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Spatial Distribution of Appropriate Aquatic Mosquitos' Larval Sites Occurrence Using Integration of Field Data and GIS Techniques

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ABSTRACT

Mosquitoes are the most important vectors of several serious diseases. They can transmit filaria, malaria, dengue fever, Rift Valley fever virus, West Nile virus zika (ZIKV) and chikungunya (CHIKV). The spatial distribution analysis of mosquito occurrence increases our understanding of the Nile Valley transmitted diseases locality, which helps the decision makers to find alternative plan to reduce the diseases spread. This paper examined patterns of environmental variability of mosquito species locality using spatial distribution models. The present study aimed to identify environmental characteristics associated with mosquito breeding sites in Gharbia Governorate, Egypt using geographical information system (GIS), field surveys and analyses of mosquito larvae and breeding water. Spatial distribution models were performed by ArcGIS $^{(10.8)}$ and statistically analyzed by R package. The results recorded the occurrence of *Culex pipiens, Cx. Perexiguus, Cx. antennatus* and *Cx. tritaeniorhynchus* in El Gharbia Governorate, Egypt, and the most common species was *Culex pipiens*. The highest diversity was (D = 0.831), and the species richness (S) recorded was 13 in Tanta City. The results revealed that regarding TDS, an insignificant variation ($P > 0.05$) was detected between all studied sites and (Temperature and PH), (TDS), (PH), (TDS and Temperature) and (TDS) that were the most effective parameters in controlling species abundance within each studied site, compared to the remaining parameters.

INTRODUCTION

Global warming has increased in alarming rates during the last decades and predicted to have significant effects on species ranges in the decades to come. The continued warming leads to mosquito-borne diseases affecting human health. The higher global temperatures of some models will enhance their transmission rates and extend their geographic ranges **(Reiter, 2001; Pinsky *et al*., 2019; Lehmann *et al*., 2020; Rohr & Cohen, 2020)**.

Mosquitoes are more significant in terms of serious public health issues. According to the World Health Organization, 247 million people fell ill in tropical and subtropical regions of the world in 2006, and about a million people died from mosquito-borne diseases **(WHO, 2008)**. Mosquitoes have a vital role in the transmission of diseases including malaria, dengue (DENV), zika (ZIKV), and chikungunya (CHIKV), which infect 300 million people annually **(Franklinos *et al*., 2019)**. **WHO (2010)** reported that deaths number were estimated to be reduced in 2009 to 781,000. Various mosquito species from the genera *Culex*, *Aedes* and *Anopheles* are important vectors of several dangerous diseases **(Weaver & Reisen, 2010; Kilpatrick, 2011)**.

Numerous diseases including filariasis, malaria, dengue, and Rift Valley fever are biologically transmitted by mosquitoes **(Hassan *et al*., 2014; Qamandar & Shafeeq, 2018; Hassanain *et al*., 2019; Tamilventhan & Jayaprakash, 2019; El Mehdawy *et al*., 2021)**. Malaria **(Farid, 1940)**, the West Nile virus **(Taylor *et al*., 1956)** and dengue fever are the three mosquito-borne illnesses affecting people most frequently in Egypt **(Gaber *et al*., 2022; Fang *et al*., 2022)**.

Additionally, by accurately predicting habitat suitability using GIS techniques, it is possible to build mosquito vector control strategies that are as effective as possible **(Agarwal *et al*., 2012)**. As a result, most developed nations are using similar systems to create their own tiers of policy to reduce mosquito problems. Moreover, geographical mapping was made possible by remote sensing offering the chance to locate larval homes over a wide geographic area, which is something that is challenging or impossible to do by field surveys. In environmental studies of mosquitoes, various studies have effectively used geospatial tools (remote sensing and GIS). Finally, due to the local travel challenges associated with accessing this location for research, the information regarding the spatial distribution of mosquito species within the study area is still unavailable.

