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Modelling the association of dengue fever cases with temperature and relative humidity in Jeddah, Saudi Arabia—A generalised linear model with break-point analysis

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ABSTRACT

The aim of this study was to examine the role of environmental factors in the temporal distribution of dengue fever in Jeddah, Saudi Arabia. The relationship between dengue fever cases and climatic factors such as relative humidity and temperature was investigated during 2006–2009 to determine whether there is any relationship between dengue fever cases and climatic parameters in Jeddah City, Saudi Arabia. A generalised linear model (GLM) with a break-point was used to determine how different levels of temperature and relative humidity affected the distribution of the number of cases of dengue fever. Break-point analysis was performed to modelled the effect before and after a break-point (change point) in the explanatory parameters under various scenarios. Akaike information criterion (*AIC*) and cross validation (CV) were used to assess the performance of the models. The results showed that maximum temperature and mean relative humidity are most probably the better predictors of the number of dengue fever cases in Jeddah. In this study three scenarios were modelled: no time lag, 1-week lag and 2-weeks lag. Among these scenarios, the 1-week lag model using mean relative humidity as an explanatory variable showed better performance. This study showed a clear relationship between the meteorological variables and the number of dengue fever cases in Jeddah. The results also demonstrated that meteorological variables can be successfully used to estimate the number of dengue fever cases for a given period of time. Break-point analysis provides further insight into the association between meteorological parameters and dengue fever cases by dividing the meteorological parameters into certain break-points.

1. Introduction

There have been very few published environmental studies related to dengue fever conducted in Jeddah (Al-Ghamdi and Mahyoub, 2010). This study will attempt to compensate for the lack of studies done on environmental conditions which contribute to dengue fever. The ecology, development, behaviour and survival of mosquitoes as well as the transmission of diseases are all greatly influenced by climactic conditions. Even though temperature, rainfall and relative humidity are important, factors such as wind and the amount of sunlight can also be substantial contributors to the number of dengue cases (Reiter, 2001). In addition to climatic factors already mentioned, seasonality must also be considered (Reiter, 2001). Due to their significance, climatic factors are investigated in this study in relation to the occurrence of dengue fever in Jeddah. These factors include rainfall, rainy days, relative humidity and temperature variation (Jansen and Beebe, 2010). They cannot be considered independently but rather as a group which has a cumulative influence upon disease transmission (Jansen and Beebe, 2010). The transmission of dengue viruses is climatically sensitive for many reasons. For example, temperatures affect the reproduction, the biting activity and the distribution of the *A. aegypti* (Promprou et al., 2005). Rainfall also has an impact on the population density of female mosquitoes. The more it rains, the more breeding sites are available for the *A. aegypti* and thus the number of mosquitoes increases (Promprou et al., 2005). Furthermore, there is a distinct seasonal pattern in the outbreaks of dengue viruses which is evident in many places around the world (Promprou et al., 2005). During rainy seasons, there is an increase in dengue haemorrhagic fever hospitalisation rates which, in turn, decreases months after the end of these seasons (Eamchan et al., 1989; Gratz, 1993). It is important to note that it is not only climatic factors that determine the distribution of the *A. aegypti*, there is also a close relationship between the mosquito, its environment and human behaviour such as urbanisation, socioeconomic factors,

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building design and construction features, as well as the quality of water supply and management (Monath, 1994; Reiter, 2001).

Temperature is a crucial variable affecting the occurrence of dengue fever. First, warmer temperatures can increase the transmission rates of dengue in many ways (Promprou et al., 2005). These allow vectors to have a higher survival rate and mature much faster than they do at lower temperatures (Lindsay and Mackenzie, 1997). Laboratory experiments show that *A. aegypti* larvae can survive until water temperatures reach 34 °C, and then they begin to die when the temperature goes above that. Adults can survive until 40 °C in air temperature (Christophers, 1960). Secondly, warmer temperatures may decrease the size of mosquito larvae resulting in smaller adults that have high metabolism rates (Barbazan et al., 2002; Jetten and Focks, 1997; Mcmichael et al., 1996). Because of this high metabolic rate, the *A. aegypti* need to feed more frequently on blood and to lay eggs more often (Barbazan et al., 2002; Jetten and Focks, 1997; Mcmichael et al., 1996). Lastly, environmental temperatures have a noticeable effect on the length of the extrinsic incubation periods (EIPs) of arboviruses, viruses caused by arthropods, in their vectors which mean that the higher the temperatures the mosquitoes are exposed to after ingesting viruses, the more infectious the mosquito becomes (Lindsay and Mackenzie, 1997; Mcmichael et al., 1996). The (EIP), however, is decreased at higher temperatures (Harrington et al., 2001; Joseph, 2001; Watts et al., 1987). At 30 °C the duration of dengue viruses EIPs is 12 days, whereas in temperatures of 32 °C–35 °C, the EIP is only seven days (Focks et al., 1995).

