Asia are related to the five abovementioned dimensions of resilience. Specific parameters and variables need to be defined to determine the resilience of climate change and water sectors and linked to ICT issues. Habiba et al. (2011) describe an innovative approach in understanding climate change and water issues in terms of drought. With regard to drought resilience, the socioeconomic, institutional and physical (SIP) aspects approach was developed to determine different SIP aspects of a targeted area and provide an overview of the drought resilience of that area. The initiative therefore helps to find out the strength and weakness of different socioeconomic, institutional and physical dimensions for drought resilience. Because of this, the government and different organisations can prioritise the sector for policy considerations, can provide inputs for policy formulation, and can help to minimise the drought risk.

Multi-stakeholder cooperation in setting the research agenda

Any future research agenda needs to emphasise that partnerships are essential between all stakeholders. Often governments, NGOs and businesses accentuate what divides them rather than recognise their shared values. At the same time, research conducted in universities and other isolated forums often does not reach the intended beneficiaries. A governance framework based on the Governance Education and Technology (GET) framework offers a potential model for identifying a future research agenda (Shaw, 2010).

Interconnectivity

While a number of technologically advanced countries in the region have established extensive capacities in operating and applying tools such as earth observation satellites for disaster risk reduction and management, most developing countries have limited applications and operational service capacities. Regional cooperation should focus on developing and providing appropriate products and services that suit these limited capacities. For example, in Asia and the Pacific, regional cooperation efforts on capacity building in space applications, promoted by the ESCAP Regional Space Applications Programme for Sustainable Development, have progressed beyond the primary stage, which focused on human resources development. China is developing an eight-satellite constellation dedicated to disaster and environmental monitoring. This satellite system will be used for global data gathering and sharing, and can be used for international cooperation purposes. It comprises four optical and four synthetic aperture radar (SAR) satellites to ensure a maximum 12-hour revisiting interval during emergencies. Of this constellation, two optical satellites have been in operation and a SAR satellite will be launched soon. Any future research agenda needs to articulate the technological differences between countries, so that the capacity-building and technological limitations and possibilities can be properly understood.

Linking modern and traditional approaches

A future research agenda needs to consider the interface between traditional skills and knowledge, and the potential of ICTs to deliver timely and accurate information. There are a number of ways in which these two elements can interact. The Indian Space Research Organization (ISRO), in conjunction with the MS Swaminathan Research Foundation (MSRRF), has formulated a programme to integrate indigenous knowledge with ICTs to cope with the water-related hazards in coastal areas (Srivastava, 2008). The key problem faced in these areas was the impact of cyclones on fishermen, with no early warning system in place. Tata Teleservices used the wireless platform Binary Runtime Environment for Wireless (developed by Qualcomm) to produce smart mobile phones which were given to the local fishermen. The fishermen could then prepare for the impacts of cyclones drawing both on their indigenous knowledge and modern ICT applications.

In a study on south-central Ninh Thuan province of Vietnam, Nguyen and Shaw (2010) explained the role of ICTs in drought early warning and forecasting. Local people can observe and predict weather using traditional means and knowledge and report their observations to a forecasting centre. Therefore, in any research agenda, local skills and knowledge should be leveraged in developing drought forecasting models. This local knowledge can be linked to forecasting centres using ICTs. In another example from Gujarat, western India, Shaw et al. (2005) described the collaboration of local government, the UNDP and a local NGO to establish knowledge centres and equip them with different ICT tools and facilities. One of the key tasks of these SETU centres ("setu" means "bridge" or "link" in a local language) was to develop drought management strategies using GIS, but also by leveraging community knowledge. These resource centres were staffed by local NGO coordinators. A key lesson from the initiative was that ICTs in themselves are made more effective at the local level if coordinators facilitate their interaction with local communities.

Drawing on established networks

Already existing networks should be leveraged in establishing any future research agenda. Some potential networks to draw on in the Asia-Pacific region include the Asian University Network of Environment and Disaster Risk Management (AUEDM),[13] a network of 24 Asian universities from 17 countries, led by Kyoto University. The purpose of the network is to support capacity building to meet increasing demand for young professionals in the field of environment and disaster management; to share experiences and learn from one another's experiences; and to establish a platform to initiate collective learning. Similarly, the Asian Disaster Reduction and Response Network (ADRRN)[14] is made up by 36 national NGOs from 16 countries across the Asia-Pacific region. With a strong footprint in the region, the network members are constantly engaged with local communities, strengthening their ability to combat disasters; provide humanitarian aid like food, water, shelter and health care; and protect critical facilities like schools and hospitals. The network also works to create awareness, advocate for policy changes and improve the capacity of community-based organisations. Finally, CITYNET[15] is a network committed to helping local authorities and partners improve the lives of citizens and create urban sustainability across Asia-Pacific and beyond.

13. www.auedm.net

14. www.adrrn.net

15. www.citynet-ap.org

4. Conclusion

A recent Johannesburg workshop on ICTs, climate change and water, organised by the IDRC and APC (7-10 July 2011), was instrumental in brainstorming the possible future ICT research agenda in Asia in the water sector. One of the key focuses of the discussion was an appropriate risk communication strategy to enhance action at the community level. Risk information related to water and climate-related hazards is generated by researchers, but often not conveyed properly to the local community. Local knowledge is also not included in the process of delivering risk information. Therefore, a strong relationship between professionals, practitioners and local communities is highly desirable.

Similarly, while new innovation is important, application and implementation of existing information and research outputs are equally important. To improve the implementation process, it is important to focus on the existing civil society, university and local government networks in order to create mutually supportive learning networks in an emerging field. ■

References

ADB (2001) *Moving the Poverty Reduction Agenda Ahead in Asia and the Pacific: Long-term strategic framework of the Asian Development Bank (2001-2015)*, Asian Development Bank, Manila.

Chinese Academy of Sciences (2008) *Climate change in Asia: Knowledge gaps and research issues in China*, final report to IDRC and DFID, Format Printing Press, Kathmandu.

ESCAP (2003) Progress in the implementation of resolution relating to the theme of managing globalization, Economic and Social Commission for Asia and the Pacific 59th Session, Bangkok, Thailand, 24-30 April.

ESCAP (2009) *Statistical Yearbook for Asia and the Pacific 2009*, United Nations Economic and Cultural Commission for Asia and the Pacific, Bangkok, Thailand.

FAO (2010) Advancing Adaptation Through Communication for Development, proceedings of the technical session on communication, Third International Workshop on Community-Based Adaptation to Climate Change, Dhaka, Bangladesh, 18-24 February 2009. www.fao.org/docrep/012/i1553e/i1553e00.pdf

Ganapuram, S., Nagarajan, R., Kumar, V. R., Lavanya, N., Sylvester, G. and Balaji, V. (2009) *Disaster preparedness using IT tools: Case studies on the use of ICT and GIS derived tools for micro-level drought preparedness*, ICRISAT, Hyderabad, India. vasat.icrisat.org/images/New%20Folder/Disaster%20Preparedness%20using%20IT%20tools%20FINAL.pdf

Granit, J., Jagerskog, A., Lofgren, R., Bullock, A., de Gooijer, G., Pettigrew, S. and Lindstrom, A. (2010) *Regional Water Intelligence Report: Central Asia*, Stockholm International Water Institute, Stockholm, Sweden. www.watergovernance.org/documents/WGF/Reports/Paper-15_RWIR_Aral_Sea.pdf

Gupta S. K. and Deshpande R. D. (2004) Water for India in 2050: First-order assessment of available options, *Current Science* 86 (9), p. 1216-1224.

