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CAPACITY STRENGTHENING IN THE LEAST DEVELOPED COUNTRIES (LDCS) FOR ADAPTATION TO CLIMATE CHANGE (CLACC)

CLIMATE CHANGE AND HEALTH IN SUDAN

SECS

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FOREWORD

This study "Human Health and Climate Change" was carried out under the Capacity Strengthening of Least Developed Countries (LDCs) for Adaptation to Climate Change (CLACC) network. Primary objective of the study was to create awareness among the health professional in Sudan.

We would like to thank the focal point for Climate change in Sudan at the Higher Council for Environment and Natural Resources (HCENR) for their support, advices and contribution. We are also grateful for Dr. Wsilat Zarwoog, Ministry of Health, Malaria Control Program, for her help and provision of information during the period of study.

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EXECUTIVE SUMMARY

Sudan is a developing country and at the moment many developmental projects are being implemented. In the national strategies many major projects are also planned for the near future. Many of the these developmental projects (such as dams, agricultural projects) are likely to cause drastic changes in the environment (micro, meso, macro environment) and are likely, if not carefully managed, to encourage the spread of diseases (malaria, bilharzias etc.). The joint negative impacts of climate change and lack of development could be very dangerous and might threaten the health of a large number of people in the country. Risk reduction requires the collaboration, cooperation and serious attention of policy makers (health, irrigation, agriculture authorities) as well as the affected stakeholders.

Malaria is one of the most important health problems in Sudan. The current study confirmed precious findings of presence of correlations between malaria disease and the different climatic factors (rainfall, relative humidity, and temperature). Three areas were studied; they were quite different in their ecology and consequently in the livelihoods practiced by the inhabitants. In Central Sudan (Sennar) the high peak of the disease was found to occur during autumn and winter and that was found to correlate significantly with the rainfall and percent of relative humidity. In Northern Sudan (Dongola) the proportion of the disease was found to correlate significantly with temperature only, however, no differences were found between seasons. That was expected as the northern state is very arid (desert) and its average rainfall doesn't exceed 75 mm/ year and the seasonal variation in humidity range between 17-26%. In western Sudan (Elobied), in spite of the fact that it is more humid than Northern Sudan, no significant seasonal trend was found and the temperature was not found to significantly affect the proportion of the disease. Western Sudan in general is characterised by acute water shortage and accordingly the citizens use different methods (ponds, barrels etc.) for water storage all the year around which was found to provide suitable environment for reproduction of mosquito and accordingly was found to cause increase in incidents of malaria epidemics. The relationship between the climatic factors and the proportion of the disease was found to be offset by the availability of stored water not only in western Sudan but also in many different parts of the country.

Flood events were also found to cause malaria epidemics in Sudan, even in the arid and semi-arid zones (due to increase of the Nile level during rainy season or due to local torrential rainfall). With climate change, extremes (drought, floods) are expected to increase in frequency, and accordingly malaria epidemics may increase. Careful planning and environmental management are required to avoid future epidemics and disasters. Preparedness is needed to reduce the risk of malaria expanding into new areas (as temperature become more suitable *e.g.* high land) and seasons (winter) as was speculated from modelling for the disease in western Sudan for the years 2030 and 2060.

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Section I

1 Introduction to climate change and health

In recent years there has been a great deal of scientific and public debate on the impacts of climate change and global warming (IPCC 2001). Now there is a widely held view that global warming and climate change will have mostly negative impacts on human health (Confalonieri et al., 2007) and specifically harmful alterations to infectious diseases such as malaria (Tren 2002b). Industrialized countries face increasing health challenges with climate change. Epidemiological studies conducted in industrialized countries have shown that climate-mediated air pollution has had a substantial impact on people with asthma, chronic bronchitis and heart conditions. However, the impacts of climate change on the Least Developed Countries (LDCs) appear to be much more harmful. These impacts can be considered through the third assessment report of the IPCC which provides information on the impacts and vulnerability of the main regions in which LDCs are located, namely, Sub-Sahara Africa, Asia and the small islands states (IPCC 2001).

In LDCs, rising temperature and humidity have facilitated the spread of many vector-borne infectious diseases including malaria, kala-azar, diarrhoeal diseases, cholera and malnutrition. The increasing prevalence and mortality due to communicable diseases, has not only affected the populations' health, but also burdens societies by lowering productivity, increasing medical costs, and taxing the tenuous health care systems that are characteristic of many LDCs (Huei and Tzu-Ming 2005). If communicable diseases spread to nearby countries and adapt to new environments, the impact resulting from the synergic effects of climate and disease epidemics presents a serious hazard to international health. There are many historical examples of such outcomes, including the spread of cholera from Asia to Europe, Africa, and the Americas since the 1800s and the recent spread of SARS from China to many Asian countries in 2003.

Africa is the most vulnerable region to climate change, as a result of the low adaptive capacity of the African population (IPCC, 2001). This low capacity is due to the extreme poverty of many Africans, frequent natural disasters such as droughts and floods, and rainfall dependent agriculture. Africa already has a highly variable and unpredictable climate, and global warming is worsening that situation. In the Sahel, there has been on average a decrease in annual rainfall over the past 30 years, consistent with climate change models (Simms, 2004). The main impacts of climate change in Africa and other LDCs will therefore be on water resources, food security and agriculture, natural resources management and biodiversity, and human health (Huq *et al*., 2003).

As global warming increases, it becomes evident that it will lead to serious direct impacts on human health around the world. Direct effects of climate change on human health will include heat stress, with associated cardio-vascular complications, as well as the physical and psychological impact of storms, floods and other extremes climate events (Simms 2004). Indirect effects will also take place because of the close relationship between climatic conditions and health determinants such as insect and rodent populations (Simms 2004). The distribution and abundance of vector organisms (disease carriers) and intermediate hosts are affected by both physical (e.g. temperature, humidity, rainfall) and biological factors (e.g. vegetation, host species, competitors, predators etc.) in the ecosystem. Changes in climate may alter the distribution of important vector species and increase the spread of diseases to new areas. For instance, highland populations that fall outside areas of stable endemic malaria transmission may be particularly vulnerable to increases in malaria due to climate warming. Not only will climate change worsen various current health problems, it may also bring new and unexpected ones (IPCC 2001). Additionally, illnesses such as meningitis infections appear to be affected by warming and reduced precipitation as epidemics are more prevalent in areas of low humidity. Regions where climate change will reduce rainfall levels could become at risk of meningitis epidemic. Flooding and extra demand on diminishing water sources could also increase the pollution and contamination of streams, wells, and other water sources in rural areas with parasites such as *Giardia*, *amoeba* and *cryptosporidium* (IPCC 2001).

2 Climate change

2.1 Sudan's Climate

Sudan is located in northeast Africa in the tropical zone between latitudes 3-22^{0}N and longitudes 22-38^{0}E sloping from South to North. It is bounded on the east by the Red Sea and an extension of the Ethiopian Plateau. The vast plains of the country are interrupted by a few widely separated hills and mountains, mainly in the west, central and extreme south, which affect climatic features for whole the country.

The main factor determining the climate of the region is the seasonal shift of the Inter-Tropical Convergence Zone (ITCZ), the front of which moves with the changing zenithal position of the sun. During the winter months, from October to March, there is high air pressure over the Sahara and dry north winds blows across Sudan and towards the ITCZ, which may lie as far south as the Tropic of Capricorn. With the advance of the sun towards the summer solstice, the zone of convergence of northerly and southerly air streams moves northwards across Sudan, and moist, unstable air is drawn from the South Atlantic Ocean (Wickens, 1976).

2.2 Drought

The African continent has a long history of rainfall fluctuations of varying lengths and intensities. The worst droughts were those of the 1910s, which affected east and west Africa alike (Gommes, 1996). They were generally followed by increasing rainfall amounts, but negative rainfall trends were again observed from 1950 onwards culminating in the severe sahelian in 1984. FAO classified Sudan and other African countries (Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal) as being the driest and most variable in Africa. Runs of dry years and runs of wet years are a typical feature of the regional climate of the countries in this group where extreme years (either good or bad) are more likely than average ones (Gommes, 1996). Sudan is part of the Sudano-sahel region and consequently has been exposed to a series of recurring dry years. Drought has thus become a normal phenomenon that affects many of its regions. Two types of drought have been identified (SFNC, 2003); occasional droughts (due to seasonal or inter-year variations in rainfall) and long-term droughts covering wide areas. Both types are caused or aggravated by the influence of man on the environment (e.g. reduction in vegetation cover, changes in the albedo effect, changes in the local climate, the greenhouse effect). Between 1961 and 1998, episodes of drought affected Sudan with varying severity. This period witnessed two widespread droughts during 1967-1973 and 1980-1984 with the more recent the most severe. The same period witnessed a series of localised droughts during 1987, 1989, 1990, 1991, and 1993, mainly in western Sudan (Kordofan and Darfur) and part of central Sudan. Droughts occur frequently in areas affected by desertification, and are generally a feature of the natural climate. Yet the relation between desertification, drought, and human influence on the both, is complex (Koohafkan, 1996). Strong demographic pressure has increased demand on land resources, and this demand if further aggravated when cash-crop farming spreads, generally harming subsistence farmers and to the rangelands used by nomadic people.

2.3 Floods

Floods also threaten Sudan. There are two types of floods that affect the country; localized floods caused by exceptionally heavy rainfall, and runoff (flash flood) and widespread floods caused by overflow of the river Nile and its tributaries.

Following two consecutive years of serious drought, extensive floods in northern Sudan have displaced tens of thousands of people, destroyed crops and aggravated the already precarious food supply situation in the affected areas (FAO, 2001). During the year 2001, heavy rains in the Blue Nile catchment areas in the Ethiopian highlands caused an overflow of the Nile River and submerged many villages and settlements. Water levels in the Nile were reported to be higher than those of 1988 (FAO, 2001), when the river burst its banks and caused massive destruction. The worst flood-affected areas are northern and eastern sections along the Nile, including areas around the capital city Khartoum. South Darfur State has also suffered from flash floods due to torrential rains. Large numbers of inhabited islands on the Nile have been evacuated; but several villages and towns remain isolated by the floods. Access to the affected population is generally difficult due to damage to main roads and bridges.

3 Current Health Issues in Sudan

Sudan has 25 State Ministries of Health (SMoH), one in each State. The Federal Ministry of Health (FMoH) is responsible for the development of national health policies, strategic plans, and monitoring and evaluation systems for health activities and statues. The SMoH are mainly responsible for policy implementation, detailed health programming and project formulation. The implementation of the national health policy is undertaken through the district health system based on the primary health care strategy (RBM 2005).

