



## Research article

## Impact of meteorological parameters on mosquito population abundance and distribution in a former malaria endemic area, central Iran

Tahereh Sadat Asgarian, Seyed Hassan Moosa-Kazemi<sup>\*</sup>, Mohammad Mehdi Sedaghat<sup>\*\*</sup>

Department of Medical Entomology &amp; Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

## HIGHLIGHTS

- Populations of mosquitoes were larger during the dry months.
- The mean monthly temperature below 30 °C was most suitable for mosquitoes.
- There was a non-significant relationship between wind speed and mosquitoes.

## ARTICLE INFO

Keywords:  
Abundance  
Mosquito  
Rainfall  
Temperature

## ABSTRACT

Meteorological parameters, have been identified as an important factor involved in the transmission of vector-borne diseases. Mosquitoes are extremely sensitive to weather conditions. The aim of this study was investigate the correlation between meteorological parameters and the abundance of mosquitoes in Kashan County. Mosquitoes were collected using four different traps, including hand catch, animal baited bed net trap (usually a cow), human baited bed net trap and BG-Sentinel trap with CO<sub>2</sub> from May to December 2019. A total number of mosquitoes collected were 1756 out of which 1621 (92.31%) were *Culex*, 22 (1.25%) *Culiseta* and 113 (6.44%) *Anopheles* in nine species. Most mosquitoes were collected by BG-Sentinel trap with CO<sub>2</sub> (63.78%). Monthly distribution of the mosquitoes indicated different monthly peaks. Their high density were recorded in September and were low in December. The spearman's correlation of the mosquito abundance and the meteorological parameters shows that correlation of the number of total collected mosquitoes with relative humidity and precipitation (Rainfall) was weak negative, and there was weak correlation with wind speed, and positive strong correlation with temperature. Data collected with various trap types and mosquito correlation with meteorological parameters in this study can be used for mosquito surveillance and control programs. However, meteorological parameters affect the abundance of mosquitoes, but their impact is complex and most of these variables are species specific.

## 1. Introduction

Emerging and re-emerging diseases are a great threat to human and animal health (Feldmann et al., 2002). Urbanization, increases in populations, degradation of the natural environment and international trade and travel has been caused that arthropod vectors of disease spread from tropical areas into temperate areas (Rogers and Packer, 1993). Climate through the effect on the time and intensity of vector-borne diseases, affects their distribution (Epstein et al., 1998; Gubler et al., 2001). Pathogens of malaria, filariasis, Zika, Chikungunya diseases, West Nile and Dengue fever were transmitted by mosquitoes to humans (Gould and

Higgs, 2009; Gasperi et al., 2012). *Anopheles* mosquito species are responsible for the transmission of malaria, but the majority of mosquito species from the genera of *Culex* and *Aedes* are responsible for the transmission of arboviruses to humans (Tabachnick, 1991). Climate change will have short- and long-term impacts on disease transmission and a direct impact on the epidemiology of vector-borne diseases (Githeko et al., 2000).

It is commonly said that the abundance of mosquitoes is related to climate (Watson et al., 1996, 1998). Immature stages in the aquatic environment and as adults of mosquitoes are extremely sensitive to weather conditions and therefore there are concerns about mosquito-borne disease

\* Corresponding author.

\*\* Corresponding author.

E-mail addresses: [moosakazemi@tums.ac.ir](mailto:moosakazemi@tums.ac.ir) (S.H. Moosa-Kazemi), [sedaghat@hotmail.co.uk](mailto:sedaghat@hotmail.co.uk) (M.M. Sedaghat).

(Epstein, 2000). In warmer climates and when the water temperature rises, larval to mature is short, adult female mosquitoes are blood feeding more frequently, thus increase pathogen transmission (Githeko et al., 2000).

The main weather factors are the temperature, relative humidity and precipitation (Almeida Costa et al., 2010; Khan et al., 2018). The quality and quantity of mosquito breeding sites are affected by precipitation (Tian et al., 2015; Jemal and Al-Thukair, 2018).

Temperature and precipitation, limit distribution of mosquitoes and range of diseases transmitted by them because the biology of the vector is affected (Epstein et al., 1998; Gubler et al., 2001). To detect, and monitor mosquitoes, surveillance programs are required (Paphitou et al., 2017). Global warming have significant effects on vector-borne diseases. Biology of mosquitoes is very diverse and climatic variability is led to increased variability in mosquito communities and diseases transmitted by them (Rogers and Packer, 1993; Subak, 2003). Climatic changes may affect longevity, activity and spread of vector mosquitoes (Roiz et al., 2014; Almeida Costa et al., 2010). A higher temperature increase the replication and spread of arboviruses (Kilpatrick et al., 2008), as a result, the time of mosquito infection to transmission of the virus to humans is shortened (Takahashi, 1976). Moreover, higher temperatures change human behavior via increase outdoor activities and humans and mosquitoes will be more in contact (Konno, 1969; Bi et al., 2007). Environmental changes cause to alter interactions among vectors, reservoirs, pathogens, and human (Institute of Medicine, 2003). As a result, certain vector-borne diseases may increase in one area and decrease in another (Weicheld, 2015).

Temperature affects the hatching time of mosquito eggs (Hawley et al., 1989; Hanson and Craig, 1994; Impoinvil et al., 2007; Mohammed and Chadee, 2011). Temperature stress during the stages of larvae and pupae have carry-over effects on fecundity and survival of adults (Ezeakacha and Yee, 2019). Temperature also has a direct impact on mosquito adult stage. When temperature decreased, female longevity of *Culex* spp. increased (Giota et al., 2014). Drakou et al. (2020) reported that temperature affects host searching activity of *Cx. pipiens*, *Ae. detritus* and *Ae. caspius* population.

