The ICTs, Climate Change Adaptation and Water Project Value Chain: *A Conceptual Tool for Practitioners*

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2012

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The research presented in this publication is the result of work commissioned by the International Development Research Centre (http://www.idrc.ca) and the Association for Progressive Communications (http://www.apc.org), which had the key objective of informing the research support agenda of the IDRC in the field of ICTs, climate change and water. It has also been published as a chapter in the book "Application of ICTs for Climate Change Adaptation in the Water Sector".

Executive Summary

Water resources are one of the cornerstones of socio-economic 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 communication 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 paper 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 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 document 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, July 7th-10th 2011[2]); and on research conducted by the authors in the field of ICTs, climate change, water and development.

[1] The paper draws upon principles from the sustainable livelihoods approach (SLA), the ICT4D Value Chain, and the concepts of digital poverty and adaptive capacity.
[2] Further information about the workshop is available at: http://ccw.apc.org/

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 ito 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.

1. 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 (IDB, 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, 2007). 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 (Cliche and Saravia, 2011; Shaw, 2011; Ochola and Ogada, 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.

1.1. 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

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[3] ICTs are defined as technologies that process or communicate digital data (Heeks & Leon, 2009b).

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, 2003; Parry et al., 2007; 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 (IDB, 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, 2009). It 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 (IDB, 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, 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 (FAO, 2008; Ludi, 2009).

- **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, socio-economic 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 climatic stimuli and events, in order to alleviate its impacts or take advantage of the opportunities that may arise from change – 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.

2. 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, 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 in section 1.1:

(a) **Adaptation to Changes in Water Supply**, relates to changes in precipitation patterns, loss in snowcaps, 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 on water reservoirs, irrigation systems, capacity expansions, levees and wastewater treatment facilities, among others.

(b) **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).

(c) **Adaptation to Changes in Water Availability**, addresses water deficit at the national and sub-national 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.

(d) 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 multi-stakeholder 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.

(e) 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 constitutes 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 (UNCTAD, 2009; UNCTAD, 2010; ITU, 2011) have been linked to improved access to development opportunities, employment and income generation, and broader access to health, education and government services (ibid).

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.

2.1. ICTs and Water Resources Adaptation

While the impact of climate change and climate variability on water resources is well documented (IPCC, 2001, IPCC, 2007, UN-Water 2010), less is know 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 modify 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 (IHP, 2011). ICTs' potential in this area includes enabling cross-sectoral and interdisciplinary 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.

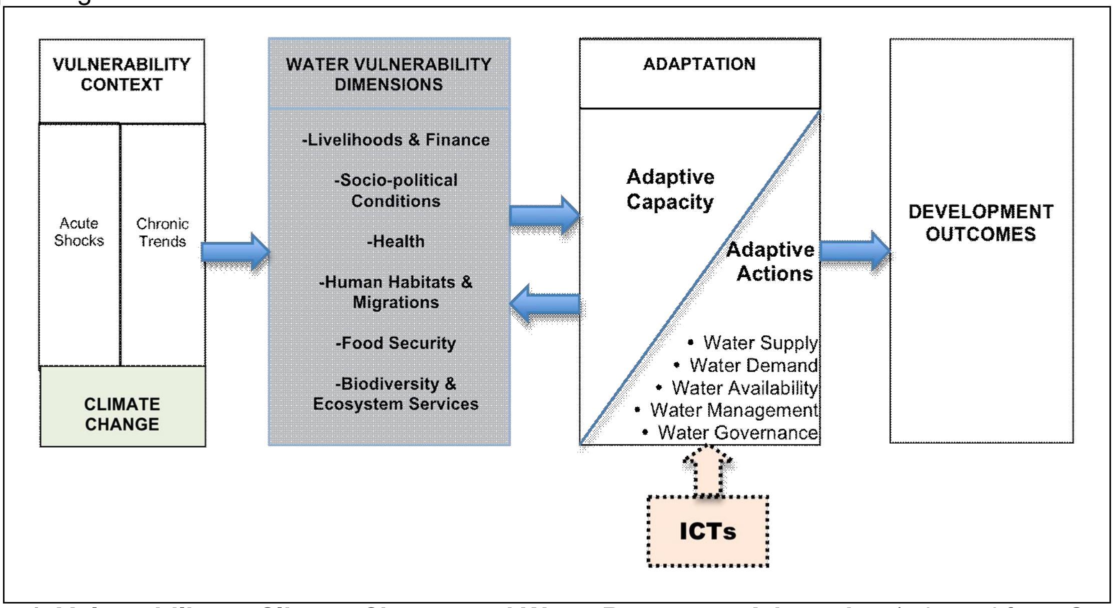

Figure 1. Vulnerability to Climate Change and Water Resources Adaptation (adapted from Ospina & Heeks, 2010).

