Role of climatic factors in the incidence of dengue in Port Sudan City, Sudan

Elsiddig Noureldin [1] and Lynn Shaffer [2]

[1]National Center for Disease Control and Prevention (NCDC), Ministry of Health, Jazan, Saudi Arabia (Correspondence to: Elsiddig Noureldin: siddignoureldin@hotmail.com). [2]Trinity Health System, Mount Carmel Health System, Columbus, United States of America

Abstract

Background: Dengue fever outbreaks have occurred in Port Sudan City, Sudan, during the last 2 decades. Climatic factors may play a role in dengue incidence.

Aims: This study aimed at dribbing the relationship between climatic factors and dengue fever incidence in Port Sudan during 2008–2013.

Methods: This ecological study entailed secondary data analysis of dengue fever cases and climate information to explore which climatic factors predict the incidence of dengue fever. The Wilcoxon rank sum test and multiple linear regression examined the association between number of dengue fever cases and climatic factors during lag times of 1–6 months.

Results: Relative humidity and maximum and minimum temperatures were correlated with dengue incidence in Port Sudan at different time intervals during 2008–2010. Precipitation and relative humidity were correlated with dengue fever during 2011–2013. However, 3–5-month lagged relative humidity was the strongest explanatory variable for the incidence of dengue.

Conclusion: Dengue transmission appears sensitive to climatic variability. Elucidating the role of climatic factors in dengue fever helps in risk assessment and prevention of epidemics.

Keywords: dengue, infection control, incidence, climate, Port Sudan

Introduction

Dengue is a viral disease transmitted to humans by the bite of infected females of the main mosquito vector *Aedes aegypti* and to a lesser extent *Aedes albopictus* (*1*). Traditionally, the World Health Organization (WHO) has classified dengue into three categories according to severity: dengue fever, dengue haemorrhagic fever and dengue shock syndrome (*2*). The clinical characteristics of dengue are sudden onset of severe fever, pain behind the eyes (retro-orbital), nausea, swollen lymph nodes (lymphadenopathy), intense headache, muscle pain (myalgia), gastrointestinal problems, joint pain and rash (*3*). Dengue haemorrhagic fever and dengue shock syndrome cause lethal complications that include severe haemorrhage, plasma leakage, organ impairment, fluid accumulation, and respiratory distress (*3*).

Dengue fever is considered by WHO to be the most important mosquito-borne viral disease. Dengue incidence has increased > 10-fold throughout the last 3 decades, with a currently estimated 50–100 million annual cases distributed over > 100 countries. WHO has advocated the development of preventive and proactive measures to limit dengue transmission and outbreaks (*4*).

Previous investigators have examined factors that affect populations of *Ae. aegypti* and subsequent dengue fever incidence. Unplanned urbanization and climatic factors, including high temperatures and rainfall, might contribute to epidemics of dengue (*5,6*). *Aedes* mosquitoes are found in urban settings, especially in tropical areas, where they maintain a sustainable relationship with humans, which has led to re-emergence of dengue virus infections (*7*). Climatic factors of temperature, rainfall and humidity are thought to have the most potential to affect the maturation periods, habitats, survival time and vectorial capacity of *Aedes* mosquitoes (*8*). Researchers from various geographic areas have reported significant associations between temperature, relative humidity, precipitation and dengue distribution and transmission, e.g., India (*9*), Thailand (*10*), Malaysia (*11*), Viet Nam (*12*), Philippines (*13*), Indonesia (*14*), and Singapore (*15*). For example, Karim et al. (*16*) in Dhaka, Bangladesh, found positive significant correlations between the 2-month-lagged relative humidity, rainfall, maximum temperature, and the reported monthly dengue cases. Other researchers reported no effect of climatic factors on the incidence of dengue fever/dengue haemorrhagic fever (*15,17*). Also, in Central Visayas, Philippines, Picardal and Elnar (*18*) found no correlation between dengue cases and rainfall or temperature. Given these variable findings, it is possible that the effects of climatic factors such as precipitation, temperature and relative humidity may depend on the normal conditions of a particular geographic area.

In the last 2 decades, Port Sudan City has witnessed several dengue outbreaks, and the incidence of dengue

was estimated as 94 cases per 10 000 during the 2010 outbreak in which 3765 cases were reported (*19,20*). There have been no ecological investigations of the role of climatic factors on the incidence of dengue fever in Sudan, particularly in Port Sudan, where most of the dengue fever/dengue haemorrhagic fever in the country has occurred. Since climatic factors are thought to affect the population of *Ae. aegypti* and dengue fever incidence, this information could be helpful in planning for public health preventive and control measures in this region.