Humidity affects longevity, blood feeding behavior, mating, dispersal and oviposition of mosquitoes. The results one study to examine risk factors in the Japanese encephalitis (JE) transmission, indicated that monthly mean maximum and minimum temperatures, rainfall, humidity were positively related to mosquito density in Changsha in South China (Tian et al., 2015). Therefore climatic factors and their relationship with mosquito activity are valuable for surveillance programs and mosquito control management.

Depending on the classification of the tribe Aedini, there are 70 species and 8 (or 12) genera of Iranian mosquitoes (Azari-Hamidian et al., 2020). Mosquitoes transmit two protozoa, two bacteria, four filaria, and seven arbovirus in Iran (Azari-Hamidian et al., 2019; Pour-iayevali et al., 2019). Malaria is a major endemic infectious disease in Iran. *Anopheles* species is responsible for the transmission of malaria and seven *Anopheles* species have been reported as vectors of malaria in Iran (Vatandoost et al., 2019). *Anopheles superpictus sensu lato (s.l.)* is most abundant and distributed species among *Anopheles* in Kashan County (Asgarian et al., 2021). This research aims to provide insight into the impact of climatic variables on native adult mosquito abundance and activity in Kashan County.

## 2. Materials and methods

### 2.1. Study area

Mosquitoes were collected throughout Kashan County (33.9850° N, 51.4100° E). Kashan is located in the north of Isfahan Province, central Iran, includes four districts, Central, Qamsar, Niasar, and Barzok Districts. Due to the impact of the central desert of Iran on Kashan County, it has a dry climate. The average high temperature is approximately 26.2 °C and low average is about 12.1 °C. The average low relative humidity is

27% and average high is 56.4 %. Kashan rainfall is Mediterranean, so Kashan rainfall season corresponds to the cold season and early spring and its dry season coincides with the summer season. One of the effective factors in Kashan climate is local winds that often blow from the desert towards Kashan (I.R. of Iran Meteorological Organization, 2014).

Meteorological data of various climatic variables, including precipitation, relative humidity (mean, maximum and minimum), wind speed and temperature (mean, maximum, minimum) during the study period, and daily weather conditions for our study were procured from the records of Kashan meteorological organization.

This research was approved by the Ethical Committee of Tehran University of Medical Sciences (TUMS) (No.: IR.TUMS.VCR.REC.1397.1001).

### 2.2. Mosquito collection

Mosquitoes were collected using four different traps, including Hand Catch (HC), Animal Baited Bed Net Trap (ABBNT) (usually a cow), Human Baited Bed Net Trap (HBBNT), and BG-Sentinel Trap (BG) with CO<sub>2</sub> from May to December 2019. In Hand Catch method, mosquitoes resting on indoor and outdoor surfaces were collected by using mouth- or battery-powered aspirators.

Collected mosquitoes were transmitted to the lab and placed in a freezer -20 °C for at least 20 min to die. Mosquitoes were identified based on a valid diagnostic key to Iran at the species level (Azari-Hamidian and Harbach, 2009). Mosquito trapping sites were selected based on observed mosquito activity, access to trapping site, private property and risk of trap vandalism or theft. Locations for trapping sites were determined using Global Positioning System (GPS). Arch Map 10.5 software was used to create a geographic database of adult mosquito sampling sites and mapping the sites of collection and distribution of the most important species of medicine (Figure 1).

Mosquito larvae were collected using a standard 350 ml capacity mosquito dipper from April to late December 2019. Larvae were transparent in lactophenol and individually mounted in Berlese's fluid on a microscope slide and identified by morphological characters and valid keys (Shahgudian, 1960; Zaim and Cranston, 1986; Azari-Hamidian and Harbach, 2009) Some mosquitoes specimens were deposited in the museum of medical entomology, TUMS.

### 2.3. Statistical analysis

The relationships of temperature, relative humidity, wind speed and precipitation (Rainfall), with abundance of adult mosquitoes were investigated on monthly by using Spearman's correlation method. The data were analyzed in IBM SPSS Statistics 26. P < 0.05 were considered as statistically significant.

## 3. Results

### 3.1. Mosquito collection results

A total number of adults of mosquitoes collected using various traps from May to December 2019 were 1756 out of which 1621 (92.31%) were *Culex*, 22 (1.25%) *Culiseta* and 113 (6.44%) *Anopheles* in nine species including two of the genus *Anopheles*, six *Culex*, and one *Culiseta*. Overall, *Cx. pipiens* (57.63%) was the predominant species followed by *Cx. theileri* (25.17%) and *An. superpictus s. l.* (6.15%). Most mosquitoes were collected by BG- Sentinel trap with CO<sub>2</sub> (63.78%) and *Cx. pipiens* (65.44%) was the most abundant species in this trap (Table 1).

A total of 9789 larvae were collected from urban and, rural areas of four districts of Central, Qamsar, Niasar, and Barzok in Kashan County, which included 13 species from *Anopheles* 772 (7.89%), *Culiseta* 1706 (17.42%) and *Culex* 7311 (74.69%). *Culex pipiens* had the highest abundance with 3658 (37.36%). We have already reported the results of larval sampling (Asgarian et al., 2021).

