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Environmental and Socio-Economic Determinants of Malaria Rate in Sudan

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Abstract: The aim of this study was to investigate the relationship among malaria, climate variables and socio-economic factors in Sudan. The health production modification model was applied to examine the relations between climate variability (average temperature and average rainfall) and socio-economic factors, with the malaria rate per State in Sudan. The results of the model found that there are significant relations between the malaria rate, rainfall and water bodies, while there are no significant relations between malaria rate and temperature, percentages of the cultivated area to uncultivated, human development index and population density. Therefore, an in-depth study using monthly data and adding more control variables is needed.

Keywords: Climate variability, HDI, health production model, malaria rate

INTRODUCTION

Malaria is the highest morbidity and mortality disease in the world, with 50% of the world's population, representing about 3.3 billion people, at risk of contracting malaria (WHO, 2011). In 2004, malaria killed around 1.3 million people, 90% of them children under the age of five (Watkins, 2007). According to the World Malaria Report (2011), of the 216 million cases of malaria in 2010, most of the deaths occur among children in Africa where a child dies of malaria every minute and the disease accounts for approximately 22% of all childhood deaths.

Geographically, spatial malaria is distributed according to the interaction between the vector, parasite, host and human environments. Figure 1 shows the geographical distribution of malaria in the world, which is intensive in the tropical regions.

Malaria is most complex for countries in the poorest continent, Africa (Stock, 2004). Only the northern and southern parts of Africa are free of malaria; see Figure 1, which have the richest countries in Africa. Gallup and Sachs (2001) mentioned that India, which is the country classified as having the greatest number of poor people in the world, has a severe malaria problem. Haiti has the highest incidence of malaria in the Western Hemisphere and is also the poorest country in that hemisphere (Gallup and Sachs, 2001).

The report of Poverty in Sub-Saharan Africa: The Situation in the OIC Member Countries (2007), mentioned that malaria is a major cause of deaths of children, in which 30-50% of hospital admissions in Africa relate to malaria. Figure 2 shows the malaria rate (number of cases per 1000) in sub-Saharan African countries (Poverty in Sub-Saharan Africa: The Situation in the OIC Member Countries, 2007). Sudan is located in the centre of the African countries in terms of malaria rates, where the malaria rate is approximately 10% in Sudan. While some African countries are located as having a high rate of malaria, such as Uganda with a malaria rate of around 50%, others are classified as having a relatively low rate of malaria, such as Comoros around 0.5%, Fig. 2.

There are many factors that are attributed to the rapidly increasing disease burden of malaria, such as El Niño cycles and global warming and also other factors, such as population movement to malarious regions; changing agricultural practices, including the building of dams and irrigation schemes; deforestation and the weakening of health systems in poor countries, among others (Sachs and Malaney, 2002).

According to the (UNDP, 2011) the total population of Sudan of around 44, 632 includes the population of south Sudan, with the urban population comprising around 40.8% of the total population. The expenditure on health is 1.3 (% of GDP), life expectancy at birth is 61.5 (years), the expenditure on education is 27.8 (% of GDP), adult literacy rate, both sexes is 70.2 (% aged 15 and above), gross national income per capita is 1,894 (PPP international $) (UNDP, 2011).

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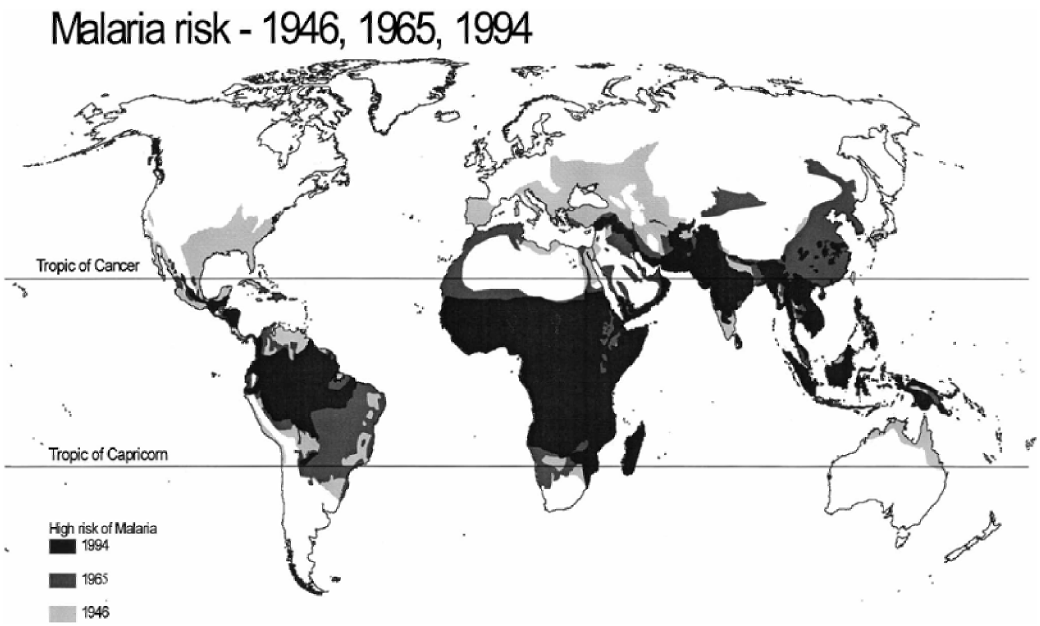