Habiba, U., Shaw, R. and Takeuchi, Y. (2011) Drought risk reduction through a socio-economic, institutional and physical approach in northwestern region of Bangladesh, *Environmental Hazards*, 10 (2), p. 121-138.

Hoanh C. T., Guttman, H., Droogers, P. and Aerts, J. (2003) *Water, Climate, Food and Environment in the Mekong basin in southeast Asia*, contribution to the ADAPT project, Institute of Environmental Studies, Amsterdam.

ITU (2009) *Information Society Statistical Profiles 2009: Asia and the Pacific*, ITU Telecommunication Development Sector. www.itu.int/ITUD/ict/material/ISSP09-AP_final.pdf

Kien, T., Hanh, T., Cuong, H. and Shaw, R. (2010) Identifying linkages between rates and distributions of malaria, water-borne diseases and influenza with climate variability and climate change in Vietnam, in Shaw, R., Pulhin, J. and Pereira, J. (eds) *Climate Change Adaptation and Disaster Risk Reduction: Issues and challenges*, Emerald Group Publishing, UK, p. 417-449.

Kim, D. H., Yoo, C. and Kim, T. W. (2011) Application of spatial EOF and multivariate time series model for evaluating agricultural drought vulnerability in Korea, *Advances in Water Resources*, 34 (3), p. 340–350.

Liu, C. Z. (2002) Suggestion on water resources in China corresponding with global climate change, *China Water Resources*, 2, p. 36-37.

Mulyasari, F., Shaw, R. and Takeuchi, Y. (2011) Urban flood risk communication for cities, in Shaw, R. and Sharma, A. (eds) *Climate and Disaster Resilience in Cities*, Emerald Group Publishing, UK. pp 225-260.

Nguyen, H. and Shaw, R. (2010) *Compilation on Asian Monsoon Drought*, GAR 11 Report, UN ISDR.

Panchard, J. (2008) Wireless sensor networks for marginal farming in India, PhD thesis, École Polytechnique Federale Lausanne, Switzerland.

Panchard, J., Rao, S., Prabhakar, T. V., Jamadagni, H. S. and Hubaux, J. P. (2006) COMMON-Sense Net: Improved water management for resource-poor farmers via sensor networks, paper presented at the International Conference on Information and Communication Technologies and Development, Berkeley, California, 25-26 May. commonsense.epfl.ch/COMMONSense/requirements.html

Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E. (eds) (2007) *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK.

Shah, T. (2009) *Taming the Anarchy: Groundwater Governance in South Asia*, Resources for the Future, Washington D. C. and International Water Management Institute, Colombo.

Shaw, R. (2010) Climate change adaptation research in South Asia, *Asian Journal of Environment and Disaster Management*, 2 (4), p. 397-426.

Shaw, R. and Nguyen, H. (eds) (2011) *Droughts in Asian Monsoon Region*, Emerald Group Publishing, UK.

Shaw, R., Prabhakar, S. and Fujieda, A. (2005) *Community Level Climate Change Adaptation and Policy Issues*, Kyoto University.

Shaw, R. and Sharma, A. (2011) *Climate and Disaster Resilience in Cities*, Emerald Group Publishing, UK.

Shaw, R. and Takahashi, F. (2008) *Farmer's perception on climate change adaptation in Bangladesh*, Kyoto University.

Shrestha, M. S. (2011) Experiences and challenges in transboundary flood risk reduction in the HKH region, paper presented at the Workshop on Developing Capacity for Resilience to Water-Related Disasters in Pakistan through Space Applications and Flood Risk Management, Islamabad, Pakistan, 1-4 March. www.unescap.org/idd/events/2011-Pakistan-Flood-Islamabad/18-Mandera-Shrestha-Flood-Reduction-Hindu-Kush-Himalayan.pdf

Shrivastava, A. (2009) Asia's rice culture threatened, *Global Research*, 20 November. www.globalresearch.ca/index.php?context=va&aid=16199

Srivastava, S. (2008) *Adding value to IK through DRR*, IK Policy Forum, Delhi, India.

Tao, F. L., Yokozawa, M., Hayashi, Y. and, Lin, E. (2005) A perspective on water resources in China: Interactions between climate change and soil degradation, *Climatic Change*, 68 (1-2), p. 169-197.

Tyler, S. and Fajber, L. (2009) Land and water resource management in Asia: Challenges for climate adaptation, IISD background paper for the Asia regional meeting of the Dialogue in Climate Change Adaptation for Land Water Management, Hanoi, Vietnam, 19-21 January. www.iisd.org/pdf/2009/asia_background_landwater.pdf

UNDP (2010) *Human Development Report 2010*, United Nations Development Programme.

UNESCO (2009) *Water in a Changing World: Integrated water resource management in action*, Dialogue paper, United Nations Educational, Scientific and Cultural Organization.

Yu, B., Zhu, T., Breisinger, C. and Manh Hai, N. (2010) *Impacts of Climate Change on Agricultural and Policy Options for Adaptation: The Case of Vietnam*, Discussion Paper 01015, International Food Policy Research Institute. www.ifpri.org/sites/default/files/publications/ifpridp01015.pdf

06.

Innovative application of ICTs in addressing water-related impacts of climate change: Emerging research questions

Tina James

Introduction

The research questions presented in this chapter are based on consolidated expert opinion raised during a workshop supported by the International Development Research Centre (IDRC) in Johannesburg, 7-10 July 2011. The purpose of the workshop was to:

- Examine how ICTs could be used to strengthen the resilience and adaptive capacities of communities in developing countries in dealing with water insecurity resulting from climate change.
- Initiate a rigorous, evidence- and outcome-based approach to the field of climate change and water (CCW) by defining a research agenda, and identifying the research needs of practitioners working in this field.
- Share ideas, experiences and lessons from practical applications of ICTs in the water sector.

The key emerging research questions and concepts have provided a useful basis for the building of a conceptual model for ICTs, climate change adaptation and water as presented in Chapter 2.

1. Factors to consider in developing a research agenda

A number of key factors should be taken into consideration in developing a research agenda for ICT-CCW:

- First, there is need to move away from an ICT-centric approach in which ICTs are seen as the panacea for all problems in the field of climate change and water. Any future research agenda should focus on a needs-based approach to water security, and should be people-centric rather than ICT- or water-centric. ICTs should be seen as only one of many possible tools to assist communities to develop their resilience to climate change and variability. The research agenda should focus strongly on how communities deal with water security issues.
- A clear understanding is needed as to what is meant by a "community" and which communities are to be included. Many different types of communities were identified during the workshop – researchers, practitioners, the private sector, government, poor/rich communities and urban/rural communities, among others.
- The research agenda (and research questions) must take a holistic approach in which scalability has to be considered – a series of pilot projects will not address long-term needs to develop responses to climate change and climate variability.
- An ICT-CCW research agenda must build on the extensive experience already gained in the fields of ICTs, climate change and water. This will require the development of a shared vocabulary and shared definitions – many glossaries already exist in these respective fields but the direct adoption of such definitions may not be sufficient to develop a new research direction combining the three pillars of ICTs, climate change and water. For example, ICTs have been used extensively since the 1970s and 1980s in water and environmental management for the capturing, handling and analysis of data. The use of ICTs in creating new opportunities for communications and collaboration between stakeholders is however more recent and in this area there may be room for innovation and taking on board the lessons learned from other ICT-for-development applications. This may however require "tweaking" of the existing definitions and terminologies.
- A new research agenda should ensure that knowledge is translated into practice; the linkages between research/knowledge creation (including indigenous knowledge) on the one hand, and action on the other hand, should in turn be linked to policy development in support of managing water resources more effectively.
- Clear differentiation is needed between whether research deals with climate variability or climate change. The former deals with changes in the short term, whereas climate change requires a far longer-term perspective.
- There is a move toward community-driven and community-owned initiatives that develop knowledge bases for optimising and expanding available water resources, as well as for the ongoing monitoring and assessment of the status of water supplies. This brings with it a greater need to ensure that information flows and knowledge are bidirectional. Mechanisms are required which integrate formal, rigorous, research-based data and information with bottom-up, community-generated information. This could be a potential area of research interest, where the role and impact of ICTs need to be defined and better understood.

