Climate change and vector-borne diseases in Sudan

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Abstract
This review was initiated to contribute to better understanding of the relationship between vector-borne diseases (VBDs) and climate change. Secondary data was collected from published articles, books, reports, and internet sources. The discussion was based on considering different processes of climate change such as rise in temperature and humidity and correlates these changes in climatic change to the dissemination of these diseases in reference to the Sudan. The review concluded that accurate analysis of the relationship between vector-borne diseases and climate change would require interdisciplinary cooperation among epidemiologists, climatologists, biologists, and social scientists. Increased disease surveillance, integrated modeling, and use of geographically based data systems would afford measures that are more anticipatory. Understanding the linkages between climatic and ecological change as determinants of disease emergence and redistribution would ultimately help optimize preventive and early warning strategies.

Keywords: Vector Borne Diseases, Climate Change, Water Borne Discuss.

Introduction
Sudan is a vast country with a population of about 34 million (Abdel Ati, 2012), presents a diversity of ecosystems typical of dry lands with hundreds of ethnic groups. The economy of Sudan is based on agriculture and animal husbandry. Several dams were built for conservation and supply of water into canalization systems (Fig. 1). These are Sennar; Jebel Awlia; Khashm–algirba; Roseres and Merwi dams. Aswan high dam in Egypt has created a lake; one third of which is inside the Sudan. The development of such water resources has led to great modifications in the environment that favored the spread of vector-borne diseases (VBDs), (Amin and Satti, 1973; Amin, 1977; Omer, 1978). Natural water bodies in the Sudan such as rivers, rain pools, and several stretches of the Niles and their tributaries are also important habitats for spread of vector-borne diseases.

Due to scarcity of published reliable data on climate change and its impact on population health vulnerability to VBDs in Sudan, this review was meant to initiate and encourage researchers in Sudan to conduct multidisciplinary researches to better understanding of the impacts of climate change on VBDs. It was also meant to help inform policies on the best methods that would reduce the effects of VBDs to benefit the most vulnerable populations.

Methods
Data were collected through literature review from published articles and PubMed websites and from Annual Health Statistical Reports of the Federal Ministry of Health for 2011.

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The paper is divided into three parts. Part one reports on climatic change; Part two on major VBDs in the Sudan in relation to climate change and their effects on the population; Part three provides general discussion, conclusions and recommendations.

Fig. 1. Agricultural schemes in the Sudan

Climate change
The Intergovernmental Panel on Climate Change (IPCC) has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperature would increase by between 1.4 and 5.8°C by the end of the 21st Century (IPCC, 2007). The 2007 IPCC report predicts temperature rises of 1.1-6.4°C (2-11.5°F) by 2100. This is a wider range than the 1.4-5.8°C increase given in the 2001 report. However, the 2007 report goes on to say that their best estimate for temperature rise is 1.8-4.0°C (3.2-7.1°F) (Masters, 2007).

It has been estimated that vector-borne diseases account for 17% of the global disease burden due to all parasitic and infectious diseases. Every year, for example, there are around 300 million cases of malaria, 50-100 million dengue cases and 120 million filariasis cases (Tabachnick, 2010; Brower, 2001). The WHO (2010) stated “climatic conditions strongly affect water-borne diseases and diseases transmitted through insects and snails”. African countries are among the most vulnerable to the impacts of climate change (IPCC, 2001). The main impacts of climate change in Africa is on water resources, food security, agriculture, natural resources and human health (Huq et al., 2002; African plan of Action, 2012-2014, 2012). The negative impacts associated with climate change are also compounded by wide spread of poverty and human diseases (Davidson et al., 2003). Africa has a high diversity of vector species that have the potential to redistribute themselves to new climate driven habitat leading to new disease patterns (Githeko et al., 2000). Egbendewe-Mondzozo et al. (2011) showed that a
marginal change in temperature and precipitation levels would lead to a significant change in the number of malaria cases for most Africa countries by the end of the century. Hulme (1990) reported that rainfall depletion was severe in semiarid central Sudan, between 1921-50 and 1956-85 annual rainfall has declined by 15%, the length of the wet season has contracted by three weeks and the rainfall zones have migrated southwards by between 50 to 100 km.