Several factors affect the distribution and species composition of immature mosquito species, including urbanization, vegetation, climate, the physicochemical characteristics of water in the habitat and interspecific association **(Nikookar *et al*., 2017; Wilke *et al*., 2019)**.The physicochemical parameter of a mosquito breeding site expresses a vital influence on the uncomplete stage of the mosquito life cycle and has significant implications for mosquito management **(Selvan *et al*., 2015; Gao *et al*., 2018)**. It has been demonstrated that some of these factors, including pH, salinity, dissolved oxygen (DO) and total dissolved solids (TDS) affect the density of *Ae. aegypti* and *Ae. Albopictus* **(Che Dom *et al*., 2016; Nikookar *et al*., 2017)**. Data on the environmental variable influencing mosquito larval abundance, including the physicochemical parameter of the water of the breeding sites and interspecific associations are vital in survival, biodiversity, affinity, spatio-temporal distribution, and association indices of disease vectors. The data could be used for creating and implementing effective vector control programs **(El-Zeiny & Sowilem, 2016)**.

The present work aimed to study the environmental characteristics associated with mosquito breeding sites in El Gharbia Governorate, Egypt using geographical information system (GIS), field surveys and the analyses of both the mosquito larvae and breeding water. In addition, geoinformatics techniques were used to evaluate the spatial distribution of mosquito species in El Gharbia Governorate, Egypt in relation to trends in environmental characteristics.

MATERIALS AND METHODS

Study area

El Gharbia Governorate located in the middle of the Delta in the north of Egypt (31.0335° E, 30.8754° N), about 90 kilometers north of Cairo and 120 kilometers southeast of Alexandria. It covers an area of 1.942 km^2 .It includes 8 cities; namely, El Mahalla El Kubra, Kafr El Zayat, Samanoud, Tanta, Zifta, El Santa, Kotoor and Basyoun. Several water sources, a long irrigation network, several wells and seepage water are found in the governorate, as seen in Fig.(1b). This affects the prevalence and number of mosquitoes **(Kenawy & El Said, 1990)**.

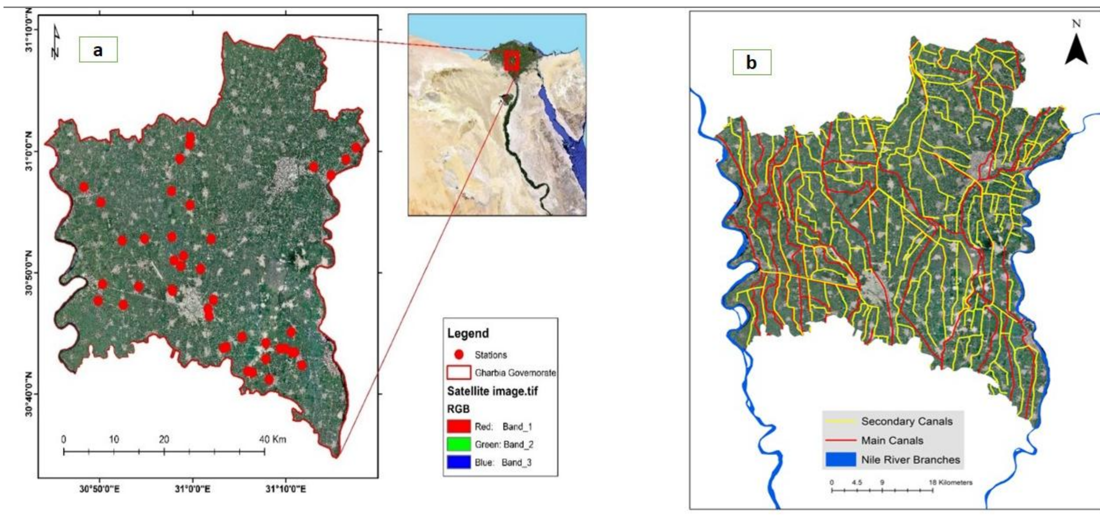


Fig.1. (a) Locations of the study area; **(b)** Water sources nearest study locations

Sample collections

The current study was designed to identify the characteristics of mosquito breeding sites by collecting samples from various locations and monitoring them in the Gharbia Governorate area in 2022. These locations' small stagnant water bodies, such as irrigated fields, drainage canals, sewage, sabkha land, cesspools, cesspits and seepage regions were used to gather mosquito larvae by dipping a small ladle with a 90cm wooden handle and a 10.5cm diameter from these locations (Fig. 2).

Larvae were collected and brought to the Research Institute of Medical Entomology in labelled glass vials with a fixative solution (70 percent ethanol) for morphological identification using the keys of **Harbach (1988)** and **Glick (1992)**. A handheld Global Positioning System device was used to coordinate each site visited (GPS, Magellan 320-USA). In addition, the Adwa (AD31) apparatus was used to test the temperature of water and total dissolved solids (TDS), whereas the Adwa (AD11) device was utilized to detect potential hydrogen (pH).

