Climate vulnerability of socio-economic systems in different forest types and coastal wetlands in Africa: a synthesis

R.A. KITULA[1], M. LARWANOU[2], P.K.T. MUNISHI[3], J.I. MUOGHALU[4] and L. POPOOLA[5]

[1]*University of Dar es Salaam, Institute of Marine Sciences, P.O. Box 668, Zanzibar, Tanzania*
[2]*African Forest Forum (AFF), C/o World Agroforestry Center (ICRAF), United Nations Avenue P.O. Box 30677 - 00100, Nairobi, Kenya*
[3]*Sokoine University of Agriculture, P.O. Box 3010 Chuo Kikuu, Morogoro, Tanzania*
[4]*Obafemi Awolowo University, Osun State, Nigeria*
[5]*Centre for Sustainable Development, University of Ibadan, Ibadan, Nigeria*

Emails: rkitula@yahoo.com, M.Larwanou@CGIAR.ORG, pmunishi2001@yahoo.com, jmuoghal@yahoo.com, l.popoola@mail.ui.edu.ng

SUMMARY

Forests, woodlands and coastal wetlands of Africa serve important ecological functions and provide goods and services that contribute significantly to livelihoods at local, national and global levels. These ecosystems however are vulnerable to climate change impacts that affect their capacity to deliver the ecosystem goods and services. Some impacts will have positive effects and can be taken as opportunities while some will have severe negative impacts that require adequate mitigation measures of the impacts to reduce the impact on the socio-economic systems. This article reviews the information on climate vulnerability of socio-economic systems in moist forests, woodlands/savannas and coastal wetlands of Africa to identify the likely impacts of climate change on livelihoods. Climate change will have profound impacts on moist forest of Africa including reduction of the capacity of the forests to supply the ecosystem goods and services that contribute to livelihoods and associated socio-economic systems. The water catchment potential of moist forests will be undermined reducing livelihoods associated with water resources. Impacts on woodlands/savannas will undermine the resources available in the woodland for human wellbeing including woodfuel, food, and other materials necessary for human health. Generally climate change will impact negatively the forest and woodland/savannas ecosystems resulting into either direct or indirect effect on the services provided by the ecosystems and associate livelihoods. But also climate impact on agriculture resulting into low production and increased dependence on forests will lead into degradation or expansion of agriculture into forests to compensate for the low production hence deforestation and degradation and more greenhouse gas (GHG) emissions. Among the major impacts of climate change on coastal wetlands include reduced water levels and under worst scenarios drying of some wetlands. Given the fact that coastal wetlands support a wide range of livelihood activities such as fisheries and multitude of livelihoods climate change will greatly undermine the capacity of the coastal wetlands to support fisheries and related livelihoods. Such impacts will negatively affect livelihoods and socio-economic systems associated with the coastal resources Monitoring and mitigating the impacts of climate change on the moist forests, woodlands/savannas and coastal wetlands is imperative for sustaining their socio-economic systems and related livelihoods.

Keywords: Africa, moist forests, woodlands/savannas, climate change, climate vulnerability, socio-economic systems

La vulnérabilité climatique des systèmes socio-économiques au sein de différents types de forêts et zones humides littorales en Afrique : synthèse

R.A. KITULA, M. LARWANOU, P.K.T. MUNISHI, J.I. MUOGHALU et L. POPOOLA

Les forêts, forêts claires et zones humides littorales de l'Afrique jouent d'importants rôles écologiques et fournissent des biens et des services qui contribuent de manière significative aux moyens de subsistance à l'échelle locale, nationale et mondiale. Ces écosystèmes sont cependant vulnérables aux impacts du changement climatique, qui a une incidence sur leur capacité à fournir les biens et services écosystémiques. Certains impacts auront des effets positifs et pourront représenter des opportunités, tandis que d'autres auront des répercussions négatives sévères nécessitant l'instauration de mesures d'atténuation adéquates afin de réduire leur incidence sur les systèmes socio-économiques. Cet article passe en revue les informations relatives à la vulnérabilité climatique des systèmes socio-économiques présents dans les forêts humides, les forêts claires/savanes et les zones humides littorales d'Afrique afin d'identifier les impacts probables du changement climatique sur les moyens de subsistance. Le changement climatique aura des répercussions profondes sur la forêt humide en Afrique, notamment la réduction de la capacité

des forêts de fournir les biens et services écosystémiques qui contribuent aux moyens de subsistance et aux systèmes socio-économiques qui y sont associés. Le potentiel de captage d'eau des forêts humides sera compromis, réduisant ainsi les moyens de subsistance associés aux ressources en eau. Les impacts sur les forêts claires/savanes affecteront les ressources disponibles dans les forêts claires pour le bien-être des populations, comme les combustibles à base de bois, la nourriture et d'autres éléments nécessaires à la santé humaine. De manière générale, le changement climatique aura une incidence négative sur les écosystèmes de la forêt et de la forêt claire/savane, avec pour résultat un effet direct ou indirect sur les services fournis par les écosystèmes et sur les moyens de subsistance qui y sont associés. L'impact climatique sur l'agriculture se traduira par une diminution de la production et une dépendance accrue sur les forêts, avec comme conséquence une dégradation ou une expansion de l'agriculture dans les forêts afin de compenser la faible production. Cette déforestation et cette dégradation entraineront une augmentation des émissions de gaz à effet de serre (GES). L'une des principales répercussions du changement climatique sur les zones humides littorales sera la réduction des niveaux d'eau ; le pire des scénarios prévoit un assèchement de certaines zones humides. Les zones humides littorales soutiennent actuellement une grande variété de moyens de subsistance. Toutefois, le changement climatique réduira fortement la capacité de ces zones à soutenir certains d'entre eux, notamment la pêche et les moyens de subsistance connexes. Ces impacts affecteront de manière négative les moyens de subsistance et les systèmes socio-économiques associés aux ressources littorales. Il est impératif de surveiller et d'atténuer les impacts du changement climatique sur les forêts humides, les forêts claires/savanes et les zones humides littorales afin d'assurer la durabilité de leurs systèmes socio-économiques et des moyens de subsistance qui y sont associés.

La vulnerabilidad climática de los sistemas socioeconómicos en diferentes tipos de bosques y humedales costeros de África: una síntesis

R.A. KITULA, M. LARWANOU, P.K.T. MUNISHI, J. I. MUOGHALU y L. POPOOLA

Los bosques, terrenos forestales y humedales costeros de África poseen importantes funciones ecológicas y proporcionan bienes y servicios que contribuyen de manera significativa a los medios de vida a escala local, nacional y mundial. Sin embargo, estos ecosistemas son vulnerables a los impactos del cambio climático que afectan a la capacidad de los ecosistemas para ofrecer bienes y servicios. Algunos impactos tendrán efectos positivos y pueden ser entendidos como oportunidades, mientras que otros tendrán efectos negativos severos que requieren medidas de mitigación adecuadas con las que reducir el impacto sobre los sistemas socioeconómicos. Este artículo revisa información sobre la vulnerabilidad climática de los sistemas socioeconómicos de los bosques húmedos, los terrenos forestales y sabanas y los humedales costeros de África, con el fin de identificar los posibles impactos del cambio climático en los medios de vida. El cambio climático va a tener un profundo impacto en los bosques húmedos de África, en particular en la reducción de la capacidad de los bosques de suministrar los bienes y servicios ecosistémicos que contribuyen a los medios de vida y los sistemas socioeconómicos asociados. El potencial de captación de agua de los bosques húmedos se verá afectado y deteriorará los medios de vida asociados a los recursos hídricos. Los impactos en los terrenos forestales y sabanas socavarán los recursos disponibles del bosque para el bienestar humano, como la leña, los alimentos y otros productos necesarios para la salud humana. En general, el cambio climático tendrá un impacto negativo en el bosque y en los ecosistemas de terrenos forestales y sabanas, lo que resultará en un efecto directo o indirecto sobre los servicios que prestan los ecosistemas y sobre los medios de vida asociados a ellos. Pero el clima tendrá también un impacto en la agricultura, que conducirá a una producción baja y a un aumento de la dependencia de los bosques que conllevará la degradación o la expansión de la agricultura hacia los bosques para compensar la baja producción, y por lo tanto más deforestación y degradación y más emisiones de gases de efecto invernadero (GEI). Entre los principales impactos del cambio climático en los humedales costeros se encuentra la reducción de los niveles hídricos y entre los peores escenarios está la desaparición de algunos humedales. Puesto que los humedales costeros albergan una amplia gama de actividades de medios de vida como la pesca y una multitud de medios de vida asociados a ella, el cambio climático socavará en gran medida la capacidad de los humedales costeros para mantener la pesca y los medios de vida relacionados. Dichos impactos afectarán negativamente a los medios de vida y los sistemas socio-económicos asociados a los recursos costeros. El monitoreo y la mitigación de los impactos del cambio climático en los bosques húmedos, los terrenos forestales y sabanas y los humedales costeros es imprescindible para el mantenimiento de los sistemas socioeconómicos y los medios de vida relacionados con ellos.

