



Original article

Characterization of mosquito larval habitats in Qatar

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ABSTRACT

Mosquito borne diseases have remained a grave threat to human health and are posing a significant burden on health authorities around the globe. The understanding and insight of mosquito breeding habitats features is crucial for their effective management. Comprehensive larval surveys were carried out at 14 sites in Qatar. A total of 443 aquatic habitats were examined, among these 130 were found positive with *Culex pipiens*, *Cx. quinquefasciatus*, *Cx. mattinglyi*, *Ochlerotatus dorsalis*, *Oc. caspius* and *Anopheles stephensi*. The majority of positive breeding habitats were recorded in urban areas (67.6%), followed by livestock (13.8%), and least were in agriculture (10.7%). *An. stephensi* larvae were positively correlated with *Cx. pipiens*, *Cx. quinquefasciatus*, and negatively with water salinity. Large and shaded habitats were the most preferred by *An. stephensi*. In addition, *Cx. pipiens* was positively associated with the turbidity and pH, and was negatively associated with vegetation and habitat size. A negative association of *Cx. quinquefasciatus* with dissolved oxygen, water temperature, and salinity, while positive with habitat surface area was observed. *Oc. dorsalis* was negatively correlated with pH, water temperature, depth, and habitat surface area, whereas salinity water was more preferable site for females to lay their eggs. These results demonstrate that environmental factors play a significant role in preference of both anopheline and culicine for oviposition, while their effective management must be developed as the most viable tool to minimize mosquito borne diseases.

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1. Introduction

Mosquitos have inhabited the globe for more than 100 million years, and they are able to adjust their biology to a wide variety of ecological conditions enabling them to breed in diversified habitats (Becker et al., 2012). However, anthropogenic activities including transcontinental mobility and international trade has enabled cross-continental movement of mosquitoes and other

economically important insects (Saead et al., 2019; Khan et al., 2014). These conditions facilitate the dispersal and establishment of exotic mosquito species in other countries (Kraemer et al., 2015). The dispersion of these vector have resulted in the transmission of several deadly diseases in the populations, and these small insects are also the major source of nuisance (Ramirez et al., 2016). Among the vector borne disease, malaria is the most substantial in Qatar, because country hires most of its labor forces from malaria endemic countries like Sudan, India, Bangladesh and Pakistan. Qatar showed a decline in malaria incidences between 1997 and 2004, and an upsurge in the latter years, between 2008 and 2015 with 4092 imported cases of malaria (Farag et al., 2018).

Mosquito have diverse habitats that allow them to colonize different kinds of environments (Rueda, 2007). They utilizes a variety of aquatic habitats such as ponds, streams, ditches, swamps, marshes, temporary and permanent pools, rook holes, tree holes,

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crab holes, lake margins, plant containers (leaves, fruits, husks, tree holes, bamboo nodes), artificial containers (tires, tin cans, flower vases, bird feeders), for breeding (Rueda et al., 2010; Service, 2012). Despite of the several advancements in the vector control methods (Benelli, 2019), the most practical way to reduce a local population is to eliminate their breeding habitats (Muzari et al., 2017), while the identification of these habitats is the crucial to apply vector control approaches, as well as for diseases preventions (Ramasamy et al., 2011). In order to achieve this, understanding the oviposition preference and ecological data such as larval habitats, species composition, and seasonal abundance, play an important role in the management of mosquitoes (Azari-Hamidian, 2011; Banafshi et al., 2013). These environmental factors that affect the presence and density of mosquito larvae have been deeply investigated, and it had also been postulated that, neglecting the understanding of larval ecology can hamper the control efforts (Godfray, 2013).

The development and survival of immature mosquitoes can be influenced by several environmental factors vegetation type, chemical and physical conditions of breeding habitats and biological characteristics (Gouagna et al., 2012). The control of the vector is mainly dependent on the understanding of relationship between aquatic phase and the environment in which they grow, and the characterization of these breeding habitats, add knowledge about the biology, ecology and population dynamics of mosquito larvae (Ferreira et al., 2015). Furthermore, this information gives data that can impact or determine the area of oviposition and the endurance, spatial and temporal dispersion of these medically significant species (Arcos et al., 2018).

The competent vector of Malaria, *Anopheles* species have been reported from the neighboring countries Saudi Arabia (Alahmed, 2012; Alahmed et al., 2019; Munawar et al. 2020), and Iran (Banafshi et al., 2013; Nikookar et al., 2015; Nikookar et al., 2018), as well as in Qatar (Kardousha, 2016). Moreover, diversity and distribution of mosquitoes in Qatar has been investigated by a limited investigators (Mikhail et al., 2009; Ahmed, 2015; Kardousha, 2015, 2016), and there is no in-depth study on physico-chemical properties of breeding habitats of mosquitoes in Qatar which necessitates conducting further studies to fill this research and knowledge gap.