Major vector-borne diseases:
Major diseases transmitted by mosquitoes in Sudan include malaria, filariasis and arbovirus-borne diseases.

1. Malaria: Malaria is the major health problem in the Sudan and the whole country is now considered endemic, with varying degrees. It is number one among the (10) diseases treated in health units (Annual Health Statistical Report, Federal Ministry of Health, 2011). The malaria endemic range from holo-endemic in the southern states to hypo-endemic in the northern states with epidemics outbreaks. The major vectors of malaria are *Anopheles gambiae*, *A. arabiensis* and *A. funestus*. Malaria incidence in Sudan was estimated to be about 9 million episodes in 2002 and the number of deaths due to malaria was about 44,000 (Abdalla *et al.*, 2007). Ali *et al.* (2008) reported that the amount of rainfalls and humidity correlated with malaria proportion in Central Sudan. Climate variability and malaria was also studied in three selected sites in Northern, Central and Western Sudan. They have indicated that, the climatologic changes in the three areas appear to have made transmission of *Plasmodium falciparum* more favorable and may account for increase in proportion of malaria. Abelaal *et al.* (2011) found that the malaria cases related to temperature increase was clearly recognized in the Northern State with 1.59% out of the state population. The highest endemic state was Blue Nile with 2.45% in the Rich Wet Savannah, and the lowest State of malaria infections was Western Darfur with 0.06% cases. The total of malaria infections in northern Sudan was 15.19% of 29 million populations. Seasonality in the transmission of Malaria has as well attracted the attention of scholars with some research output in the area. Musa *et al.* (2012) found that the climate factors were suitable for malaria transmission in the period of May to October, whereas the actual case rates of malaria were high from June to November indicating a positive correlation. Comparisons between the prediction model for June and the case rate model for July did not show a high degree of association (18%), the results later in the year were better, reaching the highest level (55%) for October prediction and November case rate.

2. Lymphatic Filariasis: Three different filarial species can cause lymphatic filariasis in humans. Most of the infections worldwide are caused by *Wuchereria bancrofti*. In Asia, the disease can also be caused by *Brugia malayi* and *Brugia timori*. Lymphatic filariasis affects over 120 million people in 73 countries throughout the tropics and sub-tropics of Asia, Africa, the Western Pacific, and parts of the Caribbean and South America (CDC, 2014). More than 90% of the filariasis cases of the WHO/EMRO Region are living in Sudan. This suggests that all Sudanese are living in filariasis endemic areas
Many factors associated with climate change will affect the world’s poor and of those disabled people will be the most severely affected. People with Lymphatic Filariasis (LF) and other disabilities in developing countries will bear the impact of climate change (Cruz, 2010).

3. Arbovirus-borne diseases: There are three important Arbovirus-borne diseases in Sudan; Dengue fever, Rift Valley and yellow fever (Photo 1).

3.1. Dengue: Dengue is a vector-borne viral infection that endangers an estimated 2.5 billion people. The disease caused by dengue ranges from a relatively minor febrile illness to a life-threatening condition characterized by extensive capillary leak. It is transmitted by the main vector, the Aedes aegypti mosquito (Whitehorn, 2010). Recent studies have confirmed the sensitivity of both malaria and dengue fever to climatic variations between years (Bouma et al., 1996; Patz et al., 1996). Dengue transmission is seasonal and usually associated with warmer, more humid weather. There is evidence that increased rainfall in many locations can affect the vector density and transmission potential (Hales et al., 2003). In Sudan Seidahmed et al. (2012) reported that Dengue is heterogeneously distributed across the neighborhoods of Port Sudan. Colon-González et al. (2013) reported that weather significantly influences dengue incidence in Mexico and that such relationships are highly nonlinear. These findings highlight the importance of using flexible model specifications when analyzing weather–health interactions. They predicted an increase of up to 40% in dengue incidence by 2080 was estimated under climate change while holding the other driving factors constant.