The present study aimed to describe the temporal relationship between climatic factors (maximum and minimum temperatures, relative humidity or rainfall) and the incidence of dengue fever in Port Sudan City, Sudan, during 2008–2013.

Methods

Study design and setting

This study was an ecological analysis of the association between climatic factors and dengue fever incidence in Port Sudan City, Sudan, for the period 2008–2013. Port Sudan is located on the Red Sea and has an arid (low precipitation) and humid (Mediterranean) climate. The mean maximum temperature is around 40°C in summer (June–September) and the mean minimum temperature is 20.5°C in winter (November–March). Total annual precipitation is 76.1 mm in the rainy season (October–January), and the annual average relative humidity is 63% (*19,21*).

Sampling frame

The sampling frame was the monthly secondary data (datasets) of the dengue fever/dengue haemorrhagic fever cases and the climatic information from 2008 to 2013. The time period 2008–2013 was chosen because it contained complete information on dengue fever/dengue haemorrhagic fever cases. The sampling frame included the monthly number of dengue fever/dengue haemorrhagic fever cases, relative humidity, temperature (maximum and minimum), and rainfall (precipitation). The data of weekly dengue cases were obtained from the Department of Epidemiology, Ministry of Health, Red Sea State, Sudan. All dengue fever cases are required to be reported to the health authorities in Port Sudan, namely the Department of Epidemiology, and all suspected cases are sent to local laboratories for confirmation of dengue infection. Laboratory tests that are dengue positive are sent to the National Public Health Laboratory in Khartoum for confirmation. The data were captured in an electronic dataset. The climatic variables were obtained from the Sudan Meteorological Authority, which collects data on temperature, relative humidity and rainfall in real time through its widely distributed sentinel meteorological stations including one in Port Sudan.

Data analysis

It was noted from the preliminary graphic analysis that the number of dengue cases was higher during 2008 through to most of 2010 and then declined significantly in 2011–2013. The reason behind that was the strong epidemiological and entomological surveillance and control measures undertaken by the Ministry of Health, Red Sea State to deal with the outbreak that started in June 2010 and continues to the present (Department of Epidemiology, Red Sea State, personal communication, 2014). Therefore, for the purposes of analysis the study period was split into 2008–2010 and 2011–2013.

Wilcoxon rank sum tests were utilized to examine the association between number of dengue fever/dengue haemorrhagic fever cases and the following factors: minimum temperature, maximum temperature, relative humidity, and rainfall for 1–6 months' lag time, according to cutoff values for the climatic factors that were identified from preliminary graphic analysis, which indicated threshold relationships between the climatic factors and dengue fever incidence, rather than dose–response relationships. Lag time indicated the number of months between the time when dengue fever cases were reported and the pattern of the climatic factor of interest. The unit of time was months, as weather data were available only in monthly units. Multiple linear regression was used to determine which independent variables still influenced the monthly number of dengue fever/dengue haemorrhagic fever cases during lag time of 1–6 months after taking into account the other climatic factors. SPSS version 20 was used for statistical analysis.
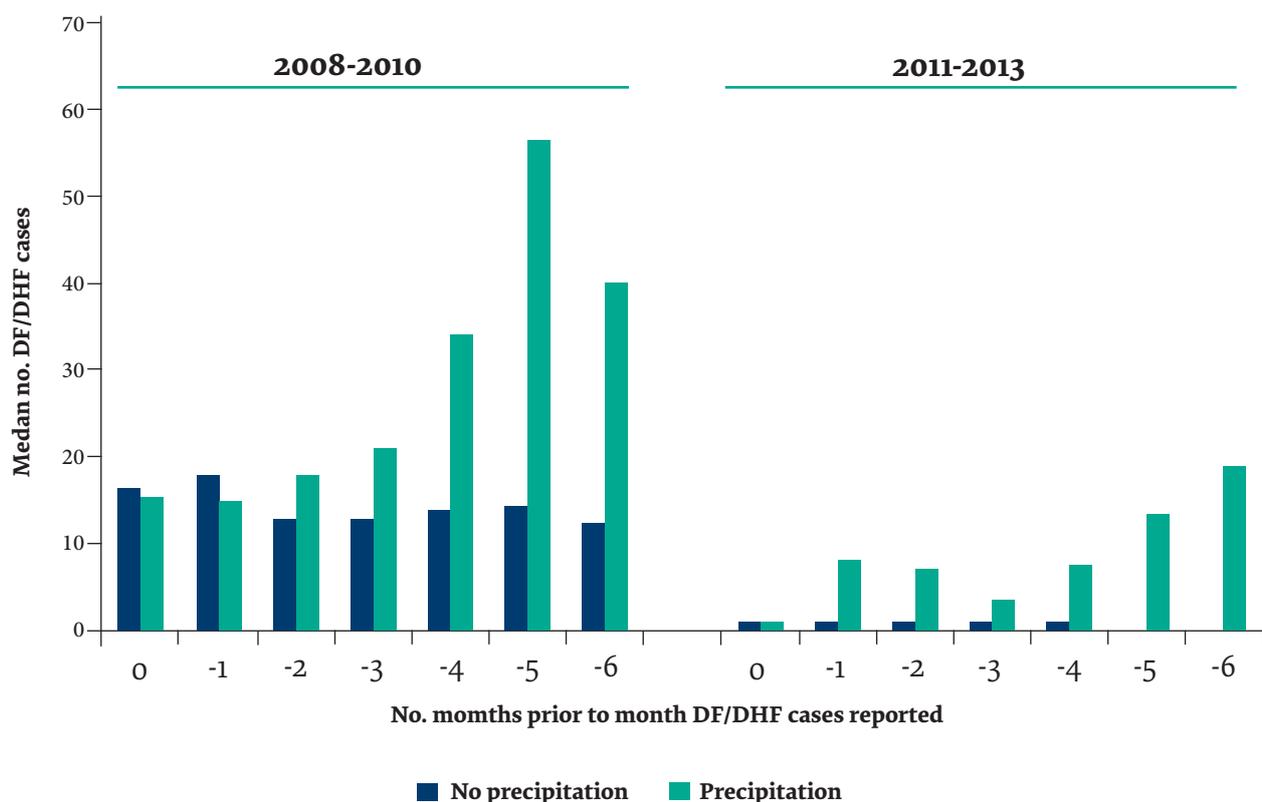
Results