It was hypothesized that some habitats and environmental factors support mosquito multiplication over others and their identification might lead to modifying the prevalent management practices for effective control of mosquito borne diseases. Hence, the main objective of this study was to test the probability that presence of mosquito larvae could be predictable on the basis of habitat characteristics and to determine whether mosquito larval habitats in the area differ from those reported around the globe.

2. Materials and methods

2.1. Study area

Qatar (50°45' and 51°40' E longitude and 24°27' and 26°10' N latitude) lies within the vast desert belt extending from North Africa to Central Asia (Fig. 1). It is about 11,627.04 km² in adjoins with Saudi Arabia (Batanouny, 1981; Yasseen and Al-Thani, 2013).

Qatar is located in a region that is considered as arid or semi-arid, among the warmest regions of the world and it has a very hot summer and mild winter. Summer is the longest season extends from May to September, fall is short season during October and November, winter from December to February and spring from March to April. Summer is characterized by intense heat and alternating dryness and humidity, with temperature ranging up to 50 °C. Whereas, the temperature during the fall and winter season

is moderate (Batanouny, 1981; Yasseen and Al-Thani, 2013). The relative humidity in Qatar usually reaches 100% round the year, but it can reach minimum percentages of 5 and 28 during July and December respectively (Abulfatih et al., 2001). The period without rain, with high air temperature and high evaporation extends from April to September. Qatar receives low rainfall, and an average of 92 mm/year was recorded between 1990 and 2008, with a high rate of evaporation (Darwish and Mohtar, 2013).

The study areas were confined to 14 stations among the country; six out of 14 stations were monthly visited: Alkhor (St.1), Rawdat Alfaras (St.2), Alkaraana (St.3), Hazm Almarkhiya (St.4), Alwakra (St.5), and Nuaija (St.6). Eight stations out of the 14 stations namely, Doha (St.7), Alrayyan (St.8), Aldafna (St.9), Alkhiesa (St.10), Umm Salal (St.11), Alshahanya (St.12), Industrial area (St.13), and Mesaieed (St.14) were surveyed according to the availability of aquatic bodies. These sites were further divided into five areas according to nature of their landscapes and were grouped as urban (Hazm Almarkhiya, Nuaija, Doha, Alrayyan, Aldafna and Alkhiesa), agriculture (Rawdat Alfaras and Umm Salal), livestock farms (Alwakra and Alshahaniya), industrial areas (Industrial Area and Mesaieed), and natural areas (Alkhor and Alkaraana).

2.2. Water body features

Biotic and abiotic factors associated with the different sampling habitats were recorded. The characteristics of larval habitat that were recorded and used for the analysis included types of the water body, water temperature (°C), dissolved oxygen as mg/l, and pH were measured using PD 300 Waterproof Hand-held pH/ Dissolved Oxygen/ Temperature meter. Water salinity (%) was recorded using Portable Refractometer (FG-211-Salinity/ATC 0–100%). Depth (cm) of the small habitats was measured with metal ruler, while depth of the larger habitats was estimated visually. Similarly, length (m) and width (m) for the smaller habitats were measured with ruler and large habitats were estimated visually and by walks. The shade of the habitats were coded as unshaded when a habitat was exposed to sun for 10–11 h, while the partially or deeply sheltered habitats were coded as shaded. The water was classified as clear and turbid. Vegetation, algae and predators were categorized either as present or absent.

Mosquito larval samples were collected during October 2015 to May 2016, using the standard dipping techniques with a plastic enamel dipper (350 ml) following the method described by (Silver, 2008; Becker et al., 2010). In each breeding habitat, 3 up to 10 dips were taken depending on the habitat size and carefully visually inspected for presence/ and absence of mosquito larvae (Silver, 2008; Becker et al., 2010). Content of the positive habitats was transferred in to a separate plastic container (500 ml) labeled with all the necessary information (i.e. station, habitat type and date) and transported to the entomology laboratory.

2.3. Mosquito's species identification

All collected samples were identified up to species level both at larval (4th instar) and adult stage. Larvae were reared under controlled laboratory conditions following standard procedures. Larval and adult identification was done under a dissecting microscope by using the taxonomic literature provided by (Al Ahmad et al., 2011; Azari-Hamidian and Harbach, 2009; Glick, 1992; Rattanarithikul, 1982; Rueda, 2004; Zaim and Cranston, 1986; Stojanovich and Scott, 1966).