2. Emerging thematic areas and possible research questions

Five thematic research areas emerged during the workshop discussions, all with a focus on water within the realm of climate change/variability and all dealing with research questions relating specifically to water issues:

- Improving the management of water resources (including improved water use and efficiency, monitoring of water quality and quantity, and managing extreme events).
- Strengthening the resilience of communities to adapt to climate change, climate variability and water stress.
- Creating more effective governance mechanisms to manage scarce water resources (power dynamics, equity, fairness, etc.).
- Building partnerships, networks and stakeholder collaboration.
- Supporting knowledge sharing, improved communications, and dissemination for awareness raising and decision making.

The list cannot be regarded as definitive, nor are the thematic areas discrete, given that there is some overlap between them. For example, to strengthen the resilience of a community to climate variability/change, one would also need to address how the dissemination of knowledge from the scientific community to vulnerable communities could be improved.

ICTs were not assigned a separate thematic area in their own right. Rather, ICTs are seen as *enablers* which could *assist* communities in dealing with specific CCW needs more effectively. Amongst other things, ICTs could play a role in: data gathering to monitor water quality and quantity; the interpretation and analysis of data; tools for decision support; forecasting and scenario planning, particularly relating to future water demand; facilitating the sharing of knowledge through the creation of networks; and providing tools for the more effective dissemination of information to a diverse range of stakeholders.

Improving the management of water resources

In order to improve the management of scarce water resources within the context of climate change and variability, it is necessary to understand the current status of both water quality and quantity in any particular context – whether at the community level, regionally or beyond. At present, there are many data gaps which exist, making an assessment of possible impacts difficult if not impossible. Of particular relevance is the need to improve water quality data in urban and peri-urban environments and water quantity data in rural environments. Data relating to extreme events such as floods, droughts, landslides and tsunamis will also have to be monitored. ICTs can play a role in the gathering, analysis and interpretation of the data.

Examples of research questions

- What are the data gaps in water quality and quantity? How can ICTs assist in filling this gap and reduce the vulnerability of affected communities? How can data credibility be improved (in terms of actual data as well as what is communicated)?
- How can ICTs assist in improving water access and increased use efficiency (e.g. vulnerability mapping, mapping existing knowledge – what is known and by whom)?
- What role can ICTs play in building community-based monitoring systems?
- How can ICTs assist in creating shared platforms for data gathered from scientific sources and those gathered through local-level monitoring and indigenous knowledge sources?
- How can ICTs be used to bridge the gap between biophysical science (quantitative) and social science (qualitative) in order to make knowledge relevant at the local level?
- How can currently used ICT tools and technologies improve data gathering and provide better data analysis, in an appropriate format, to vulnerable communities?
- What role can ICTs play in building scenarios for improved management of water resources (e.g. through the use of visualisation technologies)?
- How can ICTs be used to monitor, assess and evaluate interventions and impacts?

Strengthening the resilience of communities to adapt to climate change, climate variability and water stress

Some communities exhibit stronger coping and adapting strategies with respect to water stress resulting from climate variability and, in the longer term, from the effects of climate change. When dealing with vulnerable communities, it is important to understand the factors that contribute to their resilience (or not) and their ability to change in the face of increased water stress. This requires an examination of the social components within communities which may be the key success factors. For example, this might entail levels of commitment, motivation, presence of a champion (institutional or individual), attitude towards sharing knowledge, ability to mobilise within a community, access to knowledge, ability to have readily accessible entry points into communities, levels of awareness within the community, etc.

Examples of research questions

- What are the potential socioeconomic barriers to be addressed to implement a successful community-based monitoring system? How can ICTs assist communities to develop, maintain and monitor community-managed water supply systems?
- What alternative water supply options are available to augment existing water supplies and how can ICTs be used to identify potential water supply options?
- How can ICTs be used to educate communities in the short, medium and long term to forecast future demand and to implement management strategies?
- What are key factors for the sustainable use of ICTs in climate change adaptation in the water sector (institutional, financial, technical, social and content, the latter with regard to information and knowledge)?
- Can ICTs be used to facilitate behavioural change, resulting in better adaptation of vulnerable communities in the short term (coping) and in the longer term (adapting)?
- How can communities deal with shrinking water resources, particularly where spatial and temporal distributions are becoming more difficult? Can ICTs improve access to water in times of uncertainty? Can ICTs be used to provide early warning systems for communities?
- How can the various players in the water cycle deal with uncertainty, and how can ICTs strengthen the capacity of institutions and communities to deal with such uncertainty?
- Which specific ICTs can be used to provide short-term forecasting information to the community and to provide policy makers with the information produced by the community?

Creating more effective governance mechanisms to manage scarce water resources

The varying demands on limited water resources by different users, and the inherent tensions in ensuring fairness in water resource allocation, require attention to a number of elements. First, water needs to be seen as a common resource. Second, balancing competing uses requires a strong level of management that can negotiate between different needs and deal with conflicting demands on a scarce resource. Third, most communities do not have easy access to information on the availability and quality of the water that they use. This lack of knowledge can lead to unequal resource allocation. The use of community-based research and monitoring improves trust and empowers local groups to be proactive in responding to their challenges.

Examples of research questions

- How can water resource allocation be improved using participatory research and can ICTs support this process?
- Can ICTs play a role in ensuring equitable sharing among diverse stakeholders (e.g. industry, poor communities, rich landowners, women and youth)?
- Can the use of ICTs play a role in democratising water management and making decision-making processes more transparent?
- How can ICTs be used to enable more effective negotiation and articulation of interests between different stakeholders?
- What role can/should/do ICTs play in gender equity and other power dynamics such as between poor and rich communities, communities and industry, industry and agriculture? Do ICTs help or hinder in strengthening equity in power relationships? How does the introduction of ICTs affect the power balance in communities (e.g. will it give more or less voice to the disem-

powered, will it strengthen or weaken consensus building)?

- How can ICTs be used to enhance community social capital to address issues of water co-management (quantity and quality)?
- How can ICTs be used to bridge the gap between scientific output, implementation and practice, and policy formulation to support the equitable allocation of scarce water resources?

Building partnerships, networks and stakeholder collaboration through the use of ICTs

There are significant challenges in moving from research, and the gathering of research evidence, into action. Distinct divides and tensions exist between policy, research and action, and how these could be linked needs to be understood. Research needs to provide rigorous evidence, which must be translated into action for change (in policy and social outcomes). The emphasis on research and policy does mean that there is a disjunct between transfer of knowledge into action. This could be addressed in the research agenda through partnerships and engagement with stakeholders. However, different timelines are required for research, action and policy making.

ICTs could play a key role in linking stakeholders to: 1) strengthen existing knowledge bases; 2) allow for the more effective sharing of information and experiences between communities, here defined as communities in the broadest sense (e.g. industry, policy makers, practitioners) and 3) strengthen South-South linkages.

