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Effects of Rainfall on Malaria Occurrences in Kenya

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Abstract

In this paper, we analyze data on malaria prevalence in Kenya and investigate if there are incidences of malaria in areas formerly not prone to malaria infection. It is hoped that the findings of this study shall be used to develop strategies for combating the disease in these areas. We have thus investigated malaria trends using mathematical models thereby contributing to the global goal of curbing malaria spread and eradicating the disease. We have also studied the effect of changing rainfall patterns on malaria prevalence. There is generally a high positive correlation between Malaria prevalence and rainfall across all the provinces.

KEYWORDS: Malaria incidence rate, Mosquitoes, Rainfall, Time period, Best fit Polynomial, Trend.

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1. Introduction

The potential impact of global warming on human health has drawn local and international interest as evidenced by the recent world conference on, climate change held in Copenhagen, Denmark and more recently in Durban, South Africa. Many of the diseases that currently occur in the tropics are mosquito-borne, and it is commonly assumed that their distribution is determined by climate, and that global temperature will increase their prevalence and geographic range (Cook G. 1996, Watson R. C. 1996). Malaria is a parasitic disease which is transmitted by the female anopheles mosquito. It is diagnosed when the parasite that causes it is identified in a blood smear under a high power microscope. Malaria progresses rapidly and in its severe form can cause death.

According to the Kenya Government Ministry of Public Health and Sanitation, Division of malaria Control (MOPHS/DOMC), Malaria remains the leading cause of death among young children and also one of the most serious threats to the health of pregnant women and their newborns in Kenya. Figures from the Health Management Information Systems (HMIS) at the MOPHS indicate that 28 million Kenyans are at risk of being affected by Malaria. It accounts for 30% of outpatient visits and 15% of all hospital admissions.

The 2008 world Malaria report shows that malaria claimed 881,000 lives in 2006, of which 85% were children below the age of five (5) years. Of the total lives claimed by malaria, 801,000 (91%) were in Africa.

According to Philippe H. Martin and Myriam G. Lefebvre (1995), among continents affected by malaria, Africa is the worst off with 94 million clinical cases compared to 5 to 10 million in South East Asia, 1 to 2 million in Central and South America and fewer than 500, 000 cases in Europe including Turkey. Unicellular parasites of the genus ‘Plasmodium’ are responsible for these figures.

In Kenya the Lake Basin, Kisii Highlands, parts of the Rift Valley and the coastal region are characterized by unstable malaria transmission.

The local population has little, or no immunity to the disease and according to Cox J. et al. (2007), epidemics continue to be a significant public health issue resulting in significant morbidity and mortality.

According to Gilles and Warell (1993) the parasite can kill by infecting and destroying red blood cells, resulting in anaemia or clogging of the capillaries that carry blood to the brain resulting in cerebral malaria.

For the life cycle of malaria parasites to be complete, there must be an anopheles mosquito as a vector and a human being as a host. Philippe H. Martin and Myriam Lefebvre (1995) say that there are 380 different species of Anopheles mosquito and four different species of malaria parasite namely; *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium* *ovale, and Plasmodium malariae. Plasmodium vivax* has the broadest geographic range while P*lasmodium falciparum* is clinically the most dangerous. In Africa the predominant species of the disease causing parasite is Plasmodium *falciparum*. There are 50 to 60 species of Anopheles mosquito that carry the four parasites that causes Malaria in Humans. The life cycle of the parasite involves transmission both from mosquito to man and from man to mosquito.

The life cycle in man starts with the bite of an infected female Anopheles mosquito. The mosquito, through its saliva, transfers hundreds to thousands of *plasmodium sporozoites* into the bloodstream, and hence into the liver of man. They mature in the liver after which they re-invade the blood stream as *merozoites* and pursue their development in the red blood cells. These further develop into another stage called *trophozoites* and this is the one normally visible in the blood smear under a high power microscope.

The species *Plasmodium vivax* and *Plasmodium Ovale* may remain in the liver and enter the dormant stage. They may become active at later stages causing repeated relapses in the human host. The relapse time can be as long as 20 years.

In their final stages of development, these parasites differentiate sexually between male and female forms, when an uninfected mosquito bites the infected person; it picks up both male and female forms. These mate in its digestive track and the resulting *sporozoites* migrate to the salivary glands, ready to start another cycle.

The transmission dynamics of malaria are strongly influenced by climatic factors and there have been attempts to predict epidemics by the use of climatic variables that are predictors of transmission potential. Temperature, rainfall and humidity are especially important. According to Cook G. (1996), the female anopheles mosquito lays its eggs in stagnant pools of water. Moderate rainfall is thus beneficial to breeding of mosquitoes.

Temperature on the other hand affects the rate of multiplication of the parasite and hence the probability of successful transmission. According to Bruce and Chwat (1980) warmer ambient temperatures of 25º C shorten the duration of the growth cycle of the parasite and this increases the chances of transmission. Below 15 º C, the growth cycle cannot be completed and malaria cannot be transmitted. The optimal range of temperature for mosquito survival is between 20 º C and 30 º C. Excessive temperature will increase mortality and there is a threshold temperature above which death ensues. Similarly, for the mosquito to become active there is a minimum temperature. Thus there are upper and lower thresholds outside which malaria transmission is not possible.

According to Paul Reiter (2001) forest clearance eliminates species that breed in water in tree holes but provides favorable conditions for those which prefer temporary ground pools exposed to full sunlight. Sewage polluted ditches, wells, pit latrines, discarded tyres and other man-made objects provide perfect breeding sites for mosquitoes.