2.4. Data analysis

Descriptive analysis was used to calculate the abundance and frequency of mosquito larvae at different breeding habitats per

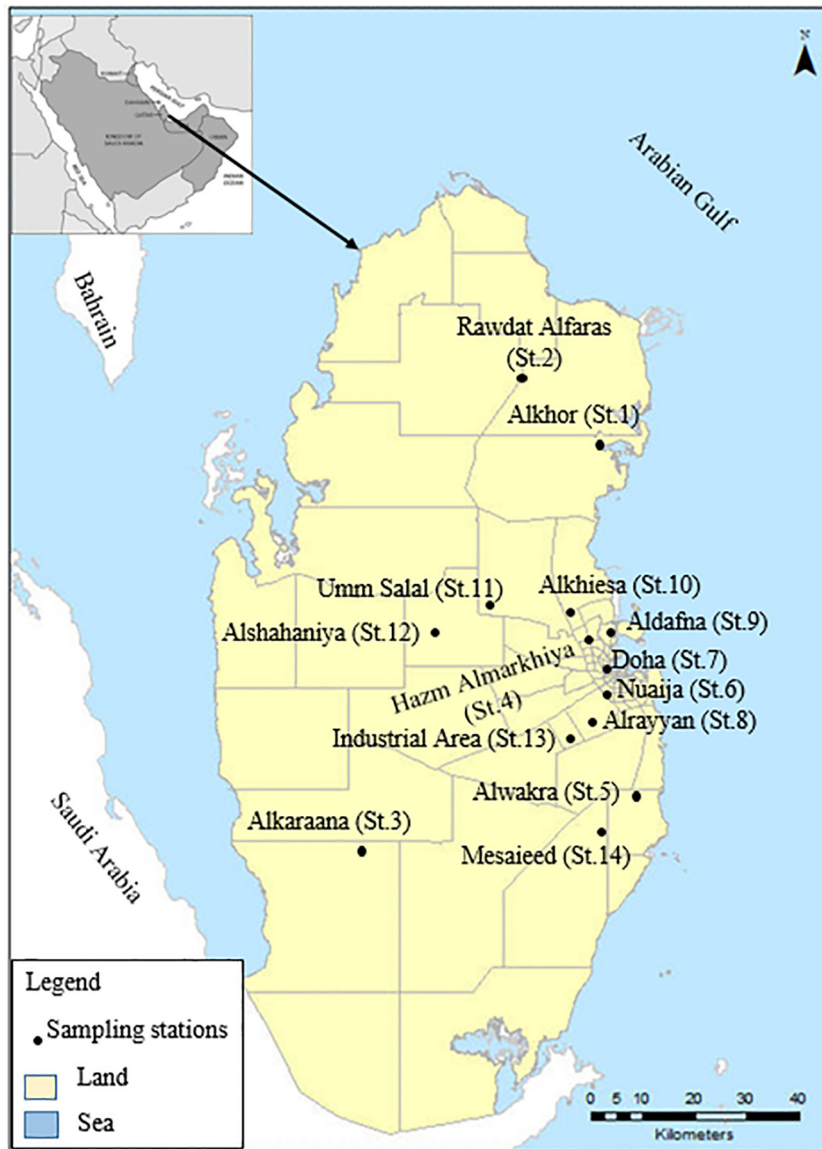


Fig. 1. Map of Qatar showing the 14 sampling stations.

stations in different regions. Chi-square test was utilized for determining association between the occurrence of mosquito larvae (negative/positive) and each physical factor (presence/absence) of the breeding habitat. Spearman rank correlation was used to correlate between larval abundance and water temperature, salinity, dissolved oxygen, pH, depth and habitat surface area for each species. A multivariable logistic regression analysis was performed with the presence/absence of mosquito larvae in the breeding habitats as the dependent variable and physico-chemical factors as explanatory variables. All the statistical analyses were performed using "STATA 12.00" (College Station, Texas 77,845 USA) and the significance level was set at $P = 0.05$.

3. Results

3.1. Type and distribution of mosquito breeding habitats

Overall 443 breeding habitats were surveyed of which 130 were found positive for mosquito larvae. The majority of the positive habitats (67.6%, $n = 88$) were in urban area followed by livestock (13.8%, $n = 18$), agriculture (10.7%, $n = 14$), industrial (5.4%, $n = 7$) and natural (2.31%, $n = 3$). In total, 11 mosquitoes breeding

habitats were identified. Out of the 130 positive habitats, drinking water pools (20%, $n = 26$), plastic containers (16.2%, $n = 21$), flooding sewage pools (16.2%, $n = 21$) and fountains (12.3%, $n = 16$) had the highest frequencies (Table 1).

3.2. The co-occurrence and abundance of mosquito larvae

Of 130 positive habitats, 83.1% ($n = 108$) were colonized by Culi-cine larvae, 5.4% ($n = 7$) was occupied by anopheline larvae and 11.5% ($n = 15$) was occupied by both genera. *Anopheles stephensi* immature stages were encountered to co-exist with both *Cx. pipiens* and *Cx. quinquefasciatus* in 7 breeding habitats. Whereas, *Cx. pipiens* and *Cx. quinquefasciatus* larvae were found co-exist only once in irrigation water pool. Overall, *Cx. quinquefasciatus* had the highest larval density (72.4 larva/dip), followed by *Cx. pipiens* (26.1), *Oc. dorsalis* (24.3) and *Oc. caspius* (20.7) whilst the lowest density was recorded for *An. stephensi* (11.1). (Table 2).

By excluding drainage, flooding sewage and tires due to their low data, water temperature was the highest in stream water (28.1 ± 8.12 °C) and lowest in the rising water table pool (20.2 ± 1.7 °C). The salinity was highest in rising water table ($4.15 \pm 1.16\%$) and lowest in drinking water pools, and fountains ($0.0 \pm 0.0\%$).