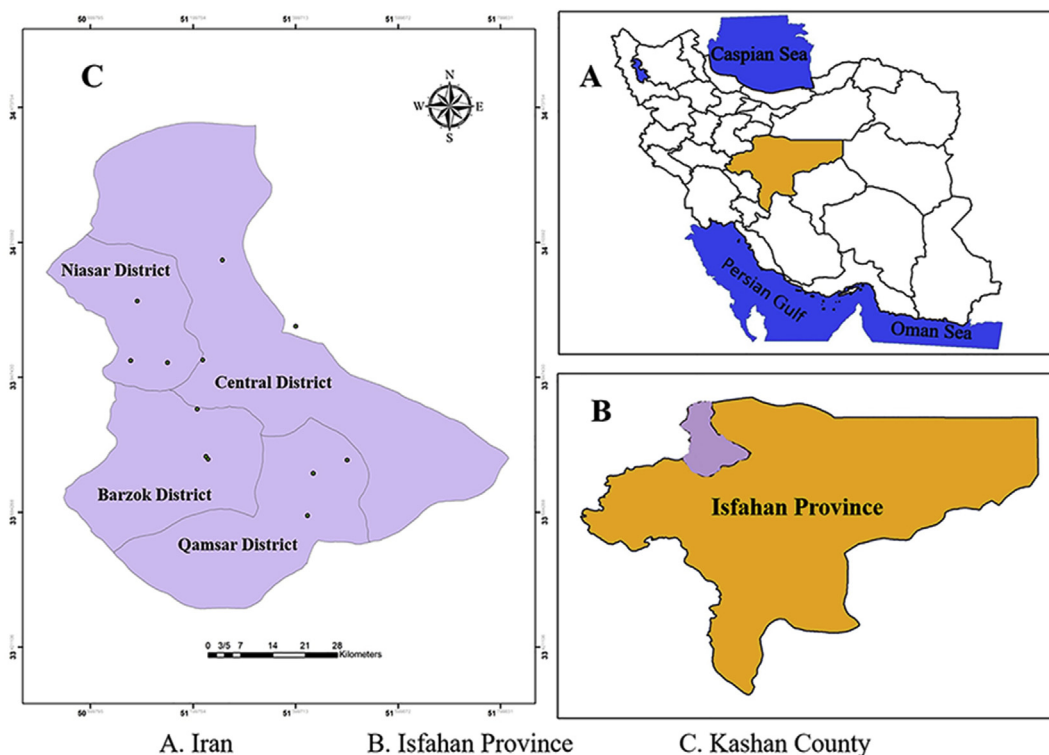


Figure 1. Adult mosquito sampling sites in Kashan County (2019).

Table 1. The collected mosquito species by various traps, Kashan County, central Iran, 2019.

Species	Hand Catch		Human Baited Bed Net Trap		Animal Baited Bed Net Trap		BG-Sentinel Trap		Total	
	n	%	n	%	n	%	n	%	n	%
<i>An. maculipennis s. l.</i>	2	1.04	1	0.26	0	0	2	0.18	5	0.29
<i>An. superpictus s. l.</i>	3	1.56	30	7.92	0	0	75	6.70	108	6.15
<i>Cs. longiareolata</i>	22	11.45	0	0	0	0	0	0	22	1.25
<i>Cx. deserticola</i>	12	6.25	0	0	0	0	46	4.11	58	3.30
<i>Cx. hortensis</i>	13	6.77	0	0	0	0	19	1.70	32	1.82
<i>Cx. mimeticus</i>	0	0	0	0	0	0	23	2.05	23	1.31
<i>Cx. perexiguus</i>	30	15.63	0	0	0	0	24	2.14	54	3.08
<i>Cx. pipiens</i>	45	23.44	219	57.78	15	23.08	733	65.44	1012	57.63
<i>Cx. theileri</i>	65	33.86	129	34.04	50	76.92	198	17.68	442	25.17
Total	192	100	379	100	65	100	1120	100	1756	100

*Culex pipiens* is distributed in many areas of the country. *Culex quinquefasciatus* is found in southern areas of Iran to Yazd County in central Iran, and reported as sympatric with *Cx. pipiens* in the central regions. Sequencing alignment of Ace.2 gene of *Cx. quinquefasciatus* and *Cx. pipiens* showed 6.5% variation in 46 bp, especially in the intron locus of gene. *Culex pipiens* complex from Iran are located in two separate clades with sister branches using a phylogenetic sequencing tree (Dehghan et al., 2013).

### 3.2. Influence of weather on mosquito abundance

Monthly distribution of the adult of mosquitoes from May to December 2019 indicated different monthly peaks. Their highest density was recorded in September and the lowest was in December (Table 2). Average of monthly temperature was decreased from 33.7 °C in August to 29.2 °C in September which was coincided with a period of low wind speed (Figure 2).

Table 2. Monthly collection of different adults of mosquito genera, Kashan County, central Iran, 2019.