Examples of research questions

- What ICT tools could be developed to support stronger integration and interdisciplinary approaches to the study of adaptation to climate variability/change (e.g. how could linkages be created between the fields of forestry, agriculture and health)?
- How can ICTs support the effective communication of research findings to influence policy in the water sector?
- How can ICTs be used in different contexts to maximise collaboration between different stakeholders in situations of water stress?
- What role can ICTs play in providing outreach between/within communities? How can localisation be effected (e.g. language, credibility of information, levels of participation and inclusiveness, mobilising local knowledge)?
- How can South-South linkages be supported, using ICTs, to promote inter-regional learning?
- How can ICTs be used to link champions across communities and increase the shared knowledge base in support of developing resilient communities?
- Who are the vulnerable groups and what are their information needs? How does meeting these needs reduce their vulnerability?
- Can ICTs play a role in increasing the role and participation of women?
- How can ICTs assist in creating a global network of researchers on water resource mapping/modelling, both for policy influence and community action?

Supporting knowledge sharing, improved communications, and dissemination for awareness raising and decision making

Different types of partnerships and linkages need to be created to ensure a holistic approach to addressing adaptation to climate change. Far more attention needs to be given to how and what communications take place between and within stakeholder groups, what information needs to be communicated, and what would be the most appropriate mechanisms and tools for optimal information sharing.

Examples of research questions

- How can ICTs be used to convert scientific information into more appropriate formats for decision makers and other key stakeholder groups?
- How can ICTs be used to package information resources in different ways for different groups (e.g. locally, in one country, in different villages, for practitioners, industry players, politicians)?
- What targeted communications strategies are needed to improve adaptability to climate change? How can ICTs be used to develop and support the implementation of such strategies?

3. Conclusion

The research questions that emerged during the ICT-CCW workshop provide a healthy springboard for developing a future research agenda. The mix of workshop participants, from four continents and a range of backgrounds (social scientists, ICT experts, climate change researchers and practitioners) added to the richness and diversity of research recommendations that can further be consolidated. The overriding conclusion that can be reached is that a holistic and integrated approach is needed, bringing together different disciplines of water and environmental management, biophysical and social sciences and ICT for development. The cross-cutting nature of an ICT-CCW research agenda creates opportunities for innovative research which straddles all these disciplines to gain new insights into how better coping and adaptation strategies can be rapidly developed for vulnerable communities facing water stress. ■

Appendices

Environmental monitoring in the Ecuadorian Amazon: How community environmental monitoring and mobile phones contribute to territorial management and planning

ECUADOR

Implementing organisations

Foundation for the Advance of Reforms and Opportunities (Grupo FARO)

Decentralised Autonomous Municipal Government of Francisco de Orellana (GADMFO)

Institute of Applied Ecology, San Francisco de Quito University (ECOLAP)

Background to project

The forests, nature and vast biodiversity of the Amazon basin in Yasuní National Park provide a great number of goods and services to the local and world population. Unfortunately, the availability of these resources is changing. While there are changes in the quality and availability of natural resources, it is unclear to what degree or on what level the changes are occurring and how harmful they are.

The use of ICTs and other state-of-the-art technologies allowed this project to contribute to the preservation and sustainable management of the natural resources found in the Ecuadorian Amazon (in the northeast corner of Yasuní National Park), through capacity building with the technical staff of the municipal government, the Parish Boards of Taracoa and Alejandro Labaka, and with civil society organisations engaged in socio-environmental monitoring, including the monitoring of water quality, soil, major fauna and flora. The internet and mobile phones played a very important role in the programme's success, as tools for coordination and dissemination.

In the first phase of the project, a group of 20 local monitors was trained in the use of equipment such as GPS, computers, cameras and binoculars. This group, with the aid of the project's implementing institutions, drew up an environmental baseline in their parishes. The results were presented in workshops and forums where the experiences of stakeholders could be discussed. The project also aimed to launch an education campaign so that the majority of the population would learn about the importance of environmental monitoring. As the campaign stated: "We cannot care for what we are unaware of."

Key issue being addressed by intervention

Yasuní National Park, and the Yasuní Biosphere Reserve (YBR) surrounding the park, is considered one of the areas of greatest biodiversity on the planet. The YBR is a complex territory with great vulnerability. The wealth of its natural resources and culture contrast with the existence of large-scale extractive industries, the expansion of the agricultural frontier, illegal trafficking in wildlife, random tourism, lack of environmental awareness and high poverty levels. Indigenous peoples of the Waorani, Shuar and Kichwa nationalities live within the YBR.

Given this reality, there is an urgent need to develop more critical and responsible local governments and citizenry, able to make proposals when solutions must be found for the environmental problems within their communities. They must work in a coordinated fashion, enforcing public policies that are consistent with the needs of the population through monitoring processes that generate reliable, replicable, measurable and comparable information over time.

Application of ICT tools

Areas in Ecuador rich in natural resources face a common problem: the serious limitation of access to the internet due to poor coverage. In the case of Orellana Province, where Yasuní National

Park is located, internet penetration in the urban sector does not exceed 15%, and in the rural sector, it is less than 8%. Despite this limitation, the overwhelming majority of local governments, compelled by the country's current constitution, focus on e-government for service delivery.

Nevertheless, the project found an innovative and successful solution to low internet coverage: complementing the use of internet with the use of mobile phones, which in this country have one of the highest penetration rates in Latin America (106%, according to the latest 2010 census). Based on this, the idea of creating a "mobile citizenry" was developed.

The idea behind mobile citizenry was very simple. The local government sent SMS messages to the public with information regarding the results of socio-environmental monitoring, such as variation in quality of water and soil and extent of the natural resources. Those interested in receiving this information registered using a form designed for this purpose. Similarly, individuals could send information to interested parties registered with the programme through SMS if they detected cases of environmental pollution, newly endangered species, logging or hunting of animals in protected areas, and the frequency and intensity of climate events such as floods and droughts.

Outcomes

Complementing the use of the internet with mobile phones as direct channels of communication between the population and authorities unleashed the potential of society to meet the challenges of oil drilling, tourism, and environmental disinformation in Yasuní National Park and its surroundings.

Among the most noteworthy achievements:

- Twenty people from two parish boards, Alejandro Labaka and Taracoa, were trained in environmental monitoring. Of the participants in the project activities, including needs assessments and training activities, 25.4% were women and 74.6% men. In terms of age groups, 87.3% were adults and 12.7% were under 18 years of age. Indigenous peoples (Waoranis, Shuar, and Kichwas) made up 54.2% of the participants while 45.8% were internal migrant farmers (*colonos*).
- The Alejandro Labaka and Taracoa parish boards participated actively in the process, assisting in meetings and logistics, including providing transportation and food for the monitoring groups.
- GADMFO planned to recognise local monitoring groups as environmental management support staff by presenting credentials to each member of the group.
- Over a three-month period, the number of persons registered to receive information from GADMFO through SMS grew from 500 to 4,000.
- In order to effectively manage the growing demand for and supply of information, GADMFO began an organisational restructuring process, in an effort to act in a coordinated manner with respect to the above-mentioned challenges.