Teklehaimanot H. D. *Et al* conducted a study of 10 Districts in Ethiopia in 2004. The districts were grouped into two climatic zones; hot and cold. The findings indicated that "In cold districts, rainfall was associated with a delayed increase in malaria cases while the association in the hot districts occurred at relatively shorter lags. In cold districts, minimum temperature was associated with malaria cases with a delayed effect; in hot districts, the effect of minimum temperature was non-significant at most lags and much of its contribution was relatively immediate."

Their conclusion was that "the interaction between climatic factors and their biological influence on mosquito and parasites' life cycle is a key factor in the association between weather and malaria."Woube M. (1997) showed that although one epidemic in Ethiopia was associated with higher rainfall, an epidemic in another year was preceded by very little rainfall. Zhou G., Minakawa N., Githeko A. K. and Yan G. (2004) showed that there was high spatial variation in the sensitivity of malaria outpatient numbers to climate fluctuations in East Africa's Highlands.

Mbogo C. M. *et al. (2003)* found the variation in the relationship between the mosquito population and rainfall in different districts in Kenya.

They attributed this variation to environmental heterogeneity. Lindsay *et al. (1996)* found a reduction in malaria infection in the Usambara Mountains of Tanzania following 2.4 times of normal rainfall. Excessive rainfall during the same period was associated with increased Malaria in south-western highlands of Uganda. Hay S. I. *et al.* (2000) analyzed long term meteorological records for four high-altitude locations in East Africa. They reported no significant trend for climatic variables in particular temperature, and concluded that "the number of Months suitable for *P. falciparum* transmission has not changed in the last century."Despite these varying results, malaria has the potential to significantly increase in response to changing weather patterns.

2. Trend of malaria prevalence in Kenya

In this study, the trend of malaria prevalence in Kenya in 1996 to 2007" was determined. We assumed that the changing rainfall patterns influenced the prevalence of malaria in Kenya between 1996 and 2007.

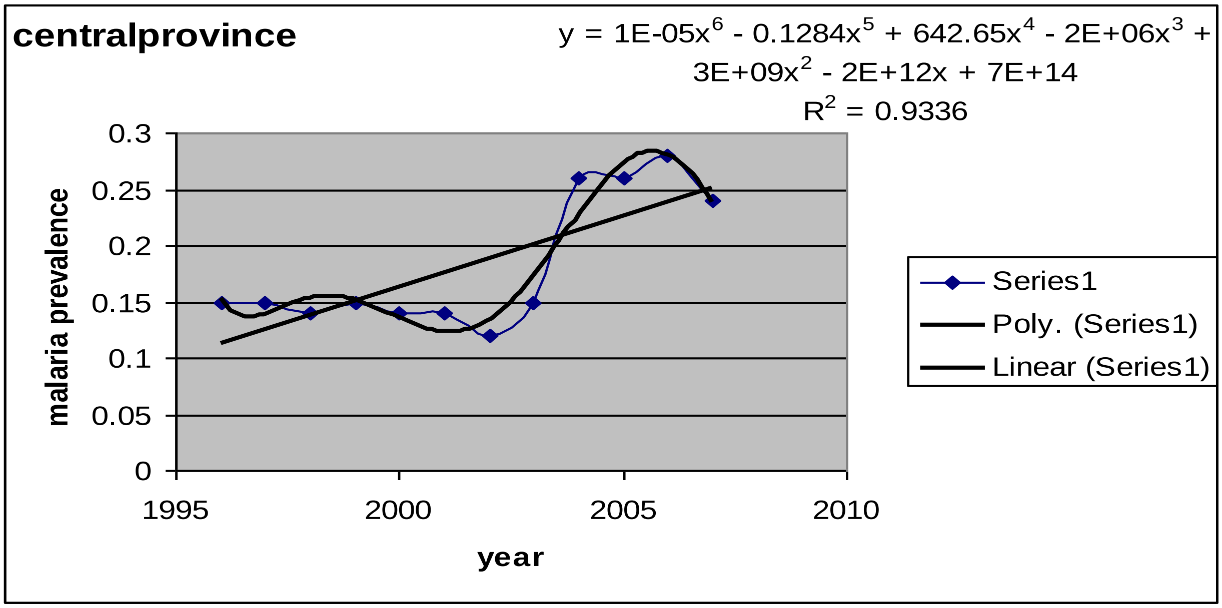
We investigated the trend of the prevalence of malaria in Kenya and the possible impacts of rainfall on malaria infections.

2.1 Data and Methods

The Ministry of Public Health and Sanitation (MOPHS), through the Division of malaria control provided the outpatient morbidity statistics by province for the year 1996 to 2007.

This data was prepared by Health Management Information System (HMIS), a unit in the MOPHS.

Using the data provided, the following graphs were plotted. The polynomials that best fitted the data were determined Province by Province. Below is the curve plots those were so determined.



The graph for the prevalence of malaria against the year for **Central Province** shows that the period 1996 to 2003 was characterized by a near stable malaria prevalence. This however changed in 2004 when there was a sharp increase rising to a peak in 2006. The linear trend line shows a steady rise in malaria prevalence.