3.2 Rift Valley fever: The disease Rift valley Fever (RVF) takes its name from the Rift Valley in East Africa because it was first described and isolated following an outbreak near Lake Nifasha in the region of the Rift Valley, Kenya in 1930 (Daubney et al., 1931). RVF primarily affects animals but also has the capacity to infect humans (Peters et al., 1994;
WHO, 2007; Archer et al., 2011). Outbreaks have been reported in Mauritania; the first one occurred in 1987 after the building of the Diama dam, which had ecological and environmental effects that favored a large-scale outbreak that resulted in 200 human deaths (Digoutte and Peters, 1989). After a period of heavy rainfall, an outbreak of Rift Valley fever occurred in southern Mauritania during September–November 2012. A total of 41 human cases were confirmed, including 13 deaths, and 12 Rift Valley fever virus strains were isolated (Sow et al., 2012). An epidemic occurred in Saudi Arabia from 26 August 2000 through 22 September 2001. A total of 886 cases were reported (Madani et al., 2003). During 2007, a large RVF outbreak occurred in Sudan with a total of 747 confirmed human cases including 230 deaths (case fatality 30.8%); although it has been estimated 75,000 were infected. It was most severe in White Nile, El Gezira, and Sennar States near to the White Nile and the Blue Nile Rivers. Notably, RVF was not demonstrated in livestock until after the human cases appeared and unfortunately, there are no records or reports of the number of affected animals or deaths (Hassan et al., 2011). Several different species of mosquitoes are able to act as vectors for transmission of the RVF virus. Among animals, the RVF virus is spread primarily by the bite of infected mosquitoes, mainly the Aedes species, which can acquire the virus from feeding on infected animals. The female mosquito is also capable of transmitting the virus directly to her offspring via eggs leading to new generations of infected mosquitoes hatching from eggs. This accounts for the continued presence of the RVF virus in enzootic foci and provides the virus with a sustainable mechanism of existence as the eggs of these mosquitoes can survive for several years in dry conditions. During periods of heavy rainfall, larval habitats frequently become flooded enabling the eggs to hatch and the mosquito population to rapidly increase, spreading the virus to the animals on which they feed (WHO, 2010). Martin et al., (2008) reported that climate change is expected to affect the geography of infectious diseases including the distribution of vector-borne diseases, such as Rift Valley fever, yellow fever, malaria and dengue, which are highly sensitive to climatic conditions. In the previous decades RVF disease attacked many countries of the Nile Basin (Faiza, 2008)

3.3 Yellow fever: Yellow fever is a disease caused by a virus, which spreads through mosquito bites. Yellow fever continues to occur in regions of Africa and South America, despite the availability of effective vaccines (Barnet, 2007). The WHO (2013) reported three suspected cases of viral haemorrhagic fever (VHF) in Kassala, Sudan and a total of 40 suspected cases of yellow fever (YF), including 10 deaths were reported from 3 October up to 17 November 2013 in 13 localities in West and South Kordofan. More than 80000 people were vaccinated in West Kordofan and South Kordofan in small-scale vaccination campaigns.

4. Leishmaniasis - Kala-azar: The first case of Kala-azar in Sudan was discovered by Neave in 1904 (Neave, 1904). Visceral leishmaniasis (VL; kala-
azar) has been among the most important health problems in Sudan, particularly in the main endemic area in the eastern and central regions (Zijlstra and El-Hassan, 2001). Cutaneous leishmaniasis (CL) in Sudan is caused by *Leishmania major*. The disease is endemic in many parts of the country. The vector is *Phlebotomus papatasi* and the animal reservoir is probably the Nile rat *Arvicanthis niloticus* (El-Hassan and Zijlstra, 2011). Muller *et al.* (2012) conducted a survey between the 5th of May and the 17th of June to estimate the VL incidence in 45 villages located in the eastern part of Gedaref State, the main endemic focus of VL in Sudan. The overall incidence rate of VL over the past year was 7.0/1000 persons per year. The crude mortality rate over the mean recall period of 409 days was 0.13/10000 persons per day. They concluded the VL is a major public health issue in Gedaref. Active VL case detection had a very low yield in a context of adequate access to care.