A number of important lessons have also been learned through the project:

- For a community to accept ICTs as working tools in their daily lives, their use must represent a solution to everyday problems.
- A willingness to make the most of the strengths of each individual was evident among the different participants, while at the same time there was a desire to share knowledge with others. Mobile technology provides an excellent opportunity to complement the internet in order to channel and coordinate the potential and capacity of individuals and to develop a team spirit.
- It is necessary to encourage willpower and commitment on the part of local leaders so they may become agents of change pushing for the sustainable use of biodiversity in their territories.
- Most of the communities engaged in the project face problems due to the impact of oil drilling and the expansion of the agricultural frontier. As a result, indigenous peoples in these territories find themselves ever more deeply immersed in patterns of unsustainable use of their resources, such as the intensive use of water for agricultural activity, hunting and indiscriminate logging. Therefore further work is vital to raise community awareness regarding its role in protecting scarce natural resources, especially water. ■

For updated project information

Contact person: Paúl Medina
Email: Pmedina@grupofaro.org
www.grupofaro.org

Introducing new techniques for water management through community radio stations and telecentres

BOLIVIA

Implementing organisation

Apachita Indigenous Communications Network

Background to project

The community of Sorasora, and the entire region of the central plateau of Bolivia, is inhabited by indigenous Aymara peoples. This region is at an altitude of 3,850 meters above sea level, with a cold and dry climate. In its arid soil, the local community grows Andean crops such as quinoa, kañiwa, fava beans, barley, potato, oca, papalisa, isaño and alfalfa for feeding dairy cattle that are acclimatised to the altitude. Agricultural production is dependent on seasonal rainfall of approximately 200 millimetres from December to February.

Lack of water in the Sorasora community has caused significant problems, including decreased weight and number of livestock, due to the long distances that must be travelled to fetch water. Many species of plants have also disappeared, causing an ecological imbalance and allowing pests and unknown diseases to develop.

Key issue being addressed by intervention

The population of Sorasora and the communities of this region lose 50% of their annual production to drought, frost and hailstorms. Up until two decades ago, local community members were able to predict the weather using ancestral knowledge and wisdom, and were able to take preventive action to face agro-climatic crises. As a result of climate change, meteorological and bio-indicators have been altered, making it extremely difficult to predict the behaviour of atmospheric phenomena, such as luminance and hydration, well enough to properly plan and manage community fields, which are used on a rotating basis.

In order to resist the effects of drought the rural population harvested seasonal rainwater in small dams (*qhuthañas*). However, there was not sufficient harvested rainwater to supply the community through the dry season, causing many animals to die.

Application of ICT tools

Community radio stations and telecentres have played an important role in raising the awareness of local community members to address the effects of drought and climate change.

Information on climate change, atmospheric conditions and methods for resisting the effects of drought was obtained through the internet, with much of the information generated within the Andean region. This information was disseminated through community radios in programmes lasting 10 to 15 minutes, translated into the native languages of Aymara and Quechua. Additionally, climate information was distributed by email to various telecentres, where the information was posted and read daily.

Outcomes

The experience and knowledge acquired through ICTs have provided motivation for individuals to share their knowledge and push for community action, such as digging wells to collect rainwater.

Using information obtained from community radio stations and telecentres, based on experience developed in other Andean regions, the Sorasora community initiated a project to bore water wells, approximately 30 to 40 metres deep, to obtain water from the subsoil. In order to complete this project, community members used newly obtained knowledge to construct a homemade manual well borer.

A number of important lessons have been learned through the project:

- Telecentres are extremely useful for isolated communities where internet penetration is not high.
- Information can be made more easily accessible through community radio stations and other low-cost media, in which information can be easily edited and translated.
- A technical support team is necessary to ensure that ICTs match community needs.

Next steps

- Gather additional information, experiences and best practices on how to obtain, use and conserve water.
- Improve access and use of ICTs, particularly community media.
- Develop and improve low-cost technologies, especially for boring small water wells in the pampas.
- Train human resources to access, codify and share information, and to monitor the distribution of knowledge and learning in the rural communities.
- Develop an information database similar to InfoAndina (www.infoandina.org) in Peru.
- Replicate the project in other communities, where resources are available. ■

For updated project information

Contact person: Felix Gutierrez Matta
Email: redapachita@bolivia.com

A participatory information platform to support adaptation in communities vulnerable to climate change

SENEGAL

Implementing organisations

Ecological Monitoring Centre (CSE)
GREEN Senegal
National Meteorology Agency of Senegal (ANAMS)
Gender Laboratory

Background to project

In Senegal, as in most Sahelian countries, the living conditions of rural populations are still closely linked to the performance of rain-fed agriculture, which in turn is highly subject to the yearly variability of the region's climate.

In the Thiès region, climate variability and climate change have a strong impact on the vulnerability of rural households. Rainfall volumes vary greatly on both an annual and a decennial basis. There has also been a trend of decreasing annual rainfall, with average annual rainfall dropping from 660 mm between 1920 and 1967, to 440 mm between 1968 and 1999. Where annual rainfall was below 300 mm, significant agricultural deficits occurred. These changes increased the vulnerability of much of the rural population in the Thiès region.

Key issue being addressed by intervention

The methods used by generations of farmers to guide their technical and economic choices are generally outdated. For example, the frequency of drought pockets during the rainy season calls into question the relevance of certain benchmarks used by farmers, such as the decision to begin sowing when the rains begin. It is important that farmers adjust their benchmarks and agricultural practices to take into account new climatic conditions.

Obtaining information on climate change and alternative technical options and knowing how to use them represent one of the challenges faced by rural populations. For many farmers, access to information sources, such as meteorological and agricultural advisories, is very limited.

In the face of this challenge, the InfoClim project was developed to help improve access by farmers and other stakeholders to relevant information for adaptation. In order to achieve this, a participatory platform for the collection and sharing of information – which we called an observatory – was established. By sharing information through this observatory, the project sought to consolidate the adaptation strategies of vulnerable populations in order to improve their living conditions.

Application of ICT tools

The observatory, which is managed by the communities, is a mechanism for producing and disseminating information to rural producers. Its objective is to serve as a platform through which farmers and other stakeholders can share their experiences and information needs. There is one observatory at the regional level and four local observatories in each of the communities. At the regional level, a Regional

Climate Change Committee ensures the functionality of the observatories and Local Committees for Climate Change Adaptation (CLCC); directs users to the appropriate technical services; facilitates the collection, processing and validation of the data/information; and promotes the integration of information generated through the project into local development plans. At the local observatory level, the CLCC identifies difficulties and information needs within the community, transmits the needs to the Regional Committee, obtains feedback and disseminates/shares the information within the community.

The observatory has the main operational characteristics of a geographical information system (GIS), enabling the display of already available thematic and base layers of information. The integration of multimedia documents in the observatory contributes towards an understanding of climatic phenomena and their impact. The platform was developed using Delphi and the cartographic components of TatukGIS 8.10 software.

Access to the GIS software is free to all stakeholders operating within the domain of the environment and climate change. It is a flexible tool that can be used in any analysis requiring access to and the simple and dynamic display of geo-referenced information, without the need to use costly and complex commercial software.

The prototype developed within the context of the InfoClim project offers two functionalities for interaction with data. First, it enables the display of spatial and statistical data. It then allows manipulation of the data using four functions:

- Addition of new data
- Modification of existing data
- Deletion of existing data
- Free recommendations, in text format.

All interactions with the database are subject to validation.

Outcomes

The project has succeeded in creating a multi-stakeholder framework for information sharing and exchange, based on a partnership model which leverages existing organisational networks. In addition, the development and use of a software package by the project's stakeholders showcases the ability of local stakeholders to use ICTs to adapt to climate change.

Key outcomes of the project were:

- The research teams involved in the project became better equipped to assess vulnerabilities related to the climate and to analyse and develop adaptation options.
- Local authorities became aware of the harmful effects of climate change and began integrating these aspects into local development plans.
- At the regional level, an inventory of dissemination channels has enabled the various project partners to come to an agreement on the structure of the observatory, the choice of information to be collected and the methods for data management. The project has enabled local stakeholders to identify their information requirements in order to consolidate their adaptation capabilities.