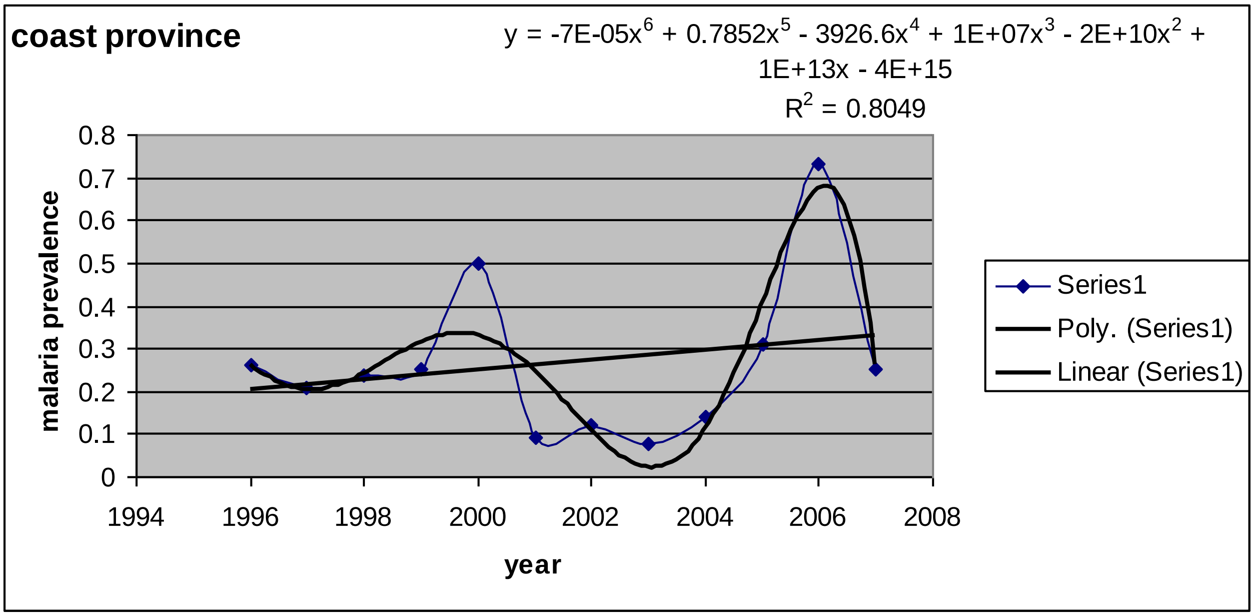
A polynomial of degree 6 was found to be the best that would fit the curve.

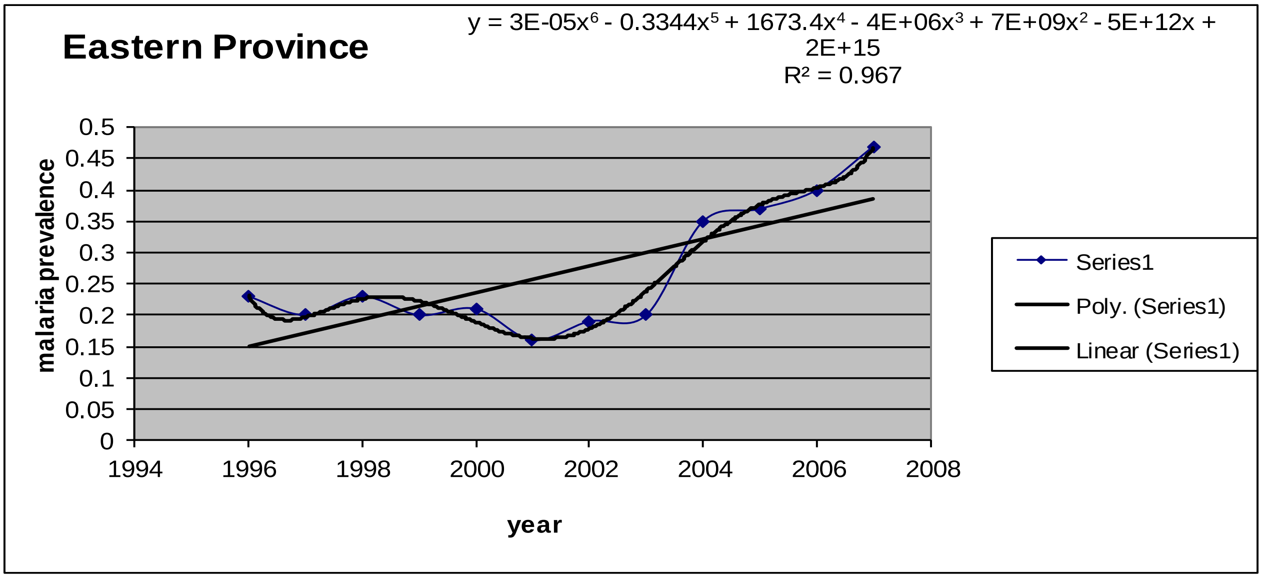
$$y = (1 \text{ x } 10^{-5})\, x^6 - 0.1284x^5 + 642.65x^4 - (2 \text{ x } 10^6)\, x^3 + (3\text{x } 10^9)\, x^2 - (2 \text{ x}10^{12})\, x + 7 \text{ x } 10^{14}$$

Coast Province has had relatively high malaria prevalence. This was maintained during the period 1996 to 1999. In 2000, there was a sharp increase where up to 50% of the population was infected. This reduced considerably the following year when it went to a low of 9% of the population. The low period was maintained for four years.

In fact in 2003, the prevalence rate went down to 8%. This suddenly changed in 2005 when it rose to 31% and in 2006; it reached its peak where a whopping 73% of the population was infected. This was the highest figure in the country during that period. The linear trend line shows a steady rise. Of the polynomials fitted on the curve, the best was one of degree 6.

$$y = (-7 \text{ x } 10^{-6})\, x^6 + 0.7852\, x^5 - 3926.6x^4 + 10^7\, x^3 - (2 \text{ x}10^{10})\, x^2 + (1\text{x}10^{13})\, x - 4 \text{ x } 10^{15}$$