Figures 1–4 illustrate the relationships between precipitation, relative humidity and maximum and minimum temperature and the number of dengue fever/dengue haemorrhagic fever cases for 2008–2010 and 2011–2013. For each climatic factor, the histogram bars show the median number of dengue fever/dengue haemorrhagic fever cases according to whether the monthly average factor was above or below the threshold value derived from graphical analysis (vertical axis), and the time lag for that particular climatic factor (horizontal axis). The number on the horizontal axis represents the number of months between the measurement of the climatic factor and the reporting of the dengue fever/dengue haemorrhagic fever cases, with negative numbers to indicate that the climatic measurement took place prior to the occurrence of the dengue fever/dengue haemorrhagic fever cases. It should be noted that although the shape of the trends for Figures 1–4 are similar for the two time periods, the total number of cases was smaller during 2011–2013.

Precipitation

Although there were some differences in the number of dengue fever/dengue haemorrhagic fever cases according to whether there was any rainfall 4–6 months prior to the dengue fever/dengue haemorrhagic fever reporting month, precipitation was not correlated with dengue incidence during any of the 6 months lag time during 2008–2010 (all *P* > 0.05, Figure 1). Nevertheless, the incidence of dengue cases at average precipitation > 0 exceeded that of

Figure 1 Number of dengue fever/dengue haemorrhagic fever cases according to the occurrence of precipitation and number of months prior to reporting

dengue incidence when there was no recorded precipitation in all months except 0 and 1 month prior to the dengue fever/dengue haemorrhagic fever reporting month during 2008–2010 (Figure 1). In contrast, for 2011–2013, although the total number of dengue fever cases was lower, the occurrence of any precipitation during 5 or 6 months prior to the dengue fever reporting month was associated with a significantly elevated number of cases (*P* = 0.0433 and 0.0298, respectively). The shape of this trend is similar to that observed for the time period 2008–2010 in that the difference in number of dengue fever/dengue haemorrhagic fever cases between conditions of no precipitation versus at least some precipitation was most extreme at 4, 5 and 6 months prior to the dengue fever/dengue haemorrhagic fever reporting period.