INTRODUCTION

Forests, woodlands and coastal wetlands of Africa serve important ecological functions and provide goods and services that contribute significantly to livelihoods at local, national and global levels (Munishi 2012). Over 590 million people in Africa live and depend on forest, woodland and wetland resources for food, fuel wood, building materials, medicines, oils, gums, resins and fodder (Faures and Santini 2008, Osman-Elasha *et al.* 2011, Muoghalu 2012a). Forests, woodlands and wetland ecosystems also contribute to economic development through trade in timber and non-timber

forest products (NTFPs), and a multitude of other ecosystem services. Wetland ecosystems in particular offer a considerable support to agriculture production especially in relation to irrigated agriculture. Forest and woodland ecosystems support agricultural production indirectly through their functions as water catchments that feed into wetlands and irrigated agriculture. (Monjane, 2009, Munishi *et al*. 2010, Kowero 2011).

There is growing evidence that climate change impacts will diminish the capacity of the forests and coastal wetlands to provide goods and services with serious implication to the livelihoods of forest and wetland dependent communities in Africa (Okali 2011). Climate change is expected to cause reduction of forest and wetland areas, a situation which will lead to a decrease in ecosystem services provided by the forests and wetlands (Lasco *et al*. 2008, Macchi *et al*. 2008, Gray 2011). Record shows that key development sectors such as forests, water resources, land, biodiversity, tourism and agriculture that are vital for livelihoods, food security and health are vulnerable to climate change impacts (IPCC 2007, Munishi 2012, Muoghalu 2012a, b). Future projections indicate that these impacts are likely to worsen over time and pose great threats to food and water availability, public health, natural resources and biodiversity in forest ecosystems in Africa (IPCC 2007, Munishi 2012, Muoghalu 2012a, b).

Understanding climate change impacts has a key role for the future management of forests, woodlands and coastal wetlands in Africa for climate change mitigation and adaptation. This article reviews the available information on climate change impact on moist tropical forests woodlands, savannas and coastal wetlands of Africa and associated impacts on socio-economic systems to identify the likely impacts of climate change on livelihoods and their responses.

CLIMATE VULNERABILITY OF SOCIO-ECONOMIC SYSTEMS IN MOIST TROPICAL FORESTS

Moist tropical forests in Africa are currently under threat from a variety of stresses such as deforestation, land degradation and heavy dependence on biomass for energy. Climate change and variability are likely to be additional stress (Okali 2011). Forestry is among the major productive sectors that are very vulnerable to climate change. (IPCC 2007, Munishi *et al*. 2010). The forestry sector will suffer from shifts in vegetation types as a response to climate change (Munishi *et al*. 2010), where sub tropical dry forests and subtropical moist forests will change to tropical very dry forests, tropical dry forest and tropical moist forest. Further, subtropical thorn woodlands (thickets) will be completely replaced or disappear, subtropical dry forests and subtropical moist forests will decline substantially. It has been predicted that (Munishi *et al*. 2010) there will be an increase in tropical very dry forests, tropical dry forests, and tropical moist forests. The constituent biodiversity in each vegetation type will shift accordingly or be driven to extinction if they cannot adapt. Species that will be more vulnerable are those with limited geographical range and drought/heat intolerant, low germination/recruitment rates, low survival rate of seedlings and limited seed dispersal/migration capabilities. Given these changes the impact of climate change the moist forest ecosystems will either influence positively or negatively the ecosystem goods and services provided by the ecosystems and hence associated socio-economic systems. Any impact on the socio-economic system associated with tropical mist forests will necessitate changes in livelihood strategies to adjust to changing conditions under different climatic regimes.

Climate change in moist forests and agricultural production

Impact of climate change on moist tropical forests will have a multitude of impacts on agricultural production and associated socio-economic systems depending on the way moist forests support/influence agriculture in different areas and how forestry and agriculture are interlinked. While tropical moist forests may have no direct impact on agriculture production, indirect effects associated with water supply, climate amelioration and livelihood dependence on forests.

Increase in temperature and rainfall as a result of climate change are projected to have significant impacts on agriculture and forestry in tropical countries of Africa (Muoghalu 2012a, Pimentel 1993, Munishi, 2012). Muoghalu (2012a) was of the opinion that the increase in weeds and pests in Central and West Africa may result in substantial rise in the use of agricultural chemicals, which in turn negatively affects environmental health. Climate change will have impacts on both forests and agriculture. In particular it will cut agricultural yields in dry and tropical regions, putting further pressure on remaining forests if farmers respond by extending cultivated areas. The impact of climate change on agriculture will result into low productivity and lead into food and cash crop insufficiency (Munishi *et al*. 2010, Munishi 2012). To compensate for the low production farmers may be forced to revert into forests as a source of livelihood. Otherwise farmers would expand their cultivated land into forests resulting into deforestation and degradation of these ecosystems. In turn these ecosystems' ability to deliver the necessary ecosystem services for human wellbeing will be undermined resulting into negative impacts on the associated socio-economic systems and livelihoods.

Moist forests, climate change, settlements and infrastructure

Scientific evidence shows that large numbers of people in Central and West Africa are currently at risk of floods particularly in coastal areas where coastal erosion is already destroying housing and tourism facilities (Niiasse *et al.* 2004, UNDP 2004, UNESCO-WWAD 2006). It was projected that floods could become common phenomena in Africa such that some regions will experience higher rainfalls and in drier regions of Africa there is likely to be a higher frequency of more intense downpours which may create flooding. Evidence shows that there occurred heavy flooding in both eastern and western Africa in 2007 (Conway 2009). Potential impacts

associated with floods were deaths and injuries from drowning, infectious diseases, exposure to toxic substances, infrastructure damage, crops and livestock damage, community breakdowns, increased psychological stress, and increased demands on health systems and social security. Future projections show that floods in Central and West Africa are likely to cause more damage to infrastructure like roads and rail network and blocking movement of goods and people in the sub-regions. Climate change may lead to industrial relocation due to sea-level rise and transitions in agro-ecological zones (Muoghalu 2012a). Many harbours and ports in coastal zone of the sub-regions will be adversely affected by floods which will be devastating economically. Prolonged droughts are projected to cause reduction in streams flows, leading to reduced hydropower production with negative effects on industrial productivity. All these events will likely exacerbate management problems relating to social services, infrastructure and technologies of production (lPCC 1996). Forests have a buffering effect on infrastructure and settlements in case of hazards associated with climate change. Floods are more severe with land degradation and especially in areas devoid of vegetation cover. Forest cover reduces overland flow and hence would ameliorate effects associated with flooding thus reducing flood damage and negative impacts of socio-economic systems that would be undermined with floods. Climate change impact on infrastructure and settlements may also result into increased poverty which will force the society to revert into natural resources such as moist forests as a source of livelihoods. In such cases the likely effect will be degradation of the functions of these ecosystems and associated livelihoods with negative implications on socio-economic systems dependent on the ecosystems. The overall result will be cyclic or a chain of effects on the ecosystem services, reverting back to negative impacts on the socio-economic systems and associated livelihoods.

Moist forests and coastal resources

Exposure to the impacts of sea levels rise depends mainly on geographical location of the area (Brooks 2003) and protection conferred by natural barriers such as mangrove ecosystems or any other coastal vegetation. The low-lying coastal areas along the West and Central Africa are considered among the areas which are expected to be most vulnerable by adverse impacts of climate change. Current evidence shows that there will be erosion and submergence of lowlands especially along the coast of Senegal, Lagos and Niger Deltas and the Gambia estuary and much of the land currently used for agriculture and livestock practices in these areas would be lost leading to socio-economic and socio-cultural problems (Muoghalu 2012a). There is increasing evidence that coastal erosion and sea-level rise will cause disappearance of the capital of Gambia in 50–60 years putting more than 42000 people at risk (Jallow *et al.* 1990). Awosika *et al.* (1994) have shown that sea-level rise of one metre, inundation may render more than 15000 km^2 of land at risk, while erosion may claim more than 300 km^2 of the Niger Delta in Nigeria. In Ghana, a small rise in sea level is projected to lead to permanent connection of lagoons to sea; penetration of salt water inland; increased coastal erosion; salinization of freshwater lagoons and aquifers; increased depth of water table in coastal areas; destruction of wetlands and associated industries and; accelerate loss of the capital Accra (Conway 2009). Mangrove forests along the cost of east and west Africa are particularly important in protection against ocean surges. Mangroves can reduce storm surge water levels by slowing the flow of water and reducing surface waves. Therefore mangroves can potentially play a role in coastal defence and disaster risk reduction, either alone or alongside other risk reduction measures such as early warning systems and engineered coastal defence structures (e.g. sea walls). Climate change will impact on mangrove ecosystems in various ways. See rise for example will likely change the status and characteristics of the intertidal zone. Mangroves are very habitat specific. Changes in the status and characteristics of the intertidal zone may possibly lead to disappearance of mangrove ecosystems, shrinking of the area under mangroves or shifts in the location of the mangrove ecosystems. Mangroves being among the breeding sites/spawning habitats for fish such changes will affect negatively fisheries production and other livelihoods associated with fisheries activities thus negative impacts on the socio-economic systems and livelihoods associated of coastal communities.