The health care delivery system in Sudan is provided through more than 6,540 health facilities comprising 2729 PHC units, 1442 dressing stations, 1468 dispensaries and 673 health centres. There are, in addition, 230 hospitals, 44 tertiary level teaching hospitals, 13 universities with medical and health science facilities, and 250 health schools and institutes. According to the 1997 statistical report, there were 3,218 specialists and physicians, 205 dentists, 302 pharmacists, 24015 nurses and midwives and 13492 paramedical staff.

The country is suffering from continuous civil strive in the south and the west, leading to successive waves of massive population movement, coupled with drought and desertification, major floods in the northern part of the country in 1998, and severe loss of human resources (brain drain) especially in health sector. This has severely affected the health infrastructure and health status of the country. These further reduce the country's ability to undertake major control effort in a sustainable way without external support.

The major health concerns are:

- A rise in the incidence of infectious diseases including malaria
- A high maternal mortality rate
- A high incidence of infant malnutrition and high infant mortality rate
- An increase in private expenditure in curative services
- A reduction in government expenditure on health (RBM, 2005).

Climate change will affect health in countries in ways consistent with existing burdens of disease. Because of this, it is important to understand general demographic, health system, and mortality specifics of a country. Table 1 lists some selected indicators for

Sudan, which may be relevant to current and future magnitudes of the health impacts of climate change in the country.

Table 1. **Selected demographic, health system, and mortality indicators for Sudan** (WHOSIS, 2008)

Indicator	Metric
Population total	37 707 000
Population annual growth rate (%)	2.2
Population living below poverty line (% living on < US$1 per day)	-
Population proportion under 15 years (%)	40
Children <5 years of age stunted for age (%)	47.6
Children <5 years of age underweight for age (%)	38.4
Environment and public health workers density (per 10 000 population)	<1.0
General government expenditure on health as percentage of total government expenditure	7[A]
Adult mortality rate (probability of dying between 15 to 60 years per 1000 population) both sexes	296
Under-5 mortality rate (probability of dying by age 5 per 1000 live births) both sexes	89
Infant mortality rate (per 1 000 live births) both sexes	62
Deaths among children under five years of age due to diarrhoeal diseases (%)	12.9[B]
Deaths among children under five years of age due to malaria (%)	21.2[B]
Population with sustainable access to improved drinking water sources (%) Total	70
" " (%) Urban	78
" " (%) Rural	64
Population with sustainable access to improved sanitation (%) Total	35
" " (%) Urban	50
" " (%) Rural	24

All metrics from 2006 unless superscript: A= 2005, B=2000

Sudan is the largest country in Africa, with 2.6 millions square Kilometres, with a similarly large, and very young, population. Almost three quarters of the population lives in rural areas and the population density in most of the country is very low. As mentioned, Sudan is one of the LDCs with an average per capita income of less than $400 a year (PRSP, 2004) and more than 85% of the population in rural areas living below the absolute poverty level. Educational levels are low and the burden of disease is heavy and widespread. Such problems have been targeted and some progress is being made towards their improvement. The comparison between actual and targeted poverty indicators is made in Table 2 below.

Table 2: **Basic Poverty Indicators for Sudan current and targeted by PRSP** (PRSP, 2004)

Poverty Indicators	Current Status	Targeted
Basic education enrolment	75.2%	90%
School intake	59.4%	70%
Illiteracy rate	50.1%	41.1%
Infant mortality rate	68/ 1000	65/ 1000
Child mortality rate	103/ 100 000	96/ 100 000
Mother mortality rate	509/ 100 000	478/ 100 000
Malaria	25	23
AIDS	1.6	1.12
Water	60	64.5
Sanitation	60	66

The health status of the Sudanese population is still a major cause of concern. Most of the health indicators in the two tables above are below the three targets set by WHO for 'health for all', specifically a low life expectancy, infant mortality rate, and crude death rate.

4 Climate variability and diseases in Sudan

The relationship between various diseases and meteorological elements has been well-documented. Climatic variations are thought to have a direct impact on the epidemiology of many vector–borne diseases. According to the World Health Organization, at least 30 diseases have emerged or resurged since 1975 (WHO 1997). Very broadly, two categories of factors contribute to the emergence or resurgence of vector-borne diseases: 1. social transitions, such as urbanization and globalization, and 2. environment changes, such as climate change and ecological disruption (McMichael 2004). Several studies using statistical models based on empirical weather data have concluded that climate change affects epidemics of vector-borne diseases, such as Ross virus Fever in Australia (Woodruff, Guest et al. 2002) and malaria in Ethiopia (Abeku, de Vlas et al. 2002). Climate changes can play crucial roles in determining factors that contribute to epidemics of vector-borne diseases. Vector borne-diseases are characteristically transmitted through the effective contact between humans and the vectors. The occurrence of the diseases depend on the triangle inter-relationship among hosts, pathogens, and vectors (Sutherst, 2004). Any alteration to the this triangle relationship will therefore impact the epidemic potential of vector-borne infectious diseases. Most importantly, vectors, pathogens, and hosts, survive and reproduce under a specific range of environmental conditions. Changes in temperature and humidity, could impact the breeding, maturation and survival of vectors, which consequently lead to changes in their geographic distribution (McMichael, 2003).

In Sudan, the relationship between climate variability and some diseases has been investigated in scattered studies and reports. Using medical and meteorological data for six years (1986-1991), it has been stated that malaria fever and asthma have good correlation with some meteorological factors. Malaria was found to have strong negative correlation coefficients with both maximum and minimum temperatures (-0.7, -0.69 respectively), and strong positive correlation with air pressure level (0.7) (Idrees 1992). El Naiem *et al* (2002) studied the role of local variation of rain fall and altitude on the presence and incidences of sandflies, thereby managing to map the risk of visceral leishmaniasis. They developed an eco-epidemiology model from environmental variables to provide detailed mapping of classified incidences of visceral leishmaniasis (VL) in Gedarif State.

Other more direct health impacts of climate have also been studied. In the year 2001 (June-August), in the Port Sudan city, some 37 out of 89 persons who were affected by sun stroke were reported to die. The increase in mortality rate was expected during that year because of the drastic increase in temperature, which reached up to 50 ^{o}C. The State Governor explained that mortality rates due to sun stroke have increased during that year. This was particularly true when compared to years 2000 and 1999, where 26 and 35 persons died because of the sun strokes respectively (Arabic News 2001).

4.1 Malaria in Sudan

Vulnerability

Malaria, as the main cause of death and absence from work in Sudan, is the country's most important public health problem. Based on government records it causes deaths of about 35 000 per year and represents the main cause of morbidity and mortality (PRSU 2004). Annually, the number of malaria cases range between 7-8 million and malaria constitutes 30–50% of all outpatient attendance, 20-30% of all hospital admission and 5-15% of all deaths. However, experts believe that the magnitude of the malaria problem in Sudan far exceeds official figures, particularly in rural areas where access to appropriate health services (approximately 20%) and epidemiological reporting systems are both very limited (SFNC 2003).

Young children are most severely affected by malaria, with one in five childhood deaths in Africa directly attributed to malaria. However mortality is not the only problem, serious long-term neurological disabilities, severe anaemia, and multiple organ failure are often experienced as a result of the infection. Sudan is no exception, and recalling that the population structure of the country is disproportionately young and rapidly growing (a broad base-pyramid), the degree of malaria vulnerability is quite alarming.

Pregnant women are also very susceptible to malaria, which causes serious adverse effects including abortion, low birth weight and maternal anaemia. It is the leading cause of maternal mortality in Sudan (Adam 2005). Recent studies in eastern Sudan suggested that *P. falciparum* malaria is common in pregnant women attending antenatal care and that anaemia is additionally an important complication (Adam 2005).

Finally, displaced persons suffer from many risk factors which contribute to malaria illness, including: specific tribe characteristics, language difficulties, insecure water sources, poor education, and difficult food expenditure. It has been recommended that language-specific education interventions along with the provision of safe water was essential for the reduction of malaria vulnerability in these populations (Saeed, 2003).
As can be seen from these differing and uniquely vulnerable populations in Sudan, any increase in malaria transmission potential instigated through climate change would have broad reaching impacts.

Vector and climate

The main vector involved in transmission is the mosquito *Anopheles arabiensis*, which is well distributed over dry savannah and semi-arid parts of the country. Mosquitoes *A. gambia* and *A.finistus* are also sometimes involved, but *Plasmodium falcipram* is the main parasite for the majority of the infections (90%) with other species *vivax*, *ovale* and *malariae* rarely found. On an epidemiological basis, the country has been divided into stable and unstable transmission zones. The unstable transmission zone consist of three epidemiological strata (Hypo –endemic stratum (desert fringe), Meso-endemic stratum (poor savannah) and urban (man made malaria) stratum (Figure 1 and Table 3). The Southern part of the country (rich wet Savannah) is characterized by stable transmission malaria, while the Central and Northern parts (poor dry Savannah) are unstable transmission zones with epidemic prone areas. Records indicate that epidemics occur only at unstable (hypo-meso endemics) transmission zones along the Nile valley and basin. Unfortunately, most of the population of the country are concentrated here and these areas are prone to inter-annual variations in climate, hydrological, and socio-economics factors.

