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Effects of Climate Change on Water Pollution in Developing Countries

Omolade O. Maigari A.U. And Sambo S.M.

Chemistry Department, School of Science Education, Federal College of Education (Technical) Gombe
P.M.B 060, Gombe, Gombe State Nigeria
E-mail: sanimsambo@hotmail.com

ABSTRACT
This paper dwelled on the Effects of climatic changes in Africa, in relation to factors such as population growth, unequal access to resources, food insecurity, poor health systems and poverty. These conditions will increase the vulnerabilities of many people in Africa. Further, Africa's low capacity in science, technology and innovation will further deepen the vulnerability and effects of climate change on water resources. African countries need to face the challenge holistically through science, technology and innovation, and establish appropriate governance, policies, regulations and measures to adapt to the challenges posed by climate change, especially as they affect water resources. It is essential to ensure greater resilience by keeping an audit or inventory of water resources with the aim of tracking the effects of climate change.
Keywords: Key words are Climate change, African water supply and food security.

1. Introduction

Water is life. This is a popular axiom in Africa, underpinning the high level of importance the people of the continent place on the resource. In all its forms: rainwater, aquifers, streams, ponds, springs, lakes, rivers, ocean water, snowpack ice and water vapour – water is an essential and central resource. Just as water is essential to life, so is the climate, which is a necessary factor that influences the availability of water, as such, changes in climate could bring about changes in water supply. The consequence of such changes can escalate to the point of drought; as in the case of excessive dryness and heat, or to the point of drastic float; as in the case of excessive rain.

Climate change is having a multitude of immediate and long-term effects on quality of water resources in developing countries especially Africa. These include flooding, drought, sea-level rise in estuaries, drying up of rivers, poor water quality in surface and ground water systems, precipitation and water vapour pattern distortions, and snow and land ice mal-distribution. These effects when compounded together have devastating effects on ecosystems and communities, ranging from economic and social effects to health and food insecurity, all of which threaten the continued existence of many regions in Africa. Vulnerability varies according to individual countries, geographical positioning and the capacity to mitigate or adapt to the changes. Coping, adapting and building the resilience capacities of African countries towards the effects of climate change on water resources requires a holistic approach involving systems thinking and risk management strategies. Solutions pivot on taking urgent action to utilize science technology and innovation, policies relevant to water audit and management, and engagement of private, civil and international sectors if a major crisis is to be averted. Many countries in Africa live under water stress, defined as those using more than 20 percent of their renewable water resources (WBGU 2003), while withdrawals of over 40 per cent mean serious water stress (Pittock 2005). For example, reports show that water withdrawal in Nigeria during the 1990s was 28 cubic metres per person per year (Gleick 2000 & World Bank 2003). The international Dialogue on Water and Climate (2004) noted that water stress will increase significantly in those regions that are already relatively dry (such as sub-Saharan Africa).

Further, a region is in a state of high water-related criticality (susceptibility of a region or its population to crises) if water scarcity coincides with a low problem-solving capacity of the population (WBGU 1998). About 25 per cent of the contemporary African population experiences water stress, while 69 per cent live under conditions of relative water abundance (Vörösmarty et al., 2005), but abundance does not necessarily mean availability.
Relative abundance does not take into account other factors such as the extent to which that water is potable and accessible, and the availability of sanitation. According to UNEP (2003), about 1,100 million people do not have

access to clean drinking water, and contaminated water is the cause of 5 million deaths every year, with the majority of these in sub-Saharan Africa.

Countries in sub-Saharan Africa are likely to suffer the most devastating effects of climate change because of their geographical location, low incomes, low technological and institutional capacity to adapt to rapid changes in the environment, as well as their greater reliance on climate-sensitive renewable natural resources sectors such as water and agriculture (Eboh 2009).

