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Dengue fever Outburst and its Relationship with Climatic Factors

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Abstract: This study aims to address the effects of climatic factors (temperature, relative humidity and rainfall) on *Aedes aegypti* mosquito density (hereinafter called mosquito density) in the Jeddah city, Saudi Arabia. Data for climatic factors, mosquito density and dengue fever cases for the years 2004 to 2011 were collected for the study period. Descriptive and bivariate statistical analyses were conducted to determine the relationship between the climatic factors and mosquito density and also between mosquito density and dengue fever cases in the city. The results show that the there is a strong correlation between mosquito density and climatic factors of temperature and relative humidity. The results also show a strong correlation between mosquito density and dengue fever cases in the city of Jeddah. The study shows a decrease in the mosquito density and thereby the dengue fever cases in Jeddah during the last couple of years. The results of the research are discussed with conclusions and recommendations.

Key words: Dengue fever · Mosquito density · Climatic factors · Jeddah · Saudi Arabia

INTRODUCTION

The number of dengue fever cases has been continuously increasing particularly in tropical regions. For example, in the year 2007, approximately 25,000 people were affected with dengue fever in Cambodia, 100,000 people in Indonesia and an increase of 50 percent was reported in Malaysia [1]. It is estimated that approximately 2.5 billion people will be at a risk of becoming infected with dengue fever in future [2]. Dengue fever poses the highest mortality threat due to viral infection in more than half of the world [3-5]. It is one the most significant mosquito borne viral disease found in humans and is a leading cause of childhood mortality in many countries of the world. Genetic evidence from strain studies suggest that the four viral types of dengue fever were independently brought into the urban cycle within the past 1000 years [6]. Dengue fever was first reported in Jeddah city of Kingdom of Saudi Arabia in 1994 and since then the disease has shown a varying degree of fluctuation over the time [7]. However, in the last few years the dengue fever cases has been increasing in the Jeddah city. The population of Jeddah is currently 4.5 million and is increasing annually by 8-10% [7]. It has been estimated that outbreaks in urban areas may affect approximately 70-80 percent population of the city in future [8]. This makes vector surveillance an important tool in formulating control strategies for reducing the spread of dengue fever in the city.

Many factors have been identified in the spread of mosquito density and their consequent dengue fever cases in a region. For example, the flight dispersal of the *Aedes aegypti* mosquito is an important factor in controlling the spread of dengue fever [9]. Various studies have shown different ranges of *Aedes aegypti* mosquito for flight distances. For example, [10] captured the mosquitoes at a distance of approximately 800 meters from the point of their release in Kenya. Similarly, Bugher and Taylor (1949) recorded the maximum distance of 1160 m in four releases from a specific point in Nigeria [11]. Morlan and Hayes (1958) reported that in the time duration of 24 hours, out of 5115 females which were released from Savannah approximately 93% were captured within 23 meters of their release point, while 1% were captured within a range of 54 to 87 meters from the release point [12]. Flight dispersal experiments conducted in an urban environment found that 60% of the females released were trapped outdoors, and the capturing process started after only half of the mosquitoes were released [9]. These data on the flight dispersal of mosquitoes are important when

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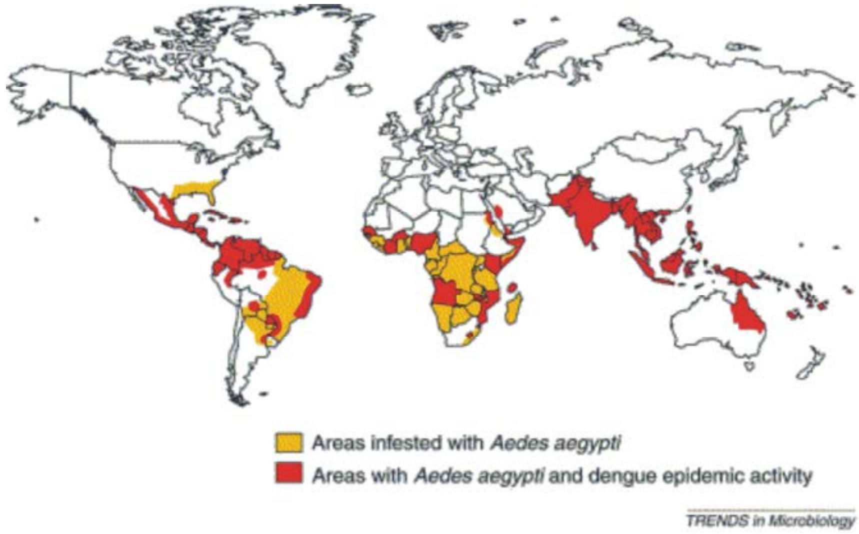