Fig. 2. Different breeding habitats of mosquito larvae in El Gharbia Governorate, Egypt

Data processing and GIS analyses

Following the identification of the several mosquito larvae species, a map for each species was created using Inverse Distance Weighting (IDW) in ArcGIS 10.8. Species abundance, species density, Simpson diversity, species richness, species evenness and Shannon Wiener index of diversity were geographically represented in each map individually. On the other hand, the environmental parameters such as TDS, temperature and PH were individually mapped to find the correlation between the spatial distribution model and environmental conditions of the mosquito sites.

Statistical analysis

Data were coded and entered using the statistical package SPSS V.22. Data were tested for satisfying assumptions of parametric tests, and continuous variables were subjected to Shapiro- Wilk and Kolmogorov-Smirnov test for normality. Probability and percentile data were standardized for normality using Arcsine Square Root. Data were presented as mean and standard deviation. ANOVA analyses were done, and post-hoc analysis was evaluated using Tukey pairwise comparison; *P*-value was considered significant at $P<0.05$, using MiniTab V 14. Pairwise regression was performed to produce predicted equation and highlight the effective physical parameters for mosquito abundance; the analysis became available using SigmaPlot V12.0. Data were visualized when possible, using R studio V 2022.02.4.

RESULTS

The spatial variation in diversity and *Culex* species richness among the different localities of the study

To figure out an understandable image about the spatial variation of *Culex* species' diversity in the study area, three different parameters were measured, Simpson index of diversity, species richness (species number in a community) in addition to species evenness, which refers to how species abundance is distributed between the species.

The spatial variation in diversity and *Culex* species richness among the different study area localities are shown in Table (1) and Figs. (3, 4). A high variation was recorded in the Simpson diversity index (D) between the study localities in the study regions. The localion recording the highest diversity was Tanta City, with D= 0.831, whereas the species richness (S) recorded was 13. While, the localities that recorded the lowest diversity were Basyun City and Samanoud City, with D= 0.507 and 0.600, respectively.The species richness (S) recorded for these localities were 2 and 3, respectively.

Table 3. Environmental indices at investigated sites

Location	Species richness (S)	Abundance	Simpson diversity	Shannon-Wiener Index of diversity (H')	Species evenness (H'/ln(S))
El-Santa	11	97	0.754	2.310	0.963
Tanta	13	55	0.831	2.077	0.810
Basyun	2	71	0.507	0.693	1.000
Kafr-Elzayat	4	17	0.721	1.236	0.892
Kotoor	6	27	0.664	1.329	0.742
Samanoud	3	26	0.600	0.950	0.864
Zefta	6	61	0.738	1.519	0.848