Salt water intrusion inland has been one of the major problems associated with climate change impact on coastal ecosystems. Salt water intrusion will change the availability of fresh water for some or all coastal ecosystems and likely disrupt all socio-economic systems dependent on them such as fresh water fisheries, agriculture production among others. Furthermore, salt water intrusion will change the edaphic/soil factors or substrate on which coastal forests and woodlands species survive. Change in the characteristics of coastal environment due to salt water intrusion will change the woodland and forest ecosystems structure or lead into disappearance/shifts in location of such forests and woodlands. This will have negative impacts on the socio-economic systems dependent on the coastal forests.

Moist forests and human health

Increased temperatures and changes in patterns of rainfall as a result of climate change are widely recognized to entail serious consequences for human health in tropical countries (Lindsay and Martens 1998). Many studies have associated changes in temperatures and rainfall patterns with diarrhoea and cholera, and stress the role of climate variability in transmission of water-related diarrheal diseases in Africa. A study to analyse a link between precipitation, temperatures, and hydrological characteristics of selected stations in Africa proved that cholera epidemics are closely associated with El Niño years (Olango *et al*. 2007). Precipitation has the potential to increase the number and quality of breeding sites for vectors such as mosquitoes, ticks, and snails and the density of vegetation, affecting the availability of resting sites (Linthicum *et al.,* 1990; Githeko *et al.* 2000). For example, disease reservoirs in rodents can increase when favourable

shelter and food availability lead to population increase, in turn leading to disease outbreaks. High diversity of vector species complexes have the potential to redistribute themselves to new climate-driven habitats leading to new disease patterns. There is a likely increase in plague, a flea-borne disease with rodents as reservoir, because of increase in the population of rodents following heavy rains as a result of an abundance of food. Increased temperature can also accelerate the development of fleas and the pathogen they carry (Githeko *et al.* 2000). Climate change is projected to cause changes in geographical distribution of tropical diseases. Whereas some diseases such as malaria will find optimum conditions in new areas, it will be checked in other regions, as climate conditions become less favourable.

Forests contribute various types of food with implications on human health (Pierce Colfer *et al*. 2006). Energy-rich food from forests that may be available during seasonal or emergency food shortages includes nuts, seeds, oil-rich fruit and tubers: e.g., seeds of *Geoffroea decorticans*, *Ricinodendron rautanenii* and *Parkia spp*.; oil of *Elaeis guineensis*, babassu, palmyra and coconut palms; protein-rich leaves such as baobab (*Adansonia digitata*) as well as wild animals, including snails, insects and larvae. Forest leaves and fruits are often good source of Vitamin A; e.g., leaves of *Pterocarpus spp*., *Moringa oleifera*, *Adansonia digitata*, gum of *Sterculia spp*., palm oil of *Elaeis guineensis*, bees and bee products and other animal food. Fats and oils are needed for syntheses of vitamin A. Forests are also a source of fruits with food contents that ameliorate Niacin deficiency. Such forest fruits and leaves rich in niacin, such as *Adansonia digitata*, fruit of *Boscia senegalensis* and *Momordica balsamina*, seeds of *Parkia spp*., *Irvingia gabonensis* and *Acacia albida*. Forest fruits and leaves, particularly fruit of *Ziziphus mauritiana*, *Adansonia digitata* and *Sclerocarya caffra*; leaves such as *Cassia obtusifolia*; and gum of *Sterculia spp*. are good source of Vitamin C thus important in controlling vitamin C deficiency. Forests are also associated with supply of material such as wood that are important in ensuring food is available in a state that can contribute to human health. Wood is the main energy source in most Third World rural communities. Its connection to health, through both nutrition and hygiene, has been highlighted. Although access to fuel wood is not a problem in most moist tropical forests, it is a problem in many dry forests and can become a problem in moist forests that are being degraded. Fuelwood shortages can affect the nutritional value of foods consumed. Hoskins (1990) points out that cooking release the nutrients in some food, making them edible and appealing. Shortages of fuelwood can also lead to undercooked food, increasing the risk of food-borne diseases (FAO 1991). Food processing that involves smoking, drying or cooking can also extend the shelf life of foods (FAO 1991). All these activities need an energy source, with wood being the most common. Lack of firewood and safe water could prompt communities to take their children, especially girls, out of school, in order to help their mothers to complete these tasks (Macchi *et al*. 2008) thus influencing the socio-economic systems of the society. Despite the considerable scientific literature on the subject, there remains real uncertainty about the future importance (and possible substitutability) of forest foods in forest peoples' lives.

Climate change will increase flooding frequency that may result into forests along the coast being replaced by wetlands or other types of ecosystems. Increase in wetlands would increase breeding sites for disease vectors. Increase in disease vectors will result in increase in human diseases with a multitude of health problems. Poor health leads into low lobar productivity, low household and community income and increased poverty. Increased poverty may result into increased dependence on natural resources such as forests hence degradation with negative impacts on the livelihoods dependent on the forests.

Forests and water resources

Forests play a vital role in sustaining water resources and aquatic ecosystems. Forest disturbance, both natural (e.g., wildfire, insects, disease, windstorms, drought) and human (e.g., timber harvesting, land conversion), can have a profound effect on hydrologic, geomorphic and ecologic processes. With climate change, natural disturbances are becoming more frequent and catastrophic. This, together with growing human disturbance, will undoubtedly affect water resources and consequently have significant implications for land managers and policy makers. Our understanding of hydrologic and ecologic response to accelerated environmental and land use change is key to the development of adaptive and mitigating strategies ensuring the continued security of water supplies and ecological values. The availability and quality of water in many regions of the world are more and more threatened by overuse, misuse and pollution, and it is increasingly recognized that both are strongly influenced by forests. Moreover, climate change is altering forest's role in regulating water flows and influencing the availability of water resources (Orlando and Burton, 2003). Forested catchments supply a high proportion of the water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas.

The water sector is vulnerable to climate change in different ways (Munishi *et al*. 2010). Accordingly rainfall patterns and soil moisture will vary due to changes in mean temperature hence affecting the runoff of rivers. It is predicted that annual flow in many rivers will decrease as a result of increasing temperatures and evaporation. On the other hand, the impacts of the variability in flow are diverse including floods in basins that experience increase in runoff. In areas where there will be a decrease in flow there will be an alteration in availability of water for different uses resulting into water use conflicts among water users.

It has been argued that the expected increase in the variability of precipitation could result in floods in the moist forest zones of the west and central Africa (Conway 2009). Flooding, exacerbated by climate change often results in increased contamination of drinking water. In this regard, when water is available it is often of poor quality thus contributing to a range of health problems including diarrhoea, intestinal worms and trachoma. Much of the sufferings from

lack of access to safe drinking water and sanitation are borne by the poor, those who live in degraded environments and are overwhelmingly women and children. Unhygienic practices because of water shortage as result of drought will also facilitate the epidemic of cholera. Pollution of water sources of rural water supplies by flooding could introduce parasites like amoeba, and cryptosporidium into drinking water (Alterholf *et al.* 1998). Increase in surface water temperature has also been associated with disease transmission. Forests therefore will be affected by climate change and as a result their capacity for maintenance of the supply of good quality water will be greatly undermined.

The moist tropical forests of Africa provide a range of goods and services to the people. Persistent droughts may lead to an increase in forest fires and desertification and as a consequence undermine the supply of ecosystem services associated with forest management and related socio-economic systems and benefits thereof. With decreasing water and firewood due to climate change the necessary time collection of water and firewood increases inflicting more pressure on already stressed communities. Sustainable forest management as a measure against climate change impact provides multiple goods and services to the people, which can improve the livelihood.

CLIMATE VULNERABILITY OF SOCIO-ECONOMIC SYSTEMS IN WOODLANDS AND SAVANNAS

Humans have interacted with woodlands and savannas for millennia contributing substantially to their livelihoods. Since time immemorial dry forests and woodlands of sub-Saharan Africa have provided diverse ecosystems goods and services to large populations of humans and livestock that depend on them. Dry forests and woodlands are profoundly important for local livelihoods. Climate change will impose additional pressures on agriculture, settlements and infrastructure, human health, water resources, forest products and fisheries, which will directly impact livelihoods of communities in the woodlands and savannas of Africa. Climate change is affecting rainfall patterns, water availability, the dynamics of droughts and bushfire frequency. These are increasingly impacting on woodland ecosystems, associated livelihoods, human health, agriculture productivity and biodiversity (Munishi *et al*., 2010; Kowero, 2010). Climate change will therefore adversely affect livelihoods, national incomes and the environment. While the woodlands are affected by climate change, they also play a key role in mitigation and adaptation to climate change (Munishi, 2012). The role of woodland ecosystems in climate change mitigation and adaptation may include increasing the resilience of rural communities to climate change and support to species to adapt to changing climate by acting as refuge during adverse climate conditions.

