UNIVERSITI PUTRA MALAYSIA

CLIMATOLOGICAL AND SOCIOECONOMIC FACTORS THAT PREDISPOSE TO THE RISK OF MALARIA IN SUDAN

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By

MOHAMMED IBRAHIM MUSA HASSAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To my mother's soul, Omalkram Mohammed Elteeb, my father, Ibrahim Musa Hassan, my wife, Marwa Osman Taha, my son, Ibrahim, my brothers, Musa and Nazar, my sisters, Omima, Amal and Ibtisam.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor Philosophy

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November 2012

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Malaria remains as one of the major health problems in Sudan. The purpose 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. Therefore, an in-depth study using monthly data and adding more control variables is needed.

We evaluated the potential clustering of incidence of malaria in Sudan using two procedures: choropleth mapping to summarize the malaria spatial data,

based on state boundaries, and geo-statistical kriging. The results indicate that the highest rate of malaria was recorded in the middle east of Sudan and south east, while low rates were observed in the western and northern parts.

To predicted and forecasting the spread of malaria in Sudan we adopted The Auto-Regressive Integrated Moving Average (ARIMA) model. The ARIMA model used malaria cases from 2004 to 2009 as a training set, and data from 2010 as a testing set, and created the best model fitted to forecast the malaria cases in Sudan for years 2011 and 2012. The ARIMAX model was carried out to examine the relationship between malaria cases and climate factors with diagnostics of previous malaria cases using the least Bayesian Information Criteria (BIC) values. The results indicated that there were four different models, the ARIMA model of the average for the overall states is $(1,0,1)(0,1,1)^{12}$. The ARIMAX model showed that there is a significant variation between the states in Sudan.

We created the prediction malaria distribution model using the Fuzzy Logic Suitability (FLS) model based on the life cycle characteristics of the *Anopheles* mosquito. This model used the climate factors – maximum and minimum temperature, rainfall and relative humidity – from years 2004 to 2010. The results of the prediction model found that the climate factors were suitable for malaria transmission from (May to October) in Sudan. While the estimation malaria model maps results showed that the malaria rate was high from (June to

November). The comparison results between prediction and estimation model discovered that the largest similarities were around 55% in the prediction of October and estimation of November.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

CLIMATOLOGICAL AND SOCIOECONOMIC FACTORS THAT PREDISPOSE TO THE RISK OF MALARIA IN SUDAN

Oleh

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Malaria masih sebagai pedih salah satu daripada masalah kesihatan yang utama di Sudan. Tujuan kajian ini ialah untuk menyiasat hubungan antara malaria, pemboleh ubah cuaca dan faktor-faktor sosioekonomi di Sudan. Model pengubahsuaian pengeluaran kesihatan digunakan untuk memeriksa hubungan-hubungan antara keberubahan iklim (suhu purata dan min hujan tahunan) dan faktor-faktor sosioekonomi, dengan kadar malaria setiap negeri di Sudan. Keputusan-keputusan model mendapati bahawa ada hubungan signifikan antara kadar malaria, hujan dan badan-badan air. Oleh itu, satu kajian mendalam menggunakan data bulanan dan menambah lebih pemboleh ubah-pemboleh ubah kawalan diperlukan.

Kami telah menilai potensi kerumunan insidens malaria di Sudan menggunakan dua prosedur: pemetaan koroplet untuk ringkaskan data reruang malaria, berdasarkan sempadan-sempadan negeri , dan kriging geo statistik. Keputusan-keputusan menunjukkan bahawa kadar tertinggi malaria telah dicatatkan di tengah timur dan tenggara Sudan, sementara kadar yang rendah telah dicerap dalam bahagian di utara dan barat.