African countries are particularly susceptible to climate change due to the desertification process, declining run-off from water catchments, declining soil fertility, dependency on subsistence agriculture, the prevalence of AIDS and vector-borne diseases, inadequate government mechanisms and rapid population growth (Anyadike, 2009). More than 70 per cent of those living in African, Caribbean and Pacific (ACP) countries work in the agricultural sectors: for these people, understanding and responding to climate change is not a theoretic discussion, it is the difference between life and death (Spore 2008).

Observational records and climate projections provide abundant evidence that water resources are vulnerable and have the potential to be strongly affected by climate change, with wide-ranging consequences for human societies and ecosystems (Bates et al. 2008). Numerous internal and external feedback paths occur between anthropogenic impairment of the water cycle and the environmental resources of the atmosphere, soils and the biosphere. Even without the additional stress of climate change, water security already is one of the most pressing issues in developing countries (WBGU 1997). In many cases, water crisis can be traced back to a failure of state control, and therefore to crisis in governance (UNESCO 2003).

According to climate model analyses, the number of people at risk due to water scarcity increases rapidly with rising temperatures towards the second half of the century, with effects in arid and semi-arid regions expected to be much larger than the global averages suggest (IPCC 2001& Parry et al. 2001). Thus in regions already under water stress today, including Africa, climate change will exacerbate the situation. For many of the water-distressed regions, global mean temperature increases above 1.5ºC are identified as leading to decreases in water supply and quality (IPCC, 2001). Bates et al. (2008) reported that warming over several decades has been linked to changes in the large-scale water cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and

extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. In other words, the challenges related to water resources are: having too much of it, having too little of it, and having un-usable resources (e.g. due to pollution or stagnation). Each of these problems may be exacerbated by climate change. Available evidence has proved that looming climate changes are already having serious consequences on the water resources of most African countries, even when the continent of Africa contributes insignificantly to the greenhouse gas emissions responsible for these changes. For example, the whole of sub-Saharan Africa accounts for only 1.59 per cent of the global greenhouse gas emission (Spore, 2008). Understanding the African-climate change-water resources nexus will provide great opportunity to proactively address the situation and chart the way forward for sustainable water resource use in Africa.

The pertinent questions to ask therefore are: what are the effects of this entire climate

changes scenario on water resources? What effect does climate change have on Africa's water resource systems? Are there clear manifestations and evidence-based effects/impacts of climate change on the water resources across the African continent? What are the ways forward in Africa towards ensuring effective and efficient water resource management today, for sustainable water resource availability tomorrow, even in the face of climate change? In the following sections we explore these questions.

2. Effects of climate change on water resources in Africa

Observable and potential effects of climate change on water resources in Africa include: flooding, drought and change in the frequency and distribution of rainfall drying-up of rivers, melting of glaciers, receding of water bodies, landslides, and cyclones among others. These effects are summarized in Table 1 according to the major effects experienced in different African countries.

2.1 Flooding

For millennia, humans have settled in floodplains in order to till fertile soils, use the flat terrain for settlements, gain easy and safe access to water and use rivers for transport (Pavel 2003). Riverine floods are a natural phenomenon; they have always occurred, and populations have benefitted from them to whatever extent possible (for example, in ancient Egypt the natural annual flooding of the Nile brought much- needed nutrients to irrigated soils). In recent times, humans have become more exposed to flood risk as encroachment into flood plains and lack of flood response plans increase the damage potential. Much of Africa is vulnerable to flooding: flood is the most prevalent disaster in North Africa, the second most common in East, South and Central Africa, and the third most common in West Africa (AWDR 2006). Floods can occur in arid areas as well as humid areas. In tropical near-coastal regions, they generally result from cyclones that can drop a year's worth of rainfall in a

