Journal of Economics and Sustainable Development
ISSN 2222-1700 (Paper) ISSN 2222-2855 (Online)
Vol.6, No.1, 2015
www.iiste.org

Assessing the Impacts of Climate Change on Water Resources: The Sub-Saharan Africa Perspective

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Abstract
This work paints a clear picture of the impacts of climate change on water resources in Sub-Saharan Africa (SSA) and showcases that the population in this section of the continent value water as much as they value life. Deteriorating water resources in SSA due to climate change have numerous negative ramifications, such as increasing food insecurity, transboundary conflicts and rising health problems among other socioeconomic consequences. While SSA countries have contributed little to the magnitude of the global problem, they stand to bear some of the serious consequences. It is imperative that the most affected vulnerable communities with climate change be given assistance and the means to diversify their economies and develop adaptive measures to climate change. Looking beyond command and control policy and regulatory measures, emphasizing on market-based approaches falls within proactive measures that can mitigate the adverse effects of climate change. Despite the number of strategies that have been identified to help SSA countries cope with the impacts of climate change on water resources, no single approach is adequate to address the problems. Since many of the impacts are subjective in nature, the holistic approach via the application of integrated methods is much solicited in addressing the challenges of climate change in SSA. Therefore, shedding more light into the SSA-climate change-water resources interconnection will provide great insight to proactively address the situation and pave the way for sustainable water resource management in SSA.

Keywords: Water resources, climate change, Sub-Saharan Africa (SSA)

1. Introduction

Sub-Saharan Africa (SSA) is blessed with abundant such minerals, forests, wildlife and rich biological diversity. However, these natural resources are largely unexploited and do not reflect the welfare of the inhabitants in the region (Custers & Matthysen, 2009). This section of the African continent can boast of some of the world's biggest tropical rain forests and highest equatorial mountains. Strategic natural resources are unevenly repartitioned. For instance, more than 20 percent of the remaining tropical forest is in the Democratic Republic of the Congo, while the river Congo, river Niger, the river Nile, river Zambezi and Lake Victoria and Lake Chad detain more than half of SSA's fresh water resources (Urama & Ozor, 2010). Many countries in SSA countries are experiencing water stress. A country or a region is termed water stressed when the population is using more than 20 percent of their renewable water resources (Vorster, 2014), whereas water withdrawals over 40 percent means such a country is experiencing severe water stress (Vörösmarty et al., 2005). For instance, reports indicate that water withdrawal in Nigeria during the 1990s stood at 28 cubic metres per person per annum (World Bank, 2003). In 2004, the International Dialogue on Water and Climate illustrated that water stress will surge significantly in SSA. Approximately 25 percent of the present-day African population faces water stress, while 69 percent enjoys conditions of relative water abundance (Rijsberman, 2006), however abundance does not necessarily depicts availability. In SSA countries, an estimated 1,100 million people depend on doubtable sources of drinking water, thus resulting in the death of 5 million people per annum (UNICEF & World Health Organization, 2002). Anthropogenic and ecological factors tend to perturbate the natural flow of the water cycle. Some of these human factors which overtime disturbs the water cycle include, but not limited to afforestation, deforestation, agriculture etc. Additionally, an increase in greenhouse emissions as a result of man's activities could influence cloud formation (Ramanathan & Carmichael, 2008). According to scientific studies, water scarcity, water pollution and, especially, global climate change represent a major challenge to water resources for humans (Stolberg et al., 2003). Human actions will further compound the issue of climate change, especially in nations that are already encountering water shortages.

SSA Countries are likely to suffer the most devastating impacts 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 (Conway, 2009). SSA 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 (Mustapha, 2012). More than 70 percent 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 (Urama, 2010).

