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Masroor Ali Khan
Public Health Pest Laboratory, Jeddah, Saudi Arabia

Shabaan Elhossary
Public Health Pest Laboratory, Jeddah, Saudi Arabia

Imtinan Akram Khan
Public Health Pest Laboratory, Jeddah, Saudi Arabia

Mohammad H Al Zahrani
Public Health Pest Laboratory, Jeddah, Saudi Arabia

Fahad S Al Zahrani
Public Health Pest Laboratory, Jeddah, Saudi Arabia

Fasial M Al Bashri
Public Health Pest Laboratory, Jeddah, Saudi Arabia

Correspondence
Masroor Ali Khan
Public Health Pest Laboratory, Jeddah, Saudi Arabia

The impact of climatic variables with GIS application on the abundance of medically important mosquitoes (Diptera: Culicidae) in Jeddah, Saudi Arabia

Masroor Ali Khan, Shabaan Elhossary, Imtinan Akram Khan, Mohammad H Al Zahrani, Fahad S Al Zahrani and Fasial M Al Bashri

Abstract
Mosquitoes are major harmful insects inside and outside our houses and play an important role in the transmission of the dreadful human and animal diseases. They also annoy humans and animals by their painful and irritating bites. Assessment of the climatic variables and mosquito abundance is important to understand the vector pathogen activity and epidemic risk. It is observed by many workers that the climate has direct effect on the mosquito abundance. The spearman's correlation values between the mosquito abundance and the climatic factors suggest that there is not a very strong significant relationship between relative humidity, temperature and rainfall with *Culex*, and *Anopheles*. There was a moderately positive correlation between dengue fever mosquito *Aedes* with temperature and relative humidity, but the association was not statistically significant. Correlation of dengue fever mosquito *Aedes* and *Anopheles* with wind speed found to be negative, but positive with *Culex.* With all the three generate correlation is statistically non-significant. The average temperature below 30 ^{0}C found to be most suitable for adult mosquito survival and favor their abundance in the area of study. It is revealed that the climatic variables are not very effective to the mosquito abundance in the study area, only congenial environment is effective in increasing the number of mosquitoes. Apart from this, the human behavior and their activities are mostly responsible for flourishing the mosquito species in this area.

Keywords: Climate, *Aedes*, *Culex*, *Anopheles,* Abundance

1. Introduction

Mosquitoes are major harmful insects inside and outside our houses and play an important role in the transmission of the dreadful human and animal diseases. They also annoy humans and animals by their painful and irritating bites. There are approximately 3000- 3500 species [1]. Fbio ALS *et al*. (2017) [2] put this number to 3700. Many of the mosquito species are among the vectors for several tropical diseases including malaria, filariasis, and many viral diseases, such as dengue fever, Chikungunya, Rift valley fever, West Nile virus, Yellow fever, Zika virus and encephalitis etc [3-5]. Some of these vector-borne diseases are emerging fast, and in particular dengue fever cases are rising and resurging in this part of Saudi Arabia.

Climate and vector-borne diseases are closely associated with each other [6, 7]. Most of the mosquito species are sensitive to climate [8]. The key determinants of mosquito abundance are the prevailing climatic factors such as temperature, precipitation and relative humidity [9].

Assessment of the climatic variables and mosquito abundance is important to understand the vector pathogen activity and epidemic risk. Many of the diseases of the tropical countries are mosquito borne [10]. It is observed that the climate has direct effect on the mosquito abundance, and the transmission and the distribution pattern of vector borne diseases [11-14]. Many reports are available on the relationship between climate change and its effects on mosquito density [15-17].

The geographic distribution and abundance of mosquitoes are governed by complex factors [18]. However, Natural and geographical factors are considered to be the key determinants for the control of the mosquito vectors, their survival, abundance and distribution [19, 9, 11].

Geographic Information System (GIS) is a widely used application to find out the size and location of mosquito breeding places and to control their activity [20]. Modeling and mapping the mosquito distribution through GIS application with GPS (Global positioning system) is a useful tool for effective mosquito control in different countries and it also help in the selection of insecticide [21].