The research has shown that the (EIP) period and viral development rate can be shortened with higher temperatures and this results in an increase in the number of infection carrying mosquitoes at a given time (Watts et al., 1987). Due to the worldwide increase in temperatures in recent times, these vectors might be able to survive over "winter" in previously non-endemic areas or increase the transmission rates in endemic regions and change the transmission period (Wu et al., 2007). In many regions minimum temperatures seem to be the most critical factor for the threshold of mosquito survival and also in limiting the rate of development to maintain the population density (Gubler et al., 2001). Feeding rates are also lowered reducing the chance for host contact by the mosquitoes and gradually reducing the rate of viral transmission (Gubler et al., 2001). A study showed that *A. aegypti* stops feeding when the ambient temperature is lower than 17 °C (Reed et al., 2001). The minimum temperature threshold temperature for dengue fever virus survival is 11.9 °C (Mccarthy et al., 2001). The virus is weak in the vector when the temperature is below 18 °C (Watts et al., 1987). Therefore, there were lower rates of dengue virus infection in the winter and in months with relatively lower temperature (Wu et al., 2007). When the monthly minimum temperature increases, however, the incidence rate of dengue fever also increases because the environmental conditions favour vector proliferation, virus replication and increased mosquito feeding frequencies (Wu et al., 2007). So, while temperature does influence larval development time and the survival rate of *A. aegypti*, temperature alone is not always a useful predictor for the spread of dengue fever (Christophers, 1960; Kamimura et al., 2002; Rueda et al., 1990). Relative humidity and rainfall also impact on mosquito survival and ecology (Jansen and Beebe, 2010).

Relative humidity is an important factor affecting the life cycle of mosquitoes, particularly mating patterns and egg lying (Wu et al., 2007). Studies have shown that heat and moisture together can greatly influence the feeding patterns of mosquitoes and how they attract each other (Mcmichael et al., 1996; Rowley and Graham, 1968; Thu et al., 1998). In addition, increasing relative humidity usually increases the vector survival rate which results in prolonging the time that they are able to feed on an infective host (Mcmichael et al., 1996; Rowley and Graham, 1968; Thu et al., 1998). Meanwhile, adult survival can be negatively affected under lower relative humidity conditions and the proportion of the vector population that survives the EIP may be decreased (Christophers, 1960). Relative humidity has an impact on longevity, mating, dispersal, and on the feeding and egg laying behaviour of mosquitoes as well as the rapid duplication of dengue fever (Hales et al., 1999; Mcmichael et al., 1996; Mellor and Leake, 2000). Mosquitoes live longer and disperse further under high relative humidity conditions (Promprou et al., 2005). As a result, they have a greater chance of feeding on infected people and surviving long enough to transmit dengue fever to other people (Promprou et al., 2005). Relative humidity can also affect the evaporation rates of vector breeding sites. There can be a disparity in the transmission of dengue fever depending on the location and this may be due to the differences in climatic variables (Promprou et al., 2005).

In addition to relative humidity, rainfall also affects the mosquito population and is an important factor in the transmission of dengue fever. Heavy rainfall and flooding can lead to outbreaks of dengue by allowing vector mosquitoes to have a higher rate of breeding (Lindsay and Mackenzie, 1997). In some cases, increased rainfall may increase larval habitat and vector population by creating a new habitat (Gubler et al., 2001; Kelly-Hope et al., 2004; Woodruff et al., 2002). The pattern of rainfall is important in terms of having an effect on the amount of mosquitoes present. Very heavy rains can flush the mosquito larvae away from breeding sites or simply destroy them. Lighter rain can replenish existing breeding sites and maintain higher levels of relative humidity (Mcmichael et al., 1996). In dry seasons with limited rainfall, mosquito habitats are created when rivers dry up leaving pools of water which provide suitable breeding sites. This favours the transmission of dengue (Gubler et al., 2001). Moreover, it is also plausible that man-made water containers such as abandoned tyres and trash water containers may not always have an effect on the transmission of dengue fever (Wu et al., 2007). Domestic water storage habits in some areas, however, can directly influence the availability of larval rearing sites (Jansen and Beebe, 2010). For instance, in regions storing water in response to expected periods of drought or low rainfall the number of productive larval sites can increase if measures are not taken to eliminate this risk. As a result, insufficient rain can lead to elevated *A. aegypti* densities (Jansen and Beebe, 2010).

Jeddah is considered to have a warm climate like many other cities in Saudi Arabia (Kalid et al., 2008). In 2009 there was a low amount of rain, with the maximum rain being 70 mm in week 48 in the winter (Presidency of Meteorology and Environment, 2011). From 2006–2009 the total amount of rain per week in Jeddah did not exceed 14 mm (Presidency of Meteorology and Environment, 2011). Due to its coastal location, Jeddah often has high relative humidity on most days of the year, especially in summer (Kalid et al., 2008). The maximum relative humidity can be over 95%. The relative humidity in winter remains quite low at 15%. These conditions play a significant role on the population density of mosquitoes (Kalid et al., 2008). Maximum temperature in Jeddah summer is about 42.8 °C. This could means that the number of dengue cases decreased due to temperatures being over 40 °C.

Dengue fever in Saudi Arabia is generally found in Jeddah city that has the highest concentration of documented cases. The aim of this study is to investigate the role of environmental factors in the temporal distribution of dengue fever in Jeddah, Saudi Arabia. It will investigate the relationship between dengue fever cases and the environmental conditions in Jeddah City to find if there is any relationship between dengue fever cases and climate in Jeddah City, what is the nature of this relationship, and how it can be best modelled.