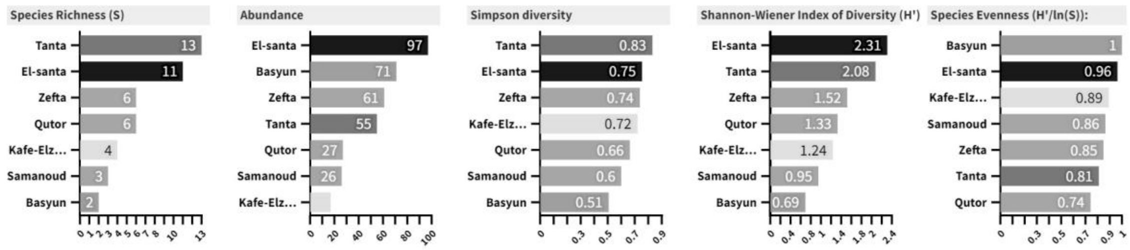
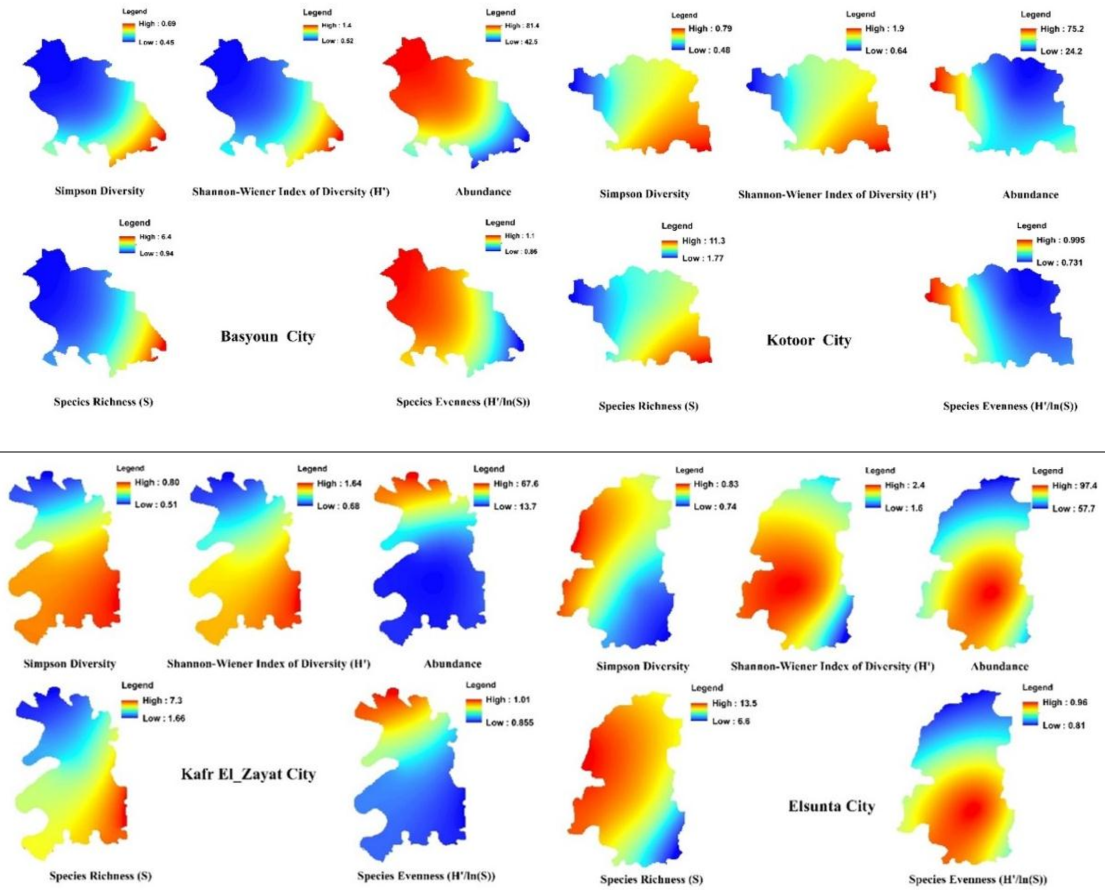