Few studies are available on the climatic variables and the use of GIS (Geographic Information System) in relation to the mosquito abundance in Saudi Arabia [8, 22-24, 39]. However, there is an urgent need to assess the role of climatic factors on the abundance of mosquito species and the employment of GIS facilities in the study area. The available literature is not sufficient to assess the impact of climatic variables on the mosquito abundance. The objective of this study was to fill up this gap and to provide a comprehensive data on mosquito abundance and improving vector surveillance through GIS application and IVM (Integrated vector management) in Jeddah, Saudi Arabia.

2. Materials and Methods

2.1 Study Area: Jeddah occupies a unique position in the kingdom as it receives millions of Hajj and Umrah pilgrims throughout the year. Jeddah is also a commercial city and a harbor with an inflow of large number of visitors coming from different parts of the country and the world. Located on the west coast of Red Sea Jeddah has a population of about 4.5 millions. (Latitude 21.29 N and Longitude 39.7 E) [25] (Fig.1). The climate is hot especially during summer when the temperature is high which might reach above 45 ^{0}C, and winter is moderately temperate. The average high temperature is approximately 35 ^{0}C and low average is about 23^0 C. The average low temperature is considered to be an ideal temperature for mosquito breeding and development [26]. The average relative humidity is approximately between 50% to 60 % and usually high due to its location near the sea. Rainfall is very scanty in this region but Subyan & Hajjar (2016) [27] recorded that rainfall level is tending to increase its intensity in Jeddah which may provide more breeding places for mosquito resulting into their abundance. The other factors like open sewage, septic tanks, water storage tanks, small cans, garbage and discarded motor tiers and water bottles etc. provides breeding places for the mosquitoes to flourish.

Meteorological data of various climatic variables was procured from the records of National Meteorology & Environment center, Jeddah.

2.2 Mosquito sampling and mapping: Adult mosquitoes were collected daily over the period from January 2016 to December 2017 by the municipality surveillance team with the help of light traps (Black Hole, Gangnam-GU, Seoul, 135-744, Korea) from 14 different municipality areas. Captured adult mosquitoes were brought to the laboratory and were immobilized by placing them in the deep freezer at -04 ^{0}C for 20 minutes. They were sorted out into different genera and sex wise to determine the male: female ratio. Later morphological identification was done with the help of standard taxonomic keys and catalogues [28-30]. Two years data from January 2016 to December 2017 was analyzed on year to year basis.

GIS was used for mapping and comparing the mosquito density and their distribution in different municipality areas. Geographic locations of the installed light traps were determined by using GPS equipment (GPS12X1 Personal Navigator, Garmin, Europe, LTD).

GIS processes ArcGIS software (version 10.1) under Microsoft windows media was used to analyze and create mosquito distribution. Jeddah shape file administration has been obtained from the Information Systems Centre in Jeddah Municipality. The digital map was corrected from different errors after the geo-reference process; it became GIS really thematic layers.

The three main mosquito genera (*Aedes*, *Culex* and *Anopheles*) were represented by three deferent color dots. The mosquito abundance was classified into 14 classes according to the 14 Jeddah municipalities.

2.3 Statistical methodology: Mosquito abundance in relation to prevailing climatic variables such as temperature, relative humidity, rainfall and wind speed was calculated on monthly basis by using Spearman's correlation method. A P- value less than 0.05 were considered as statistically significant. Data was analyzed using Stata version 14 IC statistical software.

3. Results and Discussion

A total number of mosquitoes collected during two year survey were 1,716,894 out of which 1627286 were *Culex*, 88807 *Aedes* and 801 *Anopheles* respectively. A significant difference in number of adult mosquito was observed during the light trap collections (Table -2). It was observed that the female density was greater compared to male for all collected mosquito genera (Table-1). The above mentioned mosquitoes are medically important as they are vectors to different diseases to humans and animals. Besides some medically unimportant mosquito species such as *Ochlerotatus* (*Aedes*) *caspius* (11 male and 96 Female) *and Culiseta longioreta* (*1 Female*) were also recorded during mosquito trapping. Roiz *et al* (2014) [31] mentioned the role of *O. caspius* as a vector for West Nile Virus in Spain. The role of *Ochlerotatus* (*Aedes*) *caspius and Culiseta* as a disease vector in the study area is yet to be explored [38].

