Climatic variables and transmission of falciparum malaria in New Halfa, eastern Sudan

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المتغيِّرات المناخية وسراية الملاريا المنجلية في حلفا الجديدة، بشرق السودان

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الخلاصـة: درس الباحثون دور المتغيِّرات المناخية والزراعة الـمَرْويَّة في السراية الموسمية للملاريـا في حلفـا الجديـدة، بشرق السودان. وأُجري تحليل متسلسل زمنياً بالاعتماد على المتغيرات المناخية الشهرية، والمياه المتوافرة شهرياً لِرَيِّ المحاصيل، ومعدل الشرائح الإيجابية الشهرية للملاريا، في ما بين عامَيْ 1986 و2002. وقد تم التبليـغ عـن حـالات الملاريا شهرياً على مدار العام بمتوسط 100/13.0 شخص/الشهر (11.9 – 14.2) وبنَمَط سنوي ثنـائي الـدارج في فصلَيْ الشتاء والخريف. وقد وجد أن سقوط الأمطار هـو المـتغير المنـاخي الأساسـي في سـراية المـرض، يـؤدي الهطول الغزير للأمطار إلى بدء ظهور الأوبئة. أما الحرارة، والرطوبة النسبية والري فلم تكن من العوامل الـتي يُعتـدُّ بها.

ABSTRACT The study investigated the role of climatic variables and irrigated agricultural on the seasonality of malaria transmission in New Halfa, eastern Sudan. A time-series analysis was performed using monthly climatic variables, monthly water available for irrigation of crops and monthly slide positive rate of malaria during the period 1986–2002. Cases of malaria were reported every month of the year with a mean of 13.0/100 persons/month (95% CI: 11.9–14.2), and bimodal annual pattern in autumn and winter seasons. Rainfall was the significant climatic variable in the transmission of the disease, whereas heavy rainfall was found to initiate epidemics. Temperature, relative humidity and irrigation water were not significant factors.

Variables climatiques et transmission du paludisme à P. falciparum à New Halfa au Soudan oriental

RÉSUMÉ Cette étude a évalué le rôle des variables climatiques et de l'agriculture irriguée sur la saisonnalité de la transmission du paludisme à New Halfa au Soudan oriental. Il a été procédé à une analyse de séries chronobiologiques s'appuyant sur les variables climatiques mensuelles, les volumes mensuels d'eau disponibles pour l'irrigation des cultures et le taux de positivité des lames mensuel pour la période 1986-2002. Des cas de paludisme ont été rapportés tout au long de l'année, avec une moyenne de 13,0/100 sujets/mois (IC 95 % : 11,9 - 14,2) et un profil bimodal retrouvé chaque année en automne et en hiver. La pluie s'est avérée être la variable climatique significative quant à la transmission de la maladie, les fortes chutes de pluie apparaissant comme le facteur déclenchant d'une épidémie. La température, l'humidité relative et les eaux d'irrigation n'étaient pas des facteurs importants.

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Introduction

Malaria remains one of the major public health concerns in most tropical countries. Despite continuous efforts to curb malaria transmission, the incidence in some parts of the world is reported to be increasing. The costs, morbidity and mortality associated with malaria are huge.

It has been suggested that both global climate and local environment changes may be affecting the pattern of malaria. The predictive models of the effects of global warming show a widespread expansion in the distribution of stable malaria in Africa during the next few decades [*1,2*]. Changes in the pattern of tropical weather conditions, particularly rainfall and temperature, are reported to have an important role in the increase of malaria risk [*3–5*]. Other factors such as changes in land use pattern and construction of water control systems have also been shown to have considerable effects on malaria transmission [*6,7*].

Although global warming might affect regions above 1500 m, it will probably have little influence on the stability and pattern of malaria in areas below 1500 m, where the majority of the tropical African population lives. More serious in the short and medium term are the effects of deforestation in the hill areas. Also important is the temperature governing sporogony. The duration of sporogony is rising again above the optimum (26 °C for *Plasmodium falciparum*) [*8*]. In areas with unstable malaria transmission, minor changes in the transmission parameters such as mosquito population density and longevity could have a sustainable impact on human morbidity and mortality [*8,9*]. Therefore, it is important to identify the forces that drive the proliferation of malaria transmission as a result of these changes. Although such studies on the dynamics and distribution of malaria transmission have been upgraded to the continental scale, few studies have been made on a temporal scale.