Fig. 1: Malaria risk, 1946, 1965, 1994 (Gallup and Sachs, 2001)

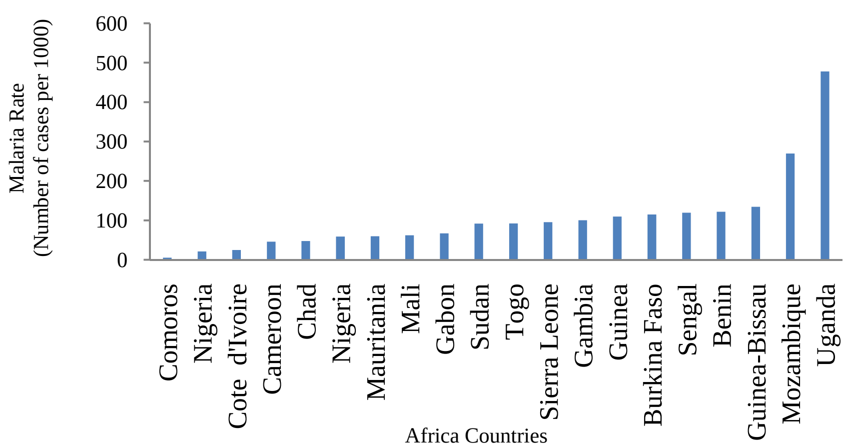

Fig. 2: Rates of malaria in Africa for the year 2004

Climate effects: According to Zhou *et al.* (2004), based on the temporal patterns across multiple highland areas they concluded that temperature and rainfall play an important role in the inter-annual variability of malaria. The temperature is a major determinant of malaria risk (Paaijmans *et al.*, 2009). Temperature and rainfall are the most important factors for distribution and population dynamics of malaria, rainfall influences transmission by its role in the mosquito life cycle, while temperature acts as a regulatory force (Martens *et al.*, 1995). The number of blood meals a mosquito takes from humans is the product of the frequency with which the vector takes a blood meal and the proportion of these blood meals that are taken from humans. The frequency of feeding mostly depends on the rapidity with which a blood meal is digested, which can be calculated by a thermal temperature sum, increasing as temperature rises (Martens *et al.*, 1995).

Human Development Index (HDI): In 1990, the UNDP introduced a new concept in the indication of development, the Human Development Index (HDI), with the objective of measuring human progress and quality of life at the overall level. The HDI is a

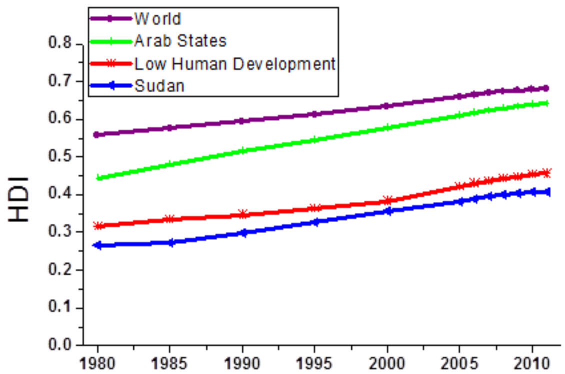

Fig. 3: Human Development Index: Trends 1980-2011 (UNDP, 2011)

summary measure of achievements of three dimensions of the human development concept: living a long and healthy life, being educated and having a decent standard of living. It combines measures of life expectancy, school enrolment, literacy and income to allow a broader view of a country's development than using income alone, which is too often equated with well-being.