Woodlands also indirectly support economies to adapt to climate change by reducing the costs of climate-related negative impacts and provision of goods and services during extreme weather events and are key assets for reducing vulnerability to the effects of climate change. Woodlands play a major role in climate change mitigation as deforestation and forest degradation is estimated to contribute to about 18% of the global carbon dioxide (greenhouse gas – GHG) emissions and have considerable potential to mitigate emissions through carbon sequestration.

Communities adjacent to woodlands and savannas in Africa are highly reliant on natural resources for subsistence and commercial purposes. For instance, in many rural sub-Saharan communities, non-timber forest products may supply over 50% of a farmer's cash income and provide the health needs for over 80% of the population, particularly among forest dependent populations (FAO 2004). Effects of climate change and increased anthropogenic activities the availability and distribution of these forest resources are expected to be affected. Persistent droughts may also lead to an increase in forest fires and desertification and as a consequence contribute to a lack of fuelwood which plays an important role in indigenous and traditional people's livelihoods. For instance, in Africa fuelwood and charcoal account for over 80% of natural energy consumption. Overexploitation of woodlands and savannas vegetation resources for fuelwood, timber and medicinal purposes may affect natural process of regeneration and growth and productivity of certain species. In Sudan and Sahel savannas roots are mined out for fuel so that the possibility of self-regeneration is slim, even if the people could afford to set aside land for this purpose.

Woodlands in Africa produce benefits for farmers living on customary or communal lands which fall into four categories: foods, such as fruit from indigenous woodland trees; other wild foods collected from woodlands, such as mushrooms and edible insects; habitat for small scale food production, such as honey, soil nutrient inputs through nutrient cycling and through nitrogen fixation. Environmental services, such as protection from soil erosion are also provided. Fodder and browse for goats and cattle; and construction timber, firewood, and other material for either domestic consumption or for local sale. Many of these benefits are also available to urban dwellers through the marketplace (Dawees 1994).

Woodlands, savannas and agriculture

In many countries of sub-Saharan Africa the majority of the people live in rural areas where the main livelihood source is subsistence crop and/or livestock production. The major zone of crop agriculture in sub-Saharan Africa is in the dry forests and woodlands; much of which is rain-fed and is therefore vulnerable to climate variability. Projection show that under climate change scenarios under rain-fed cereal production based on one crop per year would experience a decrease in production potential by –3.5% (Fischer *et al.* 2002). Increased atmospheric CO_2 will affect crop yields in the woodlands and savannas by reducing expected increases in respiration from a temperature increase and likely improving water use efficiency and growth in rice, cassava and potato crops in water-limited environment though maize, sugar cane and sorghum crops are unlikely to be affected directly by changes in CO_2 concentrations. Increasing CO_2 will likely result in lower

forage quality because of higher carbon: nitrogen ratios and higher concentration of unpalatable and/or toxic compound in plants (Fajer *et al.* 1991). Poor quality of pastures during droughts, and periods of overgrazing can result in poor health and death of livestock which impacts on food and livelihood security of livestock keepers.

Reduction of soil productivity, vegetation, cultivated lands and pasture lands in woodlands and savannas of Africa become more pronounced following periods of intense human activities and drought leading to desertification (IPCC 2007). Odjugo and Ikhuoria (2003) observed that Nigeria north of 12ºN is under severe threat of desertification and sand dunes are now common features. The sand dunes in this area have buried large area of arable lands, thus reducing viable agricultural lands and crop production. This has prompted massive emigration of people from Sahel and Sudan savanna to Guinea savanna and the rainforest belt. Many Fulanis with their herds have migrated to Guinea savanna and the rainforest belt. This has increased pressure on land in these zones resulting in conflict between the Fulanis and the crop growing in Guinea savanna. Yugunda (2002) and Yaqub (2007) reported that such clashes resulted in the death of 186 people in six northern states in Nigeria. Climate change is expected to create more suitable conditions for new and old pests like ticks, tsetse flies, and locust to expand their territories. Crop species and livestock may have to face new competitors, predators, diseases and alien species for which they have no natural defence in the biomes. Hulme (1996) reported that livestock productivity and distribution could indirectly be influenced via changes in the distribution of vector-borne livestock diseases, such as trypanosomiasis and the tick-borne diseases and corridor disease.

Climate change will have impacts on both woodlands and agriculture. In particular it will cut agricultural yields in dry especially the woodlands and savannas regions, putting further pressure on remaining woodlands if farmers respond by extending cultivated areas. The impact of climate change on agriculture will result into low productivity and food and cash crop insufficiency (Munishi *et al*. 2010, Munishi 2012). Woodlands and savannas of Africa are very prone and vulnerable to agricultural expansion especially when land productivity declines. Shifting cultivation to increase agricultural production is common in the woodlands and savannas as farmers move to compensate for the low production in agricultural production resulting from climate change. Furthermore reduced agricultural production resulting from climate change impacts may force farmers revert into forests as a source of livelihood with possible result into degradation of the woodlands and savannas. In turn these ecosystems' ability to deliver the necessary ecosystem services for human wellbeing will be undermined resulting into negative impacts on the associated socio-economic systems and livelihoods.

Climate change and infrastructure in woodlands and savannas

Woodlands and savannas of Africa contribute greatly to infrastructural development. Most of the housing in these areas is made up of construction material from the woodlands and savannas including timber, poles, withies and thatch grass. Impacts of climate change on these woodlands will negatively affect the supply of these materials impacting negatively on the status of housing and related infrastructure.

According to Muoghalu (2012b) climate variability, including the resultant extreme events such as storms, floods especially flash floods and droughts have impacted and continued to create impacts on infrastructure like human settlements, industry, electricity and transportation in woodlands and savannas of Africa. Flooding as a result of heavy rains will cause considerable damage to property and infrastructure such as road, dams, power generation, and rail network and disrupt communications among settlements impeding movement of goods and persons in woodlands and savannas of the sub-regions. For example, flooding caused by excessive rainfall experienced in 2012, and the release of water from Lagdo Dam in Cameroon and Kainji Dam in Nigeria caused flooding in most north central states in the Guinea and Sudan savanna zones of Nigeria. The flooding destroyed farmlands, buildings, and roads making it impassable and leaving many motorists and travellers stranded. Attah (2012) reported that more than 400,000 farmlands and 36,000 houses were destroyed by floods in Jigiwa State, in Sudan savanna zone of Nigeria. Munishi *et al*. 2010 gave a conservative estimate of the restoration costs of infrastructural loss in recent (2009) flooding in Kilosa District, Tanzania, at about 200B Tanzanian shillings ($160M) which is about 0.02% of the 2009 GDP for Tanzania. Based on this the potential value of GDP loss due to infrastructure damage resulting from climate change is estimated at about US$ 0.056B equivalent to $56M in 50 years to come, or an annual GDP loss of about US$ 1.12M.

The extreme weather events as a result of climate change such as flooding would continue to pose significant threat to countries of Africa achieving their national goals in agriculture, road construction, housing, health, conservation of environment and water systems. The combination of urban population pressure and decreasing water supply in catchment areas will reduce stream flow, which in turn limits hydropower production and the industrial productivity that depends on energy. Negative impacts of climate change could also create a new set of refugees, who may migrate into new settlements, seek new livelihoods and place additional demands on infrastructure (Myers 2002, McLeman and Smit 2005).

Climate change and health in woodlands and savannas

Human health in African woodlands and savannas regions is likely to suffer from increase in the incidence of diseases due to several causes, including poverty and climate change effects. Changes in temperature, precipitation and humidity that are expected to occur under different climate change scenarios will affect the biology and ecology of vectors and intermediate hosts and consequently the risk of disease transmission (Githeko *et al.* 2000). Health hazards related to climate change reported in Africa are: malaria, dysentery, trypanosomiasis, cholera, plague, Rift Valley Fever, meningitis, yellow fever, tick-borne haemorrhagic fever and other parasitic diseases and parasites like tsetse fly.

Savannas of Africa are the major meningitis belt. Molesworth *et al.* (2003) reported that about 162 million people in Africa live in areas with a risk of meningitis. Low humidity (Tikhomirov *et al.* 1997), dusty conditions and other environmental factors predispose populations to meningococcal meningitis. Sultan *et al.* (2005) reported that wind speeds in Africa the first two weeks of February experienced 85% variation in the number of meningitis cases thus linking the infection to climatic factor. Recent data from west Africa indicate that the risk of a new epizootic of Rift Valley Fever, a disease considered to be a relatively benign zoonoses for humans that periodically developed in domestic animals following heavy rains (Lefevre 1997), is increasing in the region (Fontenille *et al.* 1995) with significant exposure to the virus among livestock herders and wildlife rangers during the dry season (Olaleye *et al.* 1996).