2. Brief Literature Review

Available data on climate change projections provide ample evidence that water resources are vulnerable and have the potential to be strongly impacted by climate change, with extensive consequences for human societies and ecosystems (Ribeiro et al., 2009). 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 (Gordon et al. 2008). In many cases, water crisis can be traced back to a failure of state control, and therefore to crisis in governance (Bakker, 2010). According to the IPCC report 2001, the population exposed to water scarcity rapidly augmented with surging temperatures towards the second half of the century. In the same light, climate model analysis studies by Parry et al., 2001 show that, the impacts in arid and semi-arid regions are expected to rise above global averages. Thus, in regions already under water stress today, including Africa, climate change will further aggravate the situation. In many water-stressed regions, an increase in global mean temperature above 1.5ºC, can lead to a decrease in water supply and quality (IPCC, 2001). Available evidence shows that looming climate changes are already having serious repercussions on the water resources of most SSA countries, even when the continent of Africa contributes marginally to the greenhouse gas emissions responsible for these changes. For instance, SSA accounts for less than 1.6 percent of the global greenhouse gas emissions (Spore, 2008). Therefore, shedding more light into the African-climate change-water resources interconnection will provide great insight to proactively address the situation and pave the way for sustainable water resource management in SSA. The following sections summarize some potential effects of climate change on water resources in SSA:

In the past, floodplains served as attractive locations for settlement, agriculture, transport etc. Nowadays, these same floodplains have become podiums of frequent inundation. For instance, most parts of the SSA are vulnerable to flooding, with the East, South and Central regions having the most prevalent flood disaster, followed by West Africa (Osbahr et al, 2008). According to the Urama et al. (2010), Burkina Faso, Chad, Ethiopia, Ghana, Senegal, Sudan, Togo, Kenya, Liberia, Mali, Niger, Rwanda, Nigeria, and Uganda are the worst hit by flood in the SSA. Many of people have lost their lives and hundreds of thousands have relocated to the prevalence of floods, affecting farmland, settlement and other ecosystem services. In the same light, episodes of flood accounted for 26 percent of total disaster occurrences in Africa during 1971-2001 (Nagarajan, 2010) with devastating effects. 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, reduced the annual economic growth rate from 10 percent to 4 percent, caused 800 deaths, affected almost 2 million people, of which about 1 million needed food, displaced 329,000 people and destroyed enormous farmland, among other negative effects. The worst single flood incidents in SSA happened in East Africa: one incident in 1997 slew 2,311 people in Somalia; another in 1999 affected 1.8 million people in the Sudan (Urama et al., 2010). Floods across SSA 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 (Ribeiro et al., 2009). According to Urama et al. (2010), heavy rains and flooding since June have negatively affected more than 600,000 people in 16 West African countries. The worst hits have been Burkina Faso, Senegal, Ghana and Niger, where many lives and property have been lost to severe flooding events.

SSA is also plagued by the recurrence of droughts. By definition, drought is a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people. It is a normal, recurrent feature of climate that occurs in virtually all climatic zones, from very wet to very dry. Drought is a temporary aberration from normal climatic conditions, thus it can vary significantly from one region to another (Hisdal, et al., 2001). 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 aggravated by human induced changes in land cover. The excessive withdrawal of water through irrigation is likely going to augment the impacts of drought in SSA. Droughts have dual consequences on human activities; that is, direct and indirect consequences (Pavel, 2003). One of the direct consequences is the loss of crops, which might lead to starvation in conditions where sources of food substitutes are not available. Indirectly, water deficiencies increase the potency for disease spread. An example of a consequence of drought is illustrated in Figure 1.

