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Perspectives on water and climate change adaptation

Environment as infrastructure – Resilience to climate change impacts on water through investments in nature

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This Perspective Document is part of a series of 16 papers on «Water and Climate Change Adaptation»

'Climate change and adaptation' is a central topic on the 5th World Water Forum. It is the lead theme for the political and thematic processes, the topic of a High Level Panel session, and a focus in several documents and sessions of the regional processes.

To provide background and depth to the political process, thematic sessions and the regions, and to ensure that viewpoints of a variety of stakeholders are shared, dozens of experts were invited on a voluntary basis to provide their perspective on critical issues relating to climate change and water in the form of a Perspective Document.

Led by a consortium comprising the Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), IUCN and the World Water Council, the initiative resulted in this series comprising 16 perspectives on water, climate change and adaptation.

Participants were invited to contribute perspectives from three categories:

1 **Hot spots** – These papers are mainly concerned with specific locations where climate change effects are felt or will be felt within the next years and where urgent action is needed within the water sector. The hotspots selected are: Mountains (number 1), Small islands (3), Arid regions (9) and 'Deltas and coastal cities' (13).

2 **Sub-sectoral perspectives** – Specific papers were prepared from a water-user perspective taking into account the impacts on the sub-sector and describing how the sub-sector can deal with the issues. The sectors selected are: Environment (2), Food (5), 'Water supply and sanitation: the urban poor' (7), Business (8), Water industry (10), Energy (12) and 'Water supply and sanitation' (14).

3 **Enabling mechanisms** – These documents provide an overview of enabling mechanisms that make adaptation possible. The mechanisms selected are: Planning (4), Governance (6), Finance (11), Engineering (15) and 'Integrated Water Resources Management (IWRM) and Strategic Environmental Assessment (SEA)' (16).

The consortium has performed an interim analysis of all Perspective Documents and has synthesized the initial results in a working paper – presenting an introduction to and summaries of the Perspective Documents and key messages resembling each of the 16 perspectives – which will be presented and discussed during the 5th World Water Forum in Istanbul. The discussions in Istanbul are expected to provide feedback and come up with sug• gestions for further development of the working paper as well as the Perspective Documents. It is expected that after the Forum all docu• ments will be revised and peer-reviewed before being published.

2 Environment as infrastructure: Resilience to climate change impacts on water through investments in nature

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Environment as infrastructure: Resilience to climate change impacts on water through investments in nature

Impacts of climate change, in combination with other drivers of global change, are compromising our ability to address global economic, security and social priorities. As floods, drought and other impacts of climate change on water become more frequent or intense, economies and livelihood security will weaken. Adapting to such impacts by building resilience is integral to addressing these global priorities. As water is at the centre of climate change impacts, this demands a focus on resilience to impacts on water. The environment has a critical role in building resilience to climate change and reducing vulnerabilities in communities and economies. Well-functioning watersheds and intact floodplains and coasts provide water storage, flood control and coastal defence. They are 'natural infrastructure' for adaptation.

Reducing vulnerability to climate change requires a combination of reduced exposure to hazards, reduced sensitivity to their effects and increased adaptive capacity. In each case, the environment, its natural infrastructure and related institutions and governance have key roles to play. Experience from river basins around the world shows that exposure to hazards can be reduced through environmental means. Risk of flooding, for example, can be lessened by restoring floodplains; risk of drought can be minimized by preserving wetlands and groundwater recharge areas; and risk of coastal erosion can be reduced by protecting mangroves. Sensitivity is reduced by using sustainable river basin management to expand livelihood assets and enterprise opportunities. Critically, adaptive capacity is built through water and natural resource governance that builds flexible and coordinated institutions and dissemination of knowledge needed to empower people in planning and decision-making about adaptation. Investing in natural infrastructure and adaptive institutions provides water storage, flood control and coastal defence, while building self-organisation and learning that are characteristics of resilience needed to deal with uncertain future events.

Any rush to invest in engineered infrastructure needs to be reconsidered. The danger of maladaptation – for example infrastructure that weakens resilience – needs to be assessed. All infrastructure options must be on the table, whether engineered or natural. Policymakers need to consider portfolios of approaches that support local actions, development of engineered infrastructure where appropriate and investments in natural infrastructure. Resilience increases where the natural infrastructure of river basins is in place and where basin institutions empower self-organisation and learning. To ensure effective action on global economic, security and social priorities, resilience to climate change impacts on water is vital. With resilience as a goal, natural infrastructure must be central to effective strategies for climate change adaptation.