day. According to the BBC News (2007), about 14 countries, namely Burkina Faso, Chad, Ethiopia, Ghana, Kenya, Liberia, Mali, Niger, Nigeria, Senegal, Sudan, Togo, Uganda, and Rwanda, are the worst hit by flood in the African continent. Scores of people have died and hundreds of thousands have been displaced by the floods that have submerged much of the continent's most productive farmland, hence necessitating urgent food, shelter and medicare. In the same vein, episodes of flood accounted for 26 per cent of total disaster occurrences in Africa during 1971-2001 (Vordzorgbe 2003) with devastating effects. In North Africa, the 2001 disastrous flood in northern Algeria resulted in about 800 deaths and economic loss of about $400 million. In East Africa, the El Niño-related flood in 1997/1998 destroyed infrastructure and property worth about $1.8 billion in Kenya. In Mozambique, the 2000 flood (worsened by two cyclones), reduced the annual economic growth rate from 10 per cent to 4 per cent, caused 800 deaths, affected almost 2 million people of which about 1 million needed food, displaced 329,000 people and destroyed agricultural production land, among

other negative effects. The worst single episodes of flood in Africa occurred in East Africa: one event in 1997 killed 2,311 people in Somalia; another in 1999 affected 1.8 million people in the Sudan (AWDR, 2006). Floods across Africa are reported to be the worst in decades in some places and extend in an arc from Mauritania in the west to Kenya in the east. At least an estimated 1.5 million people are so far affected (World Food Programme, WFP, 2007). According to the Cable Network News, CNN (2009), torrential rains and flooding since June have affected 600,000 people in 16 West African nations. The worst hit have been Burkina Faso, Senegal, Ghana and Niger, where many lives and property have been lost to severe flooding events.

2.2 Drought

The term drought may refer to a meteorological drought (precipitation well below average), hydrological drought (low river flows and low water levels in rivers, lakes and groundwater), agricultural drought (low soil moisture), and environmental drought(a combination of the above) (Bates et al., 2008). The socioeconomic effects of droughts arise from the interaction between natural conditions and human-induced climate change factors such as changes in land use, land cover, and the demand for and use of water. In some cases the frequency of occurrence of droughts is exacerbated by human- induced changes in land cover. Excessive water withdrawals can increase the likelihood and effect of drought. Droughts have both direct and indirect consequences for human livelihoods (Pavel 2003). A direct consequence is crop loss, which can cause starvation if alternative food sources are not available. Indirectly, water shortages contribute to the spread of disease, because people lack water for basic hygiene. An example of a consequence of drought is shown in Figure 2, where nomads lost hundreds of their cattle due to drought.

Climate change is projected to increase the risk of drought over much of Africa in the
21st century. The regions where droughts have occurred seem to be determined largely by changes in sea surface temperatures, especially in the tropics, through associated changes in the atmospheric circulation and precipitation as seen in Table 1. Since the late 1960s, droughts have caused much suffering in Africa. Severe droughts were experienced in 1973 and 1984 when almost all African countries suffered reduced rainfall, which particularly affected several million people in the Horn of Africa, the Sahel and Southern Africa (AWDR 2006). Droughts are endemic in both Southern Africa and the Sahel region of western and northern Africa.

2.3 Water quality

Worldwide, climate-related warming of oceans, lakes and rivers has been observed over recent decades, with implications for freshwater ecosystems, such as changes in water salinity, water nutrient content, concentration of pesticides and other pollutants, salinization of groundwater, water chemistry and pH balance (Bates et al, 2008, Sommaruga-Wograth et al. 1997; Rogora et al. 2003; Psenner & Schmidt 1992).

With respect to fisheries and aquaculture, it has been projected that rising temperatures of around 1.5 to 2.0ºC will adversely affect fisheries in West African lakes (Christensen et al. 2007). In coastal regions that have major lagoons or lake systems, changes in freshwater flows and a greater inflow of saltwater into lagoons will affect inland fisheries or aquaculture (Cury & Shannon 2004). Subtle changes in key environmental variables such as temperature, salinity, wind speed and direction, ocean currents and strength of upwelling due to climate change could sharply alter the abundance, distribution and availability of fish populations. Climate change, particularly if it is reflected in reduced rainfall in many parts of Africa, would further compound the inability of the continent to meet people's demand for potable water.