The aim of this study was to plot the transmission dynamics of falciparum malaria in relation to climatic variables and irrigation water available for agriculture in the New Halfa area of eastern Sudan, based on empirical data for the period 1986–2002. This may be important for forecasting and planning of the malaria control programme in the area.

Methods

Study area

The study was carried out in the New Halfa area (located at 15° 18'–15° 21' N & 35° 33'–35° 37' E). This is 500 km from Khartoum in the middle of the second largest irrigated agricultural scheme in Sudan. Cotton and wheat are the main crops cultivated during the winter season. The region is the semi-arid dry savannah belt of Sudan. During the period of the study the mean monthly temperature was 29.4 °C (range 14.1–42.7 °C), the mean monthly relative humidity was 49.2% (range 19.0%–78.2%) and average annual rainfall was 238.7 mm (range 68.7–543.8 mm). The area is characterized by a high level of drug resistance to falciparum malaria; *Anopheles arabiensis* is the principle vector [*10–12*].

Data collection

As the New Halfa irrigated scheme is a relatively recent construction, data were only available from 1986 onwards. The slide positive rate (SPR) of malaria was the number of parasitologically confirmed clinical cases of malaria/100 persons attending/month. Results were calculated monthly from the routine reports of the health authority that collected data from patients attending 8 malaria referral laboratories in the area.

The climatic variables collected were: monthly mean maximum and minimum temperature (°C), relative humidity (%) and total rainfall (mm), as well as monthly amounts of irrigation water available for agriculture (m^3/month). The seasons were classified as: cool dry winter (November to February), hot dry summer (March to June) and autumn (July to October). Meteorological data were retrieved from the New Halfa meteorology station. The data about irrigation water were collected from the irrigation station in New Halfa town and was only available for the period 1997–2002. This data measured the monthly amount of water available for crop irrigation in the New Halfa agriculture scheme. The amount of water fluctuates depending on the yearly amount of water available in Khashm El-Girba dam reservoir and on the actual monthly amount of water released from the dam to irrigate the crops cultivated in a specific time and area.

Data analysis

Data were analysed using *SPSS*, version 12. The monthly SPR of malaria was regarded as the dependent variable, while climatic variables were independent variables. Spearman correlation analysis was conducted to examine the relationship between the independent variables and the SPR of malaria. Autoregressive integrated moving average (ARIMA) analyses were performed to account for possible auto-correlation in the time-series data. Therefore a model was

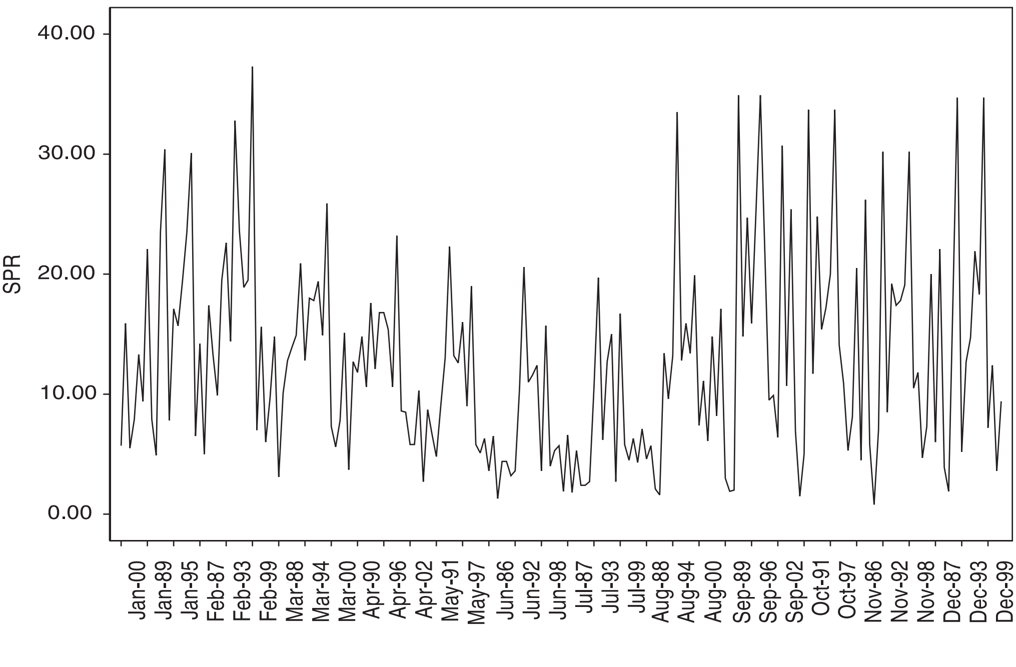

Figure 1 Monthly distribution of malaria slide positive rate (SPR) (number/100 persons/month) in the New Halfa area, 1986–2002

developed after the effect of auto-correlation had been removed and then regression analyses were used to assess the independent effect of each independent variable. $P < 0.05$ was considered significant.