Relative humidity

For 2008–2010, relative humidity started to show a positive association with dengue fever/dengue haemorrhagic fever at the 3-month lag time (*P* = 0.0025) and continued at 4 months (*P* = 0.0003) and 5 months (*P* = 0.0037) (Figure 2). The highest occurrence of average (rather than median) number of dengue cases correlated with high relative humidity at the 3-month (246.4), 4-month (253.8) and 5-month (226.4) lag times. Relative humidity < 56% compared to ≥ 56% during 3–5 months prior to the dengue fever/dengue haemorrhagic fever reporting month produced the largest difference between numbers of cases during 2008–2010. For 2011–2013, relative humid-

ity ≥ 56% was significantly associated with an increased number of dengue fever cases only at 3 months prior to the reporting of those cases, with 21.8 average (rather than median) monthly reported dengue cases compared to 6.2 cases when relative humidity was < 56% (*P* = 0.0202).
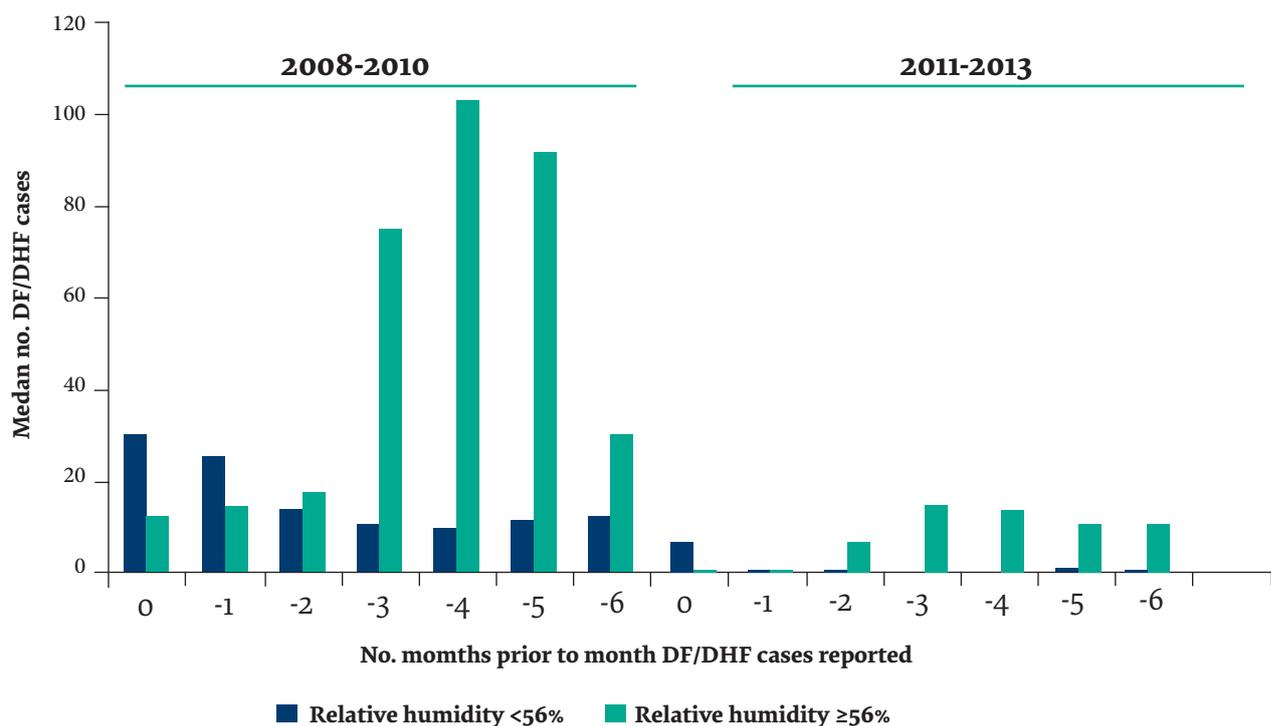
Maximum temperature

In 2008–2010, maximum temperature was significantly correlated with dengue at the 2-, 3- and 4-month lag times (*P* = 0.0196, 0.0027 and 0.0365, respectively. (Figure 3). It appeared that average maximum temperature < 35°C favoured high incidence of dengue, with average (rather than median) numbers of dengue fever/dengue haemorrhagic fever cases of 220.8, 217.4 and 186.2, respectively, compared to only 26.5, 18.7 and 49.1 when the average maximum temperature was ≥ 35°C. No significant trends were seen with respect to maximum temperature for 2011–2013 (all *P* > 0.05).

Minimum temperature

The minimum temperature was significantly correlated with dengue at the 1-, 2-, 3- and 4-month lag times (*P* = 0.0427, 0.0012, 0.0024 and 0.0215, respectively) during 2008–2010 (Figure 4). The incidence of dengue was significantly increased when the minimum temperature was < 25°C compared to ≥ 25°C. No significant trends were seen with respect to minimum temperature for 2011–2013 (all *P* > 0.05).