Flooding will cause the pollution of water of streams and other sources of rural domestic water supplies by introducing parasites such as giardia, amoeba and cryptosporidium into drinking water (Alterholf *et al.* 1998). In Senegal, *Biomphalaria pfeifferi* snails transmit *Schistosoma mansoni* during the rainy season, while *Bulinus globosus* is responsible for transmission of *S. Haematobium* during the dry season (Ernould *et al.* 1999). Thus, long-term changes in climate change can be expected to alter the distributions of snails and in turn the disease pattern (Githeko *et al.* 2000). However, the impact of climate change on the transmission of other less climate sensitive vector-borne diseases such as filariasis, onchocerciasis and schistosomiasis is not clear and may take long time to be evident (Desanker *et al.* 2001).

Woodlands and savannas contribute various types of food with implications on human health (Pierce Colfer *et al*. 2006). Energy-rich food from the woodlands that may be available during seasonal or emergency food shortages includes nuts, seeds, oil-rich fruit and tubers, protein-rich leaves, wild animals, source of Vitamin A, fruits with food contents that ameliorate Niacin deficiency, source of Vitamin C thus important in controlling vitamin C deficiency. Woodlands are widely known to be a source of material such as wood which is the main energy source connected to healthy foods and its connection to health, through both nutrition and hygiene, has been highlighted. Fuelwood shortages can affect the nutritional value of foods consumed. Hoskins (1990) points out that cooking release the nutrients in some food, making them edible and appealing. Shortages of fuelwood can also lead to undercooked food, increasing the risk of food-borne diseases and use of fuelwood in food processing, smoking, drying or cooking can also extend the shelf life of foods (FAO 1991). Woodlands are the major sources of woodfuel such as charcoal and firewood. Impact of climate change on the woodlands will likely undermine the supply of woodfuel from the ecosystem influencing the socio-economic systems and livelihoods associated with the woodlands.

Climate change and water in woodlands and savannas

Bates *et al*. (2008) pointed out that one of the most widespread and potentially devastating impacts of climate change will be how changes in the frequency, intensity and predictability of rainfall affect water availability. Water is essential to human survival, and changes in water supply will have far reaching implications, especially in the woodlands and savannas of Africa where much of the population relies on local rivers and groundwater for survival (de Wit and Stankiewicz 2006). Climate change will aggravate water stress where it currently occurs and put new places at risk (Boko *et al.* 2007). Experts predict that Africa will see increased water stress from an increase in population, economic, urbanization and degradation of catchment areas (IPCC 2007, URT 2007, Tiega 2010). These impacts will be exacerbated by climate change and variability, which will impose additional pressures on water availability, accessibility and demand (Boko *et al*. 2007). Projection shows that by 2020 more than 250 million of people in woodlands of Africa will be exposed to increased water stress due to climate change. Furthermore, water scarcity in the woodlands and savannas of Africa will decrease agricultural production which will further adversely affect food security and exacerbate malnutrition (Munishi *et al*. 2010).

Changes in precipitation and enhanced evaporation could have profound effects in some lakes, reservoirs; ground water recharge and river flow, thus affecting all water sources. Graham (1995) and Tiega (2010) reported that lakes and reservoirs in West Africa respond to climate variability through pronounced changes in storage, leading to complete drying up. Groundwater is a primary source of drinking water in East Africa and rapid population growth is expected to intensify dependence on groundwater. Based on projections of increasing aridity and changes in river flows, groundwater will recharge at a slower rate, creating decreased water availability for agricultural and household use, especially in the dry season (Gray 2011).

Based on projections of reduced rainfall some water bodies such as Lake Chad are continuing drying up. This has led to continuing decline in local access to water, crop failures, livestock deaths, collapsed fisheries and other wetland services (Tiega 2010) such that the prospects for 20 million people who depend on the lake and its rivers for water, fishing and growing vegetables are less certain (Fleshman 2007). The shrinkage has impacted negatively on large scale irrigation schemes in Nigeria, on recession agriculture in Niger, Cameroon and Chad (Tiega 2010).

Water-related problems, already serious in the eastern and southern African region, are likely to worsen as a result of climate change (ANCEM 2011). Intense rainfall events will increase the incidence of flooding in many areas. At the same time, reduced run-off will exacerbate water stress and reduce the quality and quantity of water available for domestic, crop and livestock use. Experts predict that Southern Africa will become drier, and that rainfall will increase in parts of East Africa (Munishi 2012). Drought-prone areas of Botswana and Zimbabwe are likely to become more vulnerable to climate change than more humid areas of the United Republic of Tanzania or Zambia for example. There are already signs that drought is becoming more common and more prolonged in the dry lands of Southern Africa, and drought incidence is

expected to increase as a result of higher temperatures and reduced rainfall (IFAD, 2011) influencing negatively flows in streams and water levels in water bodies.

According to IPCC (2007), URT (2007, 2009), Munishi *et al*. (2010) the water sector which is very crucial for the development of the economy will be impacted by climate change in different ways. Findings from the IPCC Fourth Assessment Report have alluded that climate change is expected to exacerbate current stresses on water resources from population growth and economic and land use change, including urbanization. In a wider context the predicted impacts of climate change on water resources in woodlands of eastern and southern Africa articulate that by 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. Agricultural production, including access to food, in many Eastern and Southern African countries is projected to be severely compromised due to water scarcity which will further adversely affect food security and exacerbate malnutrition. The water sector in eastern and southern Africa will experience both positive and negative consequences (Munishi *et al*., 2010). Woodlands and savannas are important catchments for water supply and provide a multitude of other ecosystem services. Deforestation and degradation of woodlands may reduce the capacity of these ecosystems to regulate water and control soil erosion. Degradation of these resources will undermine their capacity to deliver the multitude of ecosystem services they provide including water.

Some regions of eastern and southern Africa are particularly vulnerable to reduced precipitation, especially given that the climate trend indicates longer periods of drought and shorter periods of heavy rain. Most vulnerable are the areas of woodlands which are arid, semiarid, and dry sub humid where precipitation is lower than evapotranspiration. There is evidence that droughts are increasing in southern African dry lands and are expected to increase further as a result of increased temperatures and reduced rainfall. The catchment of Lake Tanganyika is mostly miombo woodlands of western Tanzania with the major river Malagarasi originating from the expansive miombo woodlands of central and western Tanzania. The water level for Lake Tanganyika in Tanzania has shown a decreasing trend over the past 30 years, which is associated with reduced rainfall and increased evaporation in the catchments of the Lake Tanganyika basin. The water levels in the Kiwira river in the southern highlands of Tanzania – again the major miombo woodland eco-region in Tanzania has been very variable and show a predominant decreasing trend for the past 7 years from above 1.620 m to about 1.590 m and the discharge decreased from 6.2 to 5 m^3 sec^{-1} for the period 2000–2011 which has been associated with climate change (Munishi 2012).

It has been observed that several large lakes in sub Saharan Africa registered abrupt changes and recessions of magnitudes far larger than any witnessed in recent times (Gillespie *et al*., 1983; Opere 2010) suggesting that large areas, now arid, and also humid were regularly receiving substantial tropical rainfall. It has been reported that Lake Malawi has been 50 m shallower than it has been during the last 150 years (Owen *et al*., 1990), and records of hydrological change from Lake Naivasha indicates that there were three decadal to interdecadal scale droughts in the East Africa region that matched oral historical records of famine, political unrest and large-scale migration of indigenous peoples (Verschuren, 2002).

According to Munishi (2012), climate change is having a profound impact on the composition and structure of woodland biomes in eastern and southern Africa on which millions of people depend. Ultimately Climate Change has the potential to undermine millennia of traditional custodianship of natural resources, frustrate any prospect of sustainable natural resource uses, put the livelihoods of billions of people at risk, and will impact on water availability, food security and consequently the biodiversity and associated livelihoods (Monjane 2009).

Climate change and fisheries in woodlands

The fishing industry is an important source of revenue, employment and proteins in some countries in Africa (Fleshman 2007). For example, in Senegal the industry contributes over 6% of its Gross Domestic Products (GDP) (Njaya and Howard 2006) and 47% of animal protein intake comes from fisheries (FAO 2005). More than 70% of people around Lake Tanganyika in Tanzania depend on the lake for food, water and livelihoods. However, population growth and rising water temperatures due to climate change effects has subjected fishing industry into pressure due to threats of dry up of lakes and rivers which in turn destroy fish species. It was estimated that over the past several decades nearly 30% of fish yield per unit effort in Lake Tanganyika has been declined due to among others overfishing, shoreline degradation and climate change. This has serious implications for food security and long-term conservation of the region as trends continue because the effects of a declining fishery extend far beyond the shoreline.

Fishermen in several regions, including Kigoma in Tanzania, are already searching for new ways to earn a living as climate change reduces fish stocks, squeezing food supplies and household budgets. Agriculture is seen as an attractive alternative livelihood with many fishermen, especially because farmers are entitled to subsidies under an existing government program. Growing crops for food as well as cash from oil palm are alternatives that fishermen are considering.