Figure 1 exhibits the distribution of mosquito abundance per municipality over the period from January 2016 to December 2017.The three main mosquito genera (*Aedes, Culex* and *Anopheles*) Showing the disparity in numbers during the 2016 and 2017, the different size of color dots on the map are indicating the density of the mosquito genera in different municipality areas**.**

The percentage of captured mosquitoes genera, during this study, was *Culex* (94.78%), *Aedes* (5.17%) and *Anopheles* (0.05%). Culex was more abundantly found in different municipality areas. The highest number of *culex* was collected from Al Jamaa area (298180) and the lowest from Al Janoub (45841). *Aedes* were more from Al Jamaa (13771) and lowest from Thuwol (1171). The numbers of Anopheles mosquitoes were very few from different areas. Highest number of *Anopheles* was caught from Bareman (340) and lowest (9) from Jeddah Al-Jadeedah and no *Anopheles* was trapped from Thuwol region. (Table- 2).

Monthly distribution of the mosquitoes during 2016 and 2017 indicated different seasonal peaks. *Culex* recorded in high density during December to January 2016 & 2017 respectively and was low during September. *Aedes* reached its peak during March 2016 and November 2017 and dropped to low number during December 2016 and February 2017. Further, *Anopheles* was collected more during May 2016 & 17, recorded low in July 2016 and October 2017 respectively (Table-3).The results clearly indicate that the temperature below 30 ^{0}C with 65% relative humidity and below 10 knots/hr. wind speed are appropriate conditions for the mosquitoes to flourish (Fig., 2, 3 &4). In Saudi Arabia during the months of July, August and September the temperatures are very high (Some time as high as 45 to 48 ^{0}C) may be lethal for the mosquitoes [32].

Though the average rainfall is only 2 inch annually in the study area even than it influences the abundance of mosquitoes (Fig-5). Number of mosquito increases after little rainfall. This may be attributed to the prevailing conditions in the area where the water pools are formed after little rain and remain for a long time without drying up due to high humidity.

Abundance of mosquito genera and their association with the climatic parameters is well established in different parts of the world. During the study period the monthly average maximum and minimum temperature was recorded 32 ^{0}C and 23 ^{0}C respectively. Annual average relative humidity was 62.8%. The precipitation is almost negligible. The average rainfall is only 2 inch annually. The spearman's correlation values between the mosquito abundance and the climatic factors suggests that there is a moderately significant and negative relationship between *Culex* abundance with relative humidity and temperature but it was positive with rainfall and wind speed. There was a positive correlation between dengue fever mosquito *Aedes* with temperature and relative humidity and rainfall but the association was not statistically significant. Correlation of *Aedes* density with wind speed found to be weak negative and statistically non–significant. *Anopheles* exhibit negative relationship with the temperature, relative humidity and wind speed, whereas, it was recorded positive with rainfall (Table- 4). The average temperature below 30 ^{0}C found to be most suitable for adult mosquito survival and favor their abundance in the area of study (Fig.2). The relative humidity 60% and above found to be favorable for the increase in mosquito abundance. (Fig.1-4)

Most commonly it is argued that the abundance of mosquitoes is climate related and high temperature and precipitation increases their number in space and time [33, 34]. Yasin & Al Thukair, (2016) [19] observed that climatic variables influences the mosquitoes and their activity. They found negative correlation between adult mosquitoes and temperature and a positive correlation with relative humidity and moderately low positive correlation with rainfall in eastern province of Saudi Arabia. All the climatic parameters are much interrelated therefore; it is difficult to explain the individual factor separately [8]. Roiz *et al* (2014) [31] suggested that the effects of temperature are complex on the mosquito abundance as the relationship is species specific and time depended. Bashar & Tuno (2014) [9] described the climatic variables very tightly correlated. They could not find any significant correlation between temperature and rainfall with mosquito density, but they found a positive association with relative humidity. Rahman (1993) [35] did not found any correlation between rainfall and *Anopheles* mosquitoes. Wong Koon *et al* (2013) [36] were of the opinion that population dynamics vary in different geographical regions. This study has revealed that the climatic variables are not very effective to the mosquito abundance in this area, only congenial environment is effective in increasing the number of mosquitoes. Apart from this, the human behavior and their activities are mostly responsible for flourishing the mosquito species in this area. Most of the mosquito species thrive in Jeddah due to irresponsible human behavior by providing ideal breeding places in the form of uncovered domestic water storage receptacles, artificial water pools, discarded tires, cans water bottles etc.