Next steps

- Integrate mechanisms for climate change adaptation into planning tools at national, regional and local levels. ■

For updated project information

Contact person: Amadou Sall
Email: amadou.sall@cse.sn
www.cse.sn/seninfoclim/index.html

Using ICTs to provide advisory services on agriculture, climate change and water management

BURKINA FASO

Implementing organisations

Burkina Faso Women's Action Network (RFA)

Ministry of Agriculture

Ministry of Environment

International Institute for Water and Environmental Engineering (2iE)

Background to project

Burkina Faso is an agrosilvopastoral country – a combination of crops, trees and pasture/animals are typically grown or farmed on the same piece of land – where 80% of the population's activities are focused on the agricultural sector. In recent decades, the country has experienced extreme climatic variations. The sectors most vulnerable to climate change are water, agriculture, livestock and forestry.

The overall objective of the National Water Policy (PNE), adopted in 1998, is to contribute towards rural development by providing appropriate solutions for water-related issues. The specific objectives are:

- Sustainable fulfilment of water needs
- Protection against the negative impacts of water such as flooding or erosion
- Improved public finances
- Prevention of conflicts related to the management of shared water.

According to the 2006 National Action Programme for Adaptation to Climate Variability and Change (PANA), as well as local records, there has been a general trend of decreased rainfall, increased temperatures, and an increase in the frequency and magnitude of extreme climatic events, such as torrential rain, which has caused flash floods and soil erosion.

Key issue being addressed by intervention

The agricultural areas in Burkina Faso have been hard hit by the adverse effects of climate change, including deterioration of farmlands, drought and flooding. Agricultural and rural communities require support to adapt to changing climatic conditions, particularly in the management of water resources.

This issue is also characterised by:

- Insufficient dialogue between the different stakeholders in agricultural production and climate change (researchers, local authorities, technical departments, agricultural producers, media, etc.).
- Insufficient communication/extension/advisory actions on climate change and water management via channels such as community radio, rural internet centres, and women's listening clubs (via radio and mobile telephones).

Application of ICT tools

The objective of this project was to conduct research on good practices in the areas of climate change adaptation and water resources management, disseminating the results to rural agricultural producers using tools such as community radio stations, rural telecentres, mobile telephones and solar radios.

A trip to Johannesburg, South Africa was organised for the 2010 annual seminar of the Technical Centre for Agricultural and Rural Cooperation (CTA), which is devoted to the integrated management of water resources. After various discussions, programmes for community radio stations in Burkina Faso were developed, drawing on content from the seminar, with the participation of producers, researchers and opinion leaders (traditional chiefs). These local language programmes were recorded on tape and CD-ROM and were subsequently broadcast on community radio. Clubs were formed with female agricultural producers with shared concerns, to listen to the broadcasts and to respond by telephone directly.

Outcomes

Radio broadcasts produced in local languages have enabled the population, especially those with low literacy levels, to access information related to adaptation to climate change – more specifically in the area of integrated water resource management.

Telecentres have been set up in the provinces of Boulgou, Bazega and Kadigo, and are equipped with computers with access to the internet, an agricultural library containing documents provided by the CTA, an agricultural product display section, and a reading/meeting area that can be used for radio interviews. These centres are also hubs for extension and advisory services on agriculture, climate change and water management. Trained staff support users with computer training and guidance on how to conduct research using the internet, while also promoting the sale of agricultural products.

Next steps

- Support and design new communication tools.
- Open additional telecentres.
- Build capacity of staff at telecentres.
- Develop Kadigo centre into a reference centre for online and classroom training for telecentre staff.
- Increase dissemination, monitoring and evaluation of information and project activities. ■

For updated project information

Contact person: Françoise Bibiane Yoda (RFA)
Email: femmesenaction@gmail.com, infos@femmesenaction.org

Wireless sensor networks for climate change monitoring in Kenya

KENYA

Implementing organisations

School of Computing and Informatics (SCI), University of Nairobi

Department of Meteorology, University of Nairobi

Hasso Plattner Institute (HPI) ICT4D Research School, University of Cape Town, South Africa

International Centre for Theoretical Physics (ICTP)

Background to project

Droughts, which are prevalent in many parts of Africa, including Kenya, are among the most expensive climate-related disasters in the world; their negative impacts form a complex web that spans economic, social and environmental aspects of the affected society.

Drought prediction through climate change monitoring can mitigate some of the devastating effects of droughts, especially food insecurity. In Kenya and indeed most African countries, climate monitoring is currently implemented using macro infrastructures based on expensive and well-calibrated weather stations. The stations are then sparsely deployed by governmental organisations in a relatively small number of fixed locations to provide highly technical macro information in the form of climate maps for drought and other natural disaster prediction. This project aimed to bridge the feasibility gap using a combination of emerging sensor/actuator technology and mobile phones.

Key issue being addressed by intervention

Existing drought monitoring and dissemination systems offer ineffective and macro information. In Kenya, daily, weekly, monthly and seasonal weather forecasts are disseminated via websites, radio and television stations in English. Though wireless sensor networks (WSNs) can be used, current implementations are relatively costly and middleware solutions tend to be tightly coupled to specific applications. This creates a feasibility gap that needs to be addressed through complementary technologies, systems and strategies.

Application of ICT tools

The proposed solution provides support for low-cost weather stations, which can be used by academics and civil society to build community sensor networking micro infrastructures based on off-the-shelf sensing devices. WSNs can be deployed in the environment to extend the available climate maps and prediction through (1) collection of climate data, (2) analysis of this data, (3) modelling of climate change in cities and whole countries, (4) derivation of sound policies based on the derived climate models, and (5) providing awareness to citizens, official organisations, non-governmental organisations and the private sector.

WSN-based applications are appropriate for Kenya because they:

- Are easy to use and can operate unattended.
- Have limited power requirements that can be harvested (e.g. solar power) or stored (e.g. battery).
- Are able to withstand harsh environmental conditions and communication failures and are designed to cope with the high possibility of node failures.
- Have dynamic network topology, with node mobility, covering wider geographical areas than professional weather stations.
- Are cheaper; for instance, Libelium (www.libelium.com) has launched a sensor weather station at a cost of around € 1,500, which is insignificant compared to professional weather stations that cost around € 100,000.

- Are highly scalable; additional sensors can be plugged in easily and others removed with no need for application redesign.
- Allow collection and dissemination of micro-level drought/weather parameters.
- Can be integrated with mobile phone and web applications to deliver tailor-made information to stakeholders.

Moreover, the now commonly used mobile phone can be used to collect indigenous knowledge on weather and climate changes. For example, within the scope of this project a mobile phone application implemented using Android has been used by an intermediary to collect and upload data into a database.

The following project activities were undertaken:

- Wireless sensors for sensing temperature, humidity, atmospheric pressure, precipitation, wind speed, wind direction, soil temperature and soil moisture were purchased and configured.
- In order to improve the relevance to local communities, mobile phones were used to collect indigenous knowledge that is incorporated in the design of the early warning system.
- Mobile phones were also used to disseminate alerts to locals via SMS.
- Plans were underway to support audio alerts for users who cannot read. A Natural Language Interface to Databases for English was incorporated and there were plans to develop a similar module for Kiswahili and other local languages.

Outcomes

Sensor calibration with professional weather stations

Before adopting wireless sensor boards for weather monitoring, a thorough calibration of these boards against the professional weather stations at the Kenya Meteorological Department (KMD) in Dagoretti was carried out for three months. This was to ensure acceptability of the readings from sensors by the meteorologists. Using mean absolute percentage error (MAPE) and root mean square error (RMSE), the weather sensors gave accuracies of 92% to 99%. This has led to the ongoing implementation of sensor-based weather monitoring systems at the University of Nairobi as well as the KMD.