Table 1
Types and frequency of breeding habitats per station in 14 stations of Qatar.

Area	Station name	Breeding habitat type												Frequency of positive breeding habitats per stations (%)	Frequency of positive breeding habitats per areas (%)				
		N	1	2	3	4	5	6	7	8	9	10	11			12			
Urban	Hazm Almarkhiya	35	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	11 (8.46%)	88 (67.69%)
	Nuajja	105	0	0	0	0	0	0	6	0	6	0	0	0	0	0	12 (9.23%)		
	Doha	23	12	7	2	0	0	0	1	0	0	0	0	1	23 (17.69%)				
	Alrayyan	32	1	12	15	3	0	0	0	0	1	0	0	0	32 (24.61%)				
	Aldafna	9	0	5	0	0	0	1	1	0	0	1	0	0	8 (6.15%)				
Agriculture	Alkhiesa	2	0	0	0	2	0	0	0	0	0	0	0	0	2 (1.54%)	14 (10.77%)			
	Rawdat Alfaras	44	0	0	1	0	1	8	0	0	0	0	0	0	10 (7.69%)				
Livestock	Umm Salal	4	0	0	1	0	3	0	0	0	0	0	0	0	4 (3.07%)	18 (13.85%)			
	Alwakra	38	0	0	0	0	0	0	13	0	0	0	0	0	13 (10%)				
Industrial	Alshahaniya	6	0	0	0	0	1	4	0	0	0	0	0	0	5 (3.85%)	7 (5.438%)			
	Industrial area	5	1	2	2	0	0	0	0	0	0	0	0	0	5 (3.85%)				
Natural	Mesaieed	2	0	0	0	0	0	0	0	0	2	0	0	0	2 (1.54%)	3 (2.31%)			
	Alkhor	68	0	0	0	0	0	0	0	0	0	2	0	2 (1.54%)					
	Alkaraana	70	0	0	0	0	0	0	0	0	0	1	0	1 (0.77%)					
Total	443	14	26	21	16	5	13	21	0	9	1	3	1	130					
Percentage of breeding habitats %	10.77	20	16.15	12.31	3.85	10	16.15	0	6.92	0.77	2.31	0.77							

Key: 1 drainage; 2 drinking water pool; 3 flooding sewage pool; 4, fountain; 5, irrigation water pool; 6, metal container; 7, plastic container; 8, pond; 9, rising water table pools; 10, stream; 11, treated sewage swamp; 12, tire. N, total of breeding habitats investigated per station

Dissolved oxygen was highest in treated sewage swamps (10.2 ± 2.89 mg/l) and lowest in rising water table pools (6.4 ± 0.93 mg/l). The pH was weak basic in treated sewage swamps (7.96 ± 1.01) and weak acidic in rising water table (5.8 ± 0.32) (Table 3).

3.3. Correlation of ecological variables with larval abundance

Spearman correlation analysis of mosquito larval occurrences with each measurable environmental variables showed that the presence of *An. stephensi* larvae were positively correlated with *Cx. pipiens* ($r = 0.1155$, $P < 0.05$), *Cx. quinquefasciatus* ($r = 0.1856$, $P < 0.05$) and negatively with water salinity ($r = -0.1176$, $P < 0.05$). *Cx. quinquefasciatus* was negatively associated with dissolved oxygen, salinity and habitat surface area ($P < 0.05$). *Cx. pipiens* was reversely correlated with water temperature, depth, pH and water salinity ($P < 0.05$). Similar negative correlations were obtained between *Oc. dorsalis* and pH, depth, habitat surface area but positively with water salinity ($r = 0.1826$, $P < 0.05$) (Table 4).

3.4. Association between larval occurrence and each of the physical factor of breeding habitats

An. stephensi was significantly associated with habitats without vegetation ($P = 0.001$) and predators ($P = 0.043$). *Cx. pipiens* was significantly associated with habitats without vegetation ($P = 0.000$) and more likely to be present in habitats without predators ($P = 0.032$). In addition, *Cx. quinquefasciatus* larvae were more likely to be present in habitats with Turbid water ($P = 0.000$), without vegetation ($P = 0.000$), with algae ($P = 0.05$) and without aquatic predators ($P = 0.001$) and in unshaded habitats ($P = 0.000$). Moreover, *Oc. dorsalis* larvae were more likely to occupy unshaded habitats ($P = 0.000$) and without algae ($P = 0.000$). However, due to small sample size for *Cx. mattinglyi*, and *Oc. caspius* data were not analyzed (Table 5).

Further a series of multilogistic regression analysis detected and predicted the physical parameters for presence of mosquito larvae in the breeding habitat (Table 6). The analysis revealed that water depth ($P = 0.006$) and vegetated habitats ($P = 0.000$) were unlikely

Table 2
Types and frequency of positive breeding habitats plus the average larval density/dip of mosquito species in 14 stations in Qatar.