Month	Anopheles	Culex	Culiseta	Total
May	0	122	0	122
Jun	11	216	0	227
Jul	12	322	2	336
Aug	28	308	6	342
Sep	35	468	7	510
Oct	22	122	5	149
Nov	5	48	2	55
Dec	0	15	0	15
Total	113	1621	22	1756

The spearman's correlation of the abundance of adult mosquitoes and the meteorological parameters showed that there was a strong negative

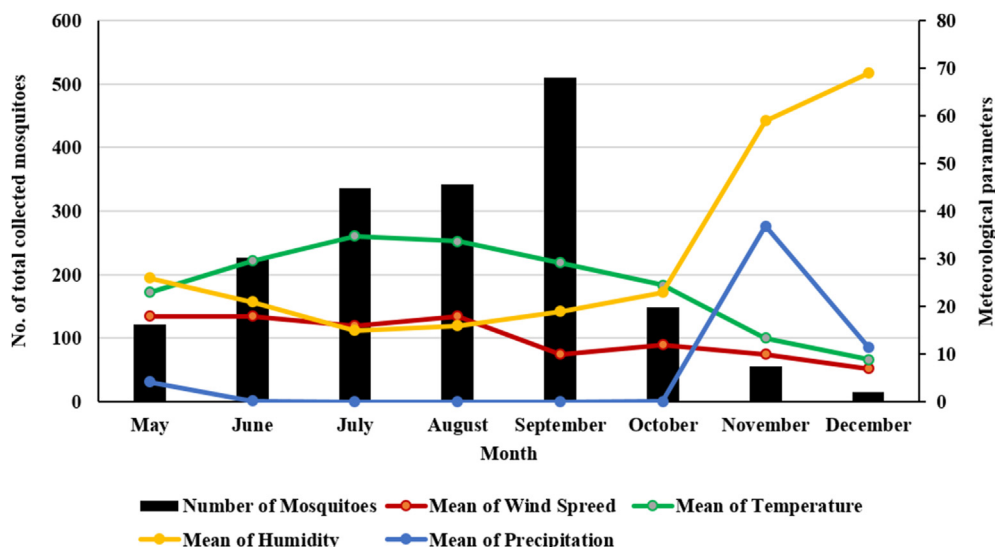


Figure 2. The collected mosquito adults and meteorological variables by month, Kashan County, central Iran, 2019.

and significant relationship between *Anopheles* abundance with relative humidity (−0.74) and rainfall (−0.84), while its relationship with temperature was a positive correlation but not statistically significant, and it was no correlation with wind speed. A strong positive correlation and significant was observed between mosquito *Culex* with temperature (0.85), while its relationship with relative humidity and rainfall was a negative relationship and significant. Also a weak positive correlation was observed between *Culex* and wind speed (0.35), but the relationship was not significant. *Culiseta* had negative correlation with the relative humidity, rainfall and wind speed, whereas, its relationship was positive with temperature, but not significant (Table 3).

Generally, our results showed that correlation of the number of total collected mosquitoes with relative humidity and precipitation (Rainfall) was weak negative, and there was weak correlation with wind speed, and positive strong correlation with temperature (Figure 3).

Most larvae were caught in dry months. In August, the larval habitats of the mosquitoes were in the best conditions to maintain the mosquito population, so the number of larvae caught in August was higher. The collected larvae and precipitation have been shown by month in Figure 4.

#### 4. Discussion

Abundance and association of mosquitoes with the meteorological parameters has been studied in some countries and meteorological parameters, have been identified as an important factor involved in the transmission of vector-borne diseases (Watts et al., 1987; Ram et al., 1998; Wu et al., 2007). Temperature, relative humidity, wind speed and precipitation affect on mosquito survival, abundance and distribution.

Table 3. The spearman's correlation values between adult mosquito abundance and climatic variables, Kashan County, central Iran, 2019.

Parameters	<i>Anopheles</i>		<i>Culex</i>		<i>Culiseta</i>	
	r-value	p-value*	r-value	p-value*	r-value	p-value*
Temperature	0.64	0.08	0.85	0.00	0.39	0.33
Relative humidity	-0.74	0.03	-0.92	0.00	-0.54	0.16
Wind speed	0.08	0.83	0.35	0.38	-0.13	0.75
Precipitation	-0.84	0.00	-0.90	0.00	-0.67	0.06

R = 1.0–0.9 (Very Strong Correlation), r = 0.89–0.7 (Strong Correlation), r = 0.69–0.4 (Moderate Correlation), r = 0.39–0.1 (Weak Correlation), \*p > 0.05 (Non-significant); P < 0.05 (significant).

Our findings indicate that mosquito abundance was low in temperatures above 30 °C, and was consistent with the results of other researchers. Ciota et al., (2014) demonstrate that temperature significantly affect larvae and adult survival, mosquito size, blood feeding, and fecundity of populations of the *Culex* mosquitoes and temperatures greater than 30 °C increased mosquito mortality (Ciota et al., 2014). Researchers in eastern province of Saudi Arabia found a positive correlation between mosquitoes with relative humidity and rainfall but observed negative correlation with temperature (Jemal and Al-Thukair, 2018). Roiz et al. (2014) highlighted the climate-mosquito abundance relationship are complex and these effects are non-linear. In Ekiti State, Nigeria, temperature and Rainfall had a significant effect on the distribution and abundance of the mosquito vectors (Simon-Oke and Olofintoye, 2015). In Jeddah, Saudi Arabia monthly distribution of *Culex*, *Aedes* and *Anopheles* during 2016 and 2017 had different seasonal peaks. The average temperature below 30 °C was suitable for adult mosquito abundance in the area of study. Correlation of *Culex*, and *Anopheles* abundance with relative humidity, temperature and rainfall was not significant. *Aedes* had a moderately positive correlation, and not statistically significant with temperature and relative humidity. There was a moderately positive correlation between dengue fever mosquito *Aedes* with wind speed, but negative with *Aedes* and *Anopheles* (Khan et al., 2018).