Table 1: Male: female ratio between all the three mosquito genera

Genus	Male	Female	Male :Female
Aedes	35584	53223	2 :3
Culex	684201	943085	3 :4
Anopheles	243	558	1 :2

Table 2: Total number of Mosquito Collected from January 2016 to December 2017

Code	Municipality	Genus		
		***Aedes* (5.17%)**	***Culex* (94.78%)**	***Anophèles* (0.05%)**
1	Um Assalam	6316	169176	43
2	Aljanoub	4671	45841#	35
3	Aljamaa	13771*	298180*	199
4	Albalad	5108	199462	10
5	Breman	4376	146826	340*
6	Alsharafyiah	5244	83583	11
7	Alazeezyiah	10184	100003	22
8	Jeddah Aljadeeda	13027	180791	9#
9	Almatar	7542	118789	16
10	Ubhor	7060	95845	51
11	Zhahaban	2998	72632	32
12	Tayba	7339	115524	33
13	Thuwol	1171#	79030	0
14	Jeddah Altharikhia (A sub division of Albalad)	0	0	0

(*Highest Mosquito Number; # Lowest Mosquito Number)

Table 3: Monthly collection of different Mosquito genera during 2016-2017.

Month	Aedes		Culex		Anopheles	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
Jan	5139	2908	167808*	93778	44	37
Feb	3091	997#	156550	41095	18	21
Mar	5479	1552	151032	66012	23	41
Apr	5708	2260	156002	80791	63	54
May	7719*	3553	99492	78253	82*	64*
Jun	4817	2333	33515	39891	23	24
Jul	2977	2421	16520	23623	11#	33
Aug	3235	4393	11498	20459	24	24
Sep	3246	3031	8717#	8807#	15	16
Oct	3181	3469	13124	15456	25	12#
Nov	2783	5007	29819	47735	33	31
Dec	2581#	6927*	48391	218918*	34	49

(*Highest Mosquito Number; # Lowest Mosquito Number)

Table 4: The spearman's correlation values between mosquito abundance and climatic variables during 2016-2017.

Parameters	Aedes		Culex		Anopheles	
	r- value	P-value*	r-value	P-value	r-value	P-value
Temperature	0.11	0.590	-0.63	0.0008	-0.25	0.234
Relative humidity	0.01	0.945	-0.42	0.0362	-0.39	0.057
Wind speed	-0.21	0.305	0.19	0.353	-0.002	0.991
Rainfall	0.12	0.574	0.42	0.039	0.19	0.367

*P > 0.05 (Non-significant); *P*< 0.05 (significant)