Breeding habitat type	N	positive habitat	<i>An. stephensi</i> (%)	<i>Cx. pipiens</i> (%)	<i>Cx. quinquefasciatus</i> (%)	<i>Cx. mattinglyi</i> (%)	<i>Oc. dorsalis</i> (%)	<i>Oc. caspius</i> (%)
Drainage	14	14	1 (7.1%)	8 (57.1)	5 (35.7%)	0 (0.0%)	0 (0.0%)	1 (7.1%)
Drinking water pools	26	26	4 (15.4%)*	15 (57.6%)*	11 (42.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Flooding sewage pools	21	21	1 (4.7%)*	1 (4.7%)	20 (95.2%)*	0 (0.0%)	0 (0.0%)	0 (0.0%)
Fountain	42	16	4 (9.5%)*	9 (21.4%)*	3 (7.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Irrigation water pools	5	5	4 (80%)*	2 (40%)*	1 (20%)*	0 (0.0%)	0 (0.0%)	0 (0.0%)
Metal container	47	13	1 (2.1%)*	11 (23.4%)*	2 (4.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Plastic container	90	21	7 (7.7%)*	3 (3.3%)	15 (16.6%)*	0 (0.0%)	0 (0.0%)	0 (0.0%)
Ponds	47	0	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Rising water table	11	9	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (9.1%)	6 (54.5%)	1 (9.1%)
Stream	66	1	0 (0.0%)	1 (1.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Treated sewage swamp	73	3	0 (0.0%)	0 (0.0%)	1 (1.3%)	0 (0.0%)	2 (2.7%)	0 (0.0%)
Tire	1	1	0 (0.0%)	0 (0.0%)	1 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total	443	130 (29.3%)	22 (4.9%)	50 (11.3)	59 (13.3%)	1 (0.2%)	8 (1.8%)	2 (0.4%)
average larval density/dip			11.1	26.1	72.4	14	24.3	20.7

* Co-existence of *An. stephensi* & *Cx. pipiens*.

* *An. stephensi* & *Cx. quinquefasciatus*.

† *Cx. pipiens* & *Cx. quinquefasciatus*; N, total number of habitat.

Table 3
The Physio-chemicals parameters (mean \pm SD) of different mosquito breeding habitats in Qatar.

Habitat type	N	Parameter Mean \pm SD			
		WT °C	Salinity %	DO mg/l	pH
Drainage	14	na	na	na	na
DWP	26	20.9 \pm 3.2	0.00 \pm 0.00	na	6.3 \pm 0.43
FWP	21	na	na	na	na
Fountain	42	23.4 \pm 6.8	0.00 \pm 0.00	7.8 \pm 1.07	6.3 \pm 0.53
IWP	5	21.7 \pm 2.4	0.35 \pm 1.47	7.1 \pm 0.07	6.5 \pm 0.71
MC	47	20.7 \pm 5.8	1.02 \pm 0.69	6.9 \pm 1.13	6.3 \pm 0.53
PC	90	23.0 \pm 4.9	0.29 \pm 0.67	6.6 \pm 0.91	6.1 \pm 0.36
Pond	47	22.4 \pm 3.9	3.69 \pm 0.48	6.9 \pm 0.60	6.4 \pm 0.88
RWT	11	20.2 \pm 1.7	4.15 \pm 1.16	6.4 \pm 0.93	5.8 \pm 0.32
Stream	66	28.1 \pm 8.1	1.51 \pm 1.33	9.0 \pm 1.97	7.6 \pm 1.24
TSS	73	27.9 \pm 5.7	0.74 \pm 1.21	10.2 \pm 2.89	7.9 \pm 1.01
Tire	1	na	na	na	na

Key: DWP, drinking water pool; FWP, Flooding sewage pools; IWP, irrigation water pool; MC, metal container; PC, plastic container; RWT, rising water table pool; TSS, treated sewage swamp; WT, water temperature; na, not applicable.

Table 4
Correlation coefficients between measurable environmental variables and mosquito larval occurrence in Qatar.

Factor variables	<i>An. stephensi</i>	<i>Cx. quinquefasciatus</i>	<i>Cx. pipiens</i>	<i>Cx. mattinglyi</i>	<i>Oc. dorsalis</i>
<i>An. stephensi</i>	1				
<i>Cx. quinquefasciatus</i>	0.1856*	1			
<i>Cx. pipiens</i>	0.1155*	-0.1188*	1		
<i>Cx. mattinglyi</i>	-0.0109	-0.0186	-0.017	1	
<i>Oc. dorsalis</i>	-0.031	-0.0532	-0.0484	-0.0065	1
pH	-0.0479	0.007	-0.1112*	-0.0119	-0.1514*
DO (mg/l)	-0.0964	-0.1192*	-0.0396	-0.0023	0.0052
Water temp °C	-0.0656	-0.1144*	-0.2513*	-0.0037	-0.0892
Salinity ‰	-0.1176*	-0.1992*	-0.1841*	0.0894	0.1826*
Water depth (cm)	-0.0134	-0.0608	0.1276*	-0.0738	-0.1466*
Habitat surface (m ²)	-0.0238	-0.2002*	-0.0911	0.0633	0.1116*