In our study during June to August and also October, the maximum temperature on some days was over 40 °C that can be lethal for the mosquitoes. The mean monthly temperature below 30 °C (29.2 °C) in September was most suitable for adult mosquito survival and abundance, which seem to be more suitable for their host searching activity. In September, some larval habitats in Central and Niasar Districts were dried, reducing the population of adult mosquitoes in October.

Bashar and Tuno (2014) studied the relationship between climatic factors and *Anopheles* mosquito abundance in Bangladesh. They reported a positive association between relative humidity with mosquito abundance, but there was no significant correlation with temperature and rainfall. In an endemic village near the Malaysia-Thailand border was not found any correlation between rainfall and *Anopheles* mosquitoes (Rahman et al., 1993).

The precipitation affects mosquito populations. Precipitation creates breeding sites for mosquitoes and larval development. On the other hand, high precipitation may decrease mosquito populations. In our study, climate difference was caused by differences in the density patterns of mosquitoes, so that populations of mosquitoes were larger during the dry months.

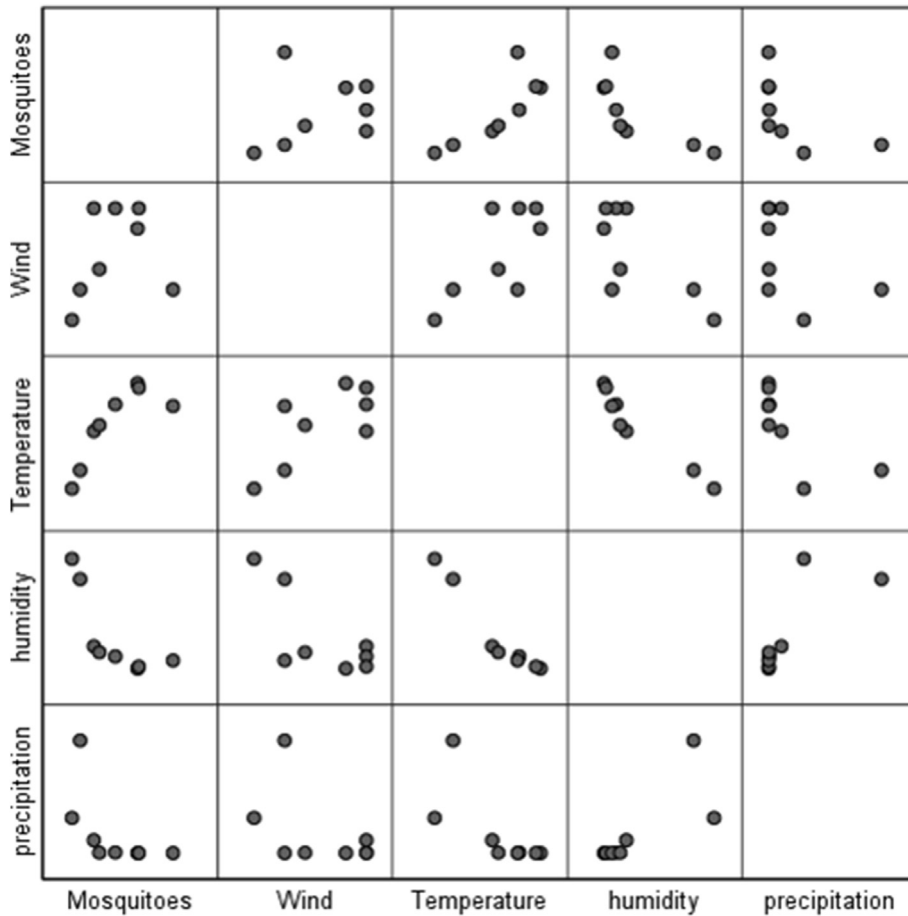


Figure 3. Scatter plot to show correlation of meteorological parameters with number of total collected mosquitoes, Kashan County, central Iran, 2019.

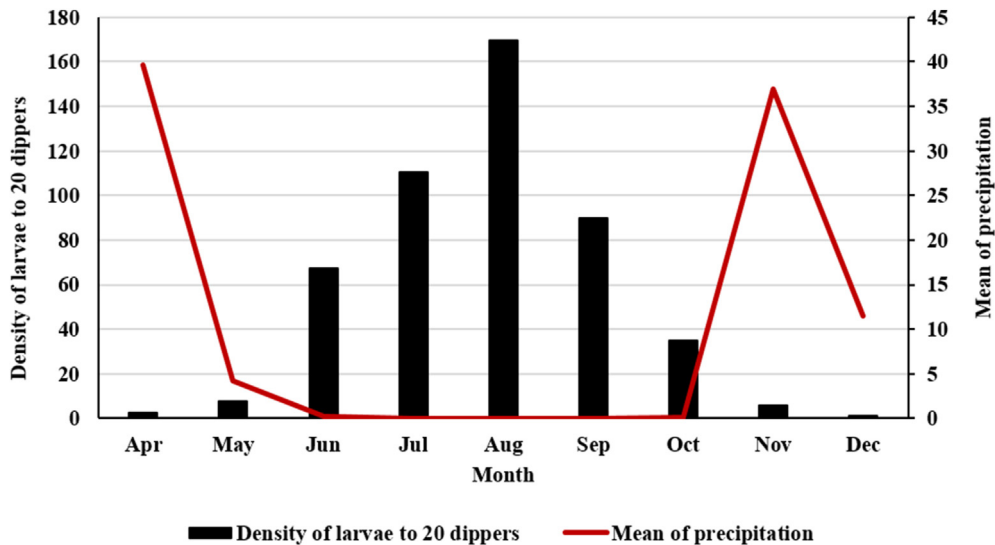


Figure 4. The collected mosquito larvae and mean of precipitation by month, Kashan County, central Iran, 2019.