Untuk meramalkan dan menjangkakan penularan wabak malaria di Sudan, kami menggunapakai model ARIMA (Auto-Regressive Integrated Moving Average). ARIMA menggunakan kes-kes malaria terpakai dari 2004 untuk 2009 sebagi satu set latihan , dan data dari 2010 sebagi satu set ujian , dan mewujudkan model terbaik sesuai untuk meramalkan kes-kes malaria di Sudan untuk tahun 2011 dan 2012. ARIMAX model dijalankan untuk memeriksa hubungan antara kes-kes malaria dan faktor-faktor cuaca dengan diagnostik-diagnostik kes-kes malaria sebelumnya menggunakan tersedikit nilai-nilai Bayesian Information Criteria (BIC). Keputusan-keputusan menunjukkan yang terdapat empat model berbeza, model ARIMA purata untuk keseluruhan negeri-negeri ialah $(1,0,1)(0,1,1)^{12}$. ARIMAX model menunjukkan yang terdapat satu variasi bererti antara negeri-negeri di Sudan.

Kami membina model ramalan penularan malaria menggunakan model 'Fuzzy Logic Suitability' (FLS) berdasarkan ciri-ciri jangka hayat nyamuk *Anopheles*. Model ini menggunakan faktor-faktor cuaca – suhu minimum dan maksimum, hujan dan kelembapan relatif – dari tahun-tahun 2004 untuk 2010. Keputusan-keputusan model telahan mendapati bahawa faktor-faktor cuaca sesuai untuk distribusi malaria dari (Mei hingga Oktober) di Sudan. Manakala malaria keputusan peta model anggaran menunjukkan bahawa kadar malaria tinggi dari (Jun hingga November). Keputusan perbandingan antara ramalan dan model anggaran mendapati bahawa persamaan-persamaan terbesar merupakan sekitar 55% dalam ramalan Oktober dan anggaran November.

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Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the study.

I certify that a Thesis Examination Committee has met on ……2012 to conduct the final examination of Mohammed Ibrahim Musa Hassan on his Doctor of Philosophy thesis entitled "Climatological and Socioeconomic Factors that Predispose to the Risk of Malaria in Sudan" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U (A)106] 15 March 1998. The Committee recommends that the student be awarded the…….. Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

Mohammed Ibrahim Musa Hassan

Date: 19 November 2012

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LIST OF ABREVIATIONS

ACF	Autocorrelation Function
AR	Autoregressive
ARIMA	Auto-Regressive Integrated Moving Average
ARIMAX	Auto-Regressive Integrated Moving Average with eXtra
BIC	Bayesian Information Criteria
CPs	Control Points
FL	Fuzzy Logic
FLS	Fuzzy Logic Suitability
FMH	Federal Ministry of Health
GA	Geo-statistical Analysts
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GISc	Geographic Information Science
GNP	Gross National Product
HDI	Human Development Index
HIV/AIDS	Acquired Immune Deficiency Syndrome
MA	Moving Average
MAPE	Mean Absolute Percentage Errors
MARA	Mapping Malaria Risk Africa

MAUP	Modifiable Areal Unit Problem
Max	Maximum
Min	Minimum
NMCP	National Malaria Control Programme
NPCC	National Population Census Council
OLS	Ordinary Least Squares
PACF	Partial Autocorrelation Function
SARIMA	Seasonal Multiplicative Autoregressive Integrated Moving Average
SMA	Sudan Meteorological Authority
TB	Tuberculosis
TPS	Thin Plate Spline
UNDP	United Nations Development Programme
USGS	United States Geological Survey
WHO	World Health Organization

CHAPTER 1

GENERAL INTRODUCTION

Malaria is considered as one of the diseases that result from a complex series of ecological interactions between malaria parasites, mosquitoes and humans. The female *Anopheles* mosquito represents the "definitive host" for the malaria parasites because the sexual cycle of parasite reproduction takes place within the mosquito's gut, while the human being, who is injected with the parasites by an infected mosquito, represents the "intermediate host" (James and Webb, 2009).