Expanding current agricultural practices will increase deforestation rates around fishing villages and may result in contributing to greenhouse gas emissions (Phillips *et al*. 2009). In addition, declining fish yields are likely to put additional pressure on natural areas and nature reserves such as Gombe and Mahale National Parks, Tanzania as people turn to wild animals as a substitute protein source (Gray 2011). Shifts from fisheries as a livelihood source to agricultural production due to impacts of climate change will likely increase the rate of land use change with accelerated conversion of woodlands into agriculture. Such shifts will lead into deforestation and shrinkage of areas under woodlands reducing the capacity of the ecosystem to supply ecosystem goods and services on which livelihoods depend thus undermining the socio-economic systems of the areas.

CLIMATE VULNERABILITY OF SOCIO-ECONOMIC SYSTEMS IN COASTAL WETLANDS

Lowlands and floodplains due to their combination of several natural resources, such as fisheries and fertile alluvial soils, often are sites of dense rural settlements as well as urban settlements, such as many coastal areas of eastern and southern Africa. Socio-economically such areas are very prone to negative impacts of climate change with consequences on poverty levels.

Impact of climate change on coastal wetlands of Africa is already being felt. The state of coastal wetlands in Africa is changing. Change in coastal wetland makes the livelihood of wetland dependent communities on highly vulnerable (Nicholls *et al.* 2007). According to (IPCC 2007) the climate change will affect water resources, agriculture, coastal resources, fisheries, management rules and settlements which, will directly impact livelihoods of wetland dependent communities in Africa.

Coastal wetlands and agriculture

Climate change is affecting the agriculture in coastal countries of Africa in several ways. Mangrove soils are often only marginally suitable for agriculture, yet the conversion of mangroves for this purpose is widespread. The impact of sea level rise due to climate change on agriculture is already being felt in some coastal countries of Africa. For example in Tanzania, scientific evidence shows that fields of rice seedlings in the Rufiji Delta are being damaged by salt water intrusion. Farmers in this area experienced fall of paddy production due to salt water intrusion.

Thus farmers have been moving away from the increasingly salty rivers, where most paddy fields are located, further out into the delta in search of fresh water and better land. But some are encroaching on protected mangrove swamps in their search for new, fertile fields. The scramble for land has created conflict between Rufiji residents and government authorities who want to stop local people invading protected sites (Kitula 2012). Boko *et al.* (2007) have shown that salt water intrusion could also affect coastal agriculture in Benin, Cote d'Ivoire and Ghana through inundation and soil salinization. Projection shows that by 2050 about 235 km^2 of rice fields in Guinea could be lost as a result of permanent flooding caused by inundation (Republique de Guinee 2002).

Coastal wetlands and settlements

Exposure to the climate change impacts is directly linked to the position of human settlements (Smit and Wandel 2006). Clausen *et al*. (2011) reported that rural coastal communities in Madagascar are generally more vulnerable to the impact of climate change than those located further inland. Cyclones were observed to have caused disruption to village life in Madagascar. For example, in Borongeny and Soahazo villages Cyclone Gafilo in 2004 triggered the relocation of both villages following flooding and destruction of houses. Similarly in 1975 a cyclone blocked the freshwater supply to Kaday village which forced the relocation of that village to its new location at Soanafindra.

Among the major coastal wetlands are mangrove ecosystems also referred to as intertidal wetlands. Mangrove ecosystems along the cost of east and west Africa are particularly important in protection against ocean surges thus protecting costal infrastructure from the severity of ocean surges and associated damages. Mangroves can potentially play a role in coastal defence and disaster risk reduction protecting coastal infrastructures from damage associated with see rise and storm surge.

Coastal wetlands and coastal resources

The coastlines of Africa are highly vulnerable to the effects of climate change due to the geology and geography of some of the region's coastal areas, the growing population density and infrastructure in the coastal zone. Moreover, large tidal variations, coupled with the potential increase in regional rainfall, suggest the potential for increased coastal hazard. Sea-level rise and increases in sea-surface temperature are the most probable major climate change-related stresses on coastal ecosystems. In particular, sea-level rise is the most obvious climate-related impact in coastal areas.

Densely settled and intensively used low-lying coastal plains, islands, and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/freshwater front, and seawater intrusion into freshwater lenses. Especially at risk are the large deltaic regions of Nigeria and Senegal, and the low-lying areas of Angola, Cameroon, Gabon, Gambia, Sierra Leone and Seychelles (Taylor *et al*. 2010, Muoghalu 2012a). International studies have projected the displacement of several million people from the region's coastal zone in the event of a one metre rise in sea level. According to Taylor *et al*. (2010) climate change is of particular significance in the Seychelles as a one metre rise in sea level could lead to the submergence of many islands resulting in a 70% loss of land, and as a coastal ecosystem mangroves would be under threat. The costs of response measures to reduce the impact of sea-level rise (30–50 cm) in the region could amount to millions of dollars per year. Among the major impacts of climate change on coastal wetlands include reduced water levels and under worst scenarios drying of some wetlands. Given the fact that coastal wetlands support a wide range of livelihood activities such as fisheries and multitude of livelihoods, climate change will undermine their capacity to support livelihoods related to fisheries. Such impacts will negatively affect livelihoods and socio-economic systems associated with the coastal resources.

Marine fisheries in Africa are usually highly dependent on resources and services provided by mangrove ecosystem, which makes the fishery sector vulnerable to climate change impacts. Climate change will bring greater variability and uncertainties regarding weather conditions, which impact directly on artisanal fisher folk whose fishing gear limit their mobility and ability to operate in adverse conditions (Faraco *et al*. 2010). In face of these changes in the environment,

traditional knowledge accumulated by these populations, which used to guide them during their fishing activities in an efficient and safe way, may become useless (Ford and Smit 2004). The effects of salt water intrusion on fisheries are already being felt in Cote d'Ivoire. The Republique de Cote d'Ivoire (2000) proved that lagoon fisheries and aquaculture are currently affected by intrusion of salt water. Climate change is also projected to bring about impacts on mangrove biodiversity such as changes in reproduction and migration periods of several species, changes in latitudinal and longitudinal distribution patterns, changes in population size and community composition and changes in the hydrological cycle (Gitay *et al.* 2002). These changes can alter seasonal and distributional patterns of fish species that are explored by artisanal fisheries, potentially impacting local livelihoods. These fisher folk are forced to adapt to the seasonal distribution and the ecology of fish, both strongly influenced by climate (Iwasaki *et al*. 2009).

Coastal wetlands and water resources

Maintaining the security of water resources is a key priority for the African poor rural population. The region already faces water stresses, and many areas are often dependent upon limited groundwater and rainfall collection. Climate change will further aggravate water shortage by extreme events such as droughts which undermine food security, or extreme rainfall events which increase the risk of flooding. Challenges to water resources management will therefore be exacerbated by sea-level rise which contribute to salt-water intrusion into available freshwater resources. As sea level rises, salt water intrusion into ground water, rivers, bays and estuaries will increase.

According to Muoghalu (2012a) rising sea level will result in the pollution of most of the water resources along the coast by intrusion of sea water and management of water resources would place greater emphasis on desalination. Scientific assessments project changing patterns of runoff and river flows in the region in the next decades, as well as increase in water management costs and increases of poor rural people affected by water stress. Coastal wetlands are among the major water reservoirs in the coastal zone. They act as water storage and purifiers ensuring constant supply of good quality water. The water capacity of wetlands will likely undermine this capacity and result into disruptions of livelihoods and socio-economic systems associated with the wetlands.

CONCLUSION AND RECOMMENDATIONS

Climate change will have direct and indirect impacts on socio-economic systems of moist forests, woodlands and savannas, and coastal wetlands of Africa. Some impacts will have positive effects and can be taken as opportunities while some will have severe negative impacts that require adequate mitigation measures of the impacts to reduce the impact on the socio-economic systems.

Climate change will have profound impacts on moist forest of Africa including reduction of the capacity of the forests to supply the ecosystem goods and services that contribute to livelihoods and associated socio-economic systems. The water catchment potential of moist forests will be undermined reducing livelihoods associated with water resources. Impacts on woodlands/savannas will likely undermine the resources available in the woodland for human wellbeing including woodfuel, food other materials necessary for human health.

Generally climate change will impact negatively the forest and woodland/savannas ecosystems resulting into either direct or indirect effect on the services provided by the ecosystems and associate livelihoods. But also climate impact on agriculture resulting into low production and increased dependence on forests will lead into degradation or expansion of agriculture into forests to compensate for the low production hence deforestation and degradation and more greenhouse gas (GHG) emissions.

Among the major impacts of climate change on coastal wetlands include reduced water levels and under worst scenarios drying of some wetlands. Given the fact that coastal wetlands support a wide range of livelihood activities such as fisheries and multitude of livelihoods climate change will greatly undermine the capacity of the coastal wetlands to support fisheries and related livelihoods. Such impacts will negatively affect livelihoods and socio-economic systems associated with the coastal resources.

Mitigating the impacts of climate change on the moist forests, woodlands/savanna and coastal wetlands is imperative for sustaining their socio-economic systems and related livelihoods.

Monitoring the impacts of climate change on moist forests, woodlands/savannas and coastal wetlands and associated socio-economic systems is important if proper and effective mitigation measures would be developed.