1 Impacts of Climate Change on Water: Why Does the Environment Matter?

Economic, security and social issues dominate the global political agenda and dictate the parameters of global policy dialogue. At a time of extreme volatility in food and energy prices, concerns over food security and energy security bring demands for rapid response and structural change from world leaders. Governments are scrambling to relieve severe strains in a world financial system increasingly shaped by globalisation and the rapid industrialisation of emerging economies. For the nearly 3 billion people worldwide living on less than $2 per day, above all, the Millennium Development Goals (MDGs) and escaping poverty are the priority (WRI, 2008). Societies are trying to respond and build progress – but doing so in the face of myriad competing and conflicting interests, and in an era of unprecedented global change driven by population growth, urbanisation, deforestation and climate change.

Climate change holds many dangers – and water is at the centre of its impacts. Climate change is expected to bring more frequent drought and floods, and alongside them, more frequent severe storms. The retreat of mountain glaciers, in the Andes and Himalayas most critically, is expected to increase risk of disaster because of flooding and mudslides, and to reduce availability of freshwater in mountain rivers in the long term. Sea-level rise will bring a higher risk of coastal inundation and erosion. Expected impacts among regions vary, but globally the numbers of people living with water scarcity is expected to climb from 1.7 billion to 3.2 billion by 2080 (IPCC, 2008).

These impacts of climate change, in combination with other drivers of global change, are compromising our ability to address global economic, security and social priorities. Floods, drought, storms, loss of land-based ice and sea-level rise lower the resilience of communities and economies. Resilience is the amount of disturbance that can be withstood before a system changes its structure and behaviour – before, for example, it breaks down (Folke et al., 2004). In the case of a resilient community, rapidly rising food prices might have little impact on economic growth, household consumption or public health, but they are much harder to cope with and may lead to social and economic disorder where resilience is low. Unless steps are taken to build resilience, climate change may mean less capability to cope with other stresses as their effects mount. Where floods or drought become more frequent because of climate change, they weaken economies and livelihood security (World Bank, 2006). When crisis then strikes – because of higher food prices, or financial system breakdown, or conflict – people are less able to cope and goals for food and energy security, economic growth or poverty reduction recede (IISD/IUCN/SEI, 2003). Adapting to climate change by building resilience to climate change impacts is therefore integral to addressing global priorities for security and development. As water dominates these impacts, this demands a focus on resilience to impacts on water.

The importance of water in mediating the myriad impacts of climate change has the effect of creating 'hot spots' of vulnerability. These are the places and regions of the globe where susceptibility to adverse impacts of climate change is high. Susceptibility is high in these locations because of exposure to hazards such as floods and drought or storm surges and because of sensitivity to their effects. These hot spots are the highest priority locations for adaptation, and include:

- low-lying deltas and coastal mega-cities – where higher frequency of flooding and coastal inundation will have the most acute impacts
- drylands – where susceptibility to more severe or more frequent water scarcity is high because of threats to food security, health and economic development
- small islands – where sensitivity to coastal erosion, inundation and salt-water intrusion is high at community and national levels
- mountains and their rivers – where retreat of glaciers and reduction in the size of winter snow packs will increase disaster risk and shift the volume and timing of downstream water availability for irrigation, industry and cities.

In the case of each hot spot, the critical question to be addressed is: How can vulnerability to the hazards faced be reduced?

From an environmental perspective, a related question is: Why does the environment matter? What difference does the environment make to resilience in communities and economies and to vulnerability to climate change?

One reason that the environment matters is that climate change impacts pose grave threats to biodiversity, threatening catastrophic loss of species in some regions of the world (Thomas et al., 2004). It is clear, therefore, that finding ways to reduce these threats needs to be a high-priority for adaptation strategies. However, it is just as important to focus on the role of the environment in providing solutions to climate change adaptation, not just the threats that the environment faces. There are links to resilience, which accord the environment a critical role in climate change adaptation.