2.4 Surface and groundwater systems

Changes in surface runoffs and groundwater flows in shallow aquifers is part of the hydrological processes that can be linked to climate variability, with implications for permanent and seasonal water bodies such as lakes and reservoirs. There is evidence of a broadly coherent pattern of change in annual runoff at the global scale, with some regions, particularly at high altitudes, experiencing an increase (Tao et al. 2003a, b; Hyvarinen, 2003;

Walter et al., 2004) while others experience a decrease, for example in parts of Africa (Milly et al., 2005). While lake levels in other parts of the world have risen (e.g. in Mongolia and China) in response to increased snow- and ice melt, lake levels in Africa have declined due to the combined effects of drought, warming and human activities.

2.5 Precipitation and water vapour

Climate model simulations for the 21st century are consistent in projecting very likely temperature increases in high latitudes and parts of the tropics, and likely decreases in some sub-tropical and lower mid-latitude regions (Manase 2009). Climate change effects resulting from warming have been easier to prove than changes in respect of precipitation. However, observational and modelling studies lead to an overall conclusion that an increase in the frequency of heavy precipitation events is likely to have occurred over most land areas over the late 20th century, and that this trend is more likely than not to include an anthropogenic contribution (IPCC 2008). Inter-annual rainfall variability is large over most of Africa, and for some regions, most notably the Sahel, multi-decadal variability in rainfall has also been substantial. For example, while the Sahel displays large multi-decadal variability with notable drying, East Africa shows a relatively stable regime with some evidence of long-term wetting, and Southeast Africa shows a basically stable regime, but with marked inter-decadal variability (Hulme 1996 cited in Pak Sum Low 2005).

2.6 Snow and land ice

Water supplies stored in glaciers and snow cover are projected to decline in the course of the century, thus reducing water availability during warm and dry periods in regions supplied by melt water from major mountain ranges, where more than 17 per cent of the world's population currently live (IPCC, 2008). According to UNEP (2009), only 11 of the 18 glaciers that covered Mount Kenya's summit a century ago remain, leaving less than one third of the previous ice cover. The ice on Mount Kenya has also become thinner. All these effects are attributable to global warming, resulting mainly from anthropogenic activities.

2.7 Sea-level rise and ocean dynamics

With focus on coastal systems and low-lying areas, the Intergovernmental Panel on Climate Change (IPCC 2007) maintained that coasts are projected to be exposed to increasing risks resulting from coastal erosion, climate change and sea-level rise. Low- lying cities situated near major rivers, deltas and estuaries are especially vulnerable to sea-level rise (Stern, 2006). For example, Lagos, currently the fifth largest city in the world and Africa's second most populous city, is highly affected by sea-level rise, coastal erosion, salt water intrusion and flooding. Empirical evidence of sea-level rise in Lagos mega-city showed that severe coastal erosion which removed over 2 kilometres of the popular Lagos beach fronts and at times the adjacent road has been on the increase since 2004, resulting in acute disruption of traffic and flooding of properties. Also, the rock moles constructed between 1908 and 1912 to protect the natural Littoral Drifts at the Bar beach were continually washed away by the coastal surge, leading to an annual erosion rate of 25 to 30 metres (Shagun et al, 2009). Changes in ocean dynamics could lead to changes in migrating patterns of fish and possibly reduced fish landings, especially in coastal fisheries (African Action 2007).

Both inland and ocean fisheries are very sensitive to varying degrees of climate fluctuations. In particular, increased ocean temperature may affect upwelling along the Gulf of Guinea, which could make the ocean waters become unsuitable for fisheries, causing a reduction in and possible collapse of fishing activities (African Action 2007). An expected rise in temperature would also cause a change in the characteristics of the ocean waters and consequently adversely affect fish habitat in the coastal zone of Africa. Most of the water resources along the coast would become polluted by intrusion of saltwater, and water resources management would place greater emphasis on desalinization.