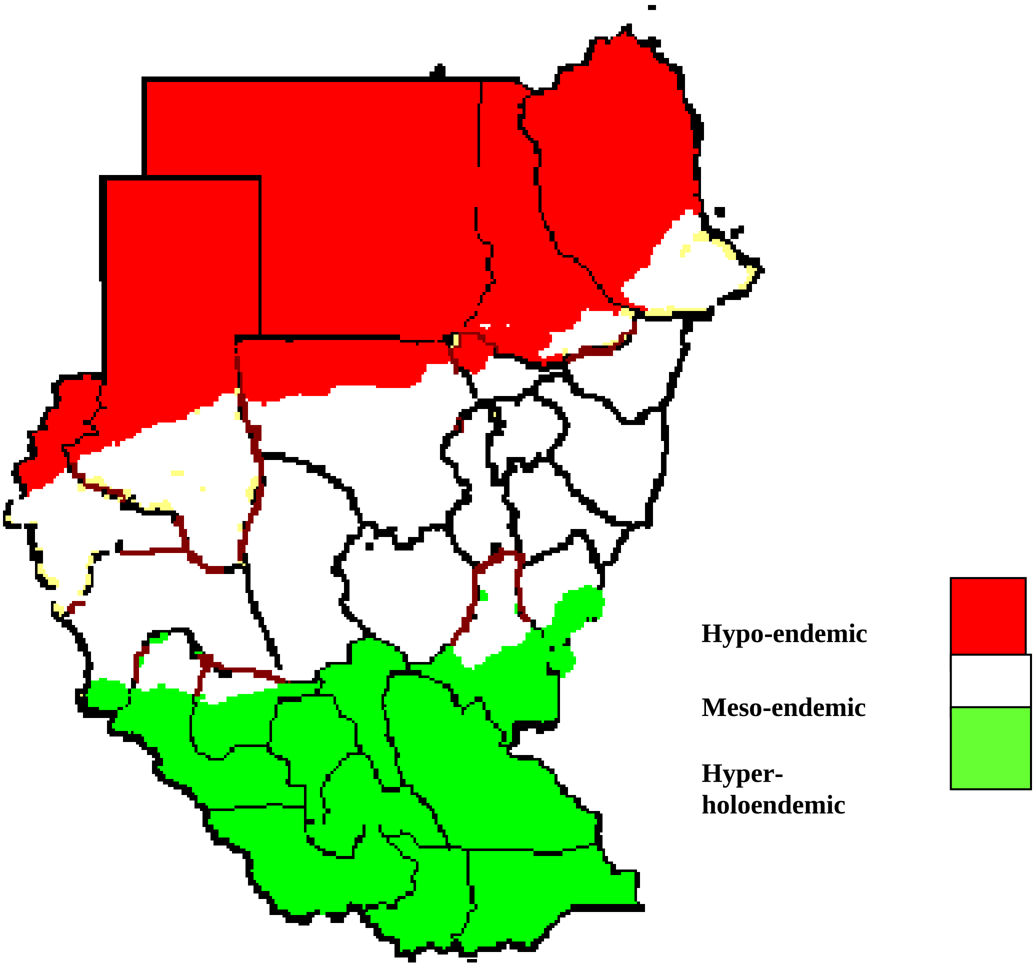

Figure 1: **Zones of Malaria Burden in Sudan** (Source: National Malaria Control Programme)

Table 3: **Sudan Malaria stratification (epidemiological strata)**

Strata	Endemicity	Population	States
Desert fringe stratum	Hypo-endemic	1 000 000	Northern, R. Nile, R. Sea, except Port Sudan
Poor Savannah	Meso-endemic	20 000 000	N.Darfour, W.Darfour, N. Kordfan, B.Nile, W.Nile, Sinnar, Gazira, Gadarif, Kassala, Khartoum
Rich wet Savannah	Hyper-endemic	4 000 000	Southern Sudan
Urban malaria	Meso-endemic	5 000 000	All large cites

Source: National Malaria Control Program

The country has a history of frequent malaria epidemics in the epidemics prone areas (hypo and meso-tendemic zones) in Khartoum state, Gezira, Sinnar, White Nile, Blue Nile, Al-Gadarif, Kassala, Red sea, Northern, River Nile, Northern Darfur, Western Darfur, Southern Darfur, Northern Kordofan ,Western Kordofan , and Southern Kordofan state (Table 4 below).

Table 4: **Epidemic malaria years in the Sudan**

Years	State	Province	Locality
1974-75 1993-94 1990-95	Gezira Gezira Gezira	Gezira Gezira Gezira	Barakat
1988	River Nile	Atbara	Atbara
1981- 1988 – 1994 –	 Khartoum Khartoum	Kh. North	El Droshab El Jeily El Seliat
1988 – 1998-	River Nile River Nile	El Damar	El Zeidab
1976- 1993- 1998-	 Gedarif & Kassala Gedarif	 Gedarif El Rahad	El Fao
1992 – 1999 -	North Kordofan	Sheikan	Khortagat
1970 – 1978 – 1988 – 1993 – 1998 – 1999-	 White Nile White Nile White Nile White Nile White Nile	Kosti	El Rank Kosti
1985 -	Gezira Gezira Gezira	Port Sudan	Toker
2001-	River Nile	Al-gold	Al-gold
1985-	Red Sea	Port Sudan	Toker
2001-	Northern	Al-gold	Al-gold
2001-	Kassala	Kassala	Kassala

Source: National Malaria Control Program

In 1974 -1975 serious malaria epidemics affected the Gezira area in the central zone. Public outcry concerning the epidemics lead to establishment of the Blue Nile Health Project (BNHP) in 1975 with contribution from the Sudan government, WHO, World Bank, Kuwait, Japan, and USA. The project focused on malaria control as a core programme component, contributing to successful Malaria control for 10 years. Malaria prevalence was reduced from 25% to < 1%; but due to discontinuation of external funds, control operations were terminated in 1989. The transmission of the disease again took on epidemic form due to reduction of local population immunity. The increasing incidence of the disease built up to appear in dramatic epidemics in 1993 - 1994.

In Al-Gedaref State, epidemic years usually followed heavy seasonal rains (e.g. 1993, 1998). An epidemic occurred in 1978 in this state following the war in Ethiopia when vulnerable, internally displaced people (IDPs) crossed the border to Kassala and Al - Gedarif states. Epidemics in River Nile State coincide with heavy floods as seen in the years 1974, 1988, 1989, and 1994.

With similar research into the factors that determine malaria epidemics, a list can be compiled. Malaria epidemics are influenced by:

- Climatic factors, such as rains, drought famine, temperature, humidity and floods.
- Successive migratory waves of population between hypo and hyper endemic areas, leading to increase malaria in the community.
- Political instability in the bordering countries and influx of refugees.
- Parasite resistance to the first line drug chloroquine.
- Vector resistance to insecticides.
- Problems in availability and affordability of the proper anti-malarial drugs, and poor accessibility to remote health facilities.
- Establishment of large agricultural projects, extensive large-scale cultivation of sugar, cotton, rice and wheat in the Gezira, Kenana extension. These projects often create new breeding sites for mosquitoes and require large contingents of seasonal labour who generally live in crowded and poor housing conditions

Climate and Malaria

Temperature affects many stages of the malaria life cycle (parasite and vector). The duration of the extrinsic phase depends on temperature and on the species of the parasite the mosquito is carrying. The extrinsic cycle normally lasts nine or ten days, but sometimes can be as short as five days (Reid 2000). As the temperature decreases, the number of days necessary to complete the extrinsic cycle increases for a given *Plasmodium* species. The extrinsic phase can cycle quickest when the temperature is 27°C. The optimum temperature for mosquitoes is 25-27°C, and the maximum temperature tolerated for both vectors and parasites is 40°C. However, there are some areas where the climate is optimal for malaria and mosquitoes are present, but there is no malaria. This is called "Anophelism without malaria" which can attributed to the mosquitoes not feeding primarily on humans or because malaria control techniques have eliminated the parasite. If any alterations, environmental or otherwise, were to occur which introduced vectors for human malaria, the potential for a malaria outbreak would be very due to the lack of immunity in the human population (Reid 2000).

Precipitation: Anopheline mosquitoes breed in water habitats, thus requiring a specific amount of precipitation in order to successfully reproduce. Too much rainfall, or rainfall accompanied by storm conditions can flush away breeding larvae. Not only the amount and intensity of precipitation, but also the time in the year (wet or dry season), affects malaria parasite survival. Rainfall also affects malaria transmission by its related increase in relative humidity and modification of temperature, which affects where and in what quantities mosquito breeding can occur.

Relative humidity also affects malaria transmission. Plasmodium parasites are not affected by relative humidity, but the activity and survival of Anopheline mosquitoes are. If the average monthly relative humidity is below 60%, it is believed that the life of the mosquito is so shortened that malaria transmission is almost impossible.

Wind may play both negative and positive roles in the malaria cycle as very strong winds can decrease biting or ovipositing by mosquitoes, while at the same time may extend the length of the flight of the mosquito. During a monsoon, wind has the potential to change the geographic distribution of mosquitoes (Reid 2000).

Section II

5 Case study: Climate variability and malaria in three sites

This case study addresses the effect of the climate change on malaria transmission in Sudan. The analysis was conducted using data on monthly climatic variables and monthly malaria proportion from three selected sites (Northern, Western and Central areas), during the 1993-2003 time period.

Analysis of data showed that the amount of rainfall and humidity during the rainy season was significantly correlated with malaria proportion in Central Sudan and was not significantly correlated in Western Sudan. No evidence was found associating mean, maximum, and minimum temperatures to malaria proportion in the two sites. However, in Northern Sudan there was significant association between temperature (mean, maximum and minimum) and malaria proportion. These climatologic changes in the 3 areas appear to have made transmission of *P. falciparum* more favourable, and therefore may account for increases in proportion of malaria in addition to the effect of other non-climatic factors.

5.1 Introduction

The occurrence of vector-borne diseases such as malaria is determined by the abundance of vectors and/or intermediate and reservoir hosts, the prevalence of disease-causing parasites and pathogens suitably adapted to the vectors, and the human or animal hosts and their resilience in the face of disease (McMichael, 1997). Local climatic conditions, especially temperature and moisture, are also determinant factors for establishment and reproduction of the *Anopheles* mosquito (Epstein *et al* 1998). The relationship, however, between climate and mosquito populations is highly complex. There are over 3,500 species of mosquito, and all breed, feed, and behave differently. Increased temperatures and higher rainfall and humidity can create more breeding pools for vectors and allowing them to develop faster. Conversely, high rainfall can wash out breeding pools and decrease vector populations. Mosquitoes are highly adaptable and use effective survival strategies to protect against both extreme heat and cold. They have been known to survive winters with temperatures as low as -10.C^{o}. *Anopheles gambiae* survives temperatures of more than 55.C^{o} in the Sudan (Tren 2002). The occurrence of vector-borne diseases is widespread, ranging from the tropics and subtropics to the temperate climatic zones. With few exceptions, they do not occur in the cold climates of the world, and are absent above certain altitudes even in mountain regions of the tropical and equatorial belt (WHO, 2001).

5.2 Climate Change and Malaria

Vectors require specific ecosystems for survival and reproduction. These ecosystems are influenced by numerous factors, many of which are climatically controlled. Changes in any of these factors will affect the survival and hence the distribution of vectors. Global climatic change projected by the Intergovernmental Panel on Climate Change (IPCC, 2001) may have considerable impact on the distribution of vector-borne diseases. A permanent change in one of the abiotic factors may lead to an alteration in the equilibrium of a ecosystem, resulting in the creation of either more or less favourable vector habitats. At the present, the projected increase in average temperatures under climate change is likely to create more favourable conditions in terms of both latitude and altitude for vectors, which may then breed in larger numbers and invade formerly inhospitable areas. Lindsay and Martens (1998) and Martens *et al* (1999) have investigated the possible changes in the distribution of malaria as a result of climate change. Increases in temperature and rainfall would likely allow malaria vectors to survive in areas immediately surrounding their current distribution limits. How far these areas will extend in terms of both altitude and latitude depends upon the extent of warming.