Figure 2 Number of dengue fever/dengue haemorrhagic fever cases according to relative humidity and number of months prior to reporting

Association of climatic factors with dengue fever/dengue haemorrhagic fever incidence

Multiple linear regression modelling was done to determine whether all of the climatic factors individually associated with an increase in dengue fever cases remained independently associated after other climatic factors were taken into account. The final regression model is displayed in Table 1. Only relative humidity < 56% versus ≥ 56% at 3, 4 and 5 months prior to the dengue fever reporting month remained independently associated with the number of dengue fever cases reported. The interaction term in the model indicates that this effect of relative humidity was greater during 2008–2011 than 2011–2013. The results also indicate that the other climatic factors do not have any significant relationship with dengue fever cases after controlling for relative humidity. In other words, the minimum temperature, maximum temperature and precipitation were strongly correlated with relative humidity, and once we took into account relative humidity, they did not add any information for predicting the number of dengue fever cases.
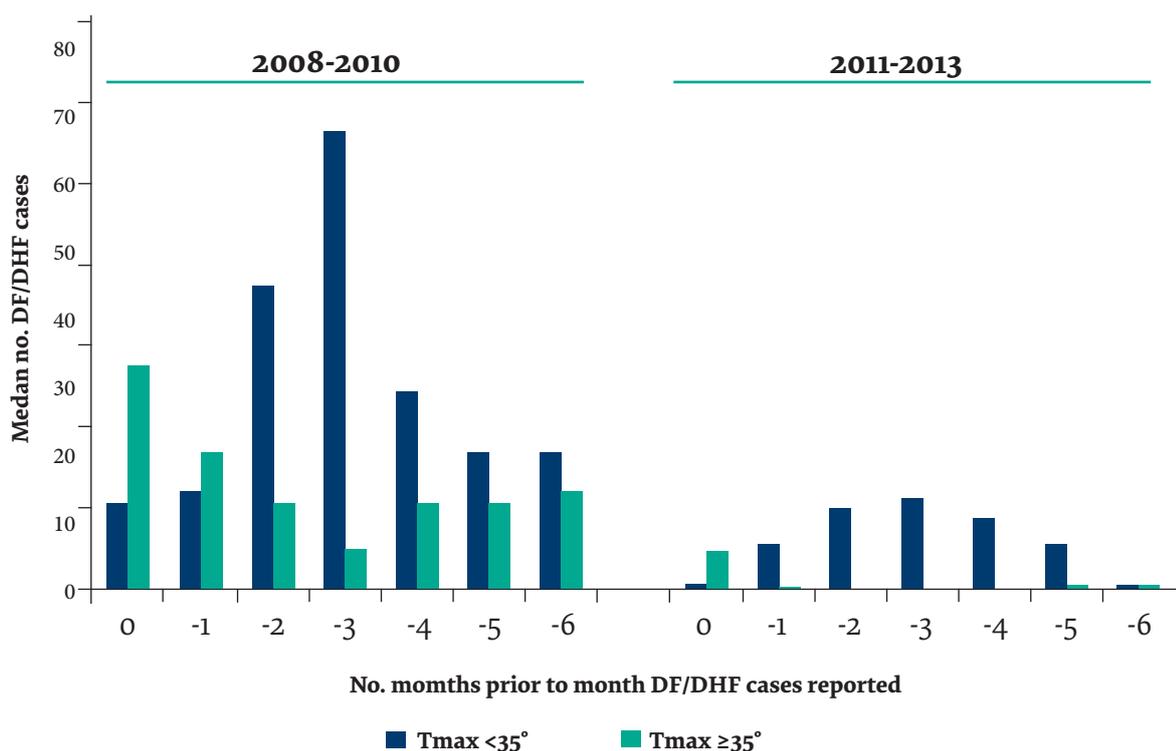
Discussion

Overall, this study suggested that relative humidity ≥ 56% was strongly and independently associated with an increased number of dengue fever/dengue haemorrhagic fever cases 3–5 months later. The lower number of cases reported during 2011–2013 also suggested that the control measures put in place in 2010 by the Ministry of Health, Red Sea State, were effective. Precipitation in 2008–2010 showed no significant association with dengue incidence, probably because most of the breeding sites were available indoors for *Ae. aegypti* mosquitoes, and this vector was therefore dependent on the behaviour of humans rather than precipitation for their survival and development (22,23). In Philippines, Singapore and Indonesia, outbreaks of dengue have occurred even in dry seasons, possibly due to practices of water storage (24). This may partly explain the weak impact of precipitation compared to other climatic factors on the dengue cases. However, the relationship between precipitation and *Ae. aegypti* population is complex (25).