3. Effects of climate change on livelihoods in Africa

In addition to its effects on the natural hydrological cycle, climate change is associated with changes in both ground and surface water supply for domestic, agricultural and industrial uses, including irrigation, hydropower generation, navigation and fishing. The effects depend on the baseline condition of the water supply system and the ability of water resource managers to respond also to population growth and changes in demands, technology, and economic, social and legislative conditions. (IPCC & TAR 2001). Hydro-meteorological disasters such as floods and droughts have major effects on food supplies, health, economic and environmental losses, and social upheaval (Pavel 2003). Thus, climate change effects are complex, they can be both direct and indirect, and they can be a serious threat to achieving poverty reduction and sustainable development.

3.1 Economic effect

Climate change can affect many important sectors of the economy by influencing the supply of and demand for goods and services (WBGU, 2008). Empirical evidence shows that there will be changes in the supply and demand of food commodities as a result of low yields resulting mainly from drought and flooding events. The changes will also affect the profitability of farming and the affordability of food. According to Miller and Yates (2005), future climate change could influence municipal and industrial water demands, as well as competing agricultural irrigation demands. Municipal demand depends on climate to a certain extent, especially for garden, lawn and recreational field watering, but rates of use are highly dependent on utility regulations. Industrial use for processing purposes is relatively insensitive to climate change as industry most often prefers to meet target outputs rather than consider the environmental implications of its activities.

The World Bank's Water Resources Sector Strategy quotes examples of effects of climate variability on economic performance. In its 2003 report, the Bank noted that the drought in Zimbabwe in the early 1990s was associated with an 11 per cent decline in GDP; the floods of 1999 in Mozambique led to a 23 per cent reduction in GDP (Pavel, 2003). The scale of these losses highlights the need for water planners and managers to have a better understanding of the mechanisms of climate variability and their relationships with hydrological extremes such as floods and droughts. Economic losses from natural disasters, including floods and droughts, increased three-fold between the 1960s and the 1980s; and ten-fold between the 1950s and the 1990s (Pavel, 2003). The poor are among those who suffer particularly from the effects of water stress due to their vulnerability and inability to adapt. An increase in surface temperature will affect the livelihoods of the 70 per cent of Africans who depend on rain-fed agriculture. This will lead to low productivity, low income, and a low standard of living, thus completing the vicious cycle of poverty also rises. Insurance companies will need to significantly increase the amount of capital they hold to be able to provide insurance cover at a level comparable to that of today (WBGU, 2008).

3.2 Food security and agricultural production

Agriculture accounts for the biggest share of the economy of African countries. For example, in COMESA, CEN-SAD, EAC, ECCAS, ECOWAS and IGAD1, agriculture accounts for between 25 per cent and 35 per cent of GDP. The availability of optimal water supply for crops determines the level of output obtained. Globally, over 80 percent of agricultural land is rain-fed and crop productivity depends solely on sufficient precipitation to meet evaporative demand and associated soil moisture distribution (FAO 2003). Where these variables are limited by climate, such as in arid and semi-arid regions of Africa, agricultural production is extremely vulnerable to climate change. With increases in temperature and precipitation distributed unevenly across the continent, food production has been declining in the last few decades, especially where it is accompanied by drought and flooding events. The productivity of agricultural, forestry and fisheries systems depends critically on the temporal and spatial distribution of precipitation and evaporation, and especially for crops, on the availability of freshwater resources for irrigation (Bates et al 2008). Changes in precipitation, and thereby in water availability, influence both productivity and species distribution (Kaiser 2001). African tropical forests may respond more sensitively than savannahs to changes in precipitation, because not only do they depend more heavily on the amount of precipitation, but also on the time of year that the precipitation occurs (Hély et al., 2006). Production systems in marginal areas face risk of increased vulnerability due to degradation of land resources through soil erosion, over-extraction of groundwater and associated salinization, and overgrazing of dry land (FAO, 2003). Therefore, the effect of climate change on irrigated agriculture will be enormous because it accounts significantly for total food produced, especially grains and vegetables. Mixed rain-fed systems in the Sahel, in the highland perennial systems of the Great Lakes region and in other parts of East Africa are particularly susceptible to climate change. Changes in the primary production of large lakes will have important effects on local food supplies. Lake Tanganyika currently provides 25-40 per cent of animal protein intake for the surrounding populations, and it is estimated that climate change is likely to reduce primary production and possible fish yields by roughly 30 per cent (Bates et al., 2008).