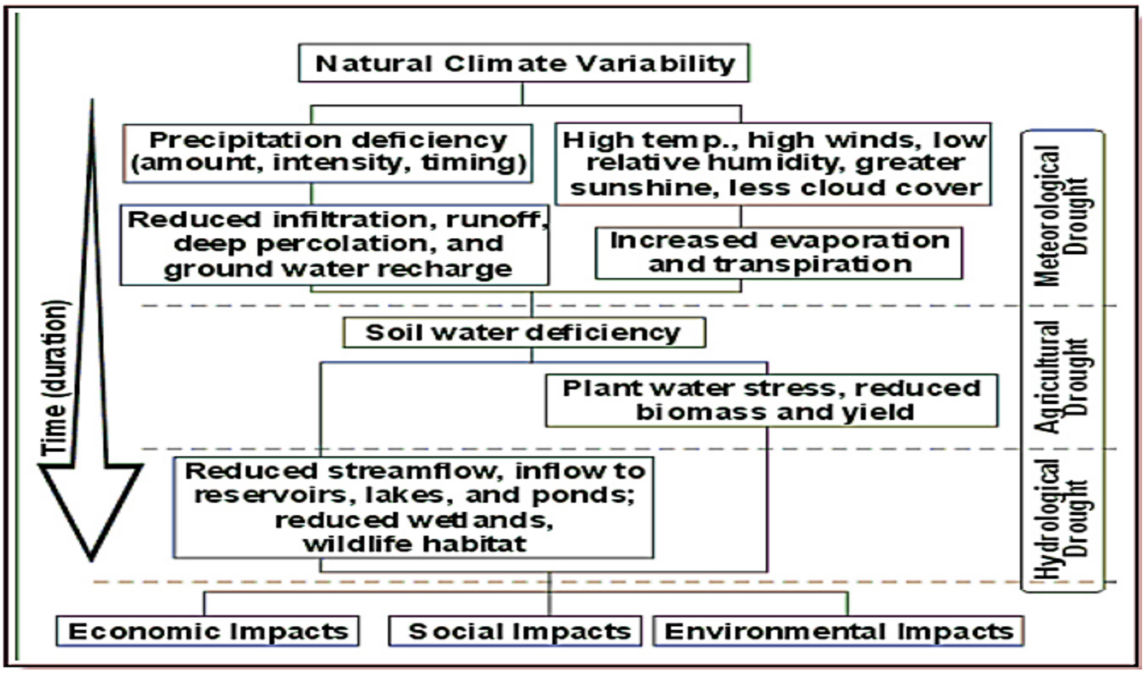

Figure 1: Flow chart illustration of the different drought progression
Source: http://www.nws.noaa.gov/os/brochures/climate/DroughtPublic2.pdf (accessed 08/01/2015)

Climate change is predicted to increase the danger of drought over much of SSA beyond the 21st century. The counties where droughts have occurred seem to be determined largely by variations in sea surface temperatures, particularly in the tropics, through related fluctuations in atmospheric circulation and precipitation. Since the late 1960s, droughts have engraved long lasting negative remarks in SSA. The worst drought cases occurred in 1973 and 1984 when almost the entire African continent suffered from reduced precipitation. The Horn of Africa, the Sahel and Southern Africa within the same period experienced the worst drought scenarios affecting several million people (Nicholson, 2001). Droughts are widespread in both Southern Africa and the Sahel region of western and northern Africa.

Water quality has also been impacted climate change. Observed over recent decades, oceans, lakes and rivers are fast changing due to an increase in temperature of global climate with implications for freshwater ecosystems, such as changes in water salinity, water nutrient (Bates et al, 2008). With respect to fisheries and aquaculture, studies have projected that increasing temperatures of around 1.5 to 2.0ºC will unfavorably affect fisheries in West African lakes (Christensen et al., 2007). In coastal areas that have major lagoons or lake systems, variations in freshwater flows and a greater invasion of salt water into lagoons will upset inland fisheries or aquaculture (Maltby, 2014). Delicate changes in key ecological variables such as temperature, salinity, ocean currents and strength of upwelling due to climate change could sharply alter the abundance, the repartition and availability of fishery resources.

Changes in surface run-off and groundwater flows in shallow aquifers is part of the hydrological processes that some researchers have associated with climate change, with consequences for permanent and seasonal water bodies such as lakes and reservoirs. There is evidence of a broadly articulate pattern of change in annual runoff at the global scale, with some regions, mostly at high altitudes, experiencing arise (Rwigi, 2014) while others experience a decline, for example in parts of SSA (Milly et al., 2005). Whereas lake levels in some location the of the world have increased (e.g. in Mongolia and China) due to increased snow and ice melt, lake levels (e.g. Lake Chad) in SSA has dropped due to the combined effects of drought, warming.