We showed that precipitation at 5 and 6 months' time lag was positively correlated with

Table 1 Linear regression describing relationship between relative humidity and monthly frequency of dengue fever/dengue haemorrhagic fever cases, 2008–2013

Model factors	Estimated coefficient	Standard error	P
Relative humidity < 56% vs. ≥ 56% at 3, 4 and 5 months	222.32	51.43	0.0001
2008–2010 vs. 2011–2013	38.34	59.82	0.5237
Interaction term	–108.63	32.0	0.0012

Figure 3 Number of dengue fever/dengue haemorrhagic fever cases according to maximum temperature and number of months prior to reporting

dengue cases in 2011–2013. This is in line with the findings of Hii et al. (26), who found a linear increase in dengue cases in Singapore at a time lag of 5–20 weeks after elevated precipitation. Vu et al. (12) reported 0–3 months' time lag after precipitation and before the incidence of dengue, while Rubio-Palis et al. (17) identified 4 months as the critical time point. Furthermore, it has been found that the abundance of *A. aegypti* adults and larvae in Port Sudan is directly proportional to relative humidity and precipitation (27).

Relative humidity ≥ 56% was significantly associated with dengue cases at 3–5 months' lag time in 2008–2010, and at 3 months' lag time in 2011–2013. Corroborating results have been reported by Ahmed (27), who found that the population density of *Ae. aegypti* larvae in Jeddah was large at 55.4% relative humidity and small at 45.4%. Banu et al. (28) in Dhaka, Bangladesh, also revealed that relative humidity was positively correlated with dengue incidence at a 4-month lag time. Relative humidity is "the amount of atmospheric moisture present relative to the amount that would be present if the air were saturated" (http://graphical.weather.gov/definitions/defineRH. html) and is a function of temperature: relative humidity increases as temperature decreases. As relative humidity has its effects on all stages of the mosquito life cycle, its combined impact with temperature significantly affects the survival rate of the mosquito, number of blood meals, and eventually its capacity to become infected and transmit dengue (29).

In our study, maximum temperature < 35°C in 2008–2010 was positively associated with dengue incidence at lag time of 2–4 months before the incidence of dengue.
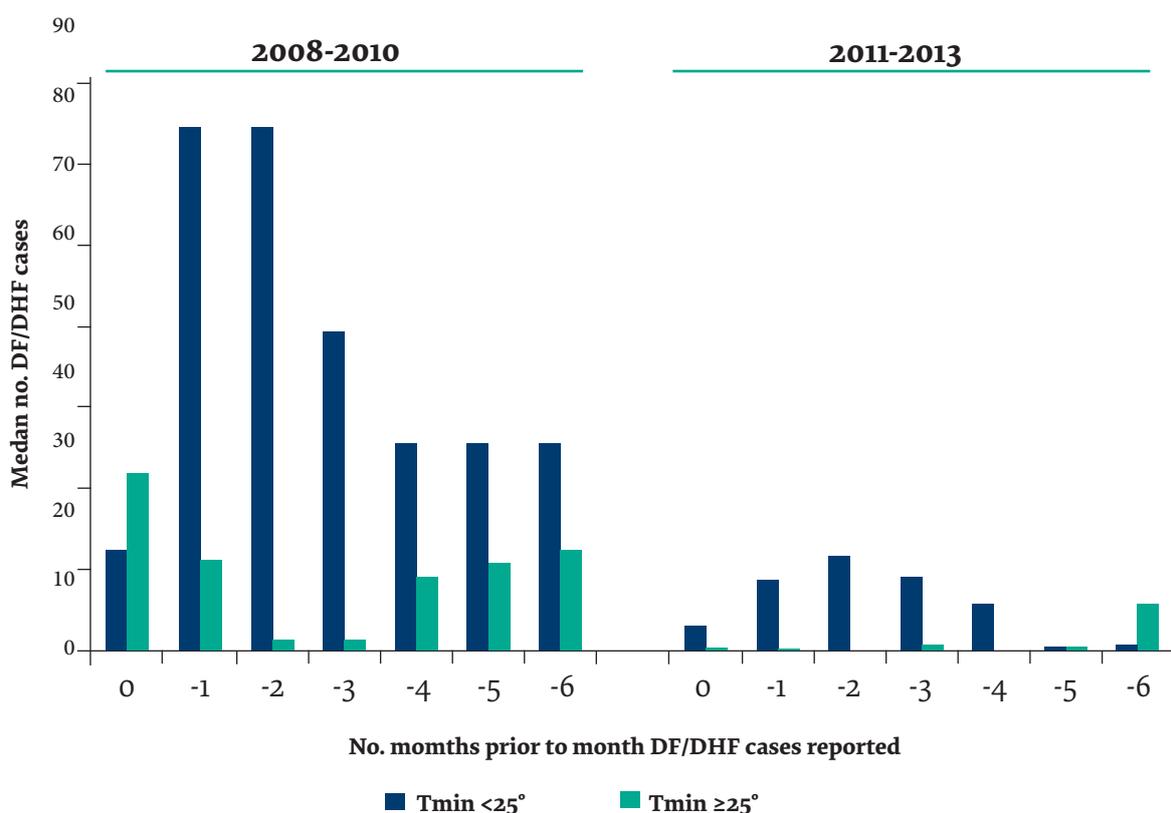
This is in accordance with the work of Depradine and Lovell (30), who found a 4-month time lag between maximum temperature and dengue incidence. Moreover, the present study revealed that average maximum temperature < 35°C favoured high incidence of dengue in Port Sudan. Similar results of an association between temperature > 26°C and dengue risk have been reported (26).