Fig. 3. Bar chart representing calculated environmental indices



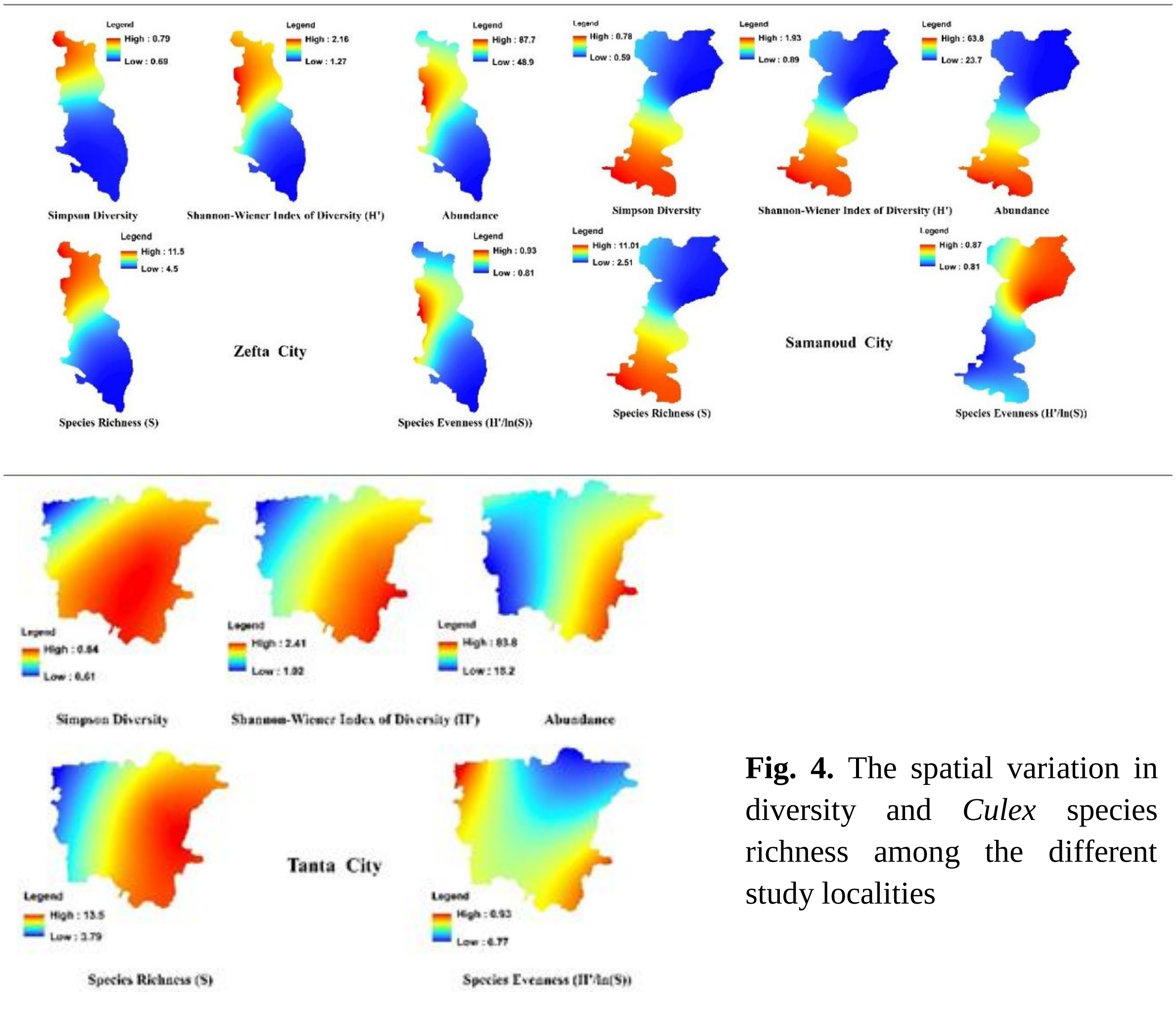


Fig. 4. The spatial variation in diversity and *Culex* species richness among the different study localities

The spatial variation in abundance of *Culex* species among different localities under study

Larvae of *Culex* species in El Gharbia Governorate, Egypt were represented by *Culex pipiens, Cx. antennatus, Cx. perexiguus* and *Cx. Tritaeniorhynchus*. The obtained results showed that, *Cx. antennatus* and *Cx. pipiens* recorded the highest value in El-Santa City and *Cx. antennatus* absence was registered in Zefta, Kafe-Elzayat and Samanoud. While, *Cx. Pipiens* are absent in Basyun. *Cx. perexiguus* occupied the highest value in Zefta City and the lowest value in the city of Samanoud. *Cx. Tritaeniorhynchus* is considered the most important species in Samanoud City while absent in Basyun (Table 2 & Figs. 5,6).

Environmental parameter associated with culex species

The immature stage of the mosquito life cycle is influenced by the physicochemical features of a mosquito breeding location. Some of these characteristics include pH, temperature and total dissolved solids (TDS). In order to investigate the statistical association between physicochemical pattern and mosquito species, temperature for mosquito proliferation usually ranges from 23.93± 4.11 ºC in Kafr Elzayat City to 28.68 ± 2.23ºC in El-Santa City. Alkaline water was recorded for the breeding sites (pH 7.81 ± 0.50 in El-Santa; 8.84 ± 1.266 in Tanta City). TDS was considered the most reliable factor that was significantly differentiated ($P< 0.05$) between all stations, ranging from (551 (mg/l) ± 355^{a} in Kafr Elzayat City to 1103 (mg/l) ± 678^{a} in Tanta City (Table 3 and Figs.7, 8).