Fig. 1: World distribution of the *Aedes aegypti* mosquito in the year 2001 (after Gubler 2002).

considering control activities. For example, if there is an identified mosquito problem in a community, attempts can be made to control them by taking into consideration the types of breeding sites in the area and the distance of these breeding sites to homes or places where urban society lives and have recursion activities [9]. This information could be very helpful when developing surveillance activities that use chemicals or insecticides as a method for eradicating the mosquito population. Hales *et al.,* (2002) describe the most efficient way of reducing the population of the mosquitoes that carry dengue fever is to remove the breeding sites and control the factors that are responsible for the increase in breeding activity [13-16].

Similarly, climatic factors help the replication and the movement of the disease agent and vector [17]. In addition, climate changes may also be important factor in expanded geographical ranges for dengue fever cases [18-23]. Many studies indicate that as the temperature of a region increases, the geographical range of mosquitoes increases to higher altitudes [24]. This has been observed in several places; for example, in Columbia, the *Aedes aegypti* mosquito's altitudinal range has increased from 1500 m to 2200 m [14, 25]. Climatic conditions strongly control the geographic distribution and abundance of *Aedes aegypti* [26, 27]. The distribution of the *Aedes aegypti* mosquito worldwide is presented in Figure 1.

Various researchers have shown that the environmental conditions strongly control the density and distribution of *Aedes aegypti,* mosquito [26-33]. Similarly, many researchers have studied the relationship between climatic factors and the biology of the *Aedes aegypti* mosquito and concluded that the temperature, humidity and rainfall significantly influence the mosquito density, their life-cycle, breeding habitats, survival and dengue viral development [9, 13, 28, 34-41]. Therefore, it is important to understand the relationship between dengue fever cases, mosquito density and changes in climate conditions. This will assist in developing mosquito reduction strategies to decrease dengue fever as a public health issue in Jeddah city.

The climatic conditions of Jeddah city play an important role in the multiplication of the *Aedes* mosquito and the transmission of dengue fever. It is important to note that there is an association between climatic factors and the spread of the dengue fever virus. However, the relationship between climatic factors and the *Aedes aegypti* mosquito is not clearly understood and thus there is a need to further explore this relationship. The relevancy of different climatic factors is certainly important to track the dengue fever transmission procedures. This study is designed to evaluate the relative effects of three climatic factors, those are, temperature, humidity and rainfall on mosquito density and their consequent dengue fever cases in the Jeddah city.

MATERIALS AND METHODS

Study Area: The study area adapted from the Google Earth Image is shown in Figure 2. The city has variety of land features such as constructed areas, coastal lines, bare sand, soil and road networks. Many factors have significant effects on the mosquito density its distribution