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REFERENCES

ALTERHOLT, T.B., LECHEVALLIER, M.W., NORTON, W.D. and ROSEN, J.S. 1998. Effects of rainfall on giardia and cryptosporidium. *Journal of American Water Works Association* **90**: 66–80.

ATTAH, D. 2012. Flood destroys 400000 farmlands, 36000 houses in Jigiwa. *The Punch* 17, No. 20,231 Tuesday September 18, 2012.

AWOSIKA, L.F., FRENCH, G.T., NICHOLLS, R.J. and IBE, C.E. 1994. The impact of sea level rise on the

coastline of Nigeria. In: Proceeding IPCC Symposium on Rising Challenges of the Sea. (123–154). Margaritta, Venezuela 14–19 March, 1992.

BATES, B.C., KUNDZEWICZ, Z.W., WU, S. and PALUTIKOF, J.P. eds. 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

BOKO, M., NIANG, L., NYONG, A., VOGEL, C., GITHEKO, A., MEDANY, M., OSMAN-ELASHA, B., TABO, R. and YANDA, P. 2007. Africa. Climate Change 2007: Impacts, Adaptability and Vulnerability. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds.) *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, UK.

CALDER, I., HOFER, T., VERMONT, S. and WARREN, P. 2013. Towards a new understanding of forests and water. FAO Corporate Document Repository. 25 pp.

CLAUSEN, A., RAKOTONDRAZAFY, H., RALISON, H.O. and ANDRIAMANALINA, L.A. 2011. Mangrove ecosystems in western Madagascar: an analysis of vulnerability to climate change. WWF, Madagascar.

CONWAY, G. 2009. *The Science of Climate Change in Africa: Impacts and Adaptation. Granthan Institute for Climate Change Discussion Paper No.* 1. Imperial College, London.

DESANKER, P.V. and MAGADZ, A.C. 2001. Africa. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Doken, D.J. and White, K.S. (eds.). Climate Change 2001: Impacts, Adaptation and Vulnerability. IPCC Working Group II, Third Assessment Report. Cambridge University Press.

FAJER, F.D., BOWERS, M.D. and BAZZAZ, F.A. 1991. The effects of enriched CO_2 $1 ospheres on the buckeye butterfly, *Junoniacoenia. Ecology* **72**: 751–754.

FAO 1991. Household Food Security and Forestry: An Analysis of Socioeconomic Issues. Forest, Trees and People Program, Swedish International Development Authority and Food and Agriculture Organization, Rome.

FAO. 2004. *Do Sustainable Livelihood Approaches have a Positive Impact on Rural Poor? A Look at Twelve Case Studies.* FAO, Rome.

FAO. 2005. *Fisheries Issues. Contribution of Aquaculture to Food Security.* FAO Fisheries and Aquaculture Department, Rome.

FARACO, L.F.D., ANDRIGUETTO-FILHO, J.M. and LANA, P.C. 2010. A methodology for assessing the vulnerability of mangroves and fisher folk to climate change. *Pan-American Journal of Aquatic Sciences* **5**(2): 205–223.

FAURES, J.M. and SANTINI, G. 2008. Water and the rural poor: Interventions for improving livelihoods in sub-Saharan Africa. FAO, Rome.

FAYE, O., GAYE, O., FONTENILLE, D., KONATE, L., HERVE, J.P., TOURE, Y., DIALLO, S., MOLEZ, J.F. and MOUCHET, J. 1995. Drought and malaria disease in the Niayesarea of Senegal. *Sante* **5**: 299–305.

FISCHER, G., SHAH, M. and VAN VELTUIZEN, H. 2002. Climate change and Agricultural Vulnerability. *Report Prepared by the International Institute for Applied Systems Analysis as a Contribution to the World Summit on Sustainable Development, Johannesburg 2002.*

FLESHMAN, M. 2007. Climate Change: Africa gets ready: Planning how to deal with higher temperatures, shifting weather. *Africa Renewal* **21**(2): 14–24.

FONTENILLE, D., TRAORE-LAMIZANA, M., ZELLER, H., MONDO, M., DIALLO, M. and GIGOUTTE, J.P. 1995. Short report: Rift Valley Fever in western Africa: isolations from Aedes mosquitoes during an interrepizootic period. *American Journal of Tropical Medicine and Hygiene* **52**: 403–404.

FORD, J.D. and SMIT, B. 2004. A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. *ARCTIC* **57**(4): 389–400.

GILLIES, M.T. 1953. The duration of the gonotrophic cycle in *Anopheles gambiae* and *Anopheles funestus* with a note on the efficiency of hand catching. *East African Medical Journal* **30**: 129–135.

GITAY, H., SUÁREZ, A., WATSON, R.T. and DOKKEN, D.J. (eds). 2002. Cambioclimático y biodiversidad. GrupoIntergubernamental de expertossobre el cambioclimático, PNUMA/UNEP, 85 p.

GILLESPIE, R., STREET-PERROTT, F.A. and SWITSUR, R. 1983. Post-glacial arid episodes in Ethiopia have implications for climate prediction. *Nature* **306**: 680–683.

GITHEKO, A.K., LINDSAY, S.W., CONFALONIERI, U.E. and PATZ, J.A. 2000. Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization* **78**(9): 1136–1147.

GRAHAM, Y. 1995. Drought dims Ghana's hydroelectric power. *World Rivers Review* **10**: 3.

GRAY, E. 2011. Climate Change Impacts to Key Ecosystems and People's Livelihoods in the Gombe-Masito-Ugalla and the Greater Mahale Project Area. Jane Goodall Institute, Frankfurt Zoological Society.

HULME, M. (ed.). (1996). *Climate Change in Southern Africa: An Exploration of some Potential Impacts and Implications in the SADC Region.* Climatic Research Unit, University of East Anglia, Norwich, United Kingdom.

IFAD 2011. Addressing Climate Change in West and Central Africa. IFAD, Rome.

IHENYEN, J., OKOEGWALE, E.E. and MENSAH, J.K. 2009. Composition of tree species in Ehor Forest Reserve, Edo State, Nigeria. *Nature and Science* **7**(8): 8–18.

IPCC. 1996. Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change Scientific Technical Analyses. Contribution of Working Group 11 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. [Watson, R.T., Zinyowera, M.C. and Moss, R.H. (eds.)] Cambridge University Press, Cambridge.

IPCC. 2007. Climate change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth

Assessment Report of the Intergovernmental Panel on Climate Change. UK: Cambridge University Press.

IUFRO. 2010. Climate Change Impacts on African Forests and People. IUFRO Occasional Paper No. 24. IUFRO Headquarters, Vienna.

IWASAKI, S., RAZAFINDRABE, B.H.N. and SHAW, R. 2009. Fishery livelihoods and adaptation to climate change: a case study of Chilika lagoon, India. *Mitig Adapt Strateg Glob Change* **14**: 339–355.

JALLOW, B.P., BARROW, M.K.A. and LEATHERMAN, S.P. 1996. Vulnerability of the coastal zone of Gambia to sea level rise and development of response strategies and adaptation options. *Climate Research* **6**: 165–177.

KITULA, R.A. 2012b. Scope, potential and implementation of mitigation activities on mangrove forests in eastern and southern Africa. A platform for stakeholders in African forestry. AFF.

KOWERO, G. 2011. Climate Change and African Forests and Tree Resources: The Stakes are Enormous. In: Chidumayo, E., Okali, D., Kowero, G. and Larwanou, M. (eds.). 2011. Climate change and African forests and wildlife resources. *African Forest Forum, Nairobi, Kenya* 252 pp.

LASCO, R.D., PULHIN, F.B., SANCHEZ, P.A.J., VILLAMOR, G.B. and VILLEGAS, K.A.L. 2008. Climate Change and Forest Ecosystems in the Philippines: Vulnerability, Adaptation and Mitigation. *Journal of Environmental Science and Management* **11**(1): 1–14.

LEFEVRE, P.C. 1997. Current status of Rift Valley Fever what lessons to deduce from the epidemic of 1997 and 1987. *Medicine Tropicale* **57**(3): 61–64.

LINDSEY, S.W. and MARTENS, W.J. 1998. Malaria in the African Highlands: past, present and future. *Bulletin of the World Health Organization* **76**: 33–45.

LINTHICUM, J.K., BAILEY, C.L., TUCKER, C.J., MITCHELL, K.D., LOGAN, T.M., DAVIS, F.G., KAMAU, C.W., THANDE, P.C. and WAGATTEH, J.N. 1990. Application of polar-orbiting meteorological satellite data to detect flooding of Rift Valley Fever virus vector mosquito habitats in Kenya. *Medical Veterinary Entomology* **4**: 433–438.

MACCHI, M., OVIEDO, G., GOTHEIL, S., CROSS, K., BOEDHIHARTONO, A., WOLFANGEL, C. and HOWELL, M. 2008. Indigenous and Traditional Peoples and Climate Change. Issues Paper. IUCN.

McLEMAN, R. and SMIT, B. 2005. Assessing the security implications of climate change-related migration. *Preprint, Human Security and Climate Change: An International Workshop,* Oslo.