Table 2. Observed species abundance at investigated sites

Location	*C. antennatus*	*C. perexiguus*	*C. pipiens*	*C. tritaeniorhynchus*
El-Santa	30	1	78	6
Tanta	3	10	38	4
Basyun	4	2	--	--
Kafe-Elzayat		9	2	6
Kotoor	22	4	1	--
Samanoud	--	--	9	17
Zefta	--	18	35	8

Fig. 5. Observed species abundance at investigated sites using R studio V 2022.02.4.

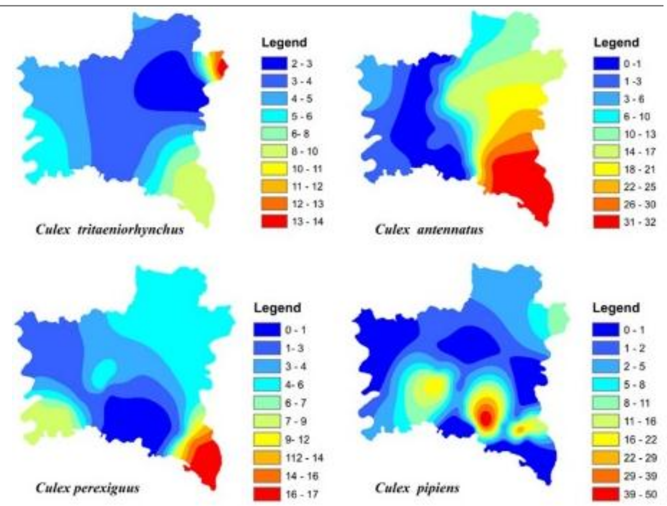


Fig. 6. Observed species abundance at investigated sites ArcGIS (10.8)

Table 1. Average± SD of recorded physical parameters at investigated sites

City	TDS	Temp.	PH
Basyun	885 ± 920^{a}	24.50 ± 0.100^{ab}	7.95 ± 0.071^{ab}
El-Santa	901 ± 678^{a}	28.68 ± 2.23^{a}	7.81 ± 0.500^{b}
Kafr Elzayat	551 ± 355^{a}	23.93 ± 4.11^{ab}	8.23 ± 0.171^{ab}
Kotoor	786 ± 518^{a}	25.73 ± 1.83^{ab}	8.42 ± 0.397^{ab}
Samanoud	823 ± 169.8^{a}	23.97 ± 0.92^{ab}	8.4 ± 0.361^{ab}
Tanta	1103 ± 678^{a}	24.53 ± 2.80^{b}	8.84 ± 1.266^{a}
Zefta	585 ± 201.7^{a}	27.60 ± 4.21^{ab}	8.15 ± 0.1975^{ab}

*Means in column that do not share a letter are significantly different.

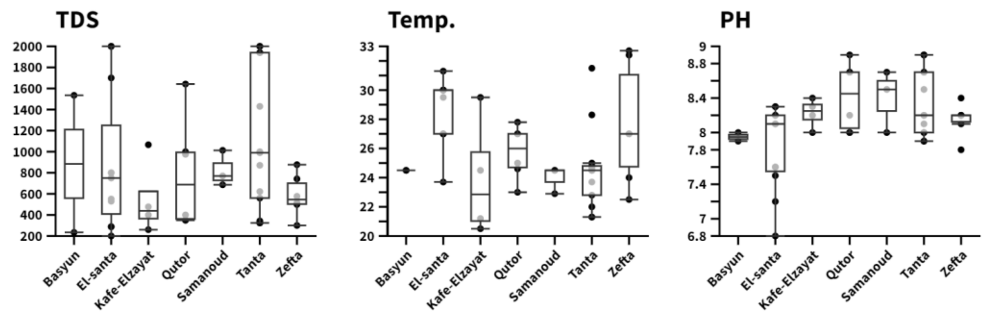


Fig. 1. Box & Whisker plot of recorded physical parameters for investigated sites