* P value < 0.05; numbers indicate correlation coefficient (r).

to occupy by *An. stephensi* larvae while large and shaded habitats were the most preferable habitats for *An. stephensi* to lay their eggs. *Cx. pipiens* was positively associated with the turbidity (P = 0.008) and water pH (P = 0.040), but negatively associated with vegetation and habitat surface area (P = 0.000). While dissolved oxygen (P = 0.009), water temperature (P = 0.000) and salinity (P = 0.022) were found to be negatively associated with presence of *Cx. quinquefasciatus* larvae. Regarding *Cx. mattinglyi* and *Oc. caspius* the data were not analyzed due to small sample size data.

4. Discussion

Qatar is mainly plane with a dry and hot climate where rainfall remains unpredictable. The breeding habitats of mosquitoes in different areas were mainly formed as a result of human activities and urbanization related factors (drainage, drinking water pools, flooding sewage pools, fountains, irrigation water pools, artificial containers either metal or plastic containers, rising water table pools, streams, treated sewage swamps and tires) serve as excellent larval breeding habitats. Generally, there is variety of suitable breeding habitats for mosquito larvae, and there was no report on habitat characteristics of mosquito larvae found in Qatar.

During the present surveys, twelve aquatic bodies at five different landscape areas were investigated, of which eleven were found positive, except the ponds. The majority of these habitats were found in the six stations at urban areas, where there is an expansion of urbanization observed in most cities of Qatar, which provides suitable breeding habitats for mosquitoes (LaDeau et al., 2015; Ramirez et al., 2016). Mosquito breeding habitats were also found in livestock farms, and agriculture areas where mosquito

prefer to live close to host to get their blood meal and availability of rotting organic materials for the larval habitats (Mwangangia et al., 2009). Industrial areas of the present study were lacking of infrastructure, which has led to the existence of habitats due to leakage of water or flooded sewage. Fewer breeding habitats were found in the natural areas, perhaps this is due to the distance from the urban or livestock areas. Therefore, it is challenging for mosquitoes to obtain their blood meal, due to less human activities there. Most of the breeding habitats in this survey, that were found favourable breeding habitats for mosquito larvae, were still water with turbidity, and presence of algae, which is similar to the other studies (Fillinger et al., 2009).

An. stephensi was found breeding in a wide range of temporary habitats during the study period. Most of these habitats were stagnant, relatively small and were partially shaded. In urban areas, it was found in drinking water pools, fountains, and drainage, while in livestock farms, this species was found breeding in plastic and metal containers, whereas, in agricultural area, irrigation water pools were found positive. These results are in agreement with the findings of (Impoinvil et al., 2008; Hanafi-Bojd et al., 2012; Keshavarzi et al., 2017). Conversely, these results are varying with some other's observations, where anopheline larvae were found colonizing small water bodies in unshaded places (Fillinger et al., 2009; Banafshi et al., 2013) stagnant water (Amani et al., 2014; Soleimani-Ahmadi et al., 2014) and polluted habitats (Emidi et al., 2017). Similar observations were seen in the previous findings from Qatar, that showed *An. stephensi* larvae were found in artificial water containers in agriculture farms in Rawdat Rashed (Ahmed, 2015). The physicochemical parameters of the breeding habitats of current findings showed that *An. stephensi* can breed in a diverse range of habitats, which is similar to the findings by

Table 5

The association between present/absent of mosquito larvae and environmental parameters.

Species	Variables	N (%)	χ^2	P value		
<i>An. stephensi</i>	Shade	unshaded	8 (36.36%)	2.17	0.140	
		shaded	14 (63.64%)			
	Turbidity	Clear	10 (45.5%)	0.14		0.702
		Turbid	12 (54.5%)			
	Vegetation	absent	12 (54.55%)	11.43		0.001
		present	10 (45.45%)			
Algae	absent	10 (45.5%)	2.71	0.100		
	present	12 (54.5%)				
Predator	absent	16 (72.7%)	4.10	0.043		
	present	6 (27.3%)				
<i>Culex pipiens</i>	Shade	unshaded	20 (40%)	3.08	0.079	
		shaded	30 (60%)			
	Turbidity	Clear	31 (62%)	3.56		0.059
		Turbid	19 (38%)			
	Vegetation	absent	27 (54%)	26.8		0.000
		present	23 (46%)			
Algae	absent	20 (40%)	2.80	0.094		
	present	30 (60%)				
Predators	absent	33 (66%)	4.62	0.032		
	present	17 (34%)				
<i>Culex quinquefasciatus</i>	Shade	Unshaded	35 (59.32%)	1.58	0.208	
		Shaded	24 (40.68%)			
	Turbidity	Clear	14 (23.7%)	17.99		0.000
		Turbid	45 (76.3%)			
	Vegetation	absent	50 (84.75%)	134.54		0.000
		present	9 (15.25%)			
Algae	absent	24 (40.7%)	3.85	0.050		
	present	35 (59.3%)				
Predators	absent	42 (71.2%)	10.35	0.001		
	present	17 (28.8%)				
<i>Ochlerotatus dorsalis</i>	Shade	Unshaded	6 (66.7%)	29.80	0.000	
		Shaded	3 (33.3%)			
	Turbidity	Clear	6 (66.7%)	1.12		0.290
		Turbid	3 (33.3%)			
	Vegetation	absent	2 (22.2%)	0.015		0.904
		present	7 (77.8%)			
Algae	absent	8 (88.9%)	15.33	0.000		
	present	1 (11.1%)				
Predators	absent	6 (66.7%)	0.82	0.364		
	present	3 (33.3%)				