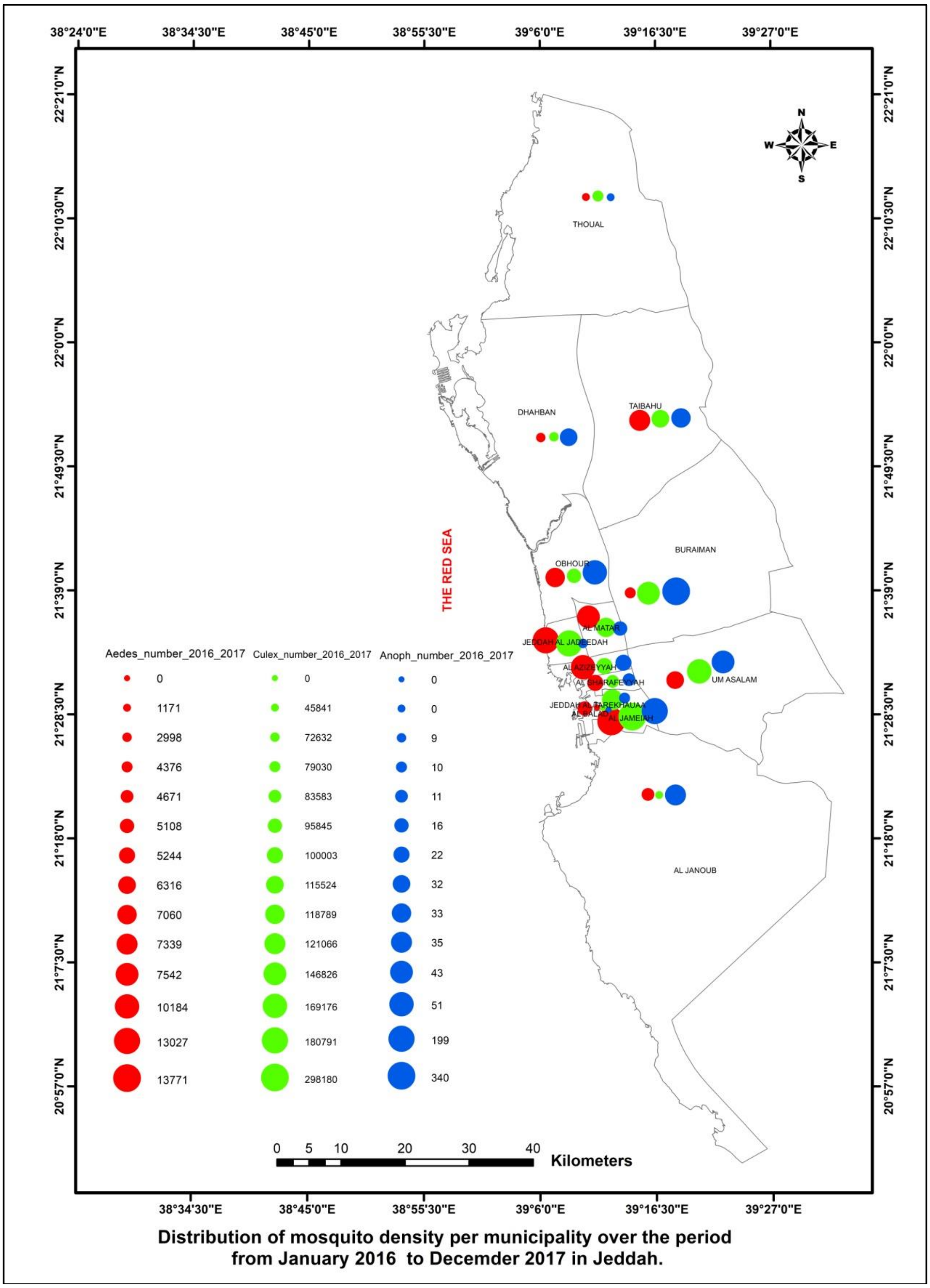

Fig 1: Map of Jeddah Saudi Arabia showing locations of Light traps and density of mosquitoes in different areas.