A significant negative relationship was observed between monthly relative humidity and number of sampled *Anopheles* and *Culex*, but relationship with *Culiseta* was not significant. In April, November and December, rainfall increased, due to floods and rapid water currents, mosquito larval habitats were destroyed, reducing the abundance of adult mosquitoes, especially in the case of *An. superpictus* s. l., *An. maculipennis* s. l., *Cx. deserticola*, *Cx. hortensis*, *Cx. mimeticus*, and *Cx.*

*perexiguus* species whose their larval habitats is on the banks of calm flowing rivers. Also, the average monthly temperature in November and December was 13.4 and 8.9 °C, respectively, so low temperature also reduced the abundance of mosquitoes. Densities of *Culex* spp. especially *Cx. pipiens* were highest in July–September. Drought conditions may be a benefit for *Cx. pipiens* because of the concentration of organic matter in urban basins and ponds (Epstein, 2001).

*Culex pipiens* prefers to lay its eggs in containers rich in organic matter, heavy rainfall cause that these containers overflow or the amount of their organic matter decrease and make them less suitable for *Cx. pipiens* (Weicheld, 2015). Increasing the temperature, to some extent, increases the development, reproduction and abundance of mosquito populations. *Culex pipiens* maintained at warmer temperatures were more infected with West Nile virus than mosquitoes maintained at cooler temperatures (Dohm et al., 2002). The initial 1999 outbreak of West Nile virus in New York was due to warm winters followed by hot, dry summers. In later years with similar climatic conditions, there was a spread of the disease (Epstein, 2001).

In study of Nejati et al. (2020) in borderline of Iran and Pakistan, wind speed and temperature had a direct significant correlation with the total number of collected mosquito while there was a non-significant positive relationship between wind speed and *Anopheles* and *Culex* in our study.

In addition to meteorological parameters and their effect on mosquito-borne diseases, human activities and behavior also play an important role in the transmission of these diseases (Gubler et al., 2001). In Kashan County changes in living conditions, land leveling, destruction of lowlands and highlands, improvement of streams and cementation of streams is major factors in the disappearance of malaria, although climate-related natural disasters such as floods may increase or change human contact with mosquitoes. Vector-borne pathogens may be affected by climate change. More research is needed to better understand the relationships of these pathogens and their vectors and climatic variables.

## 5. Conclusion

Study of weather conditions and its effect on mosquito community dynamics and disease transmission is important for performing effective surveillance and control programs (Bradford, 2005). Global warming can change pattern of rainfall and temperature and directly or indirectly affects larval habitats and the abundance of mosquitoes. Data collected with various trap types and mosquito correlation with meteorological parameters in this study can be useful for mosquito surveillance and control programs. In Kashan County, some mosquito species have the importance of health due to human-blood sucking. Because of the wide range of climates and altitudes (from 942 m in Central District to 2044 m in Barzok District) of Kashan County, monitoring and recording meteorological parameters are necessary to aware of the possibility of growing conditions new species and climate changes that are suitable for invasive species, especially *Aedes aegypti* and *Ae. albopictus*. However, meteorological parameters affect the abundance of mosquitoes, but their impact is complex and most of these variables are species specific (Roiz et al., 2014). Geographic Information Systems (GIS), and monitoring mosquito behavior in relation to environmental and climatic factors is needed for increasing our knowledge to understand these relationships.

## Declarations

### Author contribution statement

Sayed Hassan Moosa-Kazemi, Mohammad Mehdi Sedaghat: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tahereh Sadat Asgarian: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

### Funding statement

This work was supported by Tehran University of Medical Sciences (TUMS).

### Data availability statement

Data included in article/supplementary material/referenced in article.

## Declaration of interests statement

The authors declare no conflict of interest.

## Additional information

No additional information is available for this paper.

## Acknowledgements

Authors are grateful to Dr SM Asgarian for helping with field collections.