Thomson *et al.* (1999) indicated that rainfall (400-1200) and maximum temperature of 34-38°C together with type of soil and occurrence of *Acacia* and *Balanites* determine the presence of the vector *Phelebotomus orientalis*; the vector of leishmaniasis. In Gedaref State, Sudan Elnaeim *et al.* (2003) managed to map the risk of visceral leishmaniasis through study of local variation in rainfall and altitude on the presence and incidence of sand flies. Osman (2011) reported on presence of leishmaniasis among the inhabitants of a small village lies in a deserted area in the Nuba mountain, west of Sudan. The presence of leishmaniasis, in deserted areas can be explained by the disease capability to maintain internal circulation within the vectors and animal reservoirs and this can last as long as 20 years. Muller *et al.* (2011) in their survey, interviewed 17,702 households from a population of 94,369. Sixteen individuals were diagnosed with primary VL through active case-detection, and 725 reported VL treatment over the past year. The overall incidence rate of VL over the past year was 7.0/1000 persons per year. The crude mortality rate over the mean recall period of 409 days was 0.13/10000 persons per day. VL was a possible or probable cause for 19% of all deaths. Taking also into account the VL-specific mortality of 0.9/1000 per year, the incidence was estimated at 7.9/1000 per year. Overall, 12.5% of the population reported to have been treated for VL in the past. They concluded the VL is a major public health issue in Gedaref. Active VL case detection had a very low yield in a context of adequate access to care.

**5. Onchocerciasis:** Onchocerciasis is a parasitic disease caused by the filarial worm *Onchocerca volvulus*. It is transmitted through the bites of infected blackflies of *Simulium* species, which carry immature larval forms of the parasite from human to human. In the human body, the larvae form nodules in the subcutaneous tissue, where they mature to adult worms. After mating, the female adult worm can release up to 1000 microfilariae a day. These move through the body, and when they die they cause a variety of conditions, including blindness, skin rashes, lesions, intense itching and skin depigmentation. *Simulium* species breed in rapids such as dams. Onchocerciasis is a major cause of blindness in many African countries. About
half a million people are blind or visually impaired due to the disease. *Onchocerciasis* also causes ugly skin disease with depigmentation and severe unrelenting itching (WHO, 2014). Owing to the differential dispersal of nulliparous and parous flies in savanna, the annual transmission potentials were related more closely to the numbers of parous flies than to the total fly population (Duke et al., 1975). Higazi et al. (2011) assessed the status of infection transmission in 2007 in the vectors of two disease foci in Sudan: Abu Hamed in northern Sudan, which has received at least 10 years of annual treatment and Galabat focus in eastern Sudan, where only minor, largely undocumented treatment activity has occurred. Assessment of more than 30,000 black flies for *Onchocerca volvulus* infectious stage L3 larvae by using an O-150 polymerase chain reaction protocol showed that black fly infectivity rates were 0.84 (95% confidence interval = 0.0497–1.88) per 10,000 flies for Abu Hamed and 6.9 (95% confidence interval = 1.1–16.4) infective flies per 10,000 for Galabat. These results provide entomologic evidence for suppressed *Onchocerca volvulus* transmission in the Abu Hamed focus and a moderate transmission rate of the parasite in the Galabat focus.

6. **Schistosomiasis:** Schistosomiasis is now a major public health problem in the Sudan with social and economic implications. It is endemic in all states of the Sudan except the Red Sea State with varying prevalence rates from about 3% to 90% (Amin, 2012). An estimated 5.8 million people in the Sudan—around 15% of the total population—require treatment; the majority of those infected are children (WHO/EMRO, 2013). The available literature on impact of climate change on schistosomiasis is limited. In Senegal *Biomphalaria pfeifferi* transmits *Schistosoma mansoni* during the rainy season while *Bulinus globosus* is responsible for *S. haematobium* during the dry season (Githeko et al., 2000). Rainfall patterns have a distinct influence on *B. globosus* in Tanzania. In China, Zhou et al. (2008) found a temperature threshold of 15.4°C for development of *Schistosoma japonicum* within the intermediate host snail (*Oncomelania hupensis*), and a temperature of 5.8°C at which half the snail sample investigated was in hibernation. In the northern localities of Gezira Irrigation Scheme *Biomphalaria pfeifferi* is drastically reduced as a result of rise in temperature. This was reflected in low incidence of *S. mansoni* (Amin et al., 2012).