The 21st century Climate model simulations are consistent in projecting slight temperature increases in high latitudes and parts of the tropics, and likely decreases in some sub-tropical and lower mid-latitude regions

(Salinger, 2009). Climate change effects resulting from warming have been easier to prove than changes in respect of precipitation. Nevertheless, observational and modelling studies lead to an overall deduction 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 noticeable inter-decadal variability (Mutekwa, 2009).

3. Socioeconomic impacts of climate change on water resources

3.1. Economic impacts

Climate change adversely impacts significant sectors of the economy by shaping the supply and demand for goods and services (Mačiulis et al., 2009). Empirical research indicates that drought and flooding events have led to changes in the supply and demand of food commodities as a result of low yields. These changes have affected the farmers' remuneration and food affordability in some SSA countries is fast dwindling. Future climate change would potentially affect municipal and industrial water needs, as well as competing agricultural irrigation demands (Purkey et al., 2008). Municipal demand relies on climate to a certain extent, especially for garden, lawn and recreational field watering, but rates of use are highly reliant 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 deliberate on the ecological implications of its activities. The World Bank's Water Resources Sector Strategy cites examples of the effects of climate variability on economic performance. In its 2003 report, the Bank illustrated that the drought in Zimbabwe in the early 1990s was linked to an 11 percent reduction in GDP; the floods of 1999 in Mozambique resulted to a 23 percent decline in GDP (Benson and Clay, 2004). The magnitude of these losses pinpoints the need for water planners, managers and other decision makers to have a vivid understanding of the mechanisms of climate change and their connections with hydrological extremes such as floods and droughts. Associated economic losses from natural disasters, including floods and droughts, augmented threefold between the 1960s and the 1980s; and tenfold between the 1950s and the 1990s (Benson and Clay, 2004). The poor are among those who mostly suffer from the effects of water stress due to their vulnerability and inability to adapt. An increase in surface temperature affects the livelihoods of the 70 percent of Africans who depend on rain-fed agriculture. This has resulted to low productivity, falling incomes, and a low standard of living, hence completing the vicious cycle of poverty. Economic impacts from reduction of hydropower generation from Lake Kariba due to the 1991-1992 drought were assessed to be the loss of US$101 million in GDP, US$36 million in export earnings, and 3,000 jobs (Wambugu, 2010). In Mozambique, floods in 2000 cost the economy US$550 million, or 12 percent of GDP (Urama and Ozor, 2010).

One of economic signatures of climate change is on SSA largest lakes. That is, Lake Chad and Lake Victoria. Lake Chad was once noted as one of Africa's largest freshwater lakes, has shrunk considerably due to the associated climate change and human. In 1960 it covered 45,000 square kilometres, but by 1998 it had shrunk to 10,000 square kilometres (Oelkers et al., 2011) (Figure 2). On similar ground, Lake Victoria, considered the world's largest tropical lake (68,790 square kilometres) and the second-largest freshwater lake in the world, is fast losing its water (Urama and Ozor, 2010). The once-abundant tilapia lakes are slowly disappearing with increasing rates of evaporation of high temperatures as a result of climate change-human activities. The shrinking of both Lake Chad and Lake Victoria with a commensurate decline in fish stocks presents acidulous socioeconomic challenges to the African continent.