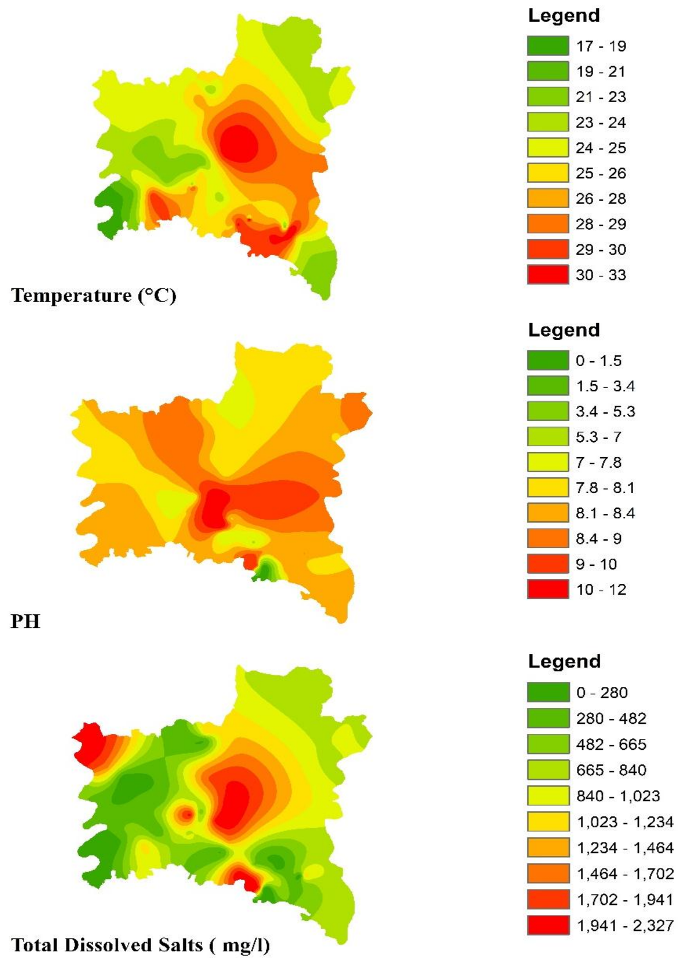
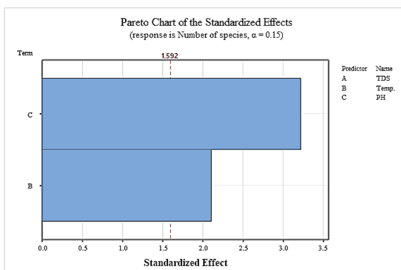
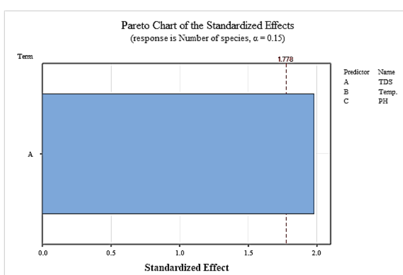
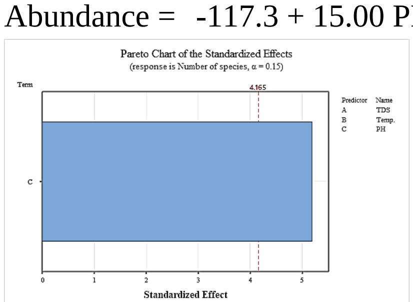
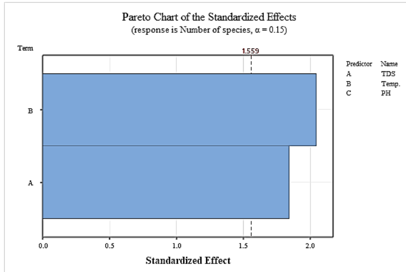
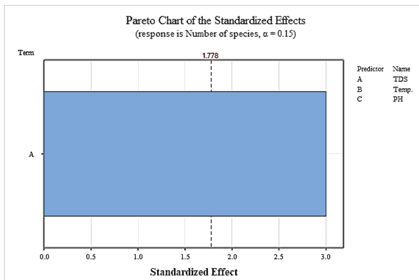


Fig. 8. Temperature, pH, and TDS associated with *Culex* species

Regression analysis is used to describe the relationship between the independent variables (physical parameters), which may affect the dependent variable (species abundance). Regression equations are set to produce estimated equations that can be used to predict the future conditions of any changes occurring in the dependent variable because of changes emerging in the independent variables. The relationship revealed that, in Basyun and Kafr El-zayat, no term was detected within physical parameters affecting species abundance. While at the remaining sites, the species abundance was predicted according to the mentioned equation displayed in Table (4), With R^2= 69.96, 49.53, 96.43, 39.56 and 69.31% for El-Santa, Kotoor, Samanod, Tanta and Zefta, respectively. To define the most effective parameter that species abundance relies on, the pareto charts in Table (4) shows that only (Temperature and PH), (TDS), (PH), (TDS and Temperature) and (TDS) were the most effective parameters in controlling species abundance within each studied site, compared to the remaining parameters.