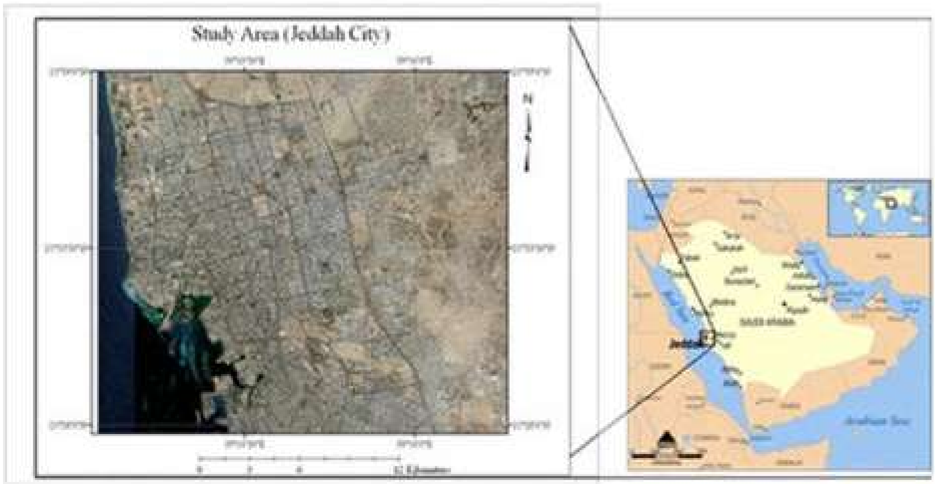

Fig. 2: Satellite image of the study area.

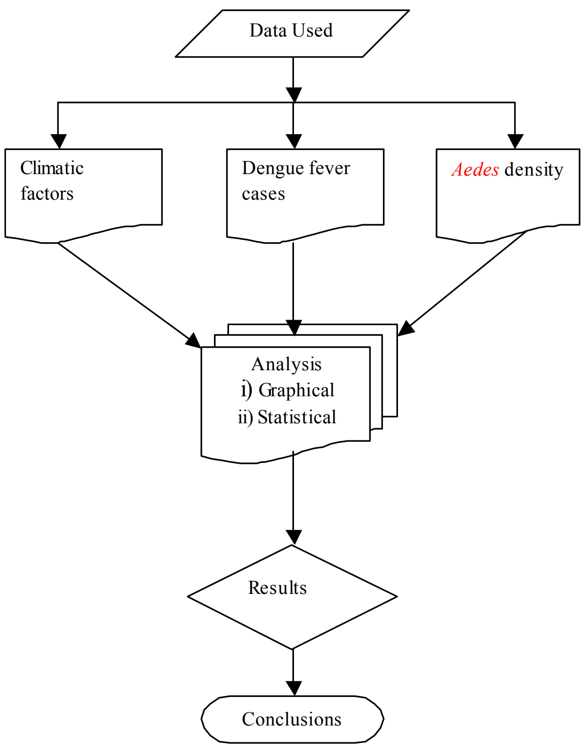

Fig. 3: Conceptual framework of the relationship between climatic conditions, *Aedes* density and dengue fever cases.

and consequent dengue fever spread in the city. These factors include high humidity, air temperatures, building constructions, overflowing sewers, and uncovered domestic water storage tanks. Although the rainfall in Jeddah city is considerably low (6 mm), relatively high temperatures (25-40°C) and high relative humidity (55%) play an important role in the increase of mosquito density in the region [42-44]. In addition, most of the residential areas exist near the coast, which is the main reason for the higher level of humidity in the city. A collection of the *Aedes* mosquito has been taken as a sample while the extent of the area from which the mosquitoes were collected is very wide.

The conceptual framework in this research is presented in Figure 3. The data were collected for the dengue fever cases, mosquito density, temperature, relative humidity and rainfall. The data were recorded daily and were compiled monthly and annually. The data were analyzed on annual basis. The mosquito population density was recorded through mosquito surveillance. A thorough sampling strategy was carried out by installing light traps in various habitats of the city. Powered aspirators were also used to collect the mosquitoes from their resting areas. The same sites were chosen where the light traps were installed, and the numbers of mosquito collected were considered to the number of mosquitoes collected through the light traps. The trapping of adult mosquitoes provide the information on the relative population size.