Drought/Flood Monitoring and Forecasting Tool

A tool has been developed to monitor and forecast droughts based on an Effective Drought Index, which uses artificial neural networks. The tool makes use of data from the sensors as well as forecast reports from the KMD. The tool was built using historical weather data for four weather stations in Kenya. The tool carries out three types of forecasts:

- Short-term – forecasts droughts/floods for one to 14 days with an accuracy of 94%.
- Medium-term – forecasts droughts/floods for two weeks up to 18 months with an accuracy of 70%.
- Long-term – forecasts droughts/floods for two years up to four years with an accuracy of 75%.

Both the results of the forecasts and real-time weather alerts from the sensors are available online.

Next steps

- The sensor-based weather stations will be installed in three additional locations in Kenya in order to monitor various parameters related to climate change. The sensed data will then be processed using servers to be located at the School of Computing and Informatics, University of Nairobi. Once in the servers, the data will be used to update the Drought/Flood Monitoring and Forecasting Tool.
- Disseminate processed data through mobile phone application.
- Integrate the alerts generated from the Drought/Flood Monitoring and Forecasting Tool with indigenous weather forecasts; this will first be piloted among the Nganyi Clan in western Kenya and then among the Mbeere people in eastern Kenya. ■

For updated project information

Contact person: Ms. Muthoni Masinde
Email: muthoni@uonbi.ac.ke
www.muthonimasinde.net

Creating computer simulations to understand the effects of non-point source pollution on water quality in the Kuils-Eerste River catchment

SOUTH AFRICA

Implementing organisations

University of the Western Cape (UWC)

Bindura University of Science Education (BUSE)

Council for Geosciences (CGS)

Background to project

The Kuils River and Eerste River are two important rivers that run through the eastern part of the Cape Metropolitan Area (CMA) in South Africa. The Kuils River joins the Eerste River, as a tributary, near Macassar. The Eerste River finally ends in False Bay forming an estuary. The Eerste-Kuils River estuary is one of the eleven estuaries draining into False Bay, which is located approximately 36 km southeast of Cape Town. The catchments of these two rivers form a larger catchment with an area of 660 km^2. A portion of this larger catchment falls within the boundary of CMA, while the remaining catchment area falls in the Stellenbosch municipality. Although the Eerste-Kuils catchments form part of urban developments, significant portions of the catchments include agricultural lands; hence they have both urban and agricultural sources of non-point source (NPS) pollution. The potential loading from the Eerste-Kuils River catchments has a great impact on the coastal waters near Eerste River estuary. This project used computer simulations to help implement NPS control programmes.

Key issue being addressed by intervention

There was an urgent need to discern whether the deterioration of Eerste-Kuils River water quality was mainly because of NPS pollution due to the present land use practices in the catchment, or was a result of the combined effect of NPS pollution and the release of effluents into the river from the Macassar sewage treatment plant. In order to answer this question it was necessary to assess the pollutant loading rate and concentration reaching a point just upriver from the sewage treatment plant. Due to the time and high expense associated with surface water monitoring techniques, however, computer simulation modelling was used to generate the information needed for the development and implementation of NPS control programmes.

Application of ICT tools

NPS pollution is an exceedingly complex phenomenon. It represents the cumulative effects of all of the land uses in a catchment and associated human activity or environmental modifications. Owing to this complexity, models that attempt to reflect the actual processes require large quantities of data, which are rarely available. Because of this, the most common method of approximating NPS pollution uses long-term average contaminant loadings for common land uses. The approach has been followed in many countries. Modelling of NPS pollution using geographical information systems (GIS) can take account of the spatial distribution of the various NPS contaminants in the surface runoff. GIS is already being used in many countries to provide estimates of NPS pollutant loads in surface water runoff and the accumulated pollutant loads in a receiving surface water body (rivers, lakes, estuaries, etc.).

Using a desktop GIS, potential NPS pollutant-loading rates can be estimated for the land use and land cover types of the Eerste-Kuils River catchment. The estimation of runoff and the associated pollutant concentrations in runoff water from each part of a catchment was dependent mainly on the land use (present and past human activities) and the infiltration properties of the underlying soil or geological deposits. All parameters were spatially dependent (in the form of maps with attribute information). GIS can easily handle the required spatial data, perform the required calculations, and store the results for further calculations and analysis.

The GIS software chosen for this modelling study was ArcView 3.2 GIS, developed by Environmental Systems Research Institute (ESRI) in the United States. In this study, water quality parameters such as nitrate, chloride, phosphorus, total nitrogen, and total suspended solids were selected for quantification of NPS pollution. The estimation of NPS pollutants in the surface runoff was based on typical event mean concentrations (EMCs). The EMC is a statistical variable, generally log-normally distributed. As these values are site specific for certain land use and soil/geologic combinations, some of these values could be used as a starting figure for initial model testing purposes or testing of the developed model code. Within a GIS, the products of spatially distributed EMCs (land-use related) and the measured or modelled runoff in each grid cell would be calculated and then summed in the downstream direction, using flow direction and flow accumulation grids generated from a digital elevation model (DEM) to establish a spatially distributed grid of average annual pollutant load in the catchment.

Outcomes

The outcomes of the project were:

- Potential sources of NPS pollution were identified.
- Remotely sensed multi-spectral high spatial resolution satellite data and recent available aerial photographs were interpreted and classified for identifying various land use/land cover types existing in the catchment.
- Runoff in the catchment was estimated based on the abovementioned information being available. The estimation of runoff using the NRCS curve number method was achieved.
- Using ArcView GIS, a mathematical model called "NPS pollutant load in runoff" was generated by writing a programme in Avenue script for estimating the pollutant loads of chosen constituents in surface runoff water.
- The model developed was used to simulate the extent of pollution and the change in pollutant loads, by changing the land use practices and simulating the resultant EMC values. The results from these studies can be used to develop a working document of action plans for pollution management in the catchment.

Next steps

A need exists for the implementation of a surface water quality programme in the catchment using the approach that is outlined in this study. The study should explore ways of involving affected communities in the Kuils-Eerste River catchment, as community involvement in the management programme is crucial for its success. ■

For updated project information

Contact person: Wisemen Chingombe (BUSE)
Email: wchingombe@gmail.com

References

Naranjo, E. (1998) A GIS based nonpoint pollution simulation model, VKI - Institute for the Water Environment, Denmark.

Petersen, C. (2002) Rapid geomorphological change in an urban estuary: A case study of the Eerste River, Cape Town, South Africa, unpublished Master's thesis, University of the Western Cape, Bellville, Cape Town, South Africa.

Taylor, V. (2000) A study of the influence of the Kuils-Eerste rivers on the people of Zandvlei and environment, *Rocknews*, a publication of the Geological Society, University of the Western Cape, Bellville, Cape Town, South Africa.

Thomas, A. (2001) A geographic information system methodology for modelling urban groundwater recharge and pollution, PhD dissertation, The School of Earth Sciences, University of Birmingham, Birmingham, UK.

Community Climate Care Centres for knowledge management and adaptation in rural Bangladesh

BANGLADESH

Implementing organisation

Bangladesh Friendship Education Society (BFES)

Background to project

Anthropogenic climate change is likely to have the heaviest impact on small, low-lying islands and coastal states. Like many other vulnerable countries, Bangladesh will face tremendous challenges from the effects of climate change. Situated between the Bay of Bengal and the North Indian Ocean to the south, and the Himalayas to the north, the country is subject to both life-giving monsoons and catastrophic disasters such as tropical cyclones, storm surges, floods, droughts, soil salinisation and erosion. This project aimed to create a network of community information centres to provide relevant climate change information at the local level.