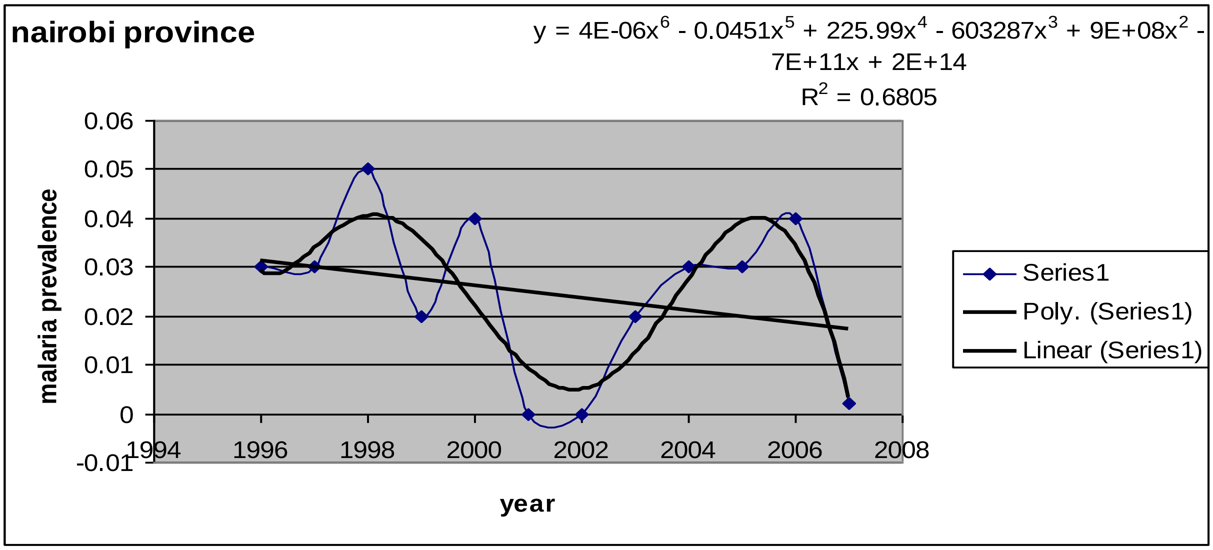


Eastern Province had near steady malaria prevalence rate between 19% and 23% from 1996 - 2003. This suddenly changed in 2004 when it rose to 36% reaching a peak of 47% in 2007. The linear trend line shows a steady rise. A polynomial of degree six best fitted the data of Eastern Province.

$y = (3\ \mathrm{x}10^{-5})\ x^{6} - 0.3344x^{5} + 1673.4x^{4} - (4\ \mathrm{x}10^{6})\ x3 + (7\ \mathrm{x}10^{9})\ x^{2\,-}(5\mathrm{x}10^{12})x + 2\ \mathrm{x}\ 10^{15}$

For **Nairobi Province**, the linear trend shows an extremely low prevalence rate which has been on the decline since 1996, reaching a low of zero in the period 2001 to 2002 before it went up, albeit slightly rising to a paltry 4% in 2006 before it came down again to below 1% in 2007. Generally there is a declining trend in malaria prevalence in this Province.

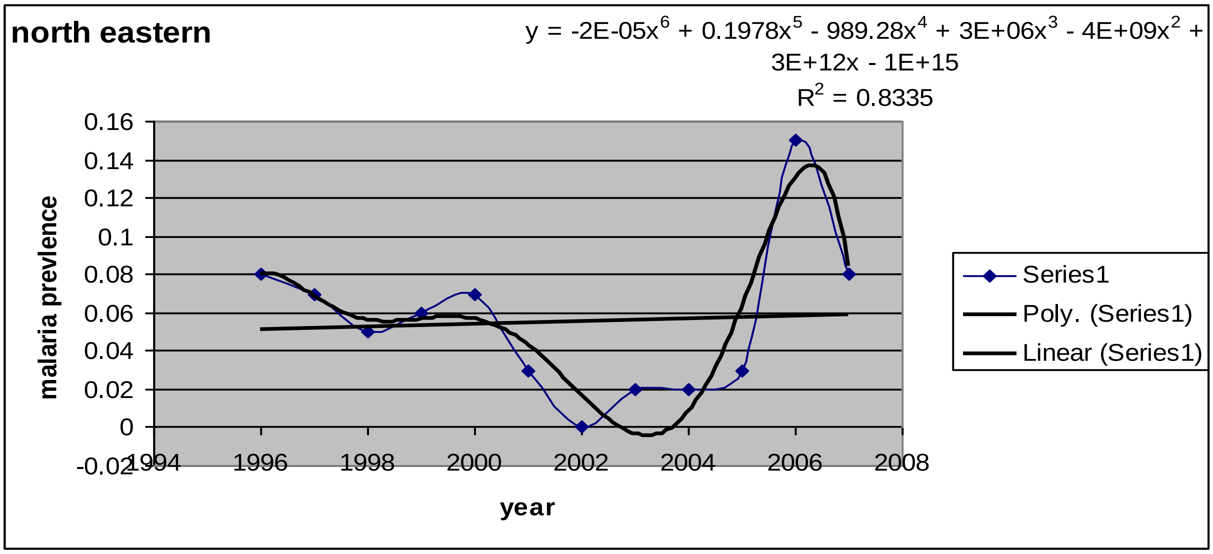
The best fit for Nairobi Province was a polynomial of order 6: $y = 4 \times 10^{-6} x^6 - 0.0451x^5 + 225.99x^4 - 603287x^3 + 9 \times 10^8 x^2 - 7 \times 10^{11} x + 2 \times 10^{14}$