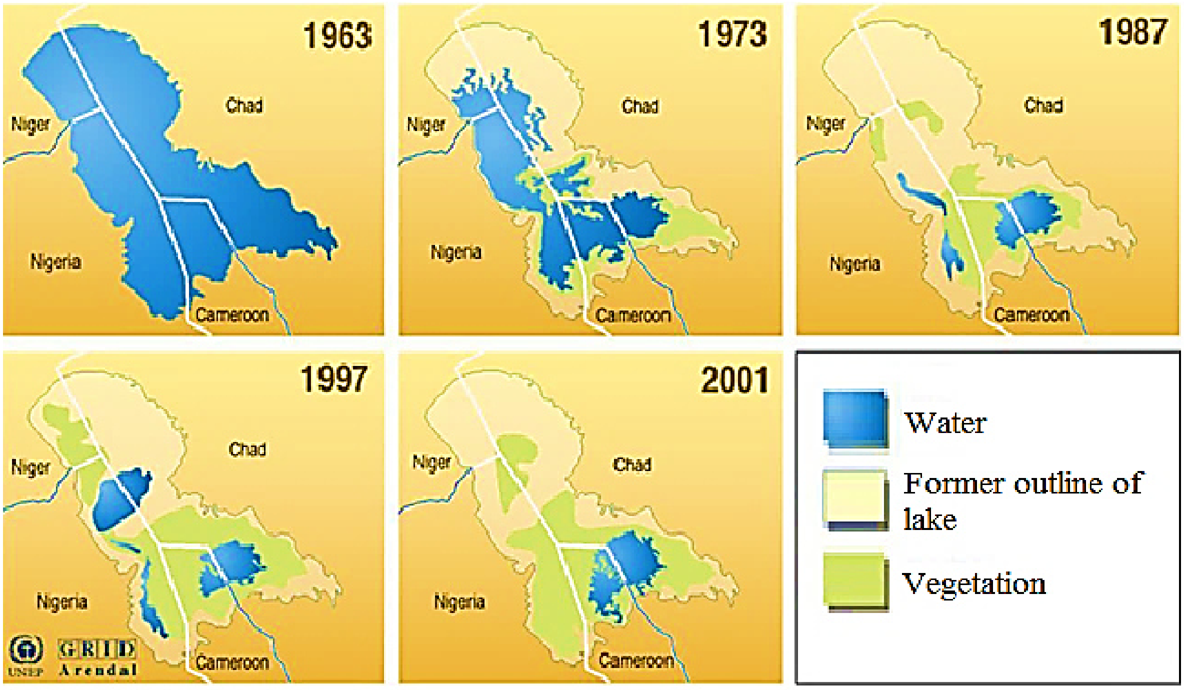

Figure 2: Shrinking of Lake Chad over time

Source: Modified from, http://blogs.discovermagazine.com/imageo/2013/10/20/lake-chad-shrinking-beauty/ (accessed 08/01/2015)

3.2. Impact on agricultural production

Agriculture accounts for the biggest share of the economy of SSA countries. The availability of optimal water supply for crops determines the level of output obtained. About 80 percent of agricultural land is rain-fed and crop productivity depends exclusively on adequate precipitation to meet the demands of evaporation and associated soil moisture distribution worldwide (Rockström et al., 2009). In arid and semiarid regions of SSA where these variables are limited by climate, agricultural production is extremely vulnerable to climate change. With increases in temperature and precipitation unevenly distributed across SSA, food production has been declining in the last few decades, especially where drought and flooding events are frequent. The productivity of agricultural, forestry and fisheries systems rely disparagingly on the sequential and spatial distribution of precipitation and evaporation, and especially for crops, on the accessibility of water resources for irrigation (Bates et al., 2008). Changes in precipitation, and thereby in water availability, shape both productivity and species repartition (Kanniah et al., 2011). SSA tropical forests Might respond more sensitively than savannahs to variations in rainfall, since they not only do depend more heavily on the amount of rainfall, but also on the duration of rainfall in the course of the year (Malhi and Wright, 2004). Production systems in fringe areas face the risk of increased vulnerability due to the degradation of land resources through soil erosion, over-extraction of groundwater and associated salinization, and overgrazing of dry land (Eriksen and Watson, 2009). Therefore, the impact of climate change on irrigated agriculture is enormous as it accounts significantly for total food produced, especially grains and vegetables. Mixed rain-fed systems in the highland perennial systems of the Great Lakes region and in other parts of East Africa are susceptible to climate change. Fluctuations in the primary production of large lakes are having important impacts on indigenous food supplies. Currently, Lake Tanganyika provides 25-40 percent of animal protein intake for the immediate populations, and it is projected that climate change is likely to shrink primary production and potential fish yields by roughly 30 percent (Ogutu-Ohwayo and Balirwa, 2006). By critically affecting crop productivity and food production, in addition to being a necessity in food production processes, water plays a significant role in food security. Therefore, food availability, accessibility and nutritional balance are indirectly threatened by the influence of climate change.