Small changes in temperature and precipitation may influence malaria epidemics in the current transmission zones (Tren 2002b; Huq 2003). Increased flooding may also facilitate the breeding of vectors and so would increase transmission in the arid zones. The Sahel, for example, could be at risk of epidemics if climate change increases flooding in the area. Variations in the extreme weather associated with El Niño cycles are likely to become more common and intense under climate change (Simms 2004). The last strong cycle of El Niño was in mid –1997 and continued through 1998 and had a major global impact. After that cycle, malaria, Rift Valley fever and cholera outbreaks were recorded in many east Africa countries.

Modelling based on IPCC (2001) scenarios suggests that temperature rises by 2100 could lead to significant increases in potential breeding grounds for malaria in parts of Brazil, Southern Africa and the Horn of Africa. In a few areas – such as parts of Namibia and the West African Sahel – malaria risk may actually fall due to excessive heat. Latitudinal and altitudinal boundaries for malaria transmission seem to be changing, as many highland areas have experienced malaria epidemics in the past few years. African cities that currently are not at risk of malaria because of their high altitudes, such as Nairobi and Harare, may be newly at risk if the range in which the mosquito can live and breed increases. It has been hypothesized that increasing temperatures could be part of the reason why malaria can now survive at higher altitudes. Many other confounding factors, however, could be causing the increase in malaria in these areas (Patz and Lindsay, 1999).

In general climate change may affect malaria as follows:

- It may increase malaria distribution where it is currently limited by temperature, so that epidemic malaria may become present in new areas.
- It may decrease distribution where it becomes too dry for mosquitoes to be sufficiently abundant for transmission.
- It may increases or decreases the suitable months of transmission. However, climate change is not expected to affect malaria in sub-Saharan Africa where endemic transmission already occurs and climate is suitable year round.

There are also many variables that affect malaria transmission in addition to climatic changes, such as environmental modification (e.g. deforestation, increases in irrigation, swamp drainage), population growth, limited access to health care systems, and lack of or unsuccessful malaria control measures (Patz and Lindsay, 1999). Some studies have been done on the subject, yielding differing results as to which factor or factors are most responsible for the increase in malaria. Most of the studies, however, do not take into account all of the factors that are related to malaria transmission. This makes it difficult to assess the true determinants of malaria in each area (Reid, 2000).

5.3 Climate change implications for the Case Study

According to a GIS distribution model developed for the purpose of converting climate data into a malaria distribution map for sub-Saharan Africa, the zones most vulnerable to future malaria epidemics due to climate change are likely to be between 4 and 11 degrees latitude (for both the *P. vivax and P. falciparum* parasites), a swath which includes Southern Sudan and parts of Kordofan Region. Sudan's first national communication focused on Transmission Potential (TP) in order to provide an indication of when and where malaria epidemics could occur in Sudan considering under projected climate change. Kordofan region was selected here for analysis largely because of the potential impact of malaria in the area. However, it was also selected to contribute to other agriculture, forestry, and water analyses to complete multi-sectoral assessment of climate change impacts on a single defined region.

In Sudan, historical records of the disease incidence are incomplete, making it impossible to create a reliable picture of baseline (pre-climate change) prevalence of malaria. Therefore, it is not possible to compare baseline disease incidence against disease incidence projected in a climate change scenario. Instead, transmission potential of malaria was used for focused analysis in order to overcome data limitations and facilitate an impact assessment.

MIASMA model (Modelling framework for health Impact Assessment of Man induced Atmospheric Changes) was employed here. The vector-borne disease model within MIASMA is designed to focus on transmission of vector-born diseases related to climate change. Equations for computation of TP were used to calculate monthly changes for five sites in Kordofan region (Elobied, En Nhud, Kadugli, Babanusa, Rashad), for the years 2030 and 2060, and a relative baseline period, 1961-1990. Average monthly temperature in the years 2030 and 2060, relative to baseline periods, were determined based on simulation results of the global circulation models.

It was here anticipated that the potential for climate change induced malaria outbreak is greater for regions surrounding Elobied station during October and December. The maximum tolerable temperature for *P. vivax* and *P. falciparum* parasites is assumed to be 32^{o} C, hence an increase in temperature beyond this is likely to increase mortality. That was true for the period of April through July, in 2030 and 2060 and in different parts of Kordofan region (Elobied, En Nhud, Kadugli, Babanusa). At each of the different sites it was expected that TP will rise above baseline throughout much of the year in both 2030 and 2060 and for both the two parasites (Figure 2).

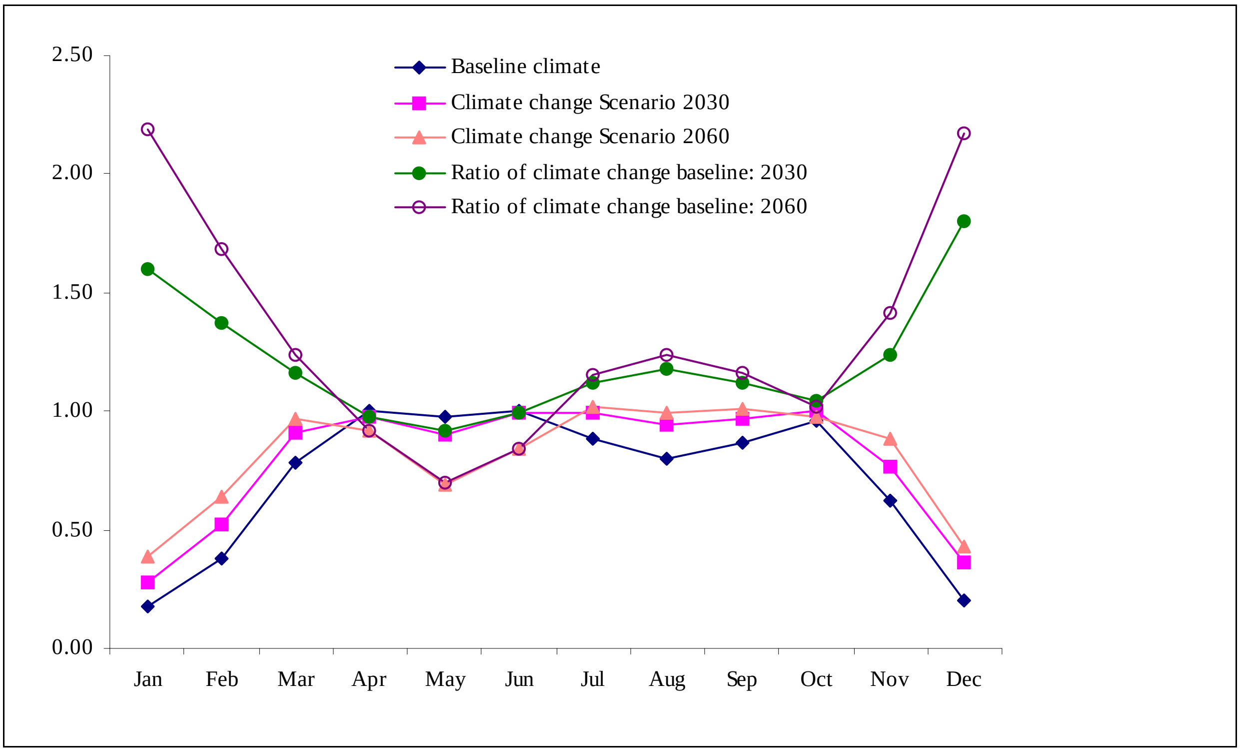

Figure 2: **Elobied Projected average transmission potential of *P. falciparum* using HADCM2 outputs.**

The results anticipated that Kordofan region will be vulnerable to future climate change-induced outbreaks of malaria. There could be significantly more severe malaria problems in the region during the winter months (November – February) in the absence of effective adaptation measures. In the months of December and January, the transmission potential of *P. falciparum* with climate change will be 75% greater than TP without climate change.

The objective of this study was to explore the impact of climate variability on malaria transmission in Sudan, through investigation of those parameters that would affect the transmission of malaria and their possible mitigation.

5.4 Data and methods

Study area

Three areas representing three different states were selected for the study, they also represent different transmission zones for malaria disease in the country. The selected states were:

- Sennar Area Sennar State (Central Sudan)
- Dongola Northern State (North Sudan)
- North Kordofan State (Western Sudan)

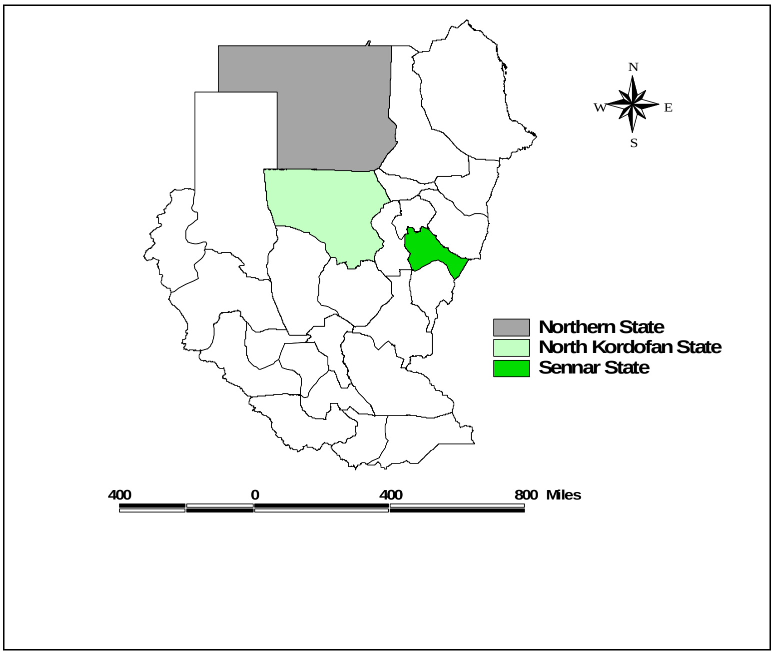

Figure 3: The location of the states where the climate variability and malaria study was conducted in Sudan

The selected states are located in different climatic/ecological zones (desert, semi-desert, savannah on clay); accordingly they are quite different from each other, particularly when we considered the land uses and the practiced livelihoods. In Sennar state (Savannah on clay) the irrigated agriculture represents the main economic activity as since the year 1925 Sennar Dam has been constructed in the state. The state also characterised by scattered woody vegetation as well as green grazing areas. On the other hand the Northern State lies in the heart of the desert, the state is quite poor regarding the natural resources, and the population is concentrated along the Nile banks where they practice agriculture (flooded and limited irrigated). North Kordofan State lies in semi-arid zone, grazing is the main livelihood, woody vegetation only exists in the southern part of the state. The incident of malaria in the three different areas was found to vary as shown in the figure below

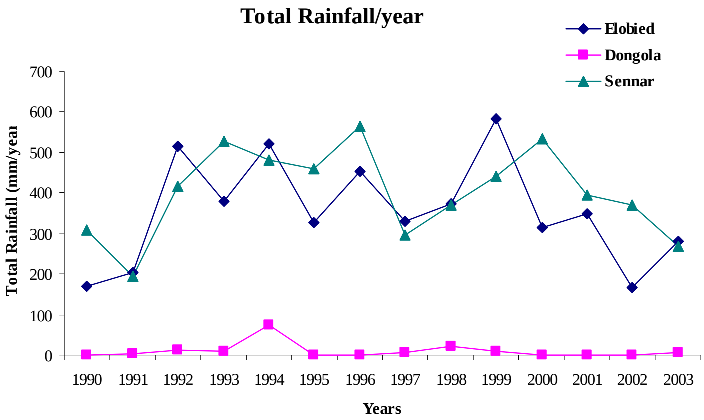

Figure 4: Total amount of Rainfall/year in Elobied, Dongola and Sennar.