Generally, there is a clear negative correlation between malaria and development and the relation between malaria and poverty. The global maps of malaria show that both poverty and malaria are highly concentrated in tropical and sub-tropical areas (Sachs and Malaney, 2002). Stratton *et al.* (2008) mentioned that poverty is an important factor of malaria; the malaria also leads to poverty, with malaria reducing economic growth and poverty limiting the health sector response. When malaria diseases are plotted against HDI, a steep downward trend in malaria diseases follows with rising HDI (Stratton *et al.*, 2008).

According to the report of Watkins (2007), the countries with the lowest levels of human development, such as Uganda, Burkina Faso and Guinea, present the highest levels of malaria mortality rates. Whereas, the countries with medium levels of human development, such as Thailand and Egypt, present lower levels of malaria mortality rates.

Figure 3 shows the human development index of Sudan, which compared to the Arab States, low HDI and world HDI from years 1980 to 2011. Sudan's HDI was equal to 0.408 in 2011, which gives the country a rank of 169 out of 187 countries with comparable data. The HDI of Arab States as a region increased from 0.444 in 1980 to 0.641 in 2011. Sudan HDI increased from 0.264 in 1980 to 0.408 in 2011, placing Sudan below the regional average (UNDP, 2011).

Agricultural practices: To understand the relation between malaria and agricultural practices one must take into account the two-way linkages. The first way is the impact of malaria on agricultural development through the effect on farmers having to spend time to care for the family members or if illness strikes at harvest time as the farmers may not be able to cultivate as much land and engage in intensive farming practices. They may then plant fewer labour-intensive crops and change cropping patterns, perhaps raising crops with a lower return. Generally, the transmission effect of malaria in the planting and harvesting seasons exacerbates the impact of the illness making it particularly damaging (Asenso-Okyere *et al.*, 2011). The second way is the effect of agricultural development on malaria due to the provision of water resource development, deforestation, wetland cultivation, crop cover and land-use changes, which all expand habitats for malaria-carrying mosquitoes (Asenso-Okyere *et al.*, 2011). The irrigation schemes generate conditions that enhance mosquito breeding and, hence, contribute to the transmission of malaria (Boelee *et al*., 2002). Agricultural production systems, such as type of farming, farming practices, farming technologies and location of farms, might lead to environmental changes that generate appropriate ecological and climatic conditions for the breeding and survival of the anopheline mosquitoes, which transmit the disease (Felix, 2009).

Population size: Malaria incidence showed a strong correlation with population size and the area of the villages (Kreuels *et al*., 2008). Historically, evidence shows that high infant and child mortality rates are linked closely to high fertility rates (Handa, 2000). According to this theory, the predictions of high-rate malaria will lead to a high fertility rate and an overall high population growth rate in regions of intense malaria transmission. These predictions are supported by cross-country evidence, although the direct causal linkage from malaria deaths to increased fertility to rapid population growth is circumstantial.

The main area wrecked by the Malaria in the world map is generally sub-Saharan African countries. That is why malaria spread is usually subjected, along with other factors, to the geographical location, such as the tropics, where we find the highest rate of infliction. The disease also affects the levels of human capital, life expectancy, initial family income and the macro-economic indicators of various kinds. The economic growth of these places is paralyzed because of the Malaria. Accordingly, the disease accumulative effects lead to a substantial annual reduction in GNP growth in these countries. Sudan is one of the sub-Saharan countries whose population is highly affected by Malaria. This study examines the relations between climate variability and change, water body, socio-economic factors and the rate of epidemic malaria per state in Sudan.

MATERIALS AND METHODS

Data collection: The data were collected from different sources, the climate factors, including temperature, rainfall and relative humidity were gathered from the Sudan Meteorological Authority (SMA) - the monthly climate data from 2004 to 2008 and the annual climate data from 2008 to 2010. The malaria data were obtained from the National Malaria Control Programme (NMCP), Sudan-the monthly malaria data from 2004 to 2008 and annual malaria data from the year 2008 to 2010. The socio-economic factors were collected from the UNDP Human Development Reports (UNDP, 2011) for 2008 to 2010 per State.

Health production modification model: (Aggrey and Douglason, 2010) modified the health production model to study the relationship between the prevalence of malaria and environmental and socio-economic variables in Uganda using cross sectional data for the year 2003.