There are numerous options for adapting to climate change impacts on water, and there are a variety of enabling mechanisms which need to be developed and coordinated for adaptation to be effectively implemented. Coping with floods, drought, storms and sea-level rise will depend on water storage, flood control and coastal defence. However, providing these functions simply by building infrastructure – such as dams, reservoirs, dikes and sea walls – will not be adequate. By itself such engineered infrastructure can weaken resilience, especially in a changing climate where the historic hydrology is no longer a viable guide to the future, because of damage caused to livelihoods and the environment (Palmer et al., 2008). Indeed, the environment has a critical role to play. Well-functioning watersheds and intact floodplains and coasts, likewise, provide water storage, flood control and coastal defence. Thus, the environment itself is infrastructure for adaptation – it is 'natural infrastructure'. Furthermore, when based on principles of good governance, sound investment strategies and learning from integrated water resources management, integrating natural infrastructure into adaptation builds resilience (Nelson et al., 2007)

2 Why Does the Environment Help to Reduce Vulnerabilities to Climate Change?

2.1 Ecosystem Services

Ecosystem services are "the benefits people obtain from ecosystems" (MA, 2005). The implication is that where ecosystems are lost or degraded, so are the services from them that people use. Ecosystem services are commonly categorised as provisioning, regulating, supporting or cultural services (MA, 2005). As examples, supply of food and freshwater are provisioning services, flood attenuation is a regulating service, nutrient cycling is a supporting service and opportunities for recreation are cultural services. Of vital importance is the undeniable fact that human well-being can be damaged when these services are degraded, or else costs must be borne to replace or restore the services lost. The impacts of environmental degradation can be social and economic, and can be felt at community, river basin and national levels.

Ecosystem services are integral to the benefits people derive from the hydrological cycle and to protection against extremes. Consider a river system draining water from upland parts of a basin through floodplains to estuaries and into a coastal zone. Benefits to people of water moving through the basin are mediated by ecosystems and depend upon their integrity. Water is stored in soils, wetlands and lakes, from whence it can be used to satisfy human needs and for production. When flows are high, water spreads across the floodplain, reducing downstream flooding and feeding recharge to underlying groundwater bodies. In estuaries and along the coast, sediments carried by the river replenish those lost through natural coastal erosion, reinforcing protection of the coast. Throughout the basin, soils are held in place by vegetation, whether natural or cultivated.

In principle, the integrity of a river basin and the ecosystems within it smooth and buffer the river's hydrograph. Extremes of flood and drought are attenuated by retention of water in soils and surface water bodies and by slowing of flow on the floodplain, and by maintenance of base flow through drainage of soils and seepage from groundwater. Degradation of the basin because of destruction of ecosystems leads to loss of these services. Clearing of vegetation and erosion of upland slopes, for example, means buffering of runoff by retention of water in soils is weakened, increasing the exposure of downstream communities to hazards from flash-flooding. Drainage and infilling of wetlands means natural water storage is lost and recharge of groundwater reduced, reducing dry-season flows and the options available for coping with drought. Where rivers are disconnected from floodplains by levees and channelisation, water is rushed downstream, raising exposure of towns and cities to flood peaks.

The structures and functions of ecosystems that combine to deliver these services and the benefits they provide for people comprise the natural infrastructure of a river basin. Without this natural river basin infrastructure, people lose benefits and are exposed to hazards and vulnerabilities they would otherwise be able to avoid or have protection against.

Examples of natural infrastructure in river basins abound. Deep, upland soils such as in the páramo grasslands of the Andes store water for use in downstream cities. Without this natural storage, more construction of dams and reservoirs would be needed (Buytaert et al., 2006). Forests in upper watersheds protect soils, retain water and stabilise slopes, reducing disaster caused by storms, as witnessed during Hurricane Mitch in Central America in 1998 when loss of life and economic costs were lower where forests remained intact (Girot, 2001). Mountain glaciers in, for example, the Andes and Himalayas are infrastructure that store and release water for use by downstream populations in agriculture and to sustain cities. Lakes, wetlands and aquifers are natural infrastructure which store water for use during drought. Intact floodplains reduce downstream flood peaks by giving rivers the space needed to dissipate peak flows. Such use of floodplains as flood control infrastructure, recognised, for example, in the Dutch policy of 'making room for the river' (V&W, 2006), has the benefit of reducing the extent and height of flood control infrastructure that must be engineered downstream. At the coast, mangroves, barrier reefs and islands protect against erosion and storm damage, but also attenuate tidal or storm surges, as witnessed in the Asian tsunami of 2004, where damage from coastal inundation was reduced where mangroves were intact (UNEP-WCMC, 2006).