As reflected in Figure 1, both adaptive capacity and adaptive actions are closely linked, yet distinctive components of adaptation. This distinction is linked 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, p.5), 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 (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.

3. 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.

3.1. 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 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 to 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, 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.

3.2 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 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.

(a) 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.

(b) 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 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

[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.

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.

(c) Project Evaluation

This stage constitutes the last of the project value chain, and involves the assessment of ICT's impact. This can be divided out 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) (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, the affordability and the accessibility of ICT tools at the individual, the community and the national levels, constraining their potential use in achievement of adaptation and development outcomes.

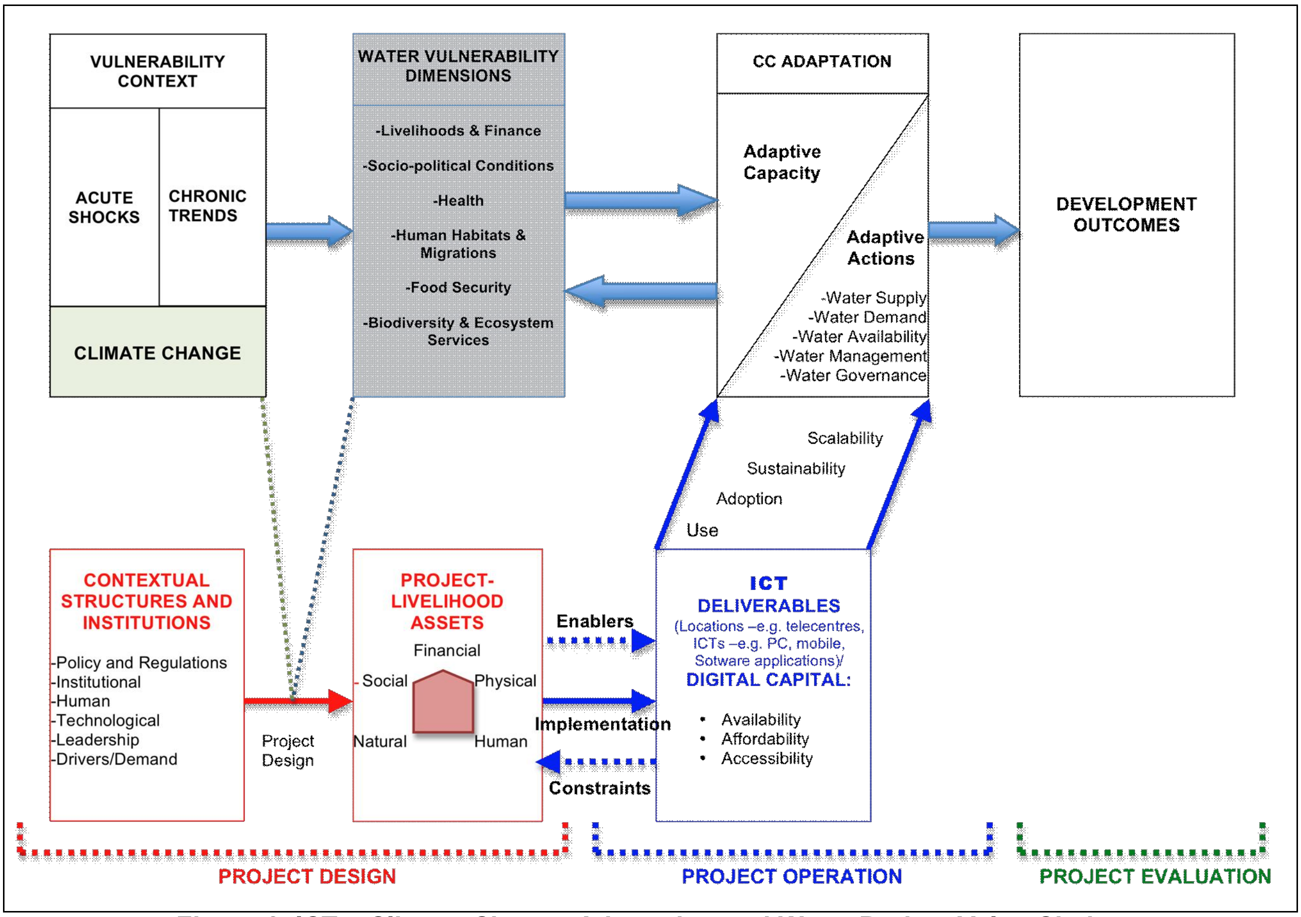

Figure 2. ICTs, Climate Change Adaptation and Water Project Value Chain

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 in section 1.1, 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 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.

[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).

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; 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 ICTs' use 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.

4. 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 on 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.

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