Minimum temperature was significantly correlated with dengue at 1–4 months' lag time in 2008–2010. Several researchers found a similar association with slight differences. For example, Depradine and Lovell (30) reported a 3-month lag time between minimum temperature and dengue incidence, and Gomes et al. (31) reported a 1-month lag. Honório et al. (32) found a positive effect of air temperature of 22–24°C on the development of *A. aegypti* but no effect was evident above 24°C in Rio de Janeiro, Brazil.

The general trends in our study seem to be that higher relative humidity at 3–5 months prior to the reporting month for dengue fever, and then lower or more moderate minimum and maximum temperatures 2–4 months before are related to large increases in the number of dengue fever cases. This is in line with the findings of Chen et al. (33), who suggested that warmer temperature at 3-months' lag, and high humidity with high mosquito population increased the rate of transmission of dengue fever in Southern Taiwan.

Although our multiple linear regression showed that the primary factor involved with dengue fever

Figure 4 Number of dengue fever/dengue haemorrhagic fever cases according to minimum temperature and number of months prior to reporting

incidence was relative humidity, it seems that relative humidity is closely linked to moderate temperatures. Moderate temperatures allow for higher relative humidity and thus optimum conditions for *Ae. aegypti* to reproduce. Valsson and Bharat (*34*) argued that there is a negative correlation between temperature and relative humidity. Therefore, the relationship between relative humidity and minimum/maximum temperatures is not necessarily one of confounding, but that minimum/maximum temperatures are precursors to, or preservers of, the level of relative humidity.

The time lag seems to suggest that it takes a few months of favourable climatic conditions to build up a large enough mosquito population that a sufficient number of people would be exposed to dengue virus. This could happen through the effect of these climatic factors on the life cycle of the dengue virus and its vector. Climatic factors influence all the developmental stages of the mosquito until it becomes an adult, then they affect virus replication and its incubation period inside the mosquito (the extrinsic incubation period) and humans (intrinsic incubation period). The latter might culminate in dengue outbreaks that may in turn be represented by a cumulative time lag (*29,35*).

The lag between climatic factors data and dengue incidence data differs depending on the corresponding lag between mosquito life stage and the expression of clinical symptoms. In the case of minimum temperature, this lag is expected to be shorter because minimum

temperature is often associated with mortality in adult mosquitoes, and longer in case of high relative humidity, which influences the hatching and survival of adult mosquitoes. Mean temperature is usually associated with all biological cycles of the vector *Ae. aegypti*, which take more time to affect the incidence of dengue (*35*). These patterns were observed in the present study.

The present study had some limitations. The cutoffs used for some of the analyses were based on visual inspection of the scatterplots. It would be beneficial to assess whether the findings of the present study could be replicated in another dataset based on a climate similar to that of Port Sudan City. In most low-income countries, dengue cases are often under- or over-reported. Moreover, those reported dengue cases might be affected by documentation of subclinical cases, public health systems availability, and case definition. Based on this, the aforementioned factors should be considered prior to identifying any associations between dengue transmission and climatic factors. Finally, this ecological analysis did not consider socioeconomic or other factors that may influence DF incidence; therefore, this study could not examine their role relative to that of climatic factors.