The black hole light traps were used to maintain the uniformity in the data collection. The black hole light trap was chosen due to a number of reasons. For example, it generates a small amount of carbon dioxide which makes it highly attractive to mosquitoes while does not make intrusive zapping sounds. Similarly, it is easy to install, cost effective and does not create unpleasant smells as compared with the 'zapper' type traps [45]. The female *Aedes aegypti* mosquito requires a meal of blood before fertilization. To find this blood meal, the mosquito is influenced by stimuli including scene, temperature, moisture, color, movement and most significantly carbon dioxide. The carbon dioxide generated by the black hole light equipment attracts the female mosquito and trap it with the help of strong ventilator through the inhaling fan. A total of fourteen sites were chosen to install the black hole light traps. The number of *Aedes* mosquito females per night per week were counted and standardized.

Meteorological data of various weather parameters were collected from the records of the National Meteorology and Environment Center and from the Surface Monthly Climatological Report, Jeddah. The climatic variables include temperature, humidity and rainfall from the year 2004 to 2011. Temperature was measured in degrees Celsius and is defined as mean average of maximum and minimum temperature. Relative humidity is the average monthly humidity based on daily records and is expressed as the percentage. Rainfall, measured in millimeters, is the amount of rainfall in a month. Similarly, the data for dengue fever cases in the Jeddah city were obtained from Ministry of Health office.

Data were analyzed to find the relationship between mosquito densities and climatic factors and also between mosquito density and dengue fever cases using Pearson correlation and multiple regression techniques. A descriptive analysis was conducted to determine the trends in the number of reported dengue fever cases and the mosquito density for the study period. Similarly, the relationship between the climatic factors (temperature, relative humidity and rainfall) and mosquito density were analyzed.

RESULTS AND DISCUSSIONS

The reported number of dengue fever cases and mosquitoes trapped for the study period (2004 to 2008) in Jeddah city are given in Table 1. It is evident from Table 1 that the total dengue fever cases (mosquito density) for the years 2004, 2005, 2006, 2007 and 2008 are 1307 (15241), 801 (11746), 301 (10604), 286 (9009) and 233 (7706), respectively. The data show that the mosquito density and dengue fever cases has a decreasing trend in the city during the study period (2004-2008) which is due to the certain administrative plans by the local administration. Similarly, the mosquito density and dengue fever cases in relation to the climatic factors of temperature, relative humidity and rainfall for the years 2004, 2005, 2006, 2007 and 2008 are shown in Figures 4 (a, b), 5 (a, b), 6 (a, b), 7 (a, b) and 8 (a, b), respectively. It is evident from these Figures that in Jeddah the average monthly temperature has an increasing trend for the months of May, June July, August and September whilst a decreasing trend for the months of October, November, December, January, February and March for the study period. It is also evident from Figures 4a, 5a, 6a, 7a and 8a that the mosquito density is highest during November, December, January and February. These results are a clear indication that the temperature range in the city (ranging from 20°C to 29°C) favour the increase in population of the mosquito density in the study area. Hopp and Foley (2003) and Tun-Lin *et al.*, (2000) have reported that the high temperatures accelarates mosquito development and increases their abundance [30, 46]. During summer months the average monthly high temperature in the city of Jeddah is more than 40°C which is not suitable for rapid mosquito growth. This agrees well with the findigs of McMichael *et al.*, (1996), which indicated that favourable temperature for mosquito growth is between 25°C to 27°C and should not exceed 40°C [14]. The current study shows that during the winter months the average monthly temperature ranges between 20°C to 29°C in Jeddah city is ideal for the increase in the mosquito population.

Table 1: Reported dengue fever cases and mosquito density in Jeddah from 2004 to 2008

	Reported dengue fever cases											
Year	January	February	March	April	May	June	July	August	September	October	November	December
2004	29	13	81	128	302	189	344	166	7	23	9	16
2005	37	40	42	65	158	192	132	59	50	5	8	13
2006	11	4	7	8	23	73	75	52	12	18	12	6
2007	3	3	5	35	38	55	54	31	27	20	14	1
2008	19	5	3	34	20	32	42	15	19	19	15	10
Mosquito density (number of *Aedes aegypti* mosquito)												
2004	2377	1091	914	943	799	712	763	462	914	1300	1348	3618
2005	1502	1109	1089	890	812	745	867	713	669	994	1034	1322
2006	1437	930	670	814	782	651	816	530	780	984	1006	1204
2007	1263	811	471	481	679	604	302	483	667	753	1237	1258
2008	2217	754	639	467	409	552	422	221	105	206	783	931