3.3 Impacts on population dynamics

Water resource use for domestic and industrial purposes is known to have generated numerous conflicts across SSA. A water crisis increases the probability among competing water users and, in situations where regulating structures are nonexistent to resolve such competition, the propensity is a water conflict (Hanjra and Qureshi, 2010). Climate change is expected to catalyze conflicts as a result of disequilibrium between water availability and population growth (Akakpo, 2012). In semi-arid SSA, pastoral nomadism is the main economic activity, with pastoral communities, including transnational migrants in search of water and new seasonal grazing (De

Haan et al., 2014). In drought conditions, pastoralists come into conflict with food crop farmers. With disappearing streams and drying up of rivers, communities are obliged to trek long distances from their own communities in search for water. The outcome has been mounting conflicts at the new water sources. A glaring example is the situation in Nigeria between the Fulani cattle rearers and the farming communities competing over grazing land and access to water bodies (Okello et al., 2014), 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 impacts, including the need to manage potential conflicts between different interest groups. Therefore, where there is increased water demand the potential of conflicts in transboundary water systems will increase. The effects of climate change are certain to displace some populations, with a significant rise in the number of environmental migrants over the coming decades. For instance, between 1970 and 2004 about 14 percent and 22 percent of the population in East and West Africa, respectively, were affected by the multiple effects of drought, extreme temperature, floods, and wind storm (Guha-Sapir et al, 20011). In many countries, the surge in flooding events, drought, soil degradation and increasing water scarcity coupled with population growth, weak/unstable institutions, poverty or a high level of dependency on agriculture entails that there is a significant risk of environmental migration happening and increasing in scale. Populations in low-lying areas and delta regions face the danger of being submerged by water, hence the only coping strategy will be to move out of the risk sites to more habitable areas (Albrecht et al., 2014). 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 (Mwaniki, 2014). This situation is worsened where there are no effective and efficient emergency management services to take care of the displaced people.

3.4 Impact on Health

In recent years, there are considerable works that shed adequate understanding on the link between climate change and health. Human health, including physical, socio-psychological well-being, depends on sufficient supply of potable water and a clean/safe environment. Health exposures to climate change are either direct (through weather patterns) or indirect (through changes in water, air, food quality and quantity, ecosystems, agriculture, livelihoods and infrastructure). Climate change causes health difficulties as a result of hunger and starvation, water stress, pests and diseases, conflicts over resources, injuries and stress from extreme weather events (Costello et al, 2009). Studies attest that the greatest health problems are in the regions where vulnerability and population growth are greatest (SSA and south Asia) (McMichael et al., 2007). Water related diseases such as cataracts in the arid and semi-arid regions of Africa are on the rise due to low cloud cover and greater intensity of solar radiation; malaria and typhoid cases are noticed to increase in regions with increasing rainfall and temperature; the prevalence cholera and dysentery has been on an increased in urban zones with frequent flooding coupled with poor disposal of wastes (Anyadike, 2009). Warmer and more humid conditions have enhanced the growth of bacteria and fungi resulting to an increase in food spoilage (Chakraborty and Newton, 2011). Malnutrition and water scarcity due to the consequences of climate change presents a health challenge in some SSA countries such as Niger, Somalia and Kenya. 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 lack access to water resources. An improved water source is one that provides 'safe' water, such as a household connection or a bore hole. In sub-Saharan Africa, 42 percent of the population is without access to improved water (Urama and Ozor, 2010).