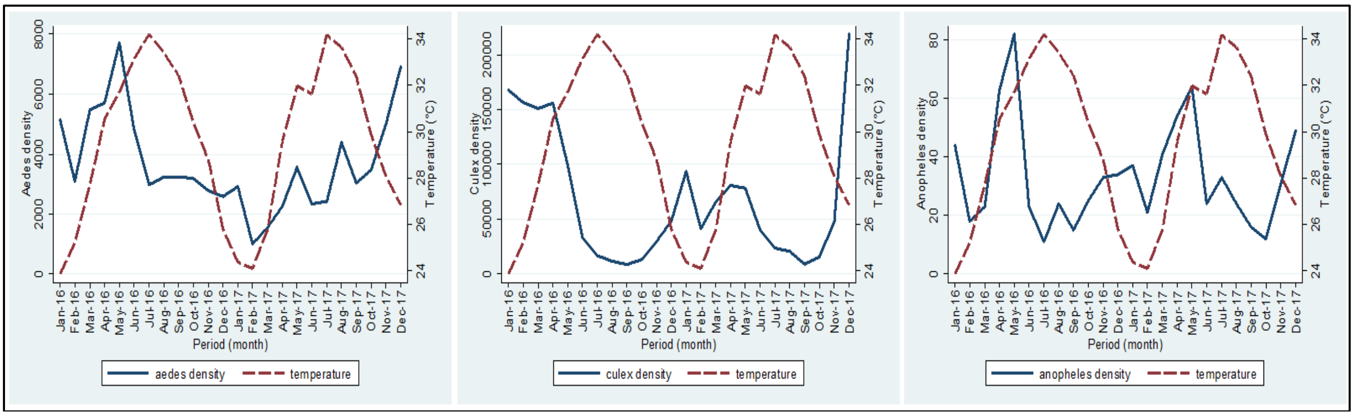

Fig 2: Influence of temperature on the abundance of *Aedes*, *Culex* and *Anopheles* during 2016-17

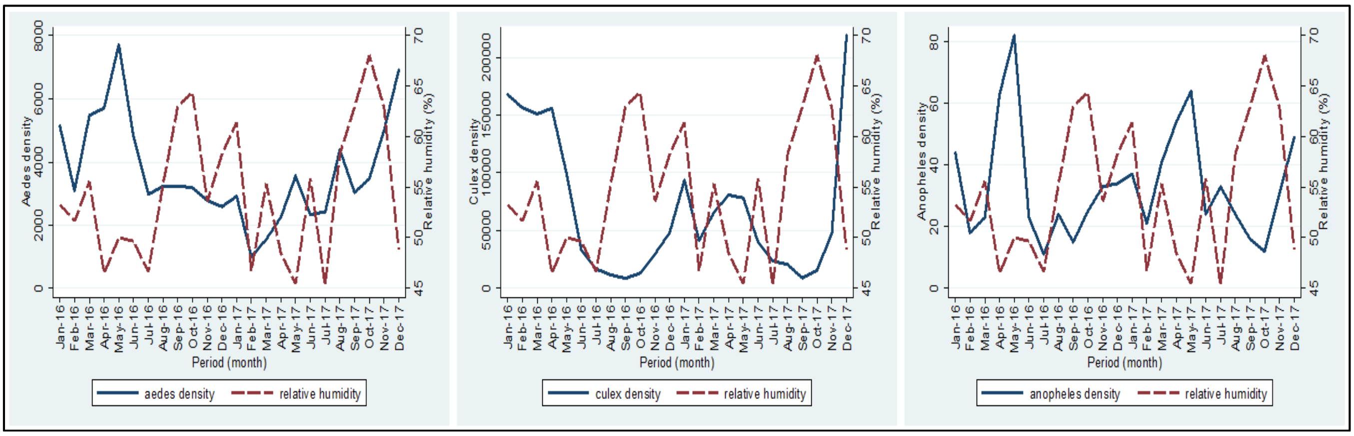

Fig 3: Influence of relative humidity on the abundance of *Aedes*, *Culex* and *Anopheles* during 2016-17