Natural infrastructure has been fundamental to water resources management, and thus to management of climate variability and extremes, throughout history. As such, natural infrastructure has been a critical instrument of development, just as has engineered infrastructure, though usually unseen and uncosted, and therefore receiving much less investment. The focus on reducing water-related vulnerabilities brought by climate change requires, however, that there is new, explicit recognition given to the role of natural infrastructure.

2.2 Reducing Vulnerability

Vulnerability to climate change combines exposure to hazards that result from the changing climate and sensitivity to their impacts when they occur. Vulnerability is thus high if changes in climate increase the exposure of populations to events such as drought, floods or coastal inundation, because of higher frequency or severity, where the ability of people to cope is limited (Yamin et al., 2005). Capacity to cope is most limited, and thus sensitivity highest, where livelihoods and the economy are based on a narrow range of assets that are easily damaged by climate hazards, with few alternate options or means of managing risk. Vulnerability is therefore especially high for the poor in those 'hot spots' where climate change exacerbates exposure to climatic hazards.

If vulnerability is a combination of exposure and sensitivity, then reducing vulnerability demands actions which will: 1. reduce exposure to hazards, 2. reduce sensitivity to their effects, and 3. build capacity to adapt. The latter component, building adaptive capacity, enables communities and nations to mobilise the decisions and resources needed to reduce vulnerability and adapt to climate change (Nelson et al., 2007). Building adaptive capacity means strengthening attributes including the availability of information and skills, access to technologies, access to economic resources and the effectiveness of institutions (Munasinghe and Swart, 2005).

Given the importance of water in climate change impacts, water management and the water sector are fundamental to each of the three components of reducing vulnerability. With appropriate actions, water managers can reduce exposure to hazards, reduce sensitivity and build adaptive capacity. In each case, the environment, its natural infrastructure, and related institutions and governance have key roles to play. For example:

- exposure to flood is reduced by restoring the function of floodplains in combination with sound land-use planning, to drought by maintaining groundwater recharge, and to coastal erosion by protecting mangroves;
- sensitivity to climate hazards is reduced by using sustainable management of river basins to expand livelihood assets and enable economic development, such as through enterprise development related to wetland fisheries or agricultural diversification and agroforestry; and
- adaptive capacity is built through water governance that builds flexible and coordinated institutions, learning and dissemination of knowledge needed to empower people in planning and decision-making related to adaptation.

Natural infrastructure, and the strategies and actions used in associated environmental management, thus need to be integral to portfolios of adaptation measures and to adaptation strategies. If natural infrastructure is overlooked in favour of engineered infrastructure, opportunities to reduce vulnerability will be missed. Moreover, the benefits of ecosystem services for development and the adaptive capacity that can emerge from reform of water governance may be lost, eroding resilience.

3 Building Resilience to Climate Change Using Natural Infrastructure

3.1 Case Story: The Komadugu Yobe Basin, Nigeria

The Komadugu Yobe River is part of the natural infrastructure of northern Nigeria. Part of the Lake Chad basin, it can be counted among the dryland hot spots of vulnerability. With a semi-arid climate, rainfall variability is high and severe drought a frequent hazard. Deep poverty characterises the basin, where population has doubled in three decades to more than 23 million. Over this same time, flow in the Komadugu Yobe has fallen by 35%, due to the combined effects of the construction of two dams since the 1970s, abstraction of water for large-scale irrigation and regional drying of the climate. A society already under social and economic crisis has thus been facing ever-increasing water stress. The river itself has been severely degraded, as the natural cycle of seasonal flows has been replaced by perennial low flows, causing loss of the services from riparian and wetland ecosystems that communities have historically relied on. Fishing, farming and herding livelihoods have been devastated as a result, because fish habitats are choked with invasive weeds, floods used by farmers to fill their soils with water are small or absent, and scarcity of water has led to conflict. The natural infrastructure of the river has been damaged, and as a result communities living with drought hazards are less able to cope. With further climate change looming, the adaptive capacity of ecosystems and communities of the Komadugu Yobe have become brittle, just when resilience is most needed.