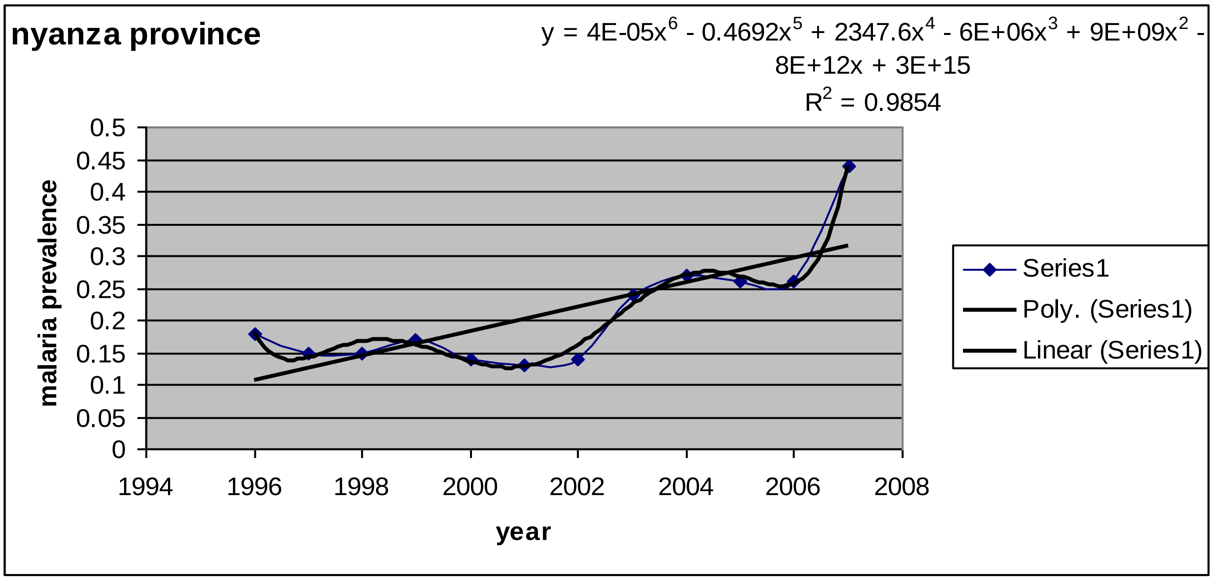
Just like **Nairobi**, the graph of **North Eastern Province** shows that this region has had very low malaria prevalence since 1996. This reduced steadily for three years before it started rising again in 1999 up to a mere 7% in 2000. This again reduced considerably to a low of 0% in 2002. From then on, it started rising again reaching a peak of 15% in 2006. The best fit for **North Eastern Province** was a polynomial of degree six:

$y = -(2 \times 10^5) x^6 + 0.1978 x^5 - 989.28x^4 + (3 \times 10^6) x^3 - (4 \times 10^9) x^2 + (3 \times 10^{12}) x - 10^{15}$.

The regression line shows a very slight increase.

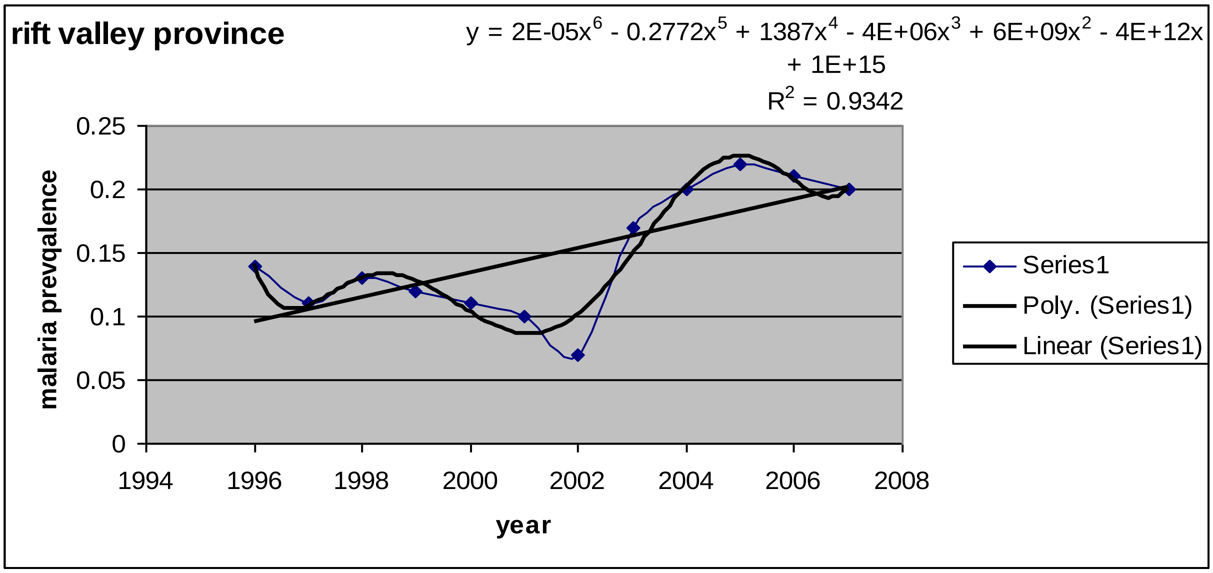


From the graph below, one can notice that malaria prevalence in **Nyanza Province** was steady from 1996 until 2002. It started rising in 2002 and has been on the rise since then reaching a high of 44% in 2007. The period 2006 – 2007 shows a very sharp rise. The regression line shows that the prevalence rate is rising.



A polynomial of order 6 best fitted the curve for **Nyanza Province**.