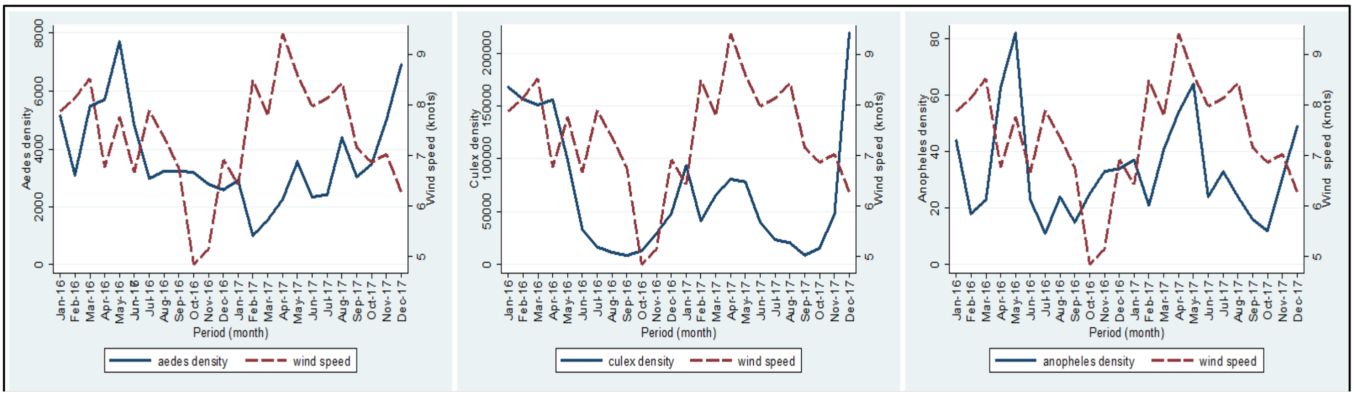

Fig 4: Influence of wind speed on the abundance of *Aedes*, *Culex* and *Anopheles* during 2016-17

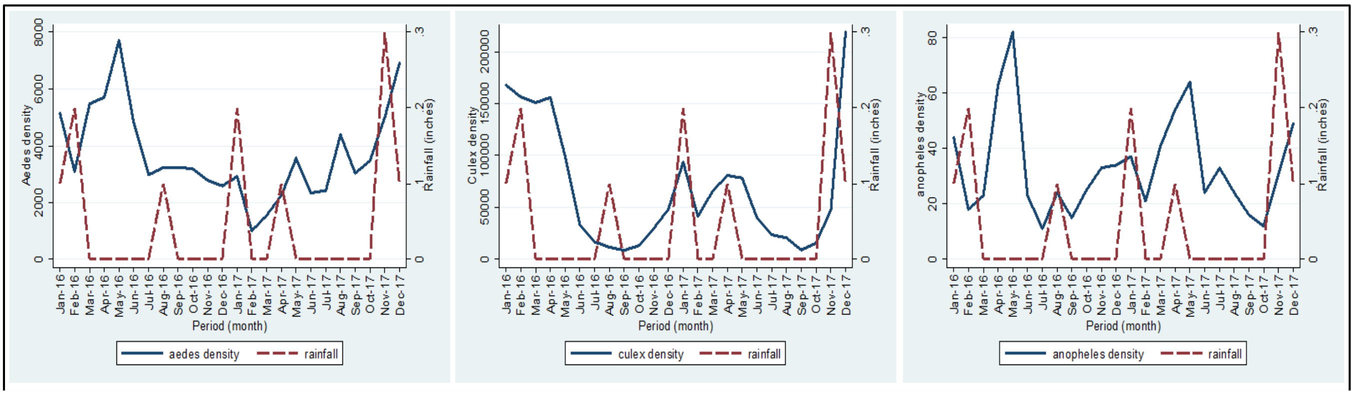

Fig 5: Influence of rainfall on the abundance of *Aedes*, *Culex* and *Anopheles* during 2016-17

4. Conclusion

Although climatic variables influence the mosquito abundance a little bit but it seems to be very complex to assess the real impact. In addition human behavior and their activities contribute to the complexity. Most of the climatic factors are species specific and may impact the mosquito borne diseases. This aspect need to be exploring intensively and require inculcating awareness among the masses about the dangers & control of the mosquito breeding sites. More studies on the abundance of mosquito vectors need to use modern technology tools such as geographic information systems (GIS) and their accessories to monitor analyses and follow mosquito behavior in relation to environmental conditions and factors. Geographical information systems (GIS) can also be used as rapid and accurate tool for the determination of some environmental factors affecting mosquito's proliferation, which can help in designing optimal mosquito vector control strategies based on precise spatial/temporal information database. Consequently, most of the developed countries are applying these systems to form their own policy levels to mitigate the mosquito problem. Furthermore, geospatial mapping offers the potential to identify mosquito habitats on a large geographic area that is difficult or impossible for using field survey [37].

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Declarations of interest: none

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