MEEHL, G.A., STOCKER, T.F., COLLINS, W., FRIEDINGSTEIN, P., GAYE, A., GREGORY, J., KITOH, A., KNUTTI, R., MURPHY, J., NODA, A., RAPER, S., WATTERSON, I., WEAVER, A. and ZHAO, Z.C. 2007. Global climate projections. In: Solomon, S., Qui, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge.

MENDELSOHN, R., DINAR, A. and DALFELT, A. 2000. Climate change impacts on African agriculture. Preliminary Analysis Prepared for the World Bank. Washington, District of Columbia.

MCIVOR, A.L., SPENCER, T., MÖLLER, I. and SPALDING, M. 2012. Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. Cambridge Coastal Research Unit Working Paper 41. Published by The Nature Conservancy and Wetlands International. 35 pages. ISSN 2050 - 7941. URL: http://www.naturalcoastalprotection.org/documents/storm–surge–reduction–By–mangroves

MOLESWORTH, A.M., CUEVAS, L.E., CONNOR, S.J., MORSE, A.P. and THOMSON, M.C. 2003. Environmental risk and meningitis epidemics in Africa. *Emerging Infectious Disease* **9**: 1287–1293.

MONJANE, M. (2009). Eastern and Southern Africa Forest and Woodlands Situational Analysis. 47 pp.

MUNISH, P.K.T., TEMU, R.P.C. and SOKA, G. 2008. Plant communities and tree species associations in a Miombo ecosystem in the Lake Rukwa basin, Southern Tanzania: Implications for conservation. Journal *of Ecology and the Natural Environment* **3**(2): 63–71.

MUNISHI, P.K.T., SHIRIMA, D., HAPPINESS, J. and KILUNGU, H. 2010. Analysis of climate change and its impact on productive sectors, particularly agriculture in Tanzania. Ministry of Finance and Economic Affairs and Vice Presidents Office, Dar es Salaam Tanzania. 106 pp.

MUNISHI, P.K.T. 2012. Climate vulnerability of biophysical and socio-economic systems in woodlands and savannas in eastern and southern Africa. A platform for stakeholders in African forestry. AFF.

MUNISHI, P.K.T., MRINGI, S., SHIRIMA, D.D. and LINDA, S.K. 2010. The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. *Journal of Ecology and the Natural Environment* **2**(12): 261–269.

MUOGHALU, J.I. 2012a. Climate vulnerability of biophysical and socio-economic systems and a description of some permanent sample plots in moist tropical forests in West and Central Africa: A platform for stakeholders in African forestry. African Forest Forum, Nairobi.

MUOGHALU, J.I. 2012b. Climate vulnerability of biophysical and socio-economic systems and permanent sample plots in savannas and woodlands of West and Central Africa. A platform for stakeholders in African forestry. African Forest Forum, Nairobi.

MYERS, N. 2002. Environmental refuges: a growing phenomenon of the 21st century. *Philosophical Transactions of Royal Society Series B* **357**: 609–613.

NIASSE, M., AFOUD, A. and AMANI, A. (eds.) 2004. *Reducing West Africa's Vulnerability to Climate Impacts on Water Resources, Wetlands and Desertification: Elements of Regional Preparedness and Adaptation.* IUCN, Gland, Switzerland and Cambridge, UK.

NICHOLLS, R.J., WONG, P.P., BURKETT, V.R., CODIGNOTTO, J.O., HAY, J.E., MCLEAN, R.F., RAGOONADEN, S. and WOODROFFE, C.D. 2007. Coastal systems and low-lying areas. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., eds.; Cambridge University Press: Cambridge, UK, pp. 315–356.

NJAYA, F. and HOWARD, C. 2006. Climate and African fisheries. *Tiempo* **59**: 13–15.

ODJUGO, P.A.O. and IKHUORIA, A.I. (2003). The impact of climate change and anthropogenic factors on desertification in the semi-arid region of Nigeria. *Global Journal of Environment Science* **2**(2): 118–126.

OKALI, D. 2011. Climate change and African moist forests. In: Chidumayo, E., Okali, D., Kowero, G. and Larwanou, M. (eds.) (2011). *Climate Change and African Forest and Wildlife Resources.* (68–84). African Forestry Forum, Nairobi, Kenya.

OLALEYE, O.D., TOMORI, O., LADIPO, M.A. and SCHMITZ, H. 1996. Rift Valley Fever in Nigeria: infections in humans. *Review of Science Technologies* **15**: 923–935.

OSMAN-ELASHA, B., CHIDUMAYO, E. and DONFACK, P. 2011. Socio-economic and gender related aspects of climate change in Africa. In: Chidumayo, E., Okali, D., Kowero, G. and Larwanou, M. (eds.) *Climate Change and African Forest and Wildlife Resources* (176–191). African Forest Forum, Nairobi.

ORLANDO, B.G. and BURTON, I. 2003. *Change: adaption of water resources management to climate change*. Gland, Switzerland, World Conservation Union (IUCN).

OPERE, A., OLAGO. D., CHIDUMAYO, E. and OSMAN-ELASHA, B. 2010. Climate Change Processes and Impacts. In Climate Change and African Forests and Wildlife Resources 18–31.

PIERCE COLFER, CJ., SHEIL, D. and KISHI, M. Forests and Human Health. Assessing the Evidence CIFOR Occasional Paper No. 45. Center for International Forestry Research 13 pp.

PIMENTEL, D. 1993. Climate changes and food supply. *Forum for Applied Research and Public Policy* **8**(4): 54–60.

P.K.T. Munishi, S. Mringi, D.D. Shirima and S.K. Linda 2010. The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. *Journal of Ecology and the Natural Environment* **2**(12), pp. 261–269.

PETER DAWEES 1994. Social and Economic Aspects of Miombo Woodlands Management in Southern Africa: Options and Opportunities for Research CIFOR Occasional Paper Na 2. 28 pp.

REPUBLIQUE DE COTE D'IVOIRE. 2000. *Communication Initiale de la Cote d'Ivoire.* Ministere del'Environnement, del'Eauet de la Foret. Abidjan.

REPUBLIQUE DE GUINEE. 2002. *Communication Initiale de la Guinee a la Convention Cadre desblations Uniessur les Changements Climatiques.* Ministere des Mines, de la Geologieet de l'Environnement, Conakry.

RUEDA, L.M. 1990. Temperature dependent development and survival rates of *Culex quinquefasciatus* and *Aedesaegypti* (Diptera: Culicidae). *Journal of Medical Entomology* **27**: 892–898.

SMIT, B. and WANDEL, J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* **16**: 282–292.

SONWA, D.J., BELE, Y.M., SOMORIN, O.A. and NKEM, J. 2010. Central Africa is not only carbon stock. Preliminary efforts to promote adaptation to climate change for forest and communities in Congo Basin. *Nature and Faune* **25**(1): 58–63.

SULTAN, B., LABADI, K., GUEGAN, J.F. and JANICOT, S. 2005. Climate drives the meningitis epidemics onset in West Africa. *PLoS Med.* **2**: 42–49.

TAYLOR, M., RAVILIOUS, C. and GREEN, E.P. 2010. Mangroves of East Africa. UNEP World Conservation Monitoring Centre (WCMC) GPA Cambridge. www.unep-wcmc.org (site viewed 18/09/2013).

TIEGA, A. 2010. The impact of climate *change* on water and wet lands and the consequences for agriculture and other natural resources. *Nature and Faune* **25**(1): 22–28.

TRIKHOMIROV, E., SANTAMARIA, M. and ESTEVES, K. 1997. Meningoccocal disease: public health burden and control. *World Health Status Quarterly* **50**: 170–177.

TURELL, M.J. 1989. Effects of environmental temperature on the vector competence of *Aedesfowleii*for Rift Valley fever virus. *Research in Virology* **140**: 147–154.

UNDP 2004. Reducing Disaster risk: A Challenge for Development. UNDP Bureau for Crisis Prevention and Recovery. New York.

UNESCO-WWAP 2006. *Water: A Shared Responsibility. United Nations World Water Development Report* 2. United Nations Educational, Scientific and Cultural Organization (UNESCO) and the United Nations World Water Assessment Programme.

URT (UNITED REPUBLIC OF TANZANIA). 2007. National Adaptation Programme of Action (NAPA). Vice President's Office, Division of Environment, Dar essalaam.

WARSAME, M., WERNSDOFER, W.H., HULDT, G. and BJORKMAN, A. 1995. An epidemic of *Plasmodium falciparum* malaria in Balcad Somalia, and its causation. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **98**: 142–145.

YAQUB, C.N. 2007. Desert encroachment in Africa: Extent, causes and impacts. *Journal of arid Environment* **4**(1): 14–20.

YUGUNDA, B.S. 2002. Socio-economic and cultural impacts of desert encroachment in Nigeria. *Journal of Environmental Dynamics* **5**(2): 19–30.

WEI A. and WINKLER R. 2015. Summary: Forests and Water in a Changing Environment. The 4th International Conference on Forests and Water in a Changing Environment, Kelowna, BC, Canada, July 6–9, 2015.