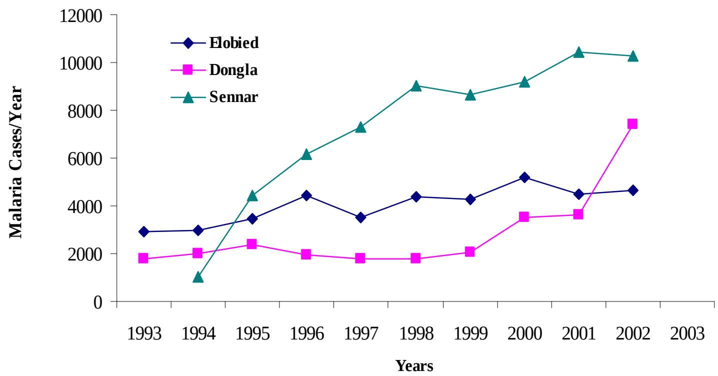

Figure 5: Total amount malaria cases/year in Elobied, Dongola and Sennar.

Data on malaria cases and meteorological figures for the three selected sites were obtained from the Malaria National Administration, for a 10 year period (1993-2002).

Data analyses

To assess the distribution of *P.falciparum* throughout the year, available monthly malaria data between 1993-2002 was used to calculate average monthly percentages. For example, the value for January is the average annual figure over ten years, the proportion of *P.falciparum* infections diagnosed during January of given years divided by the total number of *P. falciparum* cases during that period and X 100.

The monthly proportion of malaria in each site was treated as a dependent variable, and climatic variables, such as monthly mean relative humidity, monthly total rainfall and monthly mean, maximum and minimum temperatures were independent variables. Spearman's correlation analysis were undertaken to examine the relationship between monthly climatic variables and malaria proportion. The statistical analysis was conducted using the SPSS programme (Version 11).

5.5 Results

Sennar Area: Sennar State (Central Sudan)

Figure 6 below indicates that there was a monthly variation in the proportions of malaria in Sennar. The peak times in autumn, winter, and the summer months were more obvious as compared to other months.

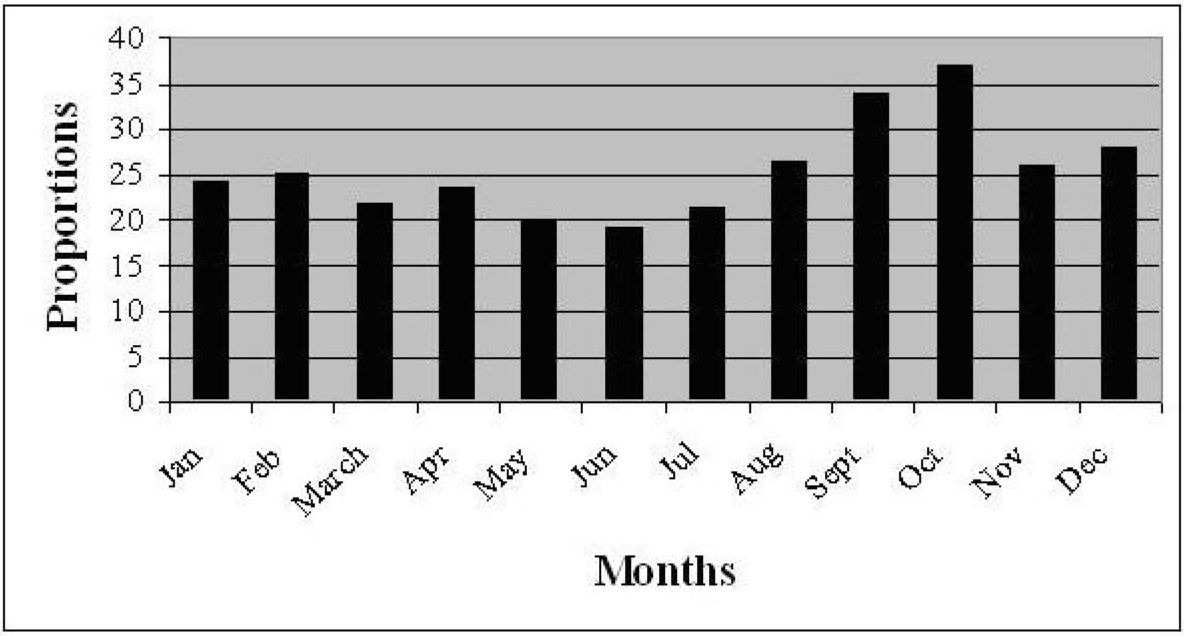

Figure 6: P. falciparum average of monthly proportions per year, Sennar: 1994-2002

Analysis of data for 1993-2002 on the proportion of P. falciparum by month (Figure 6) shows a seasonal trend. The mean temperature in the summer (40.50C) was above the critical temperature for malaria transmission (Figure 6), and the mean humidity was low (28.5%). The mean peak for malaria transmission was seen in the autumn and winter months when the mean temperatures were 35.40C and 36.30C respectively, and the mean relative humidity for both was 36.2 % and 62.1% respectively. Most inter-annual variation was seen in October at the peak of malaria transmission season (end of rainy season).

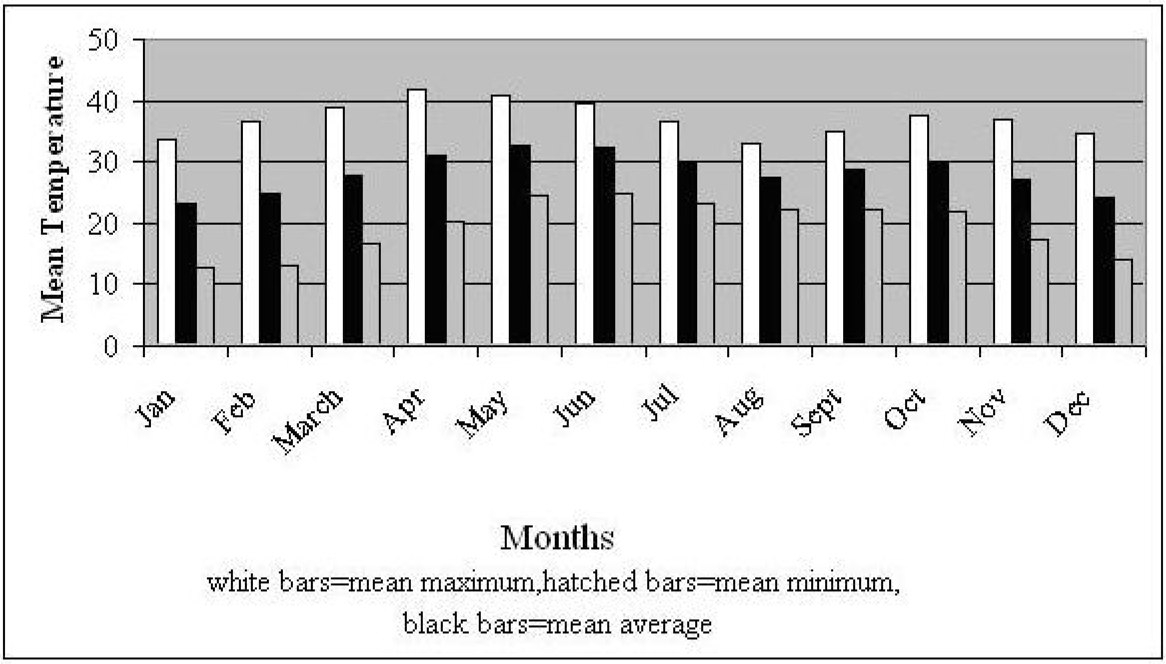

Figure 7: Mean temperature in oC, Sennar 1994-2002

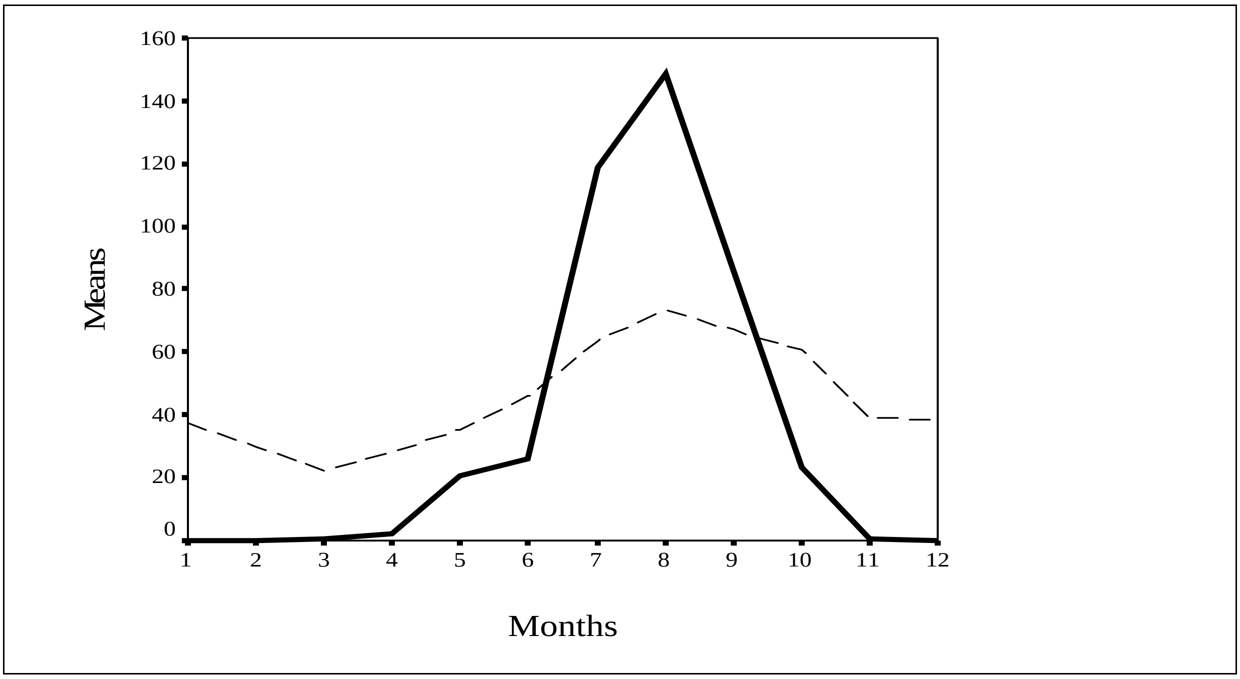

Figure 8: Mean Rainfall (Black line) and Humidity (Dotted line), Sennar: 1993-2002