By critically affecting crop productivity and food production, in addition to being a necessity in food production processes, water plays a critical role in food security. Therefore, food availability, accessibility and nutritional balance will be indirectly threatened by climate change.

3.3 Social effects: conflicts and migration

Water resource use for domestic, commercial, or industrial purposes is known to have triggered numerous conflicts across Africa. A water crisis increases the probability of competition between water use sectors and, in the absence of systems regulating such competition, the likelihood of water conflict (WBGU 2008). Climate change is anticipated to increase conflicts as a result of struggles for water use if increasing supply to meet growing demand for water resources cannot be assured, in addition to other pressures on natural and human systems, e.g. from population growth (Ozor 2009). In semi-arid Africa, pastoralism is the main economic

activity, with pastoral communities including transnational migrants in search of water and new seasonal grazing (Bates et al, 2008). In drought situations, such pastoralists may come into conflict with settled agrarian systems. With reduced runoff and drying up of rivers, communities are forced to trek long distances from their own communities to look for water. This has created pressures and tensions at the new water sources with resultant conflicts (in addition to other effects on livelihoods such as loss in person-hours). One such example is in Nigeria between the Fulani cattle rearers and the farming communities competing over grazing land and access to water bodies (Ozor 2009),

leading to the deaths of several farmers and pastoralists in the region. Miller et al. (1997) noted that any substantial change in the frequency of floods and droughts, or in the quantity and quality or seasonal timing of water availability, will require adjustments that may be costly, not only in monetary terms but also in terms of societal and ecological effects, including the need to manage potential conflicts between different interest groups. Therefore, where there is increased water demand the potential of conflicts in trans-boundary water systems will increase. The effects of climate change are certain to displace some populations, with a significant increase in the number of environmental migrants over the coming decades.

For example, between 1970 and 2004 about 14 per cent and 22 per cent of the populations in East and West Africa, respectively, were affected by the multiple effects of drought, extreme temperature, floods, slides, wave/surges, and wind storm (Raleigh et al 2007). In many countries, the increase in flooding events, submergence, drought, soil degradation and growing water scarcity in combination with high population growth, unstable institutions, poverty or a high level of dependency on agriculture means that there is a particularly significant risk of environmental migration occurring and increasing in scale. People living in low-lying islands and delta regions face the threat of being submerged by water, hence the only coping strategy will be to move out of the risk sites to more habitable areas (Ozor 2009). This movement will greatly affect such people in many ways, including loss of livelihoods, loss of social systems and values, loss of property and age-long acquired wealth, injuries and sometimes death. At the transit and destination points, migration generates the potential for conflicts of different dimensions, hunger and starvation, and health problems including epidemics (Ozor 2009). This situation is worsened where there are no effective and efficient emergency management services to take care of the displaced people.