Results

Malaria cases were reported every month of the year, with a mean SPR of 13.0/100 persons/month (95% CI: 11.9–14.2/100 persons/month). The general pattern was a bimodal annual increase in SPR during the end of the autumn (September/ October) and the cool dry season (January/February) (Figure 1). This figure shows the 2 peaks of SPR by clustering the months of the main peak (right) and minor peak (left) and months with low level of SPR (in between).

Rainfall was the only climatic variable that was significantly correlated with malaria SPR in the area over 1986–2002 ($P = 0.006$) (Table 1). This is illustrated in Figure 2, showing the relationship between heavy rainfall and the malaria epidemics that were reported in 1992 and 1998. The monthly average total rainfall was 205% higher in 1992 (95% CI: 9.1–33.0 mm) and 183% higher in 1998 (95% CI: 11.3–80.3 mm), compared with the previous 3 years (1989–91 and 1995–97) respectively. Similarly, the malaria SPR increased by 263% in 1992 in comparison with the previous 3 years [7.3/100 persons/month (95% CI: 5.4–9.1/100 persons/month)] and by 133% in 1998 in comparison with the monthly mean SPR during 1995–97 [17.3/100 persons/month (95% CI: 15.5–19.2/100 persons/month)]. The inverse relationship observed reflected the opposite position between rainfall and malaria SPR; when there was no rainfall (dry years), the highest number of cases of malaria were recorded during the cool dry season. The correlation analyses conducted for the data of these 2 epidemic years revealed a high positive relationship between SPR and monthly total rainfall ($r = 0.79$, $P = 0.001$). However, the negative association between rainfall and SPR observed during the whole period of study reflected only the pattern of malaria incidence under a control programme, when mosquitoes were intensively sprayed. The highest number of malaria cases occurred during the cool dry season (irrigation season), i.e. years 1993 and 1999 (Figure 2). In fact this was also the case of some drought years, i.e. year 1987 (Figure 2).

Table 1 Correlation between climatic variables and monthly malaria slide positive rate (SPR) in the New Halfa area, 1986–2002

Variable	Correlation coefficient	P-value
Season	0.176	0.012
Maximum temperature	–0.012	0.876
Minimum temperature	–0.013	0.864
Rainfall	–0.196	0.006
Humidity	–0.018	0.812
Irrigation water available	–0.033	0.756

Temperature, relative humidity and irrigation water showed no significant correlation with malaria SPR over 1986–2002 (Table 1). Cross-correlations conducted among the independent variables revealed a significant correlation between monthly mean relative humidity and both minimum and maximum temperature ($P > 0.001$). Also a significant correlation was found between minimum and maximum temperature ($P > 0.000$). Due to these high coefficient correlations among the independent variables, each variable was analysed with rainfall in a separate regression model to reduce this multicollinearity. The best combination was found between rainfall and

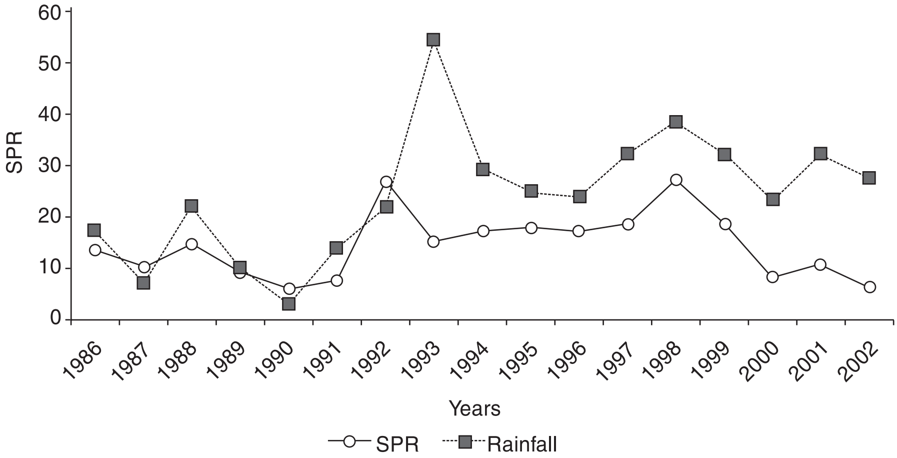

Figure 2 Relationship between annual mean of malaria slide positive rate (SPR) (number/100 persons/month) and rainfall (×10 mm) in the New Halfa area, 1986–2002

minimum temperature in comparison with other combinations of monthly maximum temperature and humidity. The effect of these factors was more pronounced during the dry years 1990 and 1991, and also the lowest SPR was reported in July (the beginning of the rainy season), following the harsh environment conditions of the hot dry season (Figure 1).