To create the correlation between socio-economic and environmental variables and malaria rate in Sudan, the present study modified the (Aggrey and Douglason, 2010) model, which used the HDI, rather than poverty rate and literacy rate. Percentages of the cultivated area to uncultivated area, rather than wetland area and deforestation rate.However, according to the availability of the data this study used the Ordinary Least Squares OLS to regress the following model in Eq. (1):

$$Y_i = \beta_0 + \beta_1 T_i + \beta_2 R_i + \beta_3 P_i + \beta_4 W_i + \beta_5 HDI_i + \beta_6 D_i + \mathcal{E}_i \dots.. \quad (1)$$

where,

Y = The malaria rate
i = 1-15 States
T = Monthly average temperature
R = Monthly average rainfall
P = Percentage of the cultivated area to uncultivated
W = The presence of a water bodies
HDI = Human development index
D = Population density

Malaria rate was expressed as a function of the population size, provided of estimates of malaria rate per State. Rainfall was calculated using the average monthly rainfall collected in a year. Temperature was estimated from the minimum and maximum average monthly temperature divided by two. The Human Development index (HDI) measures deprivation in the three basic dimensions captured in the human development index – a long and healthy life, knowledge and a decent standard of living in a given district. Cultivated area per km is the land use in agriculture activities, which is divided by non-cultivated area. Population density was estimated as the total population of the State divided by the total State area in square kilometers.

RESULTS AND DISCUSSION

The effect of climate variables on malaria transmission: Time trend analysis was adapted to examine the relation between malaria cases and monthly climatic data, such as temperature, rainfall and relative humidity. Figure 4 shows that the malaria cases in Sudan are high during (July to November), which

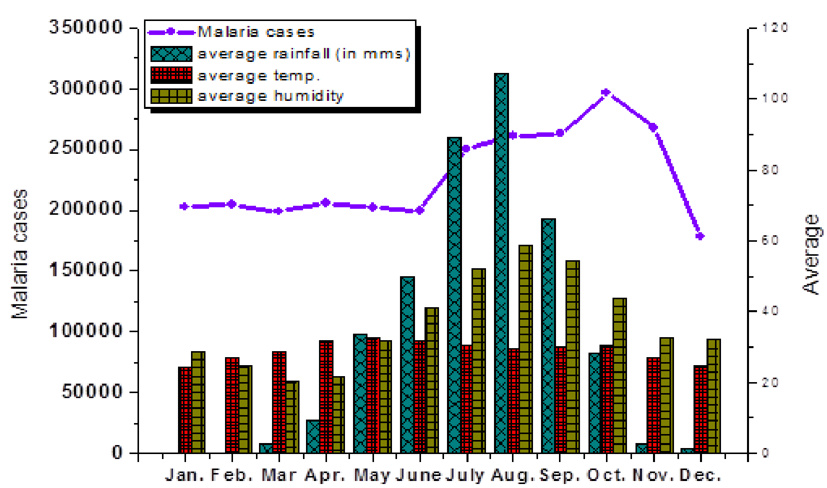

Fig. 4: Monthly climate variability and malaria cases in Sudan (2004-2008)

was strongly influenced by average monthly rainfall during the rainy season (July to September). This result is consistent with the study of Grover-Kopec *et al.* (2006) who revealed that the rainfall is largely responsible for creating the conditions that allow sufficient surface water for mosquito breeding sites and, therefore, is recognized as one of the major factors influencing malaria transmission.

A weak relation is also observed between malaria cases and the average temperature during the rainy season Fig. 4. This result does not agree with the study of Lindsay and Martens (1998) who mentioned that the temperature has a strong role in malaria transmission through its influence on the development rate of mosquito larvae and the survival rate of adult mosquitoes. Moreover, at warmer temperatures, adult female mosquitoes feed more frequently and digest blood more rapidly and the Plasmodium parasite matures more rapidly within the female mosquitoes.

The relative humidity does not directly affect the Plasmodium but may affect the activity and survival of mosquitoes. If the average relative humidity is below 60%, the life of the mosquito may be shortened to less than the extrinsic incubation period (about 2 weeks) so that there is no malaria transmission. The relative humidity and malaria cases in Sudan shows, Fig. 4, that during the malaria season (July to November) the average monthly relative humidity has a positive relation to the incidence of malaria in July to September and a negative relation in October to June due to the decrease in rainfall.