Malaria is a disease that can be transmitted to all ages of people. It is caused via parasites of the species *Plasmodium* that is spread from person to person through the bites of infected mosquitoes. It has direct relations with many other diseases like Tuberculosis (TB) and HIV/AIDS. According to the WHO (2011), there were 216 million confirmed malaria cases in 2010 and an estimated 3.3 billion people were at risk of malaria. Table 1.1 shows the estimated malaria cases and deaths in year 2010 for the WHO region, where Africa represented more than 80% and 90% for the estimated cases and estimated deaths, respectively. Sadly, most of the victims of the disease are children; one child dies every 30 seconds

from malaria in Africa; 20% of all childhood deaths in Africa are due to malaria; and people living in the poorest countries are the most vulnerable (WHO, 2011).

Table 1.1: Estimated malaria cases and deaths

Regions	Estimated cases	Estimated deaths
African Region	174 million	596 000
Americas Region	1 million	1 000
Eastern Mediterranean Region	10 million	15 000
European Region	200	0
South-East Asia Region	28 million	38 000
Western Pacific Region	2 million	5 000

(Adapted from WHO Region, 2010)

The main area affected by malaria on the world map is generally sub-Saharan African countries. The marginal change in temperature and rainfall would lead to a significant change in the number of malaria cases for most countries in Africa (Egbendewe-Mondzozo *et al.*, 2011). The change of temperature and rainfall will affect the health sector due to the change in the ecology of various vector-borne diseases, such as malaria and dengue (Bush *et al.*, 2011). Some groups are more vulnerable to threats of malaria and deaths therefrom, such as pregnant women, patients with HIV/AIDS, non-immune travellers, and, in high transmission areas, children less than five years of age.

The disease also affects the level of human capital, life expectancy, initial family income, and the macro-economic indicators of various kinds. Malaria causes a loss of an average of 1.3% of annual economic growth in countries with intense transmission (WHO, 2011). Malaria exposes families and communities in a vicious circle of poverty and marginalization, which disproportionately affects the poor who cannot afford treatment or whose access to health care is limited. As well as 22% of working days in Sudan are lost because of malaria (NMCP, 2006a). Sudan is one of the sub-Saharan countries whose population is highly affected by malaria.

1.1 Problem Statements

Malaria remains as one of the major health problems in most of the African countries, combating and treatment consumes large proportions of health budgets in these countries. Since malaria poses threats to indigenous populations as well as visitors, it acts as a deterrent to tourism and foreign investment in these countries. Hence, malaria not only affects the health status of Africa's population, but also has far-reaching economic consequences that stifle the economy.

The accurate prediction of the risk of malaria is dependent on the knowledge of a number of environmental and climatic factors that are related to its

transmission (Hay *et al.*, 1998). This study tries to summarize the most important factors – climatic, socio-economic and human – that cause and affect the malaria disease. Accurate spatial statistical and mapping of malaria risks in Sudan by using Geographic Information Systems (GIS) is considered an important tool for combating malaria.

1.2 The Objectives

The main objective of this study is to provide an understanding of the links between malaria, climate variables and socio-economic factors in Sudan by achieving the following specific objectives.

1. To examine the relationship between the environmental and socio-economic determinants and their impact on malaria rates in Sudan.
2. To investigate the spatial distribution pattern of malaria risk in Sudan.
3. To forecast malaria cases for 2011 and 2012, and examine the relationship between malaria cases and climatic factors per state in Sudan.
4. To create the climate suitability malaria maps from climate factors and actual number of malaria cases maps in Sudan, and compare between the suitability and actual malaria maps.

1.3 Significance of Study

Sudan is an agricultural country in which more than 70% of the population relies on agriculture for income, and most of the agricultural activities depend on rainfall and temperature (FAO, 2010). However, one of the major constraints that the agricultural sector faces is the wide spread of diseases, especially malaria, which leads to reduced activity and the effectiveness of the workforce, and, thus, contributes to low production and productivity. In addition, it uses funds that could be employed in other important areas to benefit the country. Despite the tremendous effect of malaria on agriculture and the population in Sudan, there is a huge information gap with regard to mapping and spatial analysis of malaria. Therefore, this study is expected to contribute effectively to the knowledge concerning the field of malaria analysis in Sudan.

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