## References

- Almeida Costa, E.A.P., Mendonça Santos, E.M., Correia, J.C., Albuquerque, C.M.R., 2010. Impact of small variations in temperature and humidity on the reproductive activity and survival of *Aedes aegypti* (Diptera, Culicidae). *Rev. Bras. Entomol.* 54 (3), 488–493.
- Asgarian, T.S., Moosa-Kazemi, S.H., Sedaghat, M.M., Dehghani, R., Yaghoobi-Ershadi, M.R., 2021. Fauna and larval habitat characteristics of mosquitoes (Diptera: Culicidae) in Kashan County, central Iran. *J. Arthropod. Borne Dis.* 15 (1), 69–81.
- Azari-Hamidian, S., Abai, M.R., Norouzi, B., 2020. *Mansonia uniformis* (Diptera: Culicidae), a genus and species new to southwestern Asia, with a review of its medical and veterinary importance. *Zootaxa* 4772 (2), 385–395.
- Azari-Hamidian, S., Harbach, R.E., 2009. Keys to the adult females and fourth-instar larvae of the mosquitoes of Iran (Diptera: Culicidae). *Zootaxa* 2078 (1), 1–33.
- Azari-Hamidian, S., Norouzi, B., Harbach, R.E., 2019. A detailed review of the mosquitoes (Diptera: Culicidae) of Iran and their medical and veterinary importance. *Acta Trop.* 194, 106–122.
- Bashar, K., Tuno, N., 2014. Seasonal abundance of *Anopheles* mosquitoes and their association with meteorological factors and malaria incidence in Bangladesh. *Parasites Vectors* 7 (1), 1–10.
- Bi, P., Zhang, Y., Parton, K.A., 2007. Weather variables and Japanese encephalitis in the metropolitan area of Jinan city, China. *J. Infect.* 55 (6), 551–556.
- Bradford, C.M., 2005. Effects of Weather on Mosquito Biology, Behavior, and Potential for West Nile Virus Transmission on the Southern High Plains of Texas. Texas Tech University.
- Ciota, A.T., Matarachero, A.C., Kilpatrick, A.M., Kramer, L.D., 2014. The effect of temperature on life history traits of *Culex* mosquitoes. *J. Med. Entomol.* 51 (1), 55–62.
- Dehghan, H., Sadraei, J., Moosa-Kazemi, S.H., Akbari Baniani, N., Nowruz, F., 2013. The molecular and morphological variations of *Culex pipiens* complex (Diptera: Culicidae) in Iran. *J. Vector Borne Dis.* 50 (2), 111–120.
- Dohm, D.J., O'Guinn, M.L., Turell, M.J., 2002. Effect of environmental temperature on the ability of *Culex pipiens* (Diptera: Culicidae) to transmit West Nile virus. *J. Med. Entomol.* 39 (1), 221–225.
- Drakou, K., Nikolaou, T., Vasquez, M., Petric, D., Michaelakis, A., Kapranas, A., Papatheodoulou, A., Koliou, M., 2020. The effect of weather variables on mosquito activity: a snapshot of the main point of entry of Cyprus. *Int. J. Environ. Res. Publ. Health* 17 (4), 1403.
- Epstein, P.R., 2000. Is global warming harmful to health? *Sci. Am.* 283 (2), 50–57.
- Epstein, P.R., 2001. West Nile virus and the climate. *J. Urban Health* 78 (2), 367–371.
- Epstein, P.R., Diaz, H.F., Elias, S., Grabherr, G., Graham, N.E., Martens, W.J., Mosley-Thompson, E., Susskind, J., 1998. Biological and physical signs of climate change: focus on mosquito-borne diseases. *Bull. Am. Meteorol. Soc.* 79 (3), 409–418.
- Ezeakacha, N.F., Yee, D.A., 2019. The role of temperature in affecting carryover effects and larval competition in the globally invasive mosquito *Aedes albopictus*. *Parasites Vectors* 12, 123.
- Feldmann, H., Czub, M., Jones, S., Dick, D., Garbutt, M., Grolla, A., Artsob, H., 2002. Emerging and re-emerging infectious diseases. *Med. Microbiol. Immunol.* 191 (2), 63–74.
- Gasperi, G., Bellini, R., Malacrida, A.R., Crisanti, A., Dottori, M., Aksoy, S., 2012. A new threat looming over the Mediterranean basin: emergence of viral diseases transmitted by *Aedes albopictus* mosquitoes. *PLoS Neglected Trop. Dis.* 6 (9), e1836.
- Githko, A.K., Lindsay, S.W., Confalonieri, U.E., Patz, J.A., 2000. Climate change and vector-borne diseases: a regional analysis. *Bull. World Health Organ.* 78 (9), 1136–1147.
- Gould, E.A., Higgins, S., 2009. Impact of climate change and other factors on emerging arbovirus diseases. *Trans. R. Soc. Trop. Med. Hyg.* 103 (2), 109–121.
- Gubler, D.J., Reiter, P., Ebi, K.L., Yap, W., Nasci, R., Patz, J.A., 2001. Climate variability and change in the United States: potential impacts on vector- and rodent-borne diseases. *Environ. Health Perspect.* 109 (suppl 2), 223–233.
- Hanson, S.M., Craig Jr., G.B., 1994. Cold acclimation, diapause, and geographic origin affect cold hardiness in eggs of *Aedes albopictus* (Diptera: Culicidae). *J. Med. Entomol.* 31, 192–201.
- Hawley, W.A., Pumpuni, C.B., Brady, R.H., Craig Jr., G.B., 1989. Overwintering survival of *Aedes albopictus* (Diptera: Culicidae) eggs in Indiana. *J. Med. Entomol.* 26, 122–129.
- Impoinvil, D.E., Cardenas, G.A., Gihture, J.I., Mbogo, C.M., Beier, J.C., 2007. Constant temperature and time period effects on *Anopheles gambiae* egg hatching. *J. Am. Mosq. Control Assoc.* 23, 124–130.