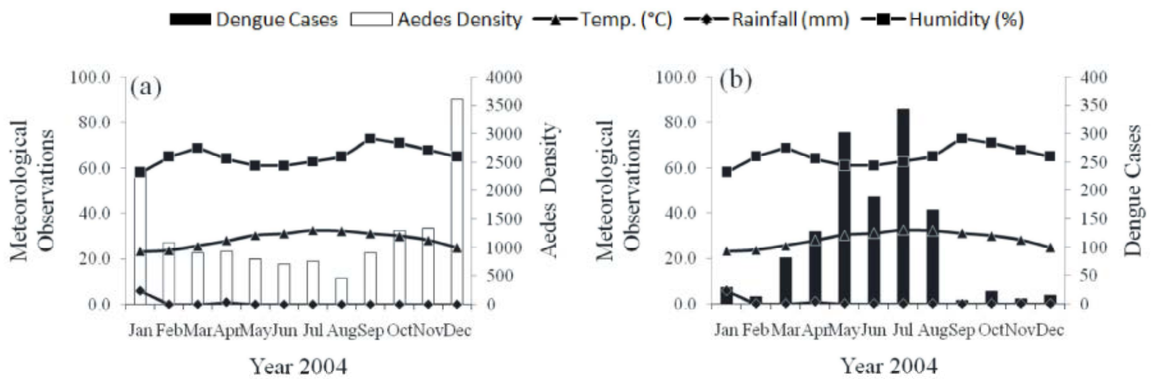

Fig. 4: The relationship between climate factors and (a) mosquito density, (b) dengue fever cases for the year 2004.

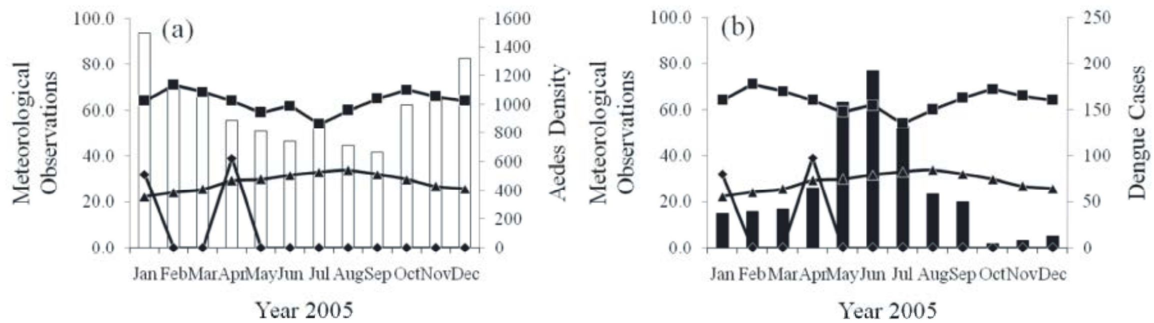

Fig. 5: The relationship between climate factors and (a) mosquito density, (b) dengue fever cases for the year 2005.