Correlation between climatic variables and monthly proportion of malaria

The general relationships of these variables are illustrated in Figure 9 below. Spearman correlation analyses were conducted for relating monthly proportion of malaria to various climatic measures. Result showed no correlation between mean monthly maximum and minimum temperature and malaria proportion (P=0.08 and P=0.8 respectively). However, the mean relative humidity and mean log rainfall were significantly correlated with monthly proportion of malaria over the study period of 10 years with P=0.05 and P=0.02 respectively. Cross-correlation among independent variables was also conducted. There was no association between monthly mean maximum and minimum temperature and malaria proportion (P=0.2 and P=0.06 respectively). Yet the association between mean relative humidity, mean log rainfall and malaria proportion was strong where regression p-values were P=0.002 and P=0.007 respectively.

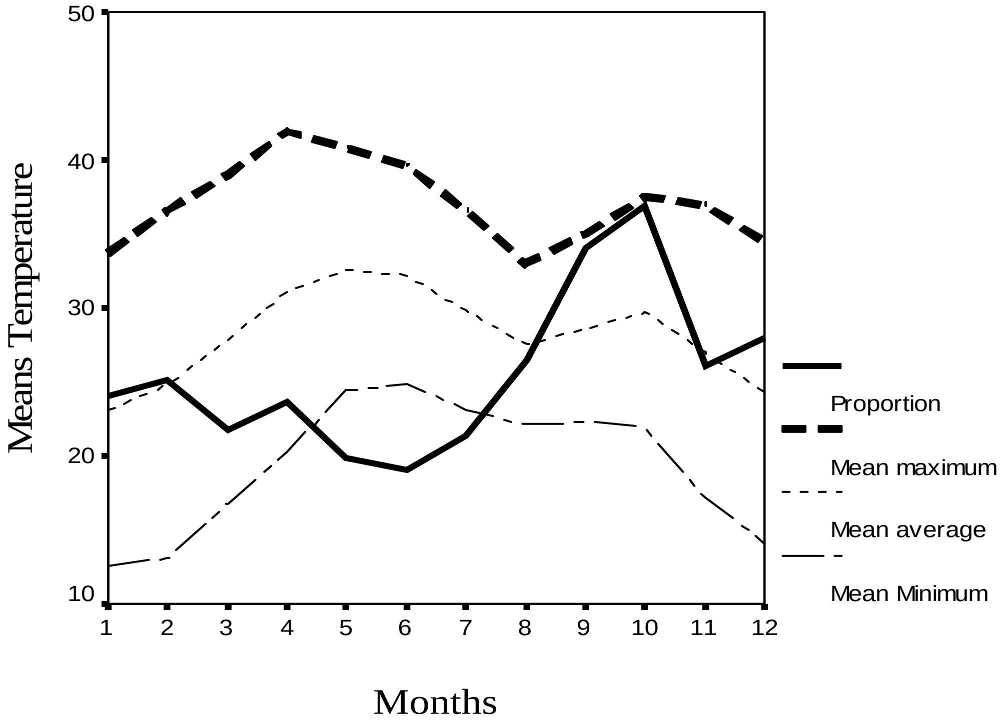

Figure 9: Mean monthly Temperature 0C (maximum, minimum & average) and malaria proportions, Sennar city 1994-2002

Climatic variable and annual malaria proportion

Table 5 below shows mean maximum and minimum monthly temperatures, mean relative humidity and mean log rainfall in different seasons. As might be expected, there was a highly significant association between seasonality and climatic variables.

Table 5: Mean climatic factors, malaria proportion by seasonality

Season	Mean max. Temp. 0C	Mean min. Temp. 0C	Mean Relative Humidity %	Mean Rainfall mm	Malaria Proportion
Winter	35.8	15.7	41.2	0	25.8
Summer	40.5	20.5	28.5	0	21.7
Autumn	36.1	23.1	62.5	714.6	27.6
p-value	0.02	0.02	0.007	0.01	0.3

Different malaria proportions were found during autumn (25.2%), winter (28.1%) and summer (21.7%) respectively; but when tested the difference was not significant (Spearman correlation analysis relating monthly proportion of malaria to various seasonality, P=0.3).

Dongola: Northern State (North Sudan)

Monthly variation in Malaria Proportion

The reviewed data indicated that there were some monthly variation in the proportions of malaria in Dongola, within winter, autumn, and the summer months as slight peaks were found over the 10 years (Figure 10 below).

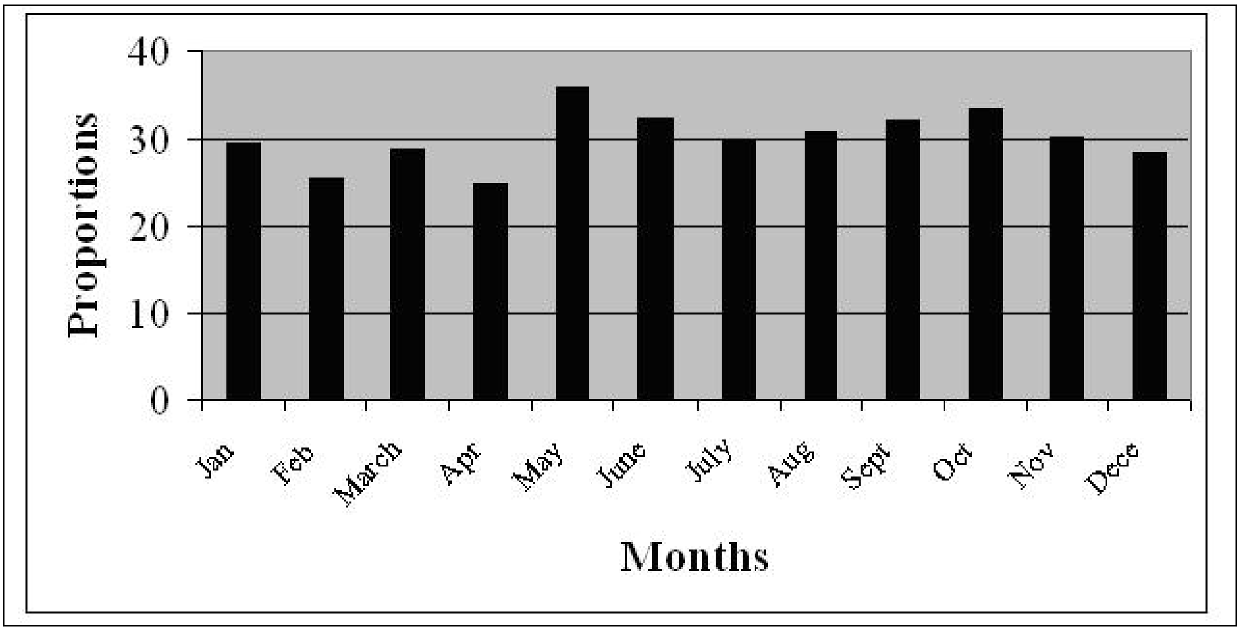

Figure 10: P. falciparum average of proportions per year, Northern 1993-2002

Climatic Variables and monthly Malaria Proportion
Analysis of data for 1993 - 2002 on the proportion of P. falciparum reported cases show a seasonal trend in Dongola. High transmission for malaria was seen from May to November related to large scheme irrigation and to the Nile flooding (Figure 10).

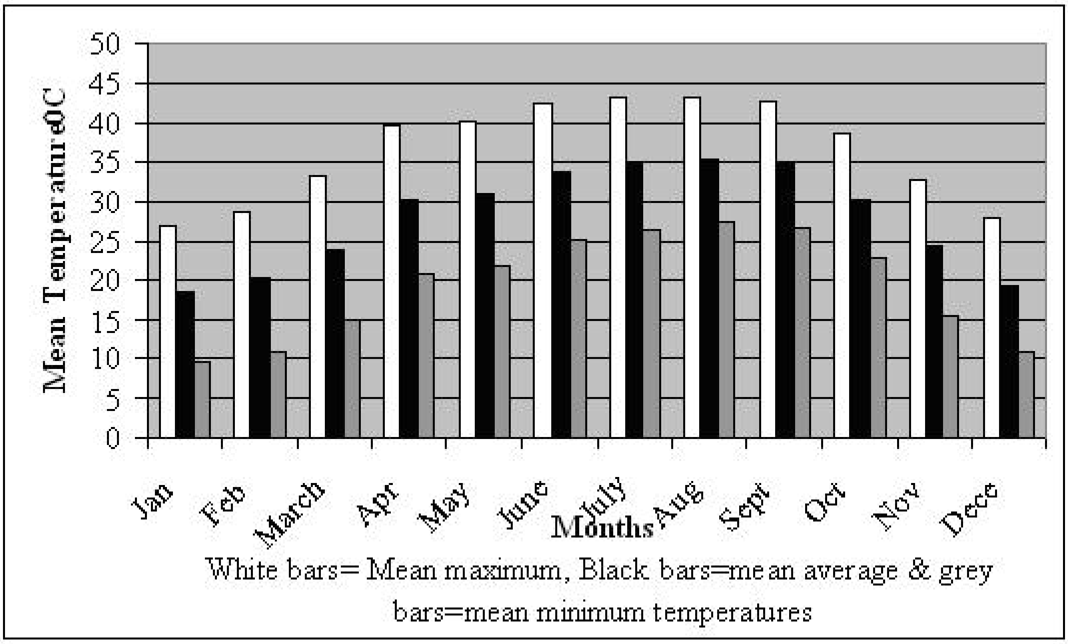

Figure 11: Mean temperature oC, Northern 1993-2002
Correlation between climatic variables and monthly proportion of malaria

Spearman correlation analyses were conducted relating monthly proportion of malaria to various monthly climatic measures. The monthly mean average and minimum temperature were significantly correlated to malaria proportion (P=0.05 and P=0.04 respectively). Yet the mean relative humidity and mean maximum temperature were not correlated with monthly proportion of malaria over the study period (P=0.1 and P=0.06 respectively with significance at P=0.05).