- Institute of Medicine, 2003. Microbial Threats to Health: Emergence, Detection, and Response. National Academy of Sciences, Washington DC.
- I.R. of Iran Meteorological Organization, 2014. Climate Profile of Kashan County. Available from. <http://www.kashanmet.ir/>.
- Jemal, Y., Al-Thukair, A.A., 2018. Combining GIS application and climatic factors for mosquito control in Eastern Province, Saudi Arabia. Saudi. J. Biol. 25 (8), 1593–1602.
- Khan, M.A., Elhossary, S., Khan, I.A., Al Zahrani, M.H., Al Zahrani, F.S., Al Bashri, F.M., 2018. The impact of climatic variables with GIS application on the abundance of medically important mosquitoes (Diptera: Culicidae) in Jeddah, Saudi Arabia. Int. J. Mosq. Res. 5 (5), 12–18.
- Kilpatrick, A.M., Meola, M.A., Moudy, R.M., Kramer, L.D., 2008. Temperature, viral genetics, and the transmission of West Nile virus by *Culex pipiens* mosquitoes. PLoS Pathog. 4 (6), e1000092.
- Konno, J., 1969. Cyclic outbreak of Japanese encephalitis among pigs and humans. Am. J. Epidemiol. 10 (2), 132–133.
- Nejati, J., Zaim, M., Vatandoost, H., Moosa-Kazemi, S.H., Bueno-Marí, R., Azari-Hamidian, S., Sedaghat, M.M., Hanafi-Bojd, A.A., Yaghoobi-Ershadi, M.R., Okati-Aliabad, H., Collantes, F., 2020. Employing different traps for collection of mosquitoes and detection of dengue, Chikungunya and Zika vector, *Aedes albopictus*, in borderline of Iran and Pakistan. J. Arthropod-Borne Dis. 14 (4), 376–390.
- Paphitou, N.I., Tourvas, A., Floridou, D., Richter, J., Tryfonos, C., Christodoulou, C., 2017. The first human case of neuroinvasive West Nile virus infection identified in Cyprus. J. Infect. Public Health. 10 (6), 891–893.
- Pouriyavevali, M.H., Rezaei, F., Jalali, T., Baniyadi, V., Fazlalipour, M., Mostafavi, E., Khakifrouz, S., Mohammadi, T., Fereydooni, Z., Tavakoli, M., Azad-Manjiri, S., 2019. Imported cases of Chikungunya virus in Iran. BMC Infect. Dis. 19 (1), 1–8.
- Rahman, W.A., Hassan, A.A., Adanan, C., 1993. Seasonality of *Anopheles aconitus* mosquitoes, a secondary vector of malaria, in an endemic village near the Malaysia-Thailand border. Acta Trop. 55 (4), 263–265.
- Ram, S., Khurana, S., Kaushal, V., Gupta, R., Khurana, S., 1998. Incidence of dengue fever in relation to climatic factors in Ludhiana, Punjab. Indian J. Med. Res. 108, 128.
- Roiz, D., Ruiz, S., Soriguer, R., Figuerola, J., 2014. Climatic effects on mosquito abundance in Mediterranean wetlands. Parasites Vectors 7 (1), 1–13.
- Rogers, D.J., Packer, M.J., 1993. Vector-borne diseases, models, and global change. Lancet 342 (8882), 1282–1284.
- Shahgudian, E.R., 1960. A key to the Anophelines of Iran. Acta Med. Iran. 38–48.
- Simon-Oke, I., Olofintoye, L., 2015. The effect of climatic factors on the distribution and abundance of mosquito vectors in Ekiti State. J. Biol. Agric. Health. 5, 142–146.
- Subak, S., 2003. Effects of climate on variability in Lyme disease incidence in the northeastern United States. Am. J. Epidemiol. 157 (6), 531–538.
- Tabachnick, W.J., 1991. Evolutionary genetics and arthropod-borne disease: the yellow fever mosquito. Am. Entomol. 37, 14–26.
- Takahashi, M., 1976. The effects of environmental and physiological conditions of *Culex tritaeniorhynchus* on the pattern of transmission of Japanese encephalitis virus. J. Med. Entomol. 13 (3), 275–284.
- Tian, H.Y., Bi, P., Cazelles, B., Zhou, S., Huang, S.Q., Yang, J., Pei, Y., Wu, X.X., Fu, S.H., Tong, S.L., Wang, H.Y., 2015. How environmental conditions impact mosquito ecology and Japanese encephalitis: an eco-epidemiological approach. Environ. Int. 79, 17–24.
- Vatandoost, H., Raeisi, A., Saghafipour, A., Nikpour, F., Nejati, J., 2019. Malaria situation in Iran: 2002–2017. Malar. J. 18 (1), 1–7.
- Watson, R.T., Zinyowera, M.C., Moss, R.H., 1996. Impacts, adaptations and mitigation of climate change: scientific- technical analyses. In: Contribution of Working Group II to the Second Assessment of the Inter Governmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.
- Watson, R.T., Zinyowera, M.C., Moss, R.H., 1998. The Regional Impacts of Climate Change: an Assessment of Vulnerability. Special Report of the Inter Governmental Panel on Climate Change (IPCC) Working Group II. Cambridge University Press, Cambridge.
- Watts, D.M., Burke, D.S., Harrison, B.A., Whitmire, R.E., Nisalak, A., 1987. Effect of temperature on the vector efficiency of *Aedes aegypti* for dengue 2 virus. Am. J. Trop. Med. Hyg. 36 (1), 143–152.
- Weicheld, J., 2015. Impact of Environmental Factors on Mosquito Population Abundance and Distribution in King County, Washington. M. Sc dissertation.
- Wu, P.C., Guo, H.R., Lung, S.C., Lin, C.Y., Su, H.J., 2007. Weather as an effective predictor for occurrence of dengue fever in Taiwan. Acta Trop. 103 (1), 50–57.
- Zaim, M., Cranston, P.S., 1986. Checklist and keys to the culicinae of Iran (Diptera; Culicidae). Mosq. Systemat. 18, 233–245.