Significant differences were found between the SPR in the hot dry season and both the cool dry and the autumn seasons, but there were no significant differences between the autumn and the cool dry seasons (Table 2). However, "year" was not significant in the regression model, reflecting the stability in the number of cases during most years of the study period, especially 1992–99 (Figure 2).

Discussion

This was the first study reporting the association between climatic variables and malaria SPR in an irrigated area in eastern Sudan. There were significant differences in the SPR of malaria between the 3 seasons. Cases of malaria were reported almost every month of the year, with a general pattern of a bimodal annual increase in SPR in the autumn and cool dry season. Clearly, the pattern of malaria transmission was completely different from that in the other parts of eastern Sudan, where transmission of the disease was restricted to the rainy season [*13*]. Despite the non-significant correlation between irrigation water and malaria SPR,

Table 2 Model of regression coefficients between monthly climatic variables and malaria slide positive rate (SPR) in the New Halfa area, 1986–2002

Variables	β	SE of β	P-value
Rainfall	–0.021	0.009	0.025
Minimum temperature	0.437	0.161	0.070
Year	–0.023	0.077	0.762
Cool dry (irrigation)	0.580	1.522	0.704
Hot dry	4.887	1.737	0.005
Autumn (rainy)	–1.441	1.450	0.338
Constant	0.203	0.674	0.764

SE = standard error.

perhaps due to the use of limiting data, the bimodal annual rate of malaria transmission could be explained by the presence of the agriculture schemes.

Previous entomological surveys in the same area reported a continuous breeding activity of *A. arabiensis* in the leakages of the irrigation system and therefore a minor peak of larvae density was investigated during the cool dry season. However, the larvae numbers of *A. arabiensis* were correlated significantly with the irrigation water [*12*]. Nevertheless, irrigated agriculture has influenced malaria incidence in this area and extended the transmission season beyond the rainy season [*14*]. The introduction of irrigated schemes in areas with seasonal rainfall has been reported to increase the incidence of malaria significantly [*15,16*].

Our findings showed a significant positive association between malaria SPR and rainfall, and epidemic malaria was associated with heavy rains. Previously, it was documented that the transmission of malaria was governed by rainfall and fluctuated considerably from year to year according to the rainfall, and heavy rains were associated with malaria epidemics [*4,5,17–19*]. The results of the present study support the model of Lindsay et al. [*3*], who found that temperature and rainfall were driving forces of the spatial distribution of the malaria vector *A. gambiae* s.l. Koenraadt et al. [*20*] showed that the numbers of the larval and adult population of *A. gambiae* s.s. and *A. arabiensis* are closely linked with rainfall, while Craig et al. [*21*] observed a direct and predictable relation between rainfall and malaria transmission. Although excessive rainfall flushes the aquatic stages of *A. arabiensis* away, leaving them stranded on the dry ground, it does not eliminate them. Thus very high rainfall is still relevant for malaria vectors, as dispersed water collections that are suitable for breeding can be created [*21–23*].

The study showed that malaria SPR was not significantly correlated with temperature. Although temperature governs mosquito survival only to a limited extent, it has a significant impact on the transmission dynamics mainly due to the specific effect on sporogenic duration [*8,24*]. However, during March to June, hot dry weather has a significant correlation with SPR (Table 2). This could be attributed to the rise in maximum temperature and decrease in relative humidity that reduces significantly the breeding activity of *A. arabiensis* [*12*]. Earlier investigations in the Sudan and elsewhere in Africa have demonstrated that relative humidity is the main determinant of the lifespan of *A. arabiensis* [*25*]. Since the evidence for the effect of climate change for expanding the areas of suitable malaria transmission is derived largely from temperature [*3*], it is likely that malaria infections in the New Halfa area will increase in response to the rise of temperature during the cool dry season.

Our findings have important implications for malaria control in areas with similar geographic, climate and environmental conditions to those of New Halfa. Both the duration and timing of malaria transmission are important factors to consider when directing efforts in malaria control.

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