(Adjuik *et al.*, 1998) explained that climatic conditions are considered to be suitable for transmission when the monthly rainfall accumulation is at least 80 mm, the monthly mean temperature is between 18 and 32°C and the monthly relative humidity is at least 60%.

Generally, malaria transmission does not start immediately with the onset of rain; usually there is a time lag during which the vector's population increases. In high transmission zones, the average monthly temperature, rainfall and relative humidity averages have to be suitable to be counted as part of the transmission malaria season and at least one-month lag of highly suitable conditions for malaria to occur.

Determinants of malaria rate: Table 1 shows the multiple linear regression result of the modified health production model. The percentage of cultivated area to uncultivated area was not shown to be a significant determinant of the rate of malaria. This result contradicts several previous studies, which showed that the percentage of cultivated area to uncultivated area is positively associated with malaria rate. Munga *et al.*

Table 1: Determinants of malaria rate: OLS estimates, dependent variable: malaria rate

Variable	Coefficient	T-statistics	p-value
HDI	-0.095	-0.621	0.538
Rainfall	0.203	3.641	0.001
Temperature	-0.175	-0.99	0.328
Population density	0.66	0.451	0.655
% of cultivate to uncultivated	0.205	1.482	0.146
Water body	8.504	5.269	0.000
	$R^2 = 0.439$	Adjusted R^2 = 0.412	DW = 1.53

(2006) concluded that land cover affects larval survivorship and adult productivity through its effects on water temperature and nutrients in the aquatic habitats. However, Somboon *et al.* (1998) observed that the relative risk of infection for people engaged in agricultural activity was three times that of people living in the residential villages.

The high temperatures lead to mosquito development and reduce the interval between blood meals, which indicates more frequent host-vector contact (Gillies and De, 1968), however, this is not supported by the present study. The annual temperature is not significant as shown in Table 1, where, the significance of temperature was equal 0.328, this finding is supported by a study presented by Aggrey and Douglason (2010) using data from Uganda. Although several studies concluded that temperature is one of the important climate factors that affect malaria transmission, this study did not concur; this could be because the present study used the annual average temperature rather than daily average temperature or monthly average temperature. In addition, it did not distinguish between maximum and minimum temperature.

In contrast to the previous study by Aggrey and Douglason (2010), the present study found that rainfall and the presence of water bodies, such as rivers and channels, were shown to be significantly related to the malaria rate in Sudan, Table 1. Because most of the irrigated agricultural projects are located near rivers to facilitate and provide irrigation water through the dams, it creates a suitable environment for the growth and proliferation of mosquitoes that transmit malaria.

Table 1 show that there is no significant association between the malaria rate and the human development index for Sudan's data. This finding contradicts (Lindoso and Lindoso, 2009) who found that 90% of malaria cases occur in the regions of Brazil that have the lowest HDI, which is a direct relationship between the prevalence of malaria disease and HDI. The malaria disease is considered to be inadequately treated because of the absence or lack of investment in projects for the development of new drugs and vaccines and existing programmes to control malaria disease.

Table 1 shows that the population density is not significant, which indicates that it has no effect on the transmission of malaria in Sudan. This result is different from the results of previous studies, such as Kreuels *et al.* (2008), who concluded that the incidence of malaria has a strong correlation with population size and the area of the villages. Historically, evidence shows that high infant and child mortality rates are closely linked to high fertility rates (Handa, 2000). According to this theory, the prediction of a high rate of malaria will lead to a high fertility rate and an overall high population growth rate in regions of intense malaria transmission. Although these predictions are supported by cross-country evidence, the direct causal linkage from malaria deaths to increased fertility to rapid population growth is circumstantial.

CONCLUSION

The present study examines the relationship between malaria rate and environmental and socioeconomic variables. To create the correlation between socio-economic and environmental variables and malaria rate in Sudan we adopted the modified health production model to create this relationship using annual cross States data. The regression results explain that there were significant relationships between the malaria rate and rainfall and water bodies. The other variables including HDI, temperature, population density and per cent of cultivated areas, were not significant. There is a need for an in-depth study using monthly data and adding more control variables to the health production model to identify the variables that could affect the malaria rate in Sudan. Climate variability will cause both increases and decreases in the areas suitable for transmission. Improving the malaria models to assess the potential impact of climate variability on malaria cases in Sudan is required. The models of malaria cases should primarily be undertaken by States with validated models, to more accurately identify those populations most at risk according to each State.

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