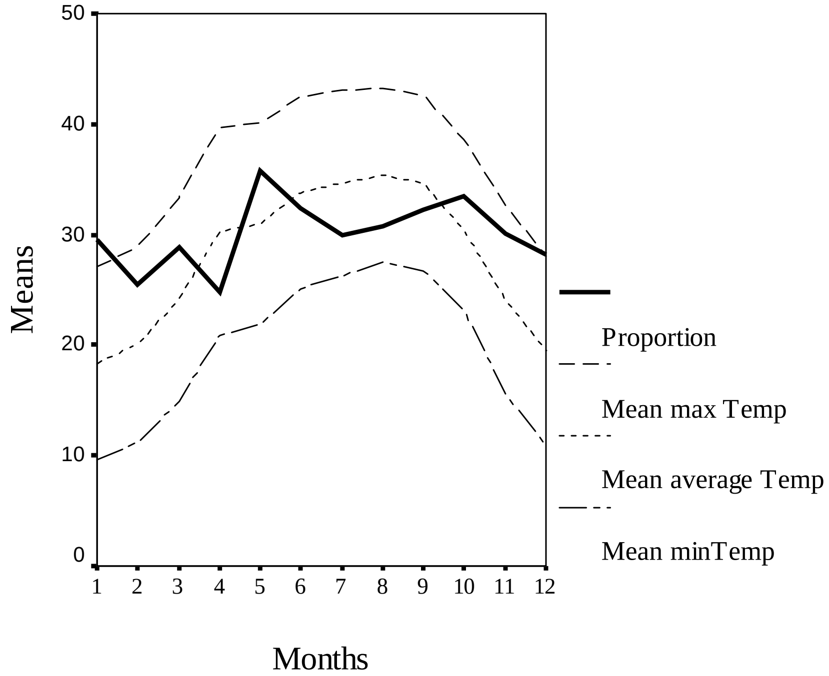

Figure 12: Mean monthly Temperature oC (maximum, minimum average) and malaria proportion, Northern 1993-2002

Climatic variable and annual malaria proportion

Table 6 below shows mean monthly maximum and minimum temperature and mean relative humidity in different seasons. Again, there was a highly significant correlation between the seasonality and climatic variables.

Table 6: Mean climatic factors, malaria proportion by seasonality

Season	Mean max. temperature	Mean average temperature	Mean min. temperature	Mean Relative humidity	Proportion
Winter	31.1	22.4	14.1	25.8	29.3
Summer	37.7	26.5	19.2	16.2	31.3
Autumn	42.8	34.6	26.4	17.4	29.8
p-value	0.003	0.003	0.005	0.007	0.6

When seasonality was included in the analysis, no differences in malaria prevalence were found between autumn (29.8%), winter (29.3%), and summer (31.3%) respectively. (Spearman correlation analysis was conducted relating monthly proportion of malaria to seasonality; with no association to malaria proportion P=0.6)

(El Obied): North Kordofan State, Western Region

Monthly variation in Malaria Proportion

Figure 13 below indicate that there was no variation in the proportions of malaria in El Obied by season. However, there was an increase in the prevalence during September, October and November as compared to the other months.

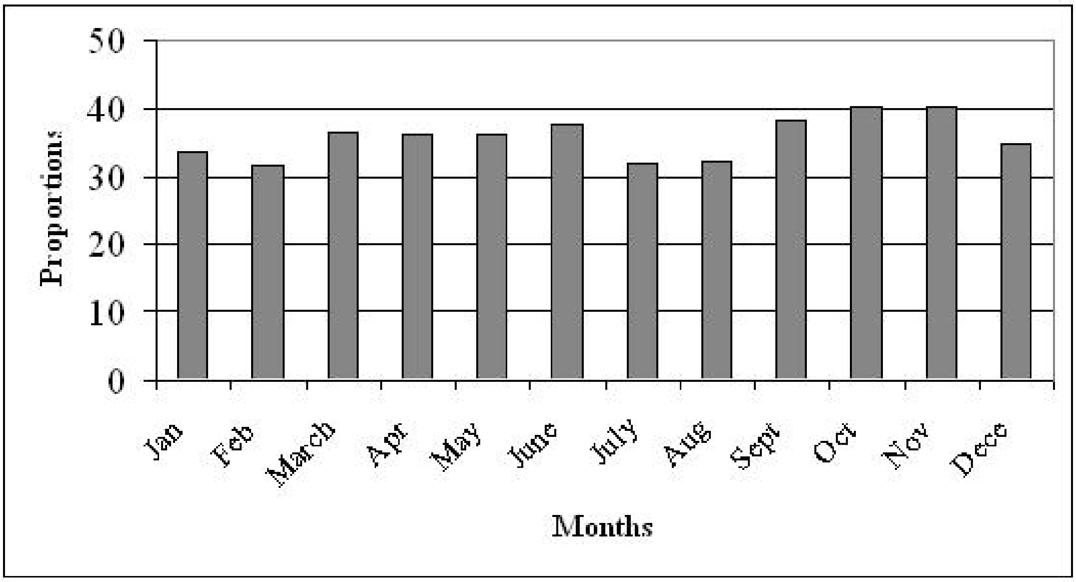

Figure 13: P. falciparum average of monthly proportions per year, El Obied 1993-2002

Climatic Variables and Monthly Malaria Proportion

Analysis of data for 1993-2002 on the proportion of the P. falciparum shows no seasonal trend in El Obied (Figure 13). According to the data, the transmission was detected all over the year due to storage of water for the dry season, with a slight increase in the proportion at the end of the rainy season and the beginning of winter.

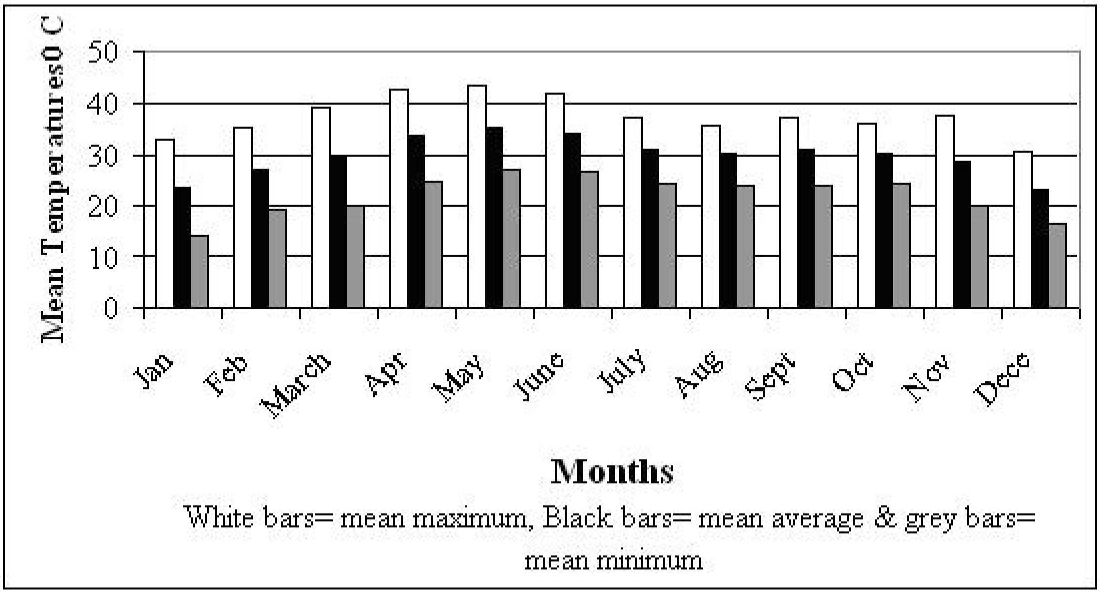

Figure 14: Mean temperature oC, El Obied 1993-2002

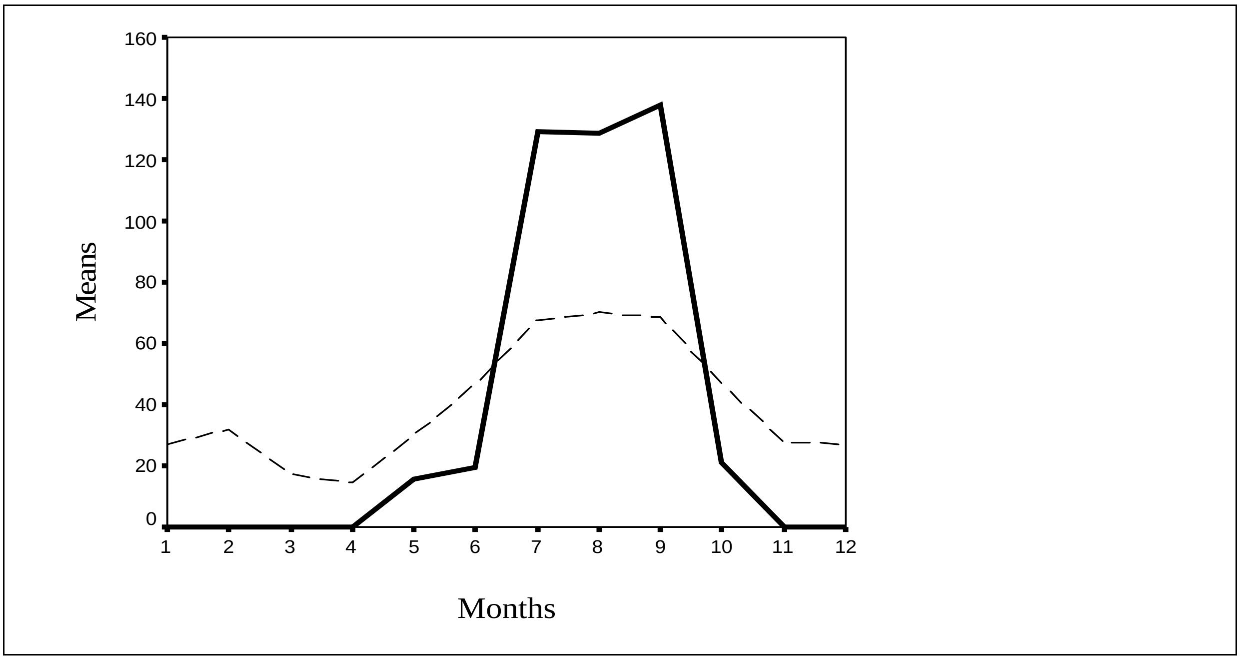

Figure 15: Mean Rainfall (Black line) and Humidity (Dotted line), El Obied: 1993-2002

Correlation between climatic variables and monthly proportion of malaria

Spearman correlation analyses were conducted relating monthly proportion of malaria to various monthly climatic measures. No correlation was found between monthly proportion of malaria and mean average (P=0.3), minimum (P=0.3) and maximum (P=0.2) temperature, mean relative humidity (P=0.1) and log rainfall (P=0.1) over the study period.