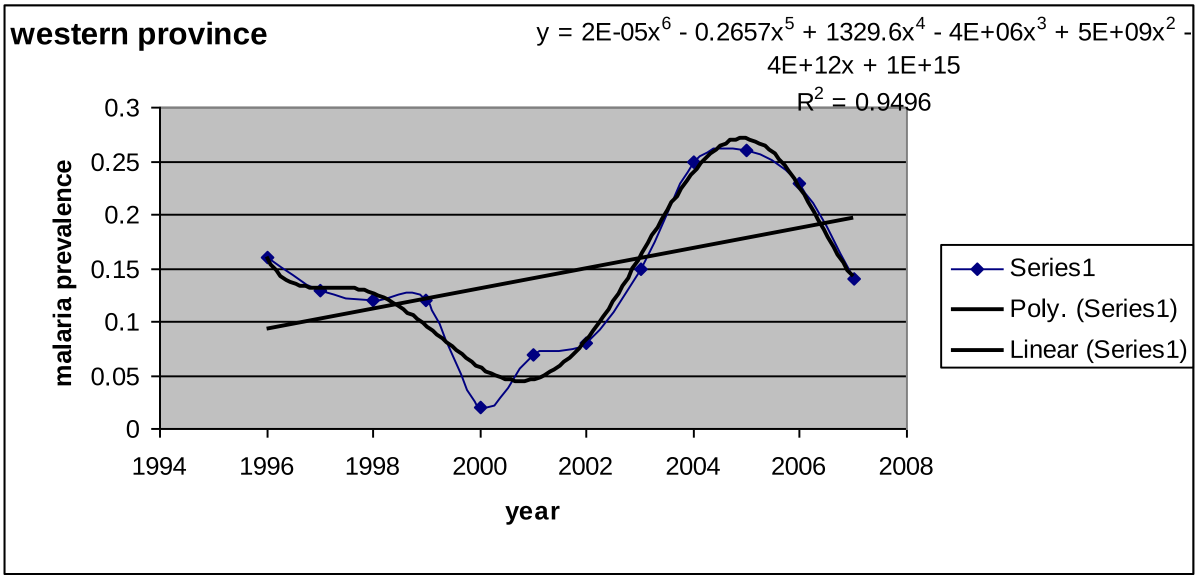
$Y = (4 \times 10^{-5})\, x^{6} - 0.4692x^{5} + 2347.6x^{4} - (6 \times 10^{6})\, x^{3} + (9 \times 10^{9})\, x^{2} - (8 \times 10^{12})\, x + (3 \times 10^{15})$.



One can notice from graph that this region had malaria prevalence declining slowly from 1996. This went on until 2002 when it went down to as low as 7% of the population. From 2002, it started rising again, reaching a peak in 2005 when the rate was 22%. The regression line shows an increase in prevalence from 1996.

The best polynomial was that of order 6.

$y = (2 \times 10^{-5})\, x^{6} - 0.2772x^{5} + 1387x^{4} - (4 \times 10^{6})\, x^{3} + (6 \times 10^{9})\, x^{2} - (4 \times 10^{12})\, x + (1 \times 10^{15})$.



There is a clear indication that the prevalence rate in this region was on the decline from 1996 to 2000 when it went down to 2%. However the situation changed from that year and it started rising, reaching a peak of 26% in 2005. The regression line shows a rising trend in prevalence rate. The best polynomial that fitted the data was one of order 6:

$y= (2x10^{-5})\ x^6 - 0.2657x^5 + 1329.6x^4 - (4\ x10^6)\ x^3 + (5\ x\ 10^9)\ x^2 - (4\ x10^{12})\ x + 10^{15}$

We observe that each of these regions exhibit a unique characteristic as observed from the curves and the regression lines. The rise in prevalence rate of malaria incidences in **Central**, **Eastern**, **Nyanza, Rift valley** and **Western** started in 2001. While in **Western** malaria incidence went down in 2006, in **Central** it went down in 2007. On the other hand, malaria incidence continued to rise in **Nyanza** and **Eastern Provinces**. **Coast Province** had a relatively high prevalence rate which rose to 73% in 2006. **North Eastern** and **Nairobi Provinces** displayed extremely low prevalence rates. The trend in **North Eastern** is rising albeit quite minimally whereas in **Nairobi** the trend is decreasing.

From the table below, it is observed that the explanatory variable (year) explains slightly above 80% of the prevalence rate for **North Eastern** and **Coast provinces**. The explanatory variable explains 98.54% of the prevalence rate for **Nyanza**. Only 68.05% of the prevalence rate in **Nairobi** is explained by the variable.

Table 2.1 Coefficient of Determination (R^2) for malaria rate against the year

	Province	R^2 (%)
1.	Central	93.36
2.	Coast	80.49
3.	Eastern	96.7
4.	Nairobi	68.05
5.	North Eastern	83.35
6.	Nyanza	98.54
7.	Rift Valley	93.42
8.	Western	94.96

3. Modeling the data using rainfall and prevalence rate

The total annual rainfall in every weather station in each of the eight Provinces was recorded for the period 1996 to 2006. It is important to note that the number of weather stations varies from one Province to another. Whereas Coast Province has seven weather stations, Western Province has only one. The total annual rainfall in all the weather stations within a Province was obtained, and the mean total annual rainfall calculated.

Regression lines were drawn and polynomials were fitted. For each Province, a scatter graph was drawn with mean total annual rainfall on the x-axis and malaria prevalence rate on the y-axis a polynomial of order 6 was found to be the best fit for all the Provinces.

Below are a scatter graph and a graph of rainfall versus prevalence rate for Western Province.