**Discussion**

Climate change is the first environmental problem in the World at present and Sudan contribution to problem of climate change is very small as its emission of green houses gases is estimated at 0.07% mostly from land use sector (Abdel Ati, 2012). Climate change poses a significant challenge to the people of Sudan (AIACC, 2006; NAPA, 2007). They are under continuous threats from excessive climate variability, recurrent drought; frequent floods and they have limited potentials to cope with adverse situations. For Sudan, climate change is not merely an environmental issue, but a serious sustainable development problem for widely spread communities. Each year, climate threats emerge, further worsening the prospects of health and livelihood of these vulnerable communities. The
ability to adapt to climate change is a critical factoring the chances of prospectively and even survival of these communities. The scenarios of climate analysis indicate that the average temperatures are expected to rise in 2030 by between 1.5-3.1 degrees Celsius in the month of August, and from 1.1 to 2.1 degrees Celsius in January. The same forecast indicates a decrease in the amount of rainfall by about 6 mm per month during the rainy seasons (Abdel Ati, 2012). Much of the impact of climate on vector borne diseases can be explained by the fact that the arthropod vectors of these diseases are ectothermic (cold-blooded) and, therefore, subject to the effects of fluctuating temperatures on their development, reproduction, behavior and population dynamics (Kenneth et al., 2008). Further Vector-borne diseases are linked to the environment by the ecology of the vectors and of their host’s behavioral activities. It is predicted that over a million death and considerable morbidity worldwide by the 21st century (WHO, 2014). Most of the vector-borne diseases that prevail in Sudan; e.g. Leishmaniasis, Kala-azar, Schistosomiasis, filariasis and Onchocerciasis, are among the so-called Neglected Tropical Diseases (NTDs). Very few studies have been carried out regarding the connection of NTDs with climate change (Campbell-Lendrun, 2003 search). Their search, largely bases on countries of high prevalence, appeared to be primarily the result of poverty (Manderson et al., 2009). Therefore, there is a need to attract fund for research in this area from the private sector and more allocation of funds from the government. Long term studies are needed because “whether climate changes increase or decrease the incidence of vector-borne diseases in humans will depend not only on the actual climatic conditions but also on local non-climatic epidemiologic and ecologic factors” (Kenneth et al., 2008). Reiter (2001) indicated that climate change has rarely been the principal determinant of the prevalence or range of the three diseases—malaria, yellow fever, and dengue; human activities and their impact on local ecology have generally been much more significant. It is therefore inappropriate to use climate-based models to predict future prevalence.

Conclusions and Recommendations
Climate change would directly affect disease transmission by shifting the vector's geographic range and increasing reproductive and biting rates and by shortening the pathogen incubation period. Climatic factors influence the emergence and reemergence of infectious diseases, in addition to multiple human, biological, and ecological determinants. Very few studies have been carried out regarding the connection of VBDs with climate change in the Sudan. Accordingly, there is a need to conduct research in this area. This would require interdisciplinary cooperation among epidemiologists, climatologists, biologists, and social scientists (Patz et al., 1996). Funds may be obtained from international or regional research calls, the private sector and more allocation of funds from the government. Furthermore, increased disease surveillance, integrated modeling, and use of geographically based data systems will afford more anticipatory measures by the medical community. Understanding the linkages between climatological and ecological change as determinants of disease emergence and redistribution will ultimately help optimize preventive strategies. The efforts
could be strengthened through capacity building of young scientists abroad in integrated modeling, and use of geographically based data systems.

**References**


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