Table 6

The key physicochemical parameters associated with presences of mosquito larvae in Qatar.

Mosquito species	Ecological variables	Odd Ratio (95% CI)	P-value
<i>An. stephensi</i>	Vegetation	0.099 (0.034–0.282)	0.000
	Shade	4.84 (1.74–13.50)	0.002
	Water depth (cm)	0.986 (0.972–1.01)	0.006
<i>Cx. pipiens</i>	Habitat surface (m ²)	1.26 (1.12–1.44)	0.000
	Turbidity	4.92 (1.50–16.08)	0.008
	Vegetation	0.029 (0.007–0.12)	0.000
	pH	2.49 (1.04–5.97)	0.040
<i>Cx. quinquefasciatus</i>	Habitat surface (m ²)	0.422 (0.194–0.966)	0.029
	DO (mg/l)	0.552 (0.353–0.861)	0.009
	Water temperature °C	0.802 (0.722–0.890)	0.000
	Salinity ‰	0.871 (0.773–0.979)	0.022
	Habitat surface (m ²)	1.175 (1.023–1.351)	0.023

Emidi et al. (2017), whereas (Amani et al., 2014) reported that *Anopheles* species prefers to breed in fresh clear water. Whereas, Amin (1989) and Ismaeel et al. (2004) reported that *An. stephensi* breeds in freshwater of domestic wells in Bahrain, which is in contrast to the current findings.

In this study *An. stephensi* larvae showed a positive association with shaded habitat, while previously many investigators reported that *An. stephensi* was a hialophilic mosquito (Minakawa et al., 1999; Impoinvil et al., 2008; Fillinger et al., 2009; Hanafi-Bojd et al., 2012; Banafshi et al., 2013). A significant association was

seen with habitats without vegetation, and habitats without predators, which is similar to other findings (Minakawa et al., 1999; Amani et al., 2014; Soleimani-Ahmadi et al., 2014). *An. stephensi* larvae are more likely to occupy the shallow and relatively large breeding habitats. Results showed that *An. stephensi* larvae had no significant association with water temperature, which is similar to finding from Ethiopia (Dejenie et al., 2011). On other hand, this study revealed that *An. stephensi* had no association with dissolved oxygen, pH, predators, and negatively associated with vegetation, which is dissimilar with the finding on anopheline larvae in Ethiopia (Dejenie et al., 2011).

During the survey, *Culex* and *Ochlerotatus* species were found in a variety of habitats including drainage, drinking water pools, flooding sewage pools, fountains, metal containers, plastic containers, rising water table pools, stream and tires present in urban regions. Majority of the culicine larvae were collected from habitats formed by leakage of drinking water pipes and flooding of sewage, similar to the findings from Kenya (Impoinvil et al., 2008). In the agriculture areas, only two *Culex* species; *Cx. pipiens* and *Cx. quinquefasciatus* were encountered in irrigation water pools, and plastic containers. In addition, in livestock farms, the two species larvae were found in plastic containers and metal containers. Two *Culex* species were encountered in most of the breeding habitats. This became evident that immature *Culex* spp have a strong degree of adaptation than other mosquitoes to utilize a variety of habitats (Dida et al., 2018). *Cx. pipiens* was collected from pools of leaking drinking water, metal containers, fountains and as well as drainage in urban areas, while similar patterns have

been reported in the neighboring countries including Saudi Arabia (Ahmed et al., 2011) and Iran (Banafshi et al., 2013). Additionally, this species was found in less frequency from agriculture and livestock areas. Previous studies from Qatar reported that, *Cx. pipiens* was found in treated sewage swamp in Alkaraana (Abushama, 1997), but this species was not found during these surveys from the same area. The preferred breeding habitats during the present study were mainly unshaded, turbid, and without vegetation. The result also showed a significant association with the absence of predators. Moreover, the findings of this study showed that *Cx. pipiens* larvae had a positive association with pH and no association with water temperature, which is in agreement with the finding from Ethiopia (Dejenie et al., 2011).