Similar graphs were drawn for all the other seven provinces and the respective polynomials of best fit and the trend lines were as follows:

Central Province

$$y = (9\text{x}10^{-17})\, x^6 + (4\text{x}10^{-13})\, x^5 - (8 \text{ x } 10^{-10})\, x^4 + (8 \text{ x } 10^{-7})\, x^3 - (4 \text{ x } 10^{-3})\, x^2 + 0.0863x - 5.5665$$

and

$$y = (3 \text{ x } 10^{-5})\, x + 0.1501$$

Coast Province

$$y = (2 \text{ x } 10^{-15})\, x^6 - (1 \text{ x } 10^{-11})\, x^5 + (4 \text{ x } 10^{-8})\, x^4 - (6 \text{ x } 10^{-5})\, x^3 + 0.056x^2 - 25.488x + 4771.7$$

and

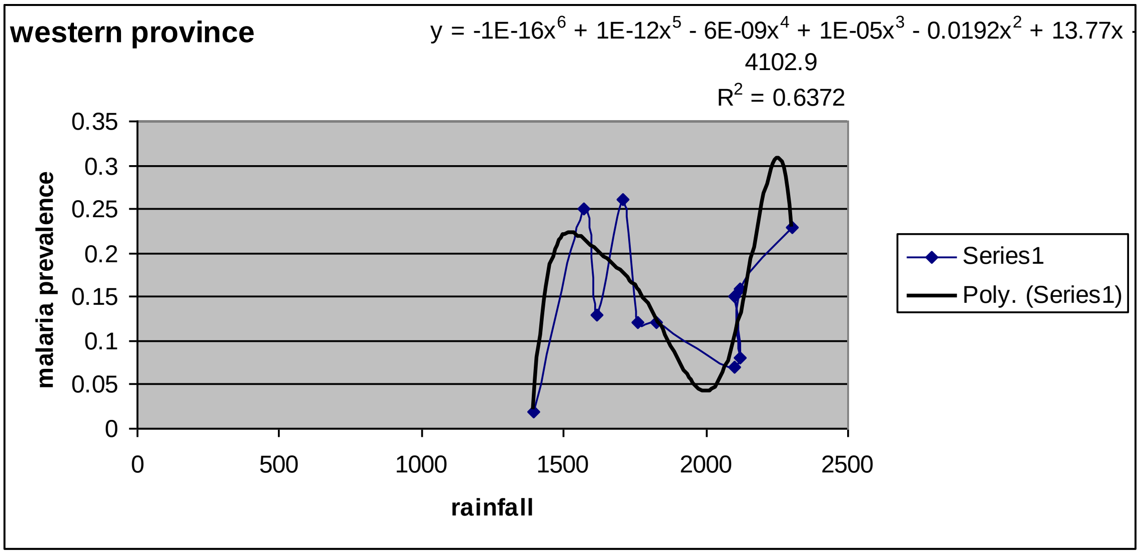
$$y = (4 \text{ x } 10^{-7})\, x + 0.2656$$

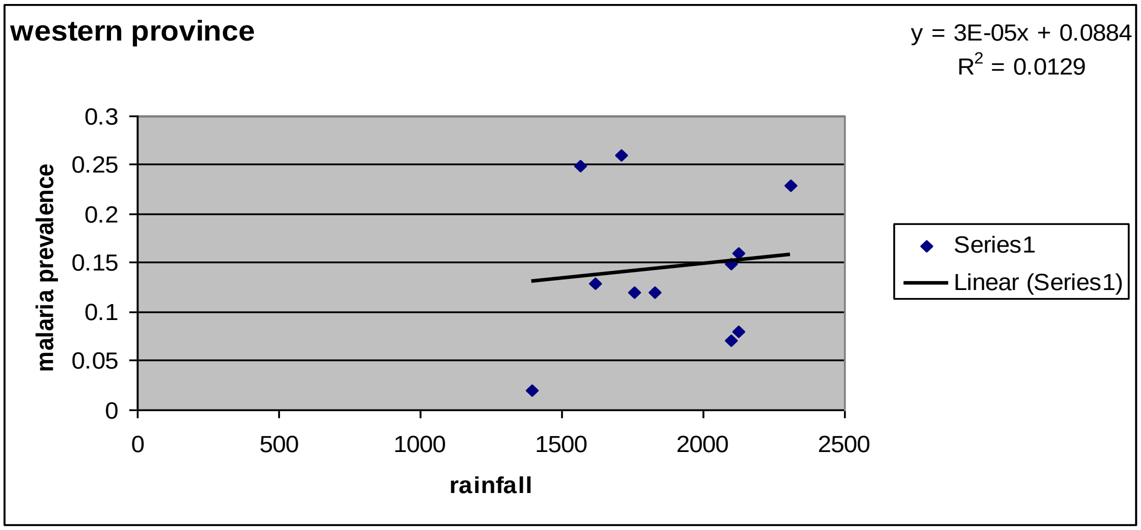
Eastern Province

$$y = (8 \text{ x } 10^{-17})\, x^6 + (5 \text{ x } 10^{-13})\, x^5 - (1 \text{ x } 10^{-9})\, x^4 + (2 \text{ x } 10^{-6})\, x^3 - 0.0016x^2 + 0.1682x - 97.163$$

and

$$y = 9 \text{ x } 10^{-6}\, x + 0.255$$





Nairobi Province

$y = -(8 \times 10^{-17})\, x^6 + (4 \times 10^{-13})\, x^5 - (9 \times 10^{-10})\, x^4 + (1 \times 10^{-6})\, x^3 - 0.0006\, x^2 + 0.1945x - 25.139$ and

$y = (6 \times 10^{-6})\, x + 0.322$

North Eastern Province

$y = -(5 \times 10^{-16})\, x^6 + (1 \times 10^{-12})\, x^5 - (2 \times 10^{-9})\, x^4 + (9 \times 10^{-7})\, x^3 - 0.0003x^2 + 0.0389x - 2.0394$ and

$y = 0.0005x + 0.0555$

Nyanza Province

Western Province

$y = -(5 \times 10^{-15})\, x^6 + (5 \times 10^{-11})\, x^5 - (2 \times 10^{-7})\, x^4 + 0.0005x^3 - 0.5806x^2 + 391.09x - 109423$ and