Crisis in the Komadugu Yobe basin has led to change. Restoring the river basin's natural infrastructure has become a source of adaptive capacity and renewed resilience. With the six federal Nigerian riparian states unable to coordinate development of water resources in the basin, and with the number of cases of conflicts over land and water resources reaching court running into the hundreds each year, the dysfunctional state of the river had become a barrier to pursuing the Millennium Development Goals in the basin. Beginning in 2006, the federal and state governments and stakeholders, including dam operators and farming, fishing and herding communities, came together to negotiate a plan for coordinating and investing in restoration and management of the basin. In addition to agreeing on a Catchment Management Plan, they drafted a 'Water Charter', spelling out the agreed principles for sustainable development of the basin and the roles and responsibilities of governments and stakeholders. Reform of water governance is enabling transparent coordination of water resources development, including remediation of degraded ecosystems and, eventually, restoration of the river's flow regime. Dialogue has reduced the number of cases of conflict to just a handful per year and governments have pledged millions of dollars in new investment for basin restoration (KYB Project, 2008).

Change achieved in the Komadugu Yobe basin has increased capacity to address critical constraints in development, such as water scarcity, conflict and degradation of natural resources. Under the agreed management plan for the basin, actions are underway to restore ecosystem services and rebuild the natural infrastructure used to cope with drought and sustain the livelihoods and enterprise development needed to reduce poverty. The new institutions and empowerment of stakeholders to participate in planning and management of water resources provide flexible capacity to respond to stresses and shocks that was missing in the past.

Where resilience in the Komadugu Yobe was weakening, it is now strengthening. Ability to adapt in the basin was spiralling downward as the structure and function of the basin – in terms of hydrology, ecology, and social development – degraded. There is promise that the spiral is now slowing and reversing, with much greater capacity for self-organisation than there was previously. Myriad problems remain and barriers to reduced poverty and increased food and water security are profound. These include lack of financial resources, access to technology, skills and knowledge including hydrological and climate information. However, with the changes underway in the basin, governments and communities are acquiring capacities to both learn and to cope with uncertain future events.

So, for the Komadugu Yobe, what difference does the environment make to vulnerability to climate change? Restoration in the basin rebuilds ecosystem services that help to reduce exposure to climatic hazards, but especially, it helps to ensure people have more of the assets needed to make fishing, farming and herding livelihoods less sensitive to climate change. Just as importantly, however, the learning, flexible institutions and investment that underpin effective management and restoration of a river basin's natural infrastructure provide vital adaptive capacity that is based on resilience (Nelson et al., 2007).

3.2 Integrating River Basin Management into Adaptation Decisions

The experience of the Komadugu Yobe is repeated in other river basins globally. The Worldwide Fund for Nature reported in 2008 how investment in the natural infrastructure of river basins and adaptive governance is reducing vulnerability to climate change (Pittock, 2008), including in:

- the Lower Danube, Eastern Europe – where increases in flooding are projected, restoration of floodplains has increased flood storage, diversified livelihood options and reconnected habitats;
- the Great Ruaha River, Tanzania – where greater water scarcity is expected, strengthening of local Water User Associations and basin management institutions has increased water use efficiency by communities, diversified livelihoods and enabled use of hydrological and climate information in decision making;
- the Yangtze Lakes, China – where likely climate change impacts include increased flooding, restoration and reconnection of 450 km^2 of lakes has enabled retention of 285 Mm^3 of floodwaters while increasing fisheries production by 15 %;
- the Rio Conchos, Mexico – where a drying climate is projected, establishment of a multi-stakeholder institution for adaptive management of the basin has led to reduced demand for water and development of conjunctive management for surface and ground waters that expand options for coping with drought;
- the Rio São João, Brazil – where climate change is expected to exacerbate pollution of coastal lagoons, new and adaptive multi-stakeholder institutions have led to a 75 % cut in wastewater discharge, investment in wetland restoration and the prospect of resurrection of the regional fishing and tourism industries.

These examples demonstrate how adaptation that is based on resilience directly integrates reduction in exposure to hazards, reduction in sensitivity to impacts and increase in adaptive capacity. The keystones in practice are natural infrastructure which lower exposure and sensitivity and flexible multi-stakeholder institutions which strengthen and widen adaptive capacity.