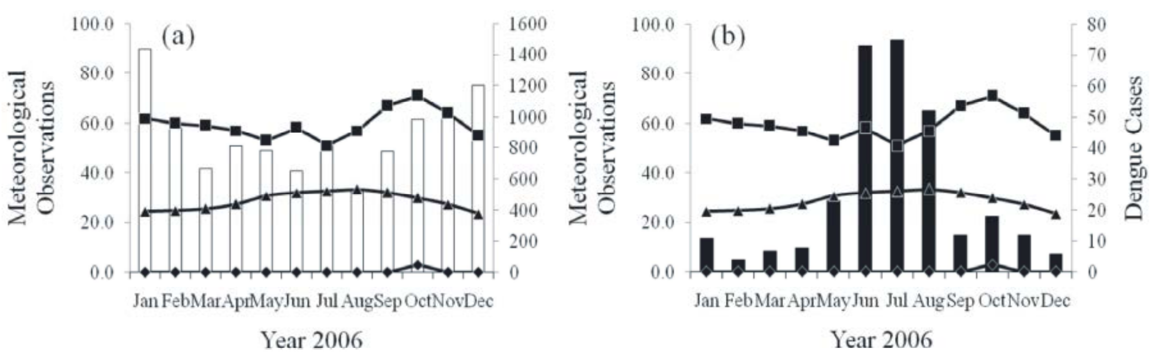

Fig. 6: The relationship between climate factors and (a) mosquito density, (b) dengue fever cases for the year 2006.

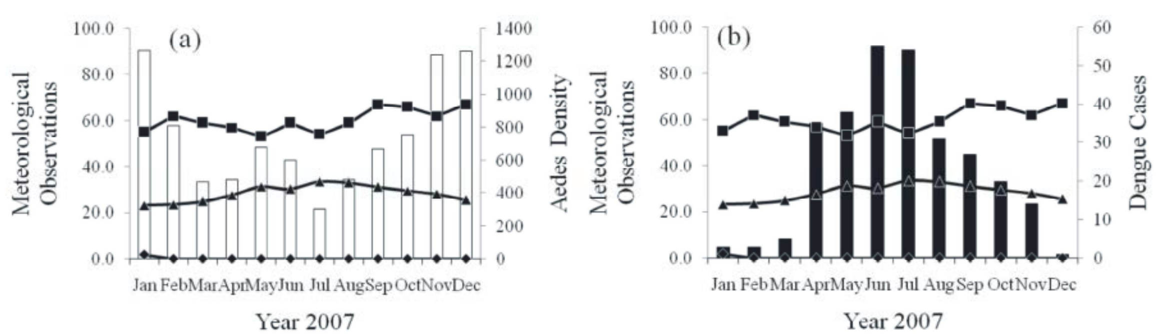

Fig. 7: The relationship between climate factors and (a) mosquito density, (b) dengue fever cases for the year 2007.

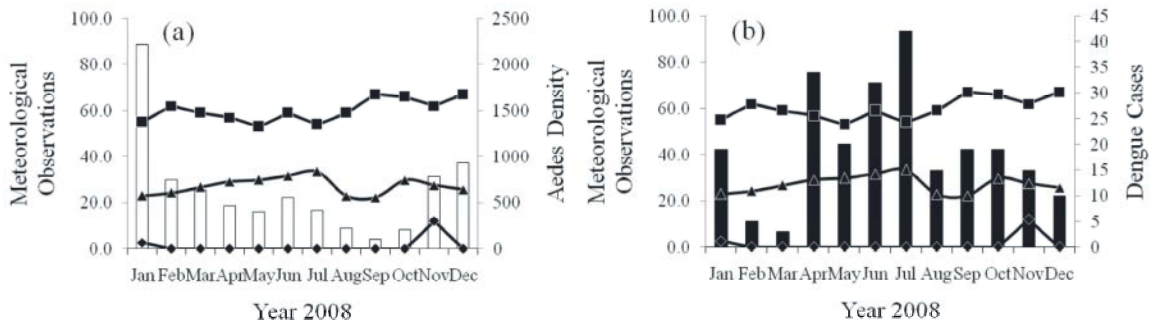

Fig. 8: The relationship between climate factors and (a) mosquito density, (b) dengue fever cases for the year 2008.

However, the effect of temperature on the mosquito survival rate is not easy to predict [47].