$y = (7 \times 10^{-5})\, x + 0.3218$

Rift Valley Province

$y = -(1 \times 10^{-14})\, x^6 + (9 \times 10^{-11})\, x^5 - (2 \times 10^{-7})\, x^4 + 0.0003x^3 - 0.2393x^2 + 96.852x - 16260$ and

$y = -(5 \times 10^{-7})\, x + 0.1422$

$y = -(1 \times 10^{-16})\, x^6 + (1 \times 10^{-12})\, x^5 - (6\times10^{-9})\, x^4 + (1 \times 10^{-5}) x^3 - 0.0192x^2 + 13.77x - 4102.9$ and

$y = 3 \times 10^{-5}\, x + 0.0884$

Table 3.1: coefficient of determination (R^2) for mean total Annual rainfall against malaria prevalence rate

	Province	R^2 (%)
1.	Central	46.16
2.	Coast	77.28
3.	Eastern	71.18
4.	Nairobi	76.13
5.	North Eastern	87.38
6.	Nyanza	76.54
7.	Rift Valley	69.27
8.	Western	63.72

The scatter graphs indicated that, no linear or non-linear relationship is discernible between malaria prevalence and mean total annual rainfall.

4. Conclusions

Polynomials of order 6 seem best suited for malaria prevalence and season (year). The graphs show that seasonal variations explain over 90% of malaria prevalence in Central, Eastern, Nyanza, Rift valley and Western Provinces.

The highest variation is in Nyanza with 98.54% of the prevalence rate explained by the seasonal variation. Nyanza is a highly endemic region. The 6th order polynomials can hence be used with certainty in these five regions to predict whether the coming season would require less or more preparedness in dealing with malaria incidences.

Coast and North Eastern Provinces have over 80% of malaria prevalence explained by the seasonal variations. The polynomials for these two regions can be used effectively as a method of predicting the prevalence rate in the coming season.

It is only Nairobi province where 68.05% of variation in malaria prevalence is explained by seasonal variations. The graphs display a relationship of a time series nature.

Using the scatter graphs, the mean total annual rainfall explains very little about malaria prevalence. The value of R^2 for all the regressions lines is very small.

However, when the polynomials are fitted, the 6th order polynomials are found to be the most suitable. The value of the R^2 varies from one province to another but is highest in North Eastern province at 87.38% and lowest in Western province at 63.72%. These figures are an indication of the significance of rainfall in malaria prevalence.

It would be reasonable to conclude that the 6th order polynomials best fitted the relationship between malaria prevalence and year, and malaria prevalence and rainfall

There is an increasing trend in malaria prevalence in Central, Eastern, Nyanza, Rift Valley and Western Provinces. This may be associated to the significantly positive correlation between rainfall and malaria prevalence. In Coast, Nairobi and North Eastern Provinces there seemed to be no significant change in malaria incidence.

The mean total annual rainfall does not give clear cut picture on malaria prevalence. However, the reasonably high values of R^2 for the polynomials shows that rainfall provides favorable climatic conditions for mosquito breeding.

References

Anderson R. M. and May R. M. (1991). Infectious Diseases of Humans, New York Oxford Science Publications.

Bruce – Chwat and de Zulueta (1980). The rise and fall of Malaria in Europe, Oxford University Press, Oxford U. K.

Cook G Ed (1996). Manson; Tropical Disease. London WB Saundess Co.

Cox J. and Hay S. I. (2007). The uncertain Burden of Plasmodium falciparum epidemics in Africa. Trends Parasitol, Vol 23: 142- 148.

Gilles H. M., Warell D. A., and Bruce Chwatt's (1993). Essential Malariology, London, Edward Arnold.

Hay S.I. et al (2000). Etiology of Interepidemic periods of mosquito –borne diseases. Proceedings of national Academy of sciences, USA Vol 97; 9335- 9339.

Lindsay S. W. and Biley M. H. (1996). Climatic change and malaria Transmission. Ann. Trop. Med. Parasitol. Vol. 90 573-588.

Lindsay S. W., Martens W. J. M. (1998). Malaria in the African highlands; Past, present and future. Bull World Health organization Vol 76:33 -45.

Mbogo C. M. et al (2003) Spatial and temporal heterogeneity of Anopheles mosquitoes and Plasmodium falciparum transmission along the Kenyan Coast. Am. J. Trop. Med. Hyg; 68:734-742

Mwangangi J. M. and Mbogo C. M. et al (2003) Blood-meal analysis for anopheles mosquitoes sampled along the Kenyan Coast. J. Am. Mosq Control Association Vol. 19: 371- 375.

Paul Reiter (2001) Environmental Health Perspectives Vol 109: Reviews in Environmental Health 141-161.

Philippe H. martin and Myriam G. Lefebvre (1997). Malaria and Climate: Sensitivity of Malaria Potential Transmission to Climate. Ambio, Vol 24 No. 4 200- 207.

Teklehaimanot H. D. et al (2004) "Weather based Prediction of Plasmodium Falciparu Malaria in Epidemic Prone Regions of Ethiopia; Malaria Journal III 1-11

Watson R. C., Zinyowera M.C., and Moss R. H., (1995). Impacts Adaptations and Mitigation of Climate change. Scientific Technical Analyses. Contribution working Group II to the second Assessment of the Intergovernmental Panel on Climate change (IPCC), Cambridge University Press.

Woube, M. (1997) "Geographical Distribution and Dramatic Increases in Incidences of Malaria: Consequences of the Resettlement Schemes in Gambela, South West Ethiopia." Indian Jour. of Malariology 34: 140-163

Zhou G. et al (2004). Spatial distribution patterns of malaria vectors and sample size determination in spatially heterogeneous environments: A case studyinthe western Kenya highland. J. Med. Entomol. No. 41(6): 1001-1009

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