4. Prospects and challenges

A number of strategies have been identified to help SSA countries cope with the impacts of climate change on water resources. However, we should bear in mind that no single approach is adequate to address the problems as illustrated. Many of the impacts are subjective, but the way forward clearly calls for a holistic approach to the challenges via the application of integrated methods. The hope is to achieve a water sustainable SSA before 2050

4.1. Institutional structure and policy effectiveness

A detail and comprehensive organization that supports and guides sustainable resource management is essential. It necessitates a strong legal and institutional structure that unequivocally specifies the main principles and strategies that need to be adhered to for sustainable use of water resources. One of the principal institutional structures for effective and efficient water resource management is that operational responsibility for the allocation and management of water resources should be devolved to the river basin level with policy development being retained at national level (World Bank, 2007). Policy instruments to achieve water management objectives should be structured to offer both incentives to enhance innovation in efficient water management and on the other hand, disincentive for malpractices. For example, zero rated VAT for gutters would encourage household water harvesting. Developing, agreeing and implementing a compensation mechanism for both upstream users and downstream users would deter unbalanced abstraction of water, thus leading to sustainability. Institutions like the agricultural extension organizations should take on new challenges in sensitizing and training local farmers on the best practices to adopt in order to minimize water stress. Extension services should embark on vigorous operations to train local people on sustainable water use strategies. It is imperative that the staff of extension organizations be re-trained on how to deploy state-of-the-art climate risk management strategies (Ozor, 2009). This would enable them to know how to apply the necessary interventions in order to scale up or replicate coping/adaptation strategies. Their training role will empower vulnerable communities to take actions that will enable them to acquire the capability to deal with issues of climate change.

4.2. Promoting disaster management and preparedness

Based on empirical studies, climate impacts which are already being felt in SSA will continue even if global warming is stopped. There is, therefore need that disaster management, which is weakly employed in many of the SSA countries be made an integral part the development process. This could be enhanced by mitigating the impacts through instituting policies that governs the erection of infrastructure to deal with risks and disasters when they occur, and mitigating the problem among the vulnerable poor communities and spreading it more widely via market mechanisms such as global insurance and capital markets. This will curb down the vulnerability of the poor communities and empower them to harness their potential for innovative ways to protect these vital resources.

5. Conclusion

This work has painted a clear picture of the impacts climate change on water resources in SSA, showcasing that the population in this fraction of the continent value water as much as they value life. The work has also expatiated on the various forms of water availability in SSA and the different purposes to which the resource is put. Climate change adversely affects the availability and quality of water resources and scientific evidence holds that the causes of climate change are complex, involving both natural forces and human activities. Human activities are rated to have significant effects and while SSA 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 manifest in the form of inundations, drought, sea-level rise, desert encroachment, drying up of rivers, poor water quality, changes in precipitation and water vapour etc. These changes are already having serious consequences on the economy of several SSA countries, on food security, social welfare and the health status of the vulnerable communities. It is imperative for vulnerable communities most affected by climate change to be assisted with means of diversifying their economic opportunities, enterprising activities with resilience mechanisms, and developing adaptive measures to climate change. It is time to look beyond command and control policy and regulatory measures to mitigate climate change. Emphasis should be oriented towards market-based approaches, such as carbon trading and exchange, which deliver incentives for local community motivation and participation in addressing problems of climate change. Despite the fact that cause, effect and relationships between climate change and water resources remains ambiguous, the impacts in SSA are expected to be the greatest, especially when this coincides with rapid population growth, unequal access to resources, food insecurity, poor health systems and poverty. These conditions will increase the vulnerabilities of many people in Africa. Furthermore, the impacts of climate change on water resources will further deepen since SSA lags behind in terms of scientific research, technological knowhow and innovation.

In this article, computational analysis or real time climate change scenarios have not been covered due to paucity in information (data) availability. Therefore, future studies employing large data sets through computation will provide robust results and pave the way for better climate change-policy options for SSA

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