Key issue being addressed by intervention

Climate change is leading to an intensification of the hydrological cycle, resulting in extensive dry and rainy seasons, raising the risk of drought and heavy flooding. According to the 2007 IPCC report, precipitation may increase by 20% to 30%, increasing Bangladesh's vulnerability to water-related disasters. Changing climates also have significant impacts on the availability, quality and quantity of accessible water. Sea level rises and other local factors have caused salinity intrusion to become a serious problem, in turn affecting agricultural production and ecosystem biodiversity.

Prolonged drought or heavy showers are equally harmful for crop cultivation in drought-prone areas. Insufficient rain leads to the rapid drying up of soil, leaving little time for farmers to prepare their land for the next crop. Unusual weather may also harm ripened crops in the fields, whereas a quick harvest can save the crop. Environmental factors in turn impact on human health, leading to malnutrition, diarrhoea, cardiovascular and respiratory diseases, and water-borne and insect-transmitted diseases. In order to combat these and other consequences of climate change, individuals and communities must find ways to cope and adapt to changing conditions.

Application of ICT tools

It was envisaged that Community Climate Care Centres would be the main hub for all activities to do with climate-related issues in the project areas. The Centres would act as hubs to collect and disseminate environmental, agricultural, weather and crisis (emergency) information at the grassroots level. Six regions of Bangladesh were selected to develop ten Climate Care Centres: Bagerhat, Pirojpur, Gopalganj, Cox's Bazar, Tangail and Chittagong.

These centres would offer a unique approach to reducing climate change vulnerability and increasing the appropriate adaptation measures, as well as to developing a more robust knowledge society. The project activities can be summarised as:

Development of Community Climate Care Centres

- *Services provided by Community Climate Care Centres*: It is envisaged that communities will be able to receive various kinds of internet-based information from the centres. The centres will also provide internet services at an affordable rate. Amongst other things, videoconferencing and e-commerce services will be available at the centre.
- *Hub for communication and information*: The centres will provide critical information during

disasters. They will support existing organisations such as the Disaster Management Bureau, Department of Social Welfare and Development and Red Cross by acting as hosts for their information and services, thereby extending their reach among grassroots communities.

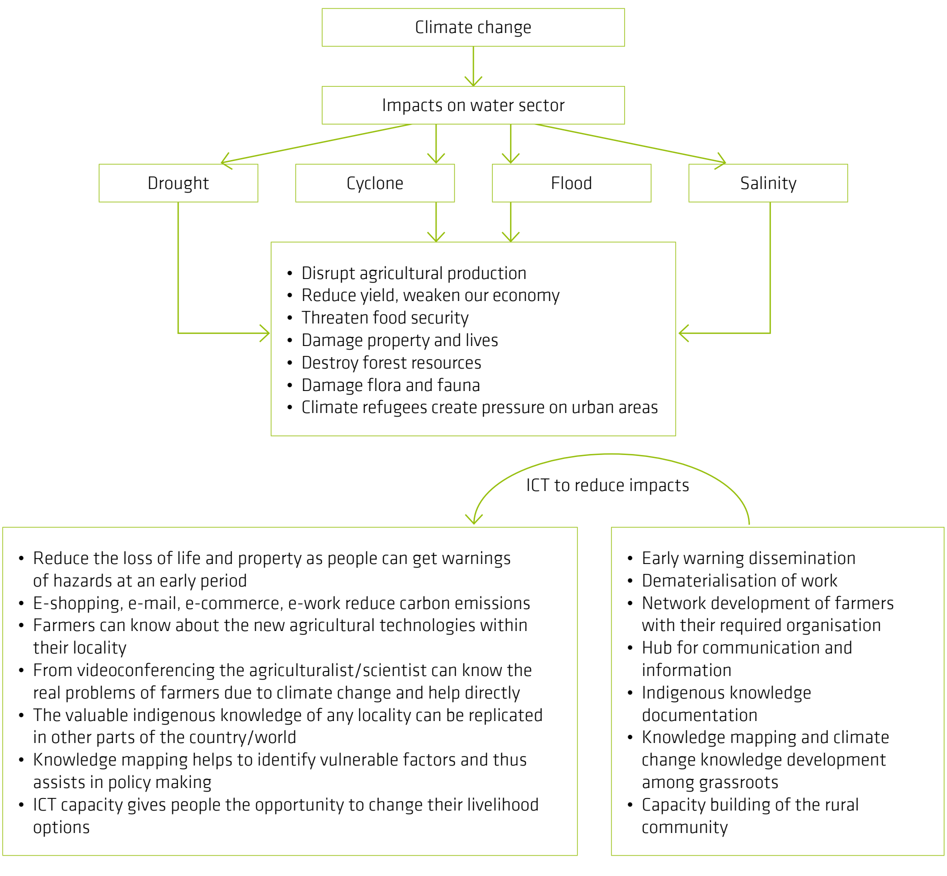
Early-warning services from Climate Care Centres

Rapid response to early warning systems can significantly reduce the loss of life and property. The project aims to improve the reach and timeliness of these systems.

- *Dissemination of early warnings*: ICT content will be developed to send early warning information through SMS text messages to the mobile phones of stakeholders before disasters occur. Collaboration may be established with community leaders to disseminate the early warnings in an organised way.
- *Collaboration with disaster management programmes provided by the government:* The centres would provide necessary information to disaster management programmes, such as the Cyclone Preparedness Programme, through mobile phone/internet to enhance disaster preparedness activities.

FIGURE 1

BFES activities to combat climate change



Source: Nelson et al. (2007)

Adaptation knowledge documentation and dissemination

- *The development of a knowledge base*: Food security is a major challenge for Bangladesh. To cope with the changing environment farmers need up-to-date information. Farmers will receive up-to-date information that is relevant to their agricultural activities in collaboration with the government of Bangladesh. Farmers will be able to learn about soil types, suitable crops, including those that can adapt to a changing environment, and rainwater harvesting techniques.
- *Indigenous knowledge collection:* Local-level climate risk and adaptation content will be developed through consultation with local communities and will be disseminated through ICTs and community meetings. Participatory rural appraisal and focus group discussions will be used. These meetings would be opportunities for information sharing on climate issues and would help local communities shape the future direction of the project.

Interactive web portal and network development

- *Website development for the centre:* The project will develop a unique website which may be linked to related government websites. All information generated through the project will be uploaded to the project website.
- *Database preparation:* All surveyed data would be assimilated into a database, allowing the government to gain grassroots-level information whenever needed. The information would be converted to GIS maps, which will graphically show existing situations.
- *Network development:* To provide appropriate information to farmers and other stakeholders the centres will build a strong network with the Ministry of Agriculture, the Soil Research Development Institute (SRDI) and other similar organisations mentioned above.

Outcomes

- Climate Change Communication Centres have been established.
- People living in remote areas are able to access the internet through the centres.
- Weather/crisis information is provided using the internet. ■

For updated project information

Contact person: Reza Salim (BFES)
Email: info@amadergram.org

APPLICATION OF ICTS FOR CLIMATE CHANGE ADAPTATION IN THE WATER SECTOR

Developing country experiences and emerging research priorities

Editors: Alan Finlay and Edith Adera

The potential of information and communications technologies (ICTs) to help communities adapt to climate change is increasingly being recognised. This book investigates this potential in the water sector. It includes theoretical considerations for project decision making, regional explorations of the application of ICTs in contexts of water stress in Latin America and the Caribbean, Africa and Asia, as well as emerging research questions in the field. Several case studies are also included to highlight the application of technology in communities and water projects.

The reports gathered here should be considered exploratory, and are written primarily from the perspective of the ICT for development sector. To this extent they break new ground, and flag key areas for further investigation in a growing concern with the sustainability of natural resources globally.

ISBN 978-92-95096-43-1