The results of the current research also show (Figures 4a, 5a, 6a, 7a and 8a) that the average relative humidity in the Jeddah city for the study years is significant for the increase in the mosquito density. Several studies have indicated that the relative humidity is strongly related to hatching and the activities of mosquitoes [24, 35, 48, 49]. Hopp and Foley (2001) found that modulated egg and larvae indices sharply increased during summer months when temperature and humidity are high [24]. In addition, the survival rate for the mosquito is also greater at higher humidity [47]. Hales *et al.,* (2002) showed that high relative humidity positively influences the survival and density of mosquitoes [13]. Favier *et al.,* (2006) found that there is a relationship between relative humidity and mosquito density [31]. Since Jeddah is a coastal city, it would be expected that relative humidity will be high for most days of the year, thus an important factor on mosquito density and dengue transmission. In current study, no significant influence of rainfall is visible (Figures 4a, 5a, 6a, 7a and 8a) on mosquito density as the average annual rainfall in the study area is only 5 mm. However, the light rainfall may influence mosquito density either by providing small fresh water resevoirs or by increasing humidity following evaporation of the remaining surface water resources. Many researchers have concluded that heavy rainfalls may not favour mosquito density as most of the mosquito eggs and larvae washed away from breeding sites. Russell *et al.,* (2009) indicated that rainfall has no significant influence on mosquito density [50]. In Jeddah, as average rainfall is very minimal thereby has negligible direct effect on mosquito density.

In present study, the relationship between climatic factors and dengue fever cases were also established. It is evident from Figures 4b, 5b, 6b, 7b and 8b that except rainfall the remaining two climate parameters (temperature and humidity) has significant effect on dengue fever cases in Jeddah. This is mainly because of the fact that the annual rainfall is negligible in each of the studied years. Dibo *et al.,* (2008) stated that only the climatic variations alone cannot explain the mosquito density and dengue distribution [36]. Abundant breeding sites and human shelters with plenty of available food are some of the other factors which may be responsible for the prevalence of dengue fever virus in the study area. Some studies have found a significant correlation between the climatic variables and the number of dengue cases. Chowell and Sanchez (2006) showed that while precipitation, mean temperature and minimum temperature had their highest correlation with dengue incidence without a lag period, maximum temperature and evaporation were mostly correlated with dengue fever incidence with a lag of one and three months [51]. The significant positive correlation of temperature and rainfall with dengue cases has been reported in other studies as well [35, 52-54].

Similarly, the statistical analyses performed between mosquito density and dengue fever with climatic factors are given in Table 2. It is evident from Table 2 that the mosquito density has a moderate (except for the year 2006) positive correlation with rainfall, while a little (except in 2005 and 2007) positive (except in 2004 and 2008) correlation with humidity. However, the correlation (negative) between mosquito density and temperature is very strong (highest in 2005 and lowest in 2008). These results are in accordance with the findings of other researchers. Depradine and Lovell (2004) showed that the increase in minimum temperature has stronger effect on mosquito density than the maximum temperature [55]. In addition they also found that higher water vapour pressure facilitates greater mosquito activity than relative humidity. On the other hand, it is also evident from Table 2 that dengue fever has a little (except for the year 2007) negative correlation with rainfall, while

Table 2: Correlation coefficient between mosquito density and dengue fever with climatic factors

Correlation	2004	2005	2006	2007	2008
Mosquito density and Rainfall	0.38	0.35	0.13	0.48	0.28
Mosquito density and Humidity	-0.14	0.37	0.23	0.35	-0.26
Mosquito density and temperature	-0.64	-0.90	-0.68	-0.59	-0.30
Dengue fever and Rainfall	-0.20	-0.11	-0.09	-0.34	-0.12
Dengue fever and Humidity	-0.48	-0.66	-0.42	-0.43	-0.45
Dengue fever and temperature	0.61	0.50	0.74	0.83	0.66
Mosquito density and Dengue fever	-0.49	-0.53	-0.48	-0.67	-0.17

a moderate negative correlation with humidity. However, the correlation (positive) between dengue fever cases and temperature is very strong (highest in 2007 and lowest in 2005). Once again this agrees well with the findigs of other researchers. Rosa-Freitas *et al.,* (2006) suggested that temperature and relative humidity have some fluctuating effects on the dengue fever cases in a year [56]. Schultz (1993) and Chadee *et al.,* (2007) suggested no association between rainfall and dengue fever [53, 57], while Ram *et al.,* (1998) demonstrated the association of dengue fever with temperature and humidity [29].