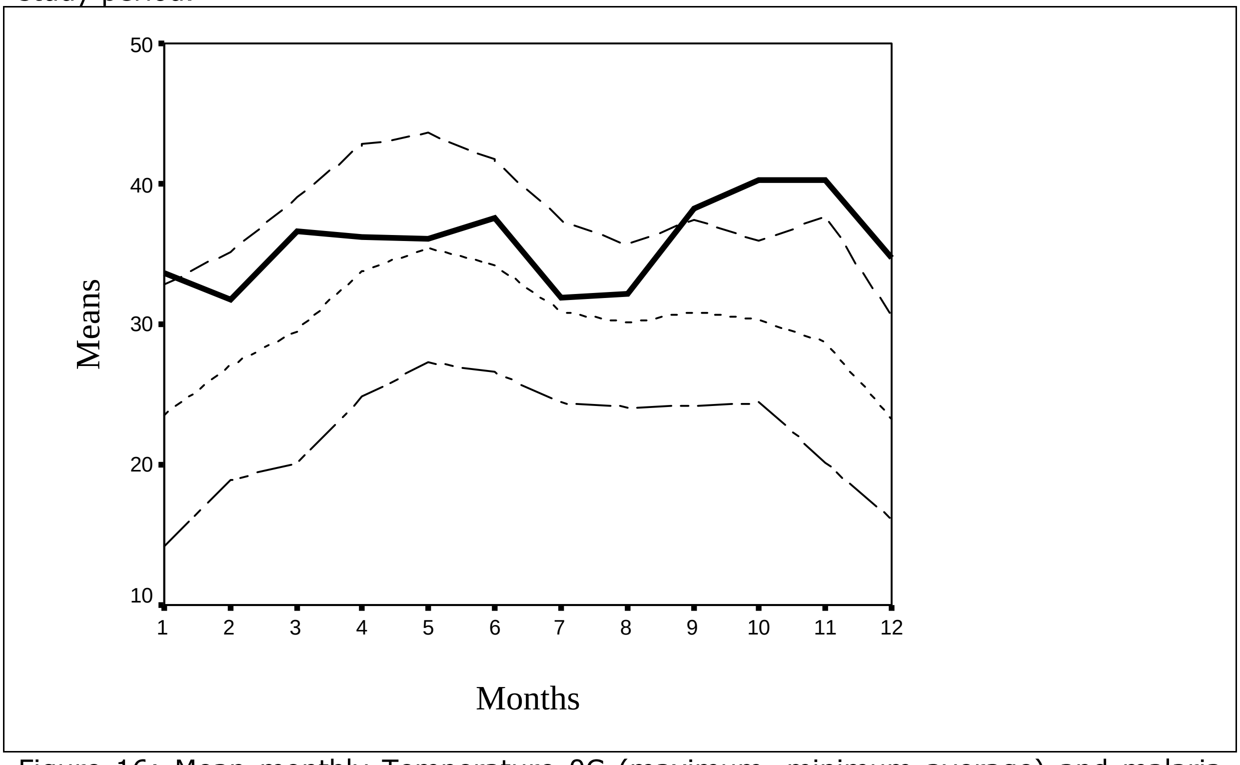

Figure 16: Mean monthly Temperature 0C (maximum, minimum average) and malaria proportion, El Obied 1993-2002

Climatic variable and annual malaria proportion

Table 7 below shows mean monthly, mean maximum, and minimum temperature and mean relative humidity in different seasons. Again, there was highly significant association between the seasonality and climatic variables.

Table 7: Means climatic factors, malaria proportion by seasonality

Season	Mean max temperature	Mean min temperature	Mean Relative humidity	Mean rainfall	Malaria proportion
Winter	34.5	17.3	28.4	0	35.1
Summer	41	24.1	20.5	13.8	36.3
Autumn	37.6	24.7	54.8	87.2	36
p-value	0.01	0.003	0.000	0.03	0.8

When seasonality was included in the analysis, there was no significant difference in the prevalence of malaria between the winter (35.1%), summer (36.3%) and autumn (36%). When Spearman correlation analysis was conducted relating monthly proportion of malaria to various seasonality, there was no association to malaria proportion (P=0.8).

5.6 Discussion

The transmission of malaria is determined by many factors, such as: vector abundance *Anopheles* species, the trend and frequency of the mosquito biting, mosquito susceptibility to the parasite, longevity of the mosquitoes, human behaviours and immunity, and social factors such as housing conditions and mosquito control measures. Climate variability that impacts the incubation rate of *Plasmodium* and the breeding activity of *Anopheles* is considered one of the important environmental contributors to malaria transmission (McMichael et. al, 1995).

Climatological factors appear to have affected the transmission of *P. falciparum* in the three sites during the study period (1993-2002). The amount of rainfall during rainy season and relative humidity were significantly positively correlated with malaria proportion in Central Sudan. These findings agree with results reported by De Zutuch *et al* (1987) and Bouma *et al* (1996) that the climatologic parameters rainfall and humidity influence malaria transmission through their effect on breeding (density) and longevity of the population respectively. In 1995 McMichael *et al* reported that rainfall plays an important role in malaria epidemiology because water not only provides the medium for the aquatic stages of the mosquito's life cycle but also increases the relative humidity and the longevity of the adult mosquito (e.g. Gambia malaria transmission is mainly during the rainy season) (Green wood 1993). But rainfall is not always required for malaria transmission alterations, as a study carried out in Ethiopia noted that an epidemic of malaria does not always follow excessive rainfall (Woube, 1997). This finding is similar to Western Sudan where the rainfall and humidity was not correlated with malaria proportion.

In the present study, no variation was observed in the monthly malaria proportion in autumn, winter, and summer months. Malaria transmission in Central Sudan occurs throughout the year and appears to be greatly influenced by rainfall and relative humidity, along with irrigation scheme. In Western Sudan, the storage of water for the long dry season increases mosquito breeding grounds, while in North Sudan malaria transmission is affected by floods as well.

Section III

6 Key vulnerabilities

The vulnerability assessment showed that the studied areas are highly vulnerable to malaria. The causes of vulnerability were also found to vary from one zone to another, however for almost all the three areas the incident of the disease and its epidemics was found to correlate positively with at least one of the climatic factors.

Drought was also found to increase malaria as it increase migration from rural to urban areas. People live in hyper, meso and hypo endemic malaria zones are quite different in their immunity to the disease. Accordingly migration might lead to epidemicity of the disease.

Variation in frequency of rainfall was reported to encourage the breeding of the mosquito. On the other hand the scarcity of rainfall reduces water resources and accordingly people had no choices other than water storage to satisfy their needs. The latter was found to create favorable environment for mosquito breeding. The disease was also reported to be strongly correlated with the flooding of seasonal streams (wadis).

However, many non climatic factors were also found worsen the situation of malaria infestation. Some of these could be summarized as:

- Improper irrigation system in agricultural schemes, including breakage of and leakage from water pipes, lack of proper drainage systems in towns and villages,
- lack of awareness
- lack of cooperation and coordination between related authorities and the NGOs
- lack of supportive health laws

The vulnerable groups were reported to be as follow:

- Pregnant women
- Children
- Refugees and internally displaced people (particularly in areas bordering Ethiopia and Eritrea)

7 Policy Recommendations

- Coordination among institutions working on environmental issues (agriculture, water, physical planning etc.) regarding the formulation of development projects;
- Improve coordination within the Ministry of Health and with other government authorities, working national and international NGOs, and local communities’ organizations;
- Political support for the different health programmes and activities, particularly those related to the control and eradication of malaria;
- Adoption of long term plans that consider impacts of climate change;
- Consideration of appropriate health laws and policies to implement upon formulation and implementation of developmental projects;
- Encouragement of scientific research and accounting for its findings in the formulation of policies and plans;
- Coordination among related authorities to reduce adverse impacts of development projects;
- Enhance implementation of heath legislation;
- Support programmes that deal with environmental awareness; and
- Provide environmental training at all levels

8 Research Recommendations

The result of this report and case-study revealed that more research needs to be done concerning increases in malaria transmission, taking into account all factors that could be relevant. Understanding the relationships between climate and malaria in an area may allow prediction of when there are likely to be epidemics. Models that can link all of the factors that affect malaria transmission are needed, including climate change factors (temperature, rainfall, humidity and wind), environmental factors (drought and desertification, Nile level rise and changing vegetation), the parasites development rate, the vector population (death rate, breeding places, density and insecticide resistance) and human population (migration, spread of drug resistance, change in immune status and spread of pathogen into new areas). The workshop that was held to discuss the finding of this study revealed very specific recommendations particularly with regard to the needs of scientific, these were:

- The problems to be studied should be clearly identified and prepared as proposals to be funded.
- Readings of rainfall, temperature in the agricultural areas should be carefully recorded and correlated to the breeding of mosquitoes.
- Humidity should be carefully monitored as well as wind speed in the study areas as they are important factors affecting mosquitoes and their intensity.
- Results presented depended on the physical factors while the biological factors e.g. breeding of mosquitoes, were not included. This has to be considered in the future studies to reflect the whole transmission picture f malaria.
- The number of researchers studying effects of climate change on malaria transmission should be increased to study the parasite and all the different factors affecting its transmission in the different parts of the country.
- Studies addressing vector behaviour and the effect of climate changes on it should be carefully be designed
- A set up of an efficient surveillance for information collection of all aspects of malaria

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