3.4 Health

Human health, incorporating physical, social and psychological well-being, depends on an adequate supply of potable water and a safe environment. As discussed in earlier sections, human beings are exposed to climate change directly through weather patterns (more intense and frequent extreme events), and indirectly through changes in water, air, food quality and quantity, ecosystems, agriculture, livelihoods and infrastructure. Health is a critical issue for three reasons: a) health is recognized by all cultures, religions, states and social groups worldwide as an asset worthy of protection; b) health is affected by all drivers of global environmental change; and c) a population's state of health can be used as an indicator to measure the effects of climate change (WBGU 2003 & Krafft et al. 2002), in a manner comparable to the key role of health within the human Development Index (HDI). Climate change induces health problems as a result of hunger and starvation, water stress, pests and diseases, resource conflicts, injuries and stress from extreme weather events (Ozor, 2009). Analyses show that the greatest health burden arising in the regions where vulnerability and population growth are greatest are in sub-Saharan Africa and south Asia (see for example, WBGU 2003). Water-related aspects of health include increased cases of cataracts (eye disease) in the arid and semi-arid regions of Africa due to low cloud cover and greater intensity of solar radiation; increased cases of malaria and typhoid due to increased rainfall and temperature; and increased cases of water-borne diseases such as cholera and dysentery

due to urban flooding and improper disposal of wastes (Anyadike 2009). Warmer and more humid conditions could enhance the growth of bacteria and mould on many types of stored foods, and this would increase food spoilage and create some specific toxicological health hazards (Ozor 2009). Due to the very large number of people that may be affected, malnutrition and water scarcity may be the most important health consequences of climate change (Bates et al. 2008). Poor health increases vulnerability and reduces the capacity of individuals and groups to adapt to climate change. The World Health Organization (WHO) and UNICEF Joint Monitoring Programme currently estimates that 1.1 billion people (17 per cent of the global population) lack access to water resources (defined as the availability of at least 20 litres of water per person per day from an improved water source within a distance

of 1 kilometre). An improved water source is one that provides 'safe' water, such as a household connection or a bore hole. In sub-Saharan Africa, 42 per cent of the population is without access to improved water (Bates et al., 2008).

4. Conclusion

This paper has described in detail the place of water resources in Africa, noting that throughout the continent, people value water as much as they value life. It has explained the various forms of water availability in Africa and the different purposes to which the resource is put. Climate change can affect the availability and quality of water resources adversely and the evidence suggests that the causes of climate change are complex, involving both natural forces and anthropogenic activities. Human activities are rated to have significant effects, and while African countries have contributed little to the magnitude of the global problem, they stand to bear some of the serious consequences. Climate change consequences on water resources manifested themselves in such events as flooding, drought, sea-level rise, drying up of rivers, poor water quality, changes in surface and groundwater systems, changes in precipitation and water vapour, and changes in snow and land ice. These alterations are already having serious effects on the economy of several African countries, on food security throughout the continent, as well as on social welfare and the health status of many disadvantaged people.

Although no conclusive evidence is yet available to prove the cause and effect relationships between climate change and water resources as shown above, the effects in Africa are likely to be the greatest, especially when they co-occur with a range of other stress factors such as population growth, unequal access to resources, food insecurity, poor health systems and poverty. These conditions will increase the vulnerabilities of many people in Africa. Further, Africa's low capacity in science, technology and innovation will further deepen the vulnerability and effects of climate change on water resources. The time to act therefore is now. African countries need to face the challenge holistically through science, technology and innovation, and establish appropriate governance, policies, regulations and measures to adapt to the challenges posed by climate change, especially as they affect water resources. It is essential to ensure greater resilience by keeping an audit or inventory of water resources with the aim of tracking the effects of climate change. This will directly aid and inform the development of location-specific strategies to cope with the effects and effects of climate change. For responding to immediate humanitarian emergencies, African governments need to set up special risk management units to assist people displaced and affected by climate change effects to enable them to live their lives normally again. In the global arena, Africa needs to have a cohesive agenda and strategy for achieving favourable negotiations at international meetings to avoid the tragic failures experienced by African nations at the Conference of the Parties (COP 15) in Copenhagen, Denmark.

Finally, there should be a culture of systems thinking in Africa that will engage the quadruple helix – science technology and innovation experts, policy makers, private sector organizations and civil society organizations. Africa as a continent of 53 nations, should utilize the collaborative and partnership opportunities available with inter - national agencies and organizations in order to respond to the multitude of complex effects of climate change, especially on water resources.

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