Regression models were constructed both with and without log transformations to find out the indicator (climatic factors) for mosquito density and dengue fever cases. The results of the current study show that the three climate parameters accounted for 32% of the variance in dengue fever cases and 42%, if log transformation is used. On the other hand, the three parameters accounted for 24% of variance in mosquito density and 35%, when log transformation is used. Many researchers have studied the relationship between dengue fever and climate parameters and found that most of the mosquito borne diseases exhibits a distinctive seasonal pattern, and climatic factors affect both the vector and pathogens they transmit [58]. However, there are several other factors such as local infrastructure, water storage units, severage systems that can have a significant impact on the mosquito density and thereby the dengue fever cases. Thus, public awareness in terms of mosquito control programs, piped water that provide running water (thus eleminating the need for water storage) and screened windows can ensure epidemics remain a historical event [2, 59]. Yet, the results in the current study support the view that a few climatic variables can explain much of the seasonal fluctuations in both geographic range and population abundance.

CONCLUSION

The current study relate that the transmission of the dengue virus is climate sensitive due to a number of reasons. For example, the favourable temperature for mosquito growth may accelerate the metabolic process in the *Aedes* mosquito resulting in the increased biting rate and thereby more egg production and abundance of the adult population. In addition, the feasible temperature range may also results in escalating the number of flights and the distance for each flight that a mosquito can cover. Similarly, humidity contributes to the transmission of dengue fever by influencing the activities and survival of the mosquito vector. Low humidity causes mosquitoes to feed more frequently to compensate for dehydration, while high relative humidity increases the metabolic process in adult mosquitoes. Rainfall directly influences the density of the mosquitoes by increasing their breeding places as they may lay eggs in any open container having even a small quantity of water. However, strong rainfall causing floods may results in the disappearance of small ponds and thereby the feasible places for mosquito breeding. Hence, the impact of rainfall on mosquito growth and distribution should be viewed within the geographical location of the study area. For example, if the region under consideration is a plain area with appropriate and fully covered sanitation systems, mosquito breeding may be less while if the region is an area where water remains stagnant for days, the area would be more vulnerable to a rapid increase in mosquito population due to rain. In Saudi Arabia, rainfalls water is normally stored for several days in small ponds that are used for washing and drinking purposes and may utilized by mosquitos for breeding. In addition, rainfall increases the percentage of relative humidity and thereby the reproductive processes of the mosquito. A rise in temperature may evaporate small ponds and other places for mosquito breeding, thus reducing the growth of mosquitoes. However, the analyses suggest that mosquito density is unlikely to be attributed to high relative humidity. Some other factors also play their role in increasing the population of mosquito density in the region. Therefore, it is necessary to analyze the environmental factors wth mosquito population densities to better understand the cause of the spread of dengue fever.

Dengue fever activity is increasing in many parts of the tropical and subtropical world. In Saudi Arabia, apart from local factors, one of the major factor for dengue fever cases is during the pilgrimage seasons of Hajj and Umra. Thus, risk of increased dengue fever activity in Saudia Arabia is quite obvious. Hence, the disease may become more endemic despite a strong control program. At present, the most effective means of controlling the spread of dengue fever is to control the density and geographical distribution of the *Aedes* mosquito. Following recommentdations are made for the control of dengue fever cases in the study area;

- The trend towards specialization at the molecular level of dengue virus and *Aedes aegypti* mosquito.
- Studies of ecology at the periphery of the ranges of the agents and their reservoirs would be especially valuable.
- Studies to develop improved, protective laboratory based surveillance systems that can provide early warnings of an impending dengue epidemic.
- More studies and further trials on rendering female mosquitoes of *Aedes aegypti* infertile by injecting bacteria into the mosquito, as conducted recently in Australia.
- Analyzing the role of mosquito control for public health insurance.

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