Cx. quinquefasciatus was widely distributed and collected from all the water sources in all the studied landscapes. A study conducted in Kenya reported its association with urban areas, where it was found mostly in organically rich water in livestock landscapes (Mwangangia et al., 2009). *Cx. quinquefasciatus* was the most dominant in most of breeding habitats and that might be due to its wide range of breeding habitats (Dida et al., 2018). These findings are similar with the results from India, where *Cx. quinquefasciatus* was documented as container-breeding mosquitoes (Gopalakrishnan et al., 2013), while in Saudi Arabia, *Cx. quinquefasciatus* was found limited to coastal areas (Abdullah and Merdan, 1995).

Cx. quinquefasciatus was found strongly associated with turbid aquatic water, without vegetation. A significant association was seen between the presence of algae and with the absence of predators which indicated that the physical parameters tend to play an important role in determining the preferred-breeding habitat. Moreover, findings of present study revealed that *Cx. quinquefasciatus* larvae were inversely associated with dissolved oxygen. These observations are in accordance with the study from Nigeria (Popoola and Otalekor, 2011). In contrast, its positive association with dissolved oxygen had also been observed (Dida et al., 2018). *Cx. quinquefasciatus* larvae had a negative correlation with water temperature and salinity, and more likely found in a relatively large habitats which is in contrast with the finding from Ethiopia regarding anopheline and culicine larvae (Dejenie et al., 2011).

Interestingly, *Cx. mattinglyi* was encountered only once during the study period with a small number of sample, and it was limited only to the rising water table at urban area of inland marshes. It preferentially seems to breed in high saline water. More investigations are required on this species from the Qatar. *Ochlerotatus* larvae were found in urban, industrial and natural areas. Two *Ochlerotatus* species showed a less diversity in larval habitats, and were encountered for the first time during present survey at three breeding habitats (rising water table pools, drainage and treated sewage swamps). *Oc. dorsalis* was encountered in the two breeding habitats, mostly found in rising water table pools in inland marshes in the urban area, and treated sewage swamps at the natural coastal area in Alkhor. It is found associated to unshaded habitats and with absence of algae. *Oc. caspius* larvae were encountered only in the urban area close to human dwellings. The larvae of this species were collected from shallow rising water table pools in the inland marshes, and from drainage water, where the salinity was 100‰ in the former habitat and with rotting organic materials in the second habitat. In agreement with this finding, previous studies conducted in the southwestern Saudi Arabia reported that larvae of this species inhabit water with highly salinity (Abdullah and Merdan, 1995; Ahmed et al., 2011).

In this study, the co-existence of *An. stephensi* larvae with *Cx. pipiens* larvae were found in drinking water pools in urban areas, and were also found in fountains, irrigation water pools and metal containers where these habitats are characterized by its relatively small size, stagnant water and presence of algae. Co-existence of

An. stephensi larvae and *Cx. quinquefasciatus* larvae were frequently found in the plastic containers in livestock farms. Whereas co-exist of *An. stephensi* and *Cx. quinquefasciatus* encountered with less frequency in flooding sewage pools and irrigation water pools at agriculture areas. *Cx. pipiens* was found to co-exist with *Cx. quinquefasciatus* in irrigation water pools. Co-existence of anopheline and culicine larvae may be attributed to its relatively small size of the container with stagnant water and rotting organic materials. The co-existing patterns of *An. stephensi* larvae with other *Anopheles* larvae were found in Iran (Hanafi-Bojd et al., 2012; Amani et al., 2014; Soleimani-Ahmadi et al., 2014), which may be due to the similar biological requirements of these species (Hanafi-Bojd et al., 2012). In addition, the ability to adapt their life to a wide range of environmental conditions (Soleimani-Ahmadi et al., 2014). Similarly, *Cx. pipiens* and *Oc. caspius* larvae were found co-exist with *Anopheles* and other *Culex* larvae in natural habitats (river edges or ground pools) in western Iran (Banafshi et al., 2013), while *Oc. caspius* larvae were found associated with *Cx. pipiens* and *Cx. quinquefasciatus* in Saudi Arabia (Abdullah and Merdan, 1995).

The current surveys revealed that most of the breeding habitats were resulted from human activities, and majority of them were found close to human dwelling, which in turn increases the risk of mosquito borne-disease. Additionally, the behavior of people of Qatar can potentially lead to the occurrence of more breeding habitats. For examples, many new houses have fountains and/or swimming pools, and these habitats were found positive with *An. stephensi* and *Cx. pipiens*. Moreover, during the drought conditions, people provides water containers for the wild birds and cats in their backyards, which were also the productive breeding habitats during this study.

5. Conclusion

These studies will help in operational programs for controlling the mosquito vectors coincides with educating the community and emphasis personal protection methods. Therefore, there is need for further investigation with emphasis on biology and ecology of mosquito larvae and adults. In future, more studies are required on the physicochemical parameters of mosquito larvae breeding habitats due to diverse larval habitats and co-existence of mosquito vectors that were incriminated in the transmission of malaria, filariasis, yellow fever and rift valley virus in the country, which expose the citizen to risk of infection.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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