Conclusion

Among other factors, dengue transmission in Port Sudan appears sensitive to variability in climate. Other factors

may include, but are not limited to, human population level, mobility, socioeconomic status, population's immune status, and human–mosquito interaction. Increasing urbanization around Port Sudan has led to a rise in population. This suggests continued likelihood of dengue fever outbreaks and the need to develop prevention and control mechanisms. As a port, dengue outbreaks in Port Sudan may represent dangers to surrounding cities, or of transporting dengue to other locations via ships. It is important to elucidate the role of climatic factors in dengue transmission because it helps in risk assessment of epidemics and facilitates preventive actions. This is especially relevant given that time lags of 2–5 months were identified, which allows for adequate planning. Future studies should integrate the analysis of climatic and nonclimatic factors that maintain a sustainable viral circulation, such as human population size, human renewal rate, household infestation, and ratio of mosquito vectors per person.

The results of this study should help to strengthen dengue surveillance and control programs in Port Sudan City, and to establish climate-based outbreak alert and early warning systems for dengue in the city and Sudan as a whole. Health authorities can synchronize efforts across meteorological departments, research institutions, and national surveillance systems to develop and integrate a climate-based dengue forecasting system.

Rôle des facteurs climatiques dans l'incidence de la dengue dans la ville de Port Soudan, Soudan

Résumé

Contexte : Des flambées de dengue sont survenues dans la ville de Port Soudan (Soudan) au cours des deux dernières décennies. Les facteurs climatiques peuvent jouer un rôle dans l'incidence de cette maladie.

Objectif : La présente étude avait pour objectif de décrire la relation entre les facteurs climatiques et l'incidence de la dengue à Port Soudan au cours de la période 2008-2013.

Méthodes : La présente étude écologique comprenait l'analyse de données secondaires sur les cas de dengue et des informations climatiques afin d'étudier les facteurs climatiques qui permettent de prévoir l'incidence de la dengue. Le test de la somme des rangs de Wilcoxon et la régression linéaire multiple ont permis d'examiner l'association entre le nombre de cas de dengue et les facteurs climatiques pendant des périodes de 1 à 6 mois.

Résultats : L'humidité relative et les températures maximales et minimales ont été corrélées avec l'incidence de la dengue à Port Soudan à différents intervalles de temps au cours de la période 2008-2010. Les précipitations et l'humidité relative ont été corrélées avec la dengue au cours de la période 2011-2013. Cependant, l'effet différé de l'humidité relative 3 à 5 mois plus tard était la variable explicative la plus forte pour l'incidence de la dengue.

Conclusion : La transmission de la dengue semble sensible à la variabilité climatique. L'élucidation du rôle des facteurs climatiques dans la dengue contribue à l'évaluation des risques et à la prévention des épidémies.

دور العوامل المناخية في الإصابة بحمى الضنك في مدينة بورتسودان في السودان

الصديق نور الدين، لين شافر

الخلاصة

الخلفية: حدثت أوبئة حمى الضنك في مدينة بورتسودان بالسودان خلال العقدين الأخيرين. وربما يكون للعوامل المناخية دور في الإصابة بحمى الضنك.

الأهداف: هدفت هذه الدراسة إلى وصف العلاقة بين العوامل المناخية ومعدلات الإصابة بحمى الضنك في مدينة بورتسودان خلال الفترة من ٢٠٠٨ إلى ٢٠١٣.

طرق البحث: تطلبت هذه الدراسة البيئية تحليل بيانات ثانوية عن حالات حمى الضنك، ومعلومات مناخية لاستكشاف العوامل المناخية التي تتنبأ بالإصابة بحمى الضنك. ونظر "اختبار ويلكوكسُن للمَرْتَبة والمجموع" والانحدار الخطي المتعدد في العلاقة بين عدد حالات حمى الضنك والعوامل المناخية خلال فارق زمني يتراوح من شهر إلى ٦ أشهر.

النتائج: وجد ارتباط بين الرطوبة النسبية ودرجات الحرارة القصوى والدنيا من جهة، ومعدلات الإصابة بحمى الضنك في بورتسودان من جهة أخرى في فترات زمنية مختلفة خلال الفترة من ٢٠٠٨ إلى ٢٠١٠. كما وجد ارتباط بين هطول الأمطار والرطوبة النسبية من جهة والإصابة بحمى الضنك من جهة أخرى خلال الفترة من ٢٠١١ إلى ٢٠١٣. ومع ذلك، كانت الرطوبة النسبية المتأخرة لمدة تتراوح من ٣ إلى ٥ أشهر أقوى متغير تفسيري لمعدلات الإصابة بحمى الضنك.

الاستنتاج: يبدو أن انتقال عدوى حمى الضنك يتأثر بتقلب المناخ. ويساعد توضيح دور العوامل المناخية في الإصابة بحمى الضنك على تقدير المخاطر والوقاية من الأوبئة.

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