River basins and river basin management thus have important benefits for climate change adaptation, but a key challenge is to ensure that effective approaches for gaining these benefits are incorporated into decision making and financing. There is a continuum of decision-making on adaptation which begins with reducing vulnerabilities by adopting best practice. There are then 'climate-justified actions' to be considered which focus on specific vulnerabilities and management of climate risks. These actions vary broadly among vulnerability hot spots, depending upon expected impacts of climate change on water scarcity, floods, disaster risk or sea-level rise. Finally, there are decisions to be made which relate to future unknowns, where scientific understanding is weak or absent.

River basin management is relevant across the continuum of decision making on adaptation. At the level of best practice, implementing integrated water resources management (IWRM) is a vital, no-regrets strategy where poor water management exacerbates climate vulnerabilities, particularly in developing countries or where there is severe degradation of land and water resources. Specific vulnerabilities are addressed through application of specific strategies devised to target water-related climate risks. Finally, well-functioning natural infrastructure and adaptive governance impart characteristics of resilience needed to deal with uncertain future events.

Decision makers will increasingly confront the reality that, yes, the environment does matter in climate change. This is not only because ecosystems are themselves threatened by climate change impacts but because the tools for management of the natural infrastructure of river basins are also tools for adaptation. What strategies will make these tools most effective?

3.3 Ecosystem-Based Adaptation

An 'ecosystems approach' to development is advocated in many strategies for conservation and sustainable development (Shepherd, 2004). It is built on policies and practices that succeed in addressing the needs of people and the environment through participation in negotiated decisions and through adaptive management. Application of an ecosystems approach to water management has been tested in river basins in different regions and climatic settings around the world. Results have demonstrated the benefits for reducing climate vulnerabilities and strengthening resilience. The lessons from these demonstrations show how tools from ecosystem-based approaches can be used in strategies for climate change adaptation (Bergkamp et al., 2003).

For example, in the Pangani River Basin in Tanzania, over-allocation of water is making water scarcity worse. The 3.4 million people of the basin are vulnerable to projected drying of the climate. With identification of this vulnerability, and backed by a national water policy based on the principles of IWRM, efforts are underway to implement 'environmental flows'. This is an ecosystem-based method for allocating water within the limits of availability, based on negotiation among stakeholders of allocations to different uses and to sustaining ecosystem services (Dyson et al., 2003). Implementation entails developing and coordinating decision-making over water allocation at local to basin scales. Institutional strengthening is thus key, as a means of enabling diverse stakeholders to participate in the discovery of options, in learning and in joint action. Both reduced vulnerability to water scarcity and resilience emerge from this process. Allocation of water to sustain natural infrastructure, such as wetlands and estuary habitats, and adaptive governance provide capacity to deal with uncertain future events.

A second example is from Guatemala, in the high-altitude upper watersheds of the Coatán and Suchiate rivers, which flow off the slopes of the Tacaná volcano to the Pacific Ocean. These watersheds have been deforested and are badly degraded in many places, with severe erosion of formerly deep soils reducing capacity for water retention. Population is high in the upper watersheds and degradation in the environment has led to a narrowing of livelihood options. Communities in the upper and lower watersheds are vulnerable to flooding caused by storms that bring high rainfall intensity, especially tropical storms and hurricanes. Flooding risk is exacerbated by the lost water-storage capacity of the eroded soils which leads to increases in the volume and rate of runoff. Disaster preparedness is a high priority for authorities in strategies for managing climatic variability and climate change adaptation. In addition, communities have formed multi-stakeholder 'micro-watershed councils' that coordinate watershed management among small groups of villages. Driven by the need to expand livelihood options to reduce poverty, these new institutions have led to diversification of farming systems, including terracing of degraded slopes and afforestation through the introduction of agroforestry. Communities are investing their labour and capital in restoration of natural infrastructure. As self-organisation expands, communities are becoming more resilient, with more adaptive capacity and – as new enterprises emerge out of diversification of livelihoods – less sensitive to specific climatic vulnerabilities such as severe storms.

Examples of ecosystem-based adaptation in river basins demonstrate important distinctions between investments in natural and engineered infrastructure. Engineered infrastructure such as dams and reservoirs, or irrigation and inter-basin transfers, lowers exposure, for example, to water scarcity, flood and food insecurity. Such schemes use top-down approaches; and capacities to cope with uncertain future events depend upon the technical tolerances incorporated into infrastructure design and operation. Investing in natural infrastructure can also be climate justified by targeting specific vulnerabilities and may require access to and adoption of new technologies. However, rather than top down, it is system-based. It benefits from vulnerability assessment and may require technologies and financing, but these are combined with capacity building and development of governance that is multi-stakeholder, flexible and adaptive. The quality of institutions complements the quality of technology. Multiple benefits can then emerge, with vulnerabilities reduced as exposure and sensitivity are lowered. Capacity to cope with future uncertainties then improves as system-based resilience rises.

3.4 Avoiding Maladaptation That Degrades Natural Infrastructure

Recognition of the critical role of natural infrastructure in adaptation to climate change impacts on water and resilience brings focus to the importance of preventing maladaptation. These are adaptations that, while addressing a specific vulnerability, end up lowering overall capacities to cope and eroding resilience. Maladaptation thus includes actions that cause natural infrastructure to degrade and weaken ecosystem services needed to lower exposure and sensitivities to climatic variability and change.

The story of the Komadugu Yobe river provides a warning of the dangers of maladaptation associated with infrastructure development that damages resilience. Capacity of communities to cope with stresses, shocks and future change fell after dams and irrigation development caused damage to the river and loss of ecosystem services. Such mistakes are liable to be repeated if the benefits of ecosystem services are not recognized in strategies for climate change adaptation. Any rush to engineer infrastructure for adaptation such as dams, levees, dikes and sea-walls needs to be reconsidered. Instead, comprehensive and resilience-based strategies for infrastructure development are needed which combine sustainable and appropriate investment in portfolios of both engineered and natural infrastructure.

4 Conclusions

Why does the environment matter in climate change adaptation? As water dominates the impacts of climate change, it matters because of the ecosystem services provided by the natural infrastructure of river basins. Healthy rivers, lakes and wetlands, functional floodplains, natural estuarine and coastal structures and groundwater recharge all reduce exposure to climatic hazards. They support livelihoods and economic development that reduce sensitivity to hazards, especially for the most vulnerable. In the hot spots of vulnerability, populations will cope better with climate change impacts on water where natural infrastructure is intact or restored than where it is degraded.

Where management and restoration of river basins and their natural infrastructure is based on multi-stakeholder governance and learning, it builds adaptive capacity. Investing in the institutions needed for flexible, participatory and adaptive management of the environment gives communities – and nations – the means to negotiate and mobilise the decisions needed to reduce vulnerability to climate change.

River basins are more resilient where natural infrastructure provides a diversity of ecosystem services and where institutions empower self-organisation and learning among multiple stakeholders. Such resilience extends to biodiversity because – by reinforcing ecosystem structure and function – ecosystem-based adaptation helps to reduce or delay threats to biodiversity from climate change. Climate change adaptation within a resilience framework will strengthen capacities to cope with uncertain future events. This is vital in a changing climate, when the past is no longer a reliable guide to future climate or hydrology and there is thus a severe lack of adequate information at the scales needed to support decision-making.

There is no claim that natural infrastructure is the sole answer to climate change adaptation. What is needed are portfolios of local actions which include engineered infrastructure (where appropriate and justified) and investments in natural infrastructure. However, dangers arise when adaptation policies fail to incorporate natural infrastructure. Without attention to natural infrastructure and appropriate investments, unforeseen impacts of engineered infrastructure development can increase vulnerabilities and weaken resilience through maladaptation.

In practical terms, policy makers need to be encouraged to ask some critical questions about the environment when developing policy on climate change adaptation:

- how can adaptation ensure economic and social resilience?
- what is the critical national natural infrastructure for climate change adaptation?
- what is the full range of infrastructure options for adaptation – including both engineered and natural infrastructure?
- what investment is needed in natural infrastructure – in term of restoration and management as well as adaptive institutions?
- what infrastructure options are most cost effective – whether natural or engineered – in terms of short-term benefits and long-term resilience?
- what packages of local actions, natural infrastructure and engineered infrastructure will be the best choice and need to be encouraged?

Such questions need to be part of the analysis of policies on climate change adaptation. They need to be asked while placing climate change and adaptation in the context of the economic, security and social priorities that dominate the global political agenda. With climate change weakening capacity to cope with shocks and stresses and thus to address these priorities, a key is for climate change adaptation to increase resilience. With resilience as a goal, the natural infrastructure and the ecosystem services it provides must form the heart of effective strategies for climate change adaptation.

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