Table (4): Regression equation of predicted species abundance depending on the recorded physical parameters for stations under study

Basyun	No term within physical parameters effect species abundance
El-Santa	Abundance = 234.3 - 2.74 Temp. - 18.58 PH (R^2= 69.96%) 
Kafr El-zayat	No term within physical parameters effect species abundance
Kotoor	Abundance = -1.18 + 0.00722 TDS (R^2= 49.53%) 
Samanod	Abundance = -117.3 + 15.00 PH (R^2= 96.43%) 

Tanta	Abundance = 23.6 + 0.00353 TDS - 0.947 Temp (R^2= 39.56%) 
Zefta	Abundance = -11.39 + 0.0369 TDS (R^2= 69.31%) 

DISCUSSION

In Egypt, mosquito species have been profoundly and successfully addressed **(El-Said & Kenawy, 1983; Kenawy *et al*., 1996, 1998; Abdel- Hamid *et al*., 2011a, b; Abdel-Hamid *et al.*, 2013; Mostafa *et al.*, 2019; Selim *et al.*, 2019)**. However, studies are limited in El Gharbia Governorate **(Abdel-Hamid *et al*., 2011b)**.

The purpose of this study was to update the most common *Culex* mosquito vectors distributed in El Gharbia Governorate, Egypt. *Culex* species were found in these areas of El Gharbia Governorate during 2022; namely, *Cx. antennatus*, *Culex pipiens*, *Cx. perexiguus* and *Cx. tritaeniorhynchus*. In Egypt, Rift Valley fever virus **(Meegan *et al*., 1980)**, the West Nile virus **(Darwish & Hoogstraal, 1981)** and human filariasis **(Gad *et al*., 1995)** were all primarily transmitted in Egypt by *Culex pipiens*. Additionally, the findings support those of **El Said and Kenawy (1983)**, **Harb *et al*. (1993)** and **Abdel- Hamid *et al*. (2013)** who discovered that *Cx. pipiens*, the primary filariasis vector, was predominating or the most frequent species, with an impact on the situation of filarial transmission in this Gov. Even though *Culex pipiens*, the primary vectors of human filariasis, were the most prevalent species, the prevailing perception persisted that filariasis was a disease of negligible public health significance in the nation.

These species were discovered in the Egyptian fauna, according to earlier research of **Abdel-Hamid *et al*. (2011a, b)**, which revealed that they were present in the Egyptian governorates of El Menoufia; viz., *Cx. pipiens*, *Cx. antennatus*, and *Cx.*

theileri. Similar findings were recorded in Eldakahlia in the studies of **Abdel-Hamid *et al*. (2013)** and **Selim *et al*. (2019)**. Additionally, the findings support those of **Abdel-Hamid *et al*. (2013)** who reported the existence of *Cu. pipiens Linnaeus*, *Cx. antennatus* and *Cx. perexiguus* in the Nile Delta area, while **Mostafa *et al*. (2019)** recorded those species in the Red Sea Governorate.

The pH of the water of the breeding sites fluctuated from 7.81 to 8.84, indicating that the water was neutral or only slightly alkaline. These results agree with those of **kenawy and El Said (1990)**, **Pelizza *et al.* (2007)**, **Oyewole *et al*. (2009)**, **Abdel-Hamid *et al*. (2011a, b)** and **Elhawary *et al.* (2020)** who observed that, mosquito larvae prefer neutral or slightly alkaline water. The observed temperature range (23.93 -28.68 ^{o}C) of the breeding water was determined; these values are comparable to 21-29^{o}C **(Kenawy *et al*., 1998)** and 23-28^{o}C **(Abdel- Hamid *et al*., 2011 a, b)**. While, a wider range (21-37^{o}C) was reported in the study of **kenawy and El Said (1990)** for culicine mosquito species in the Canal Zone. These results contradict with those of **Kenawy *et al*. (2013)** who recorded a temperature range of 17-30°C for *Cx. pipiens* and *Cu. Longiareolata* in Cairo Governorate. In this context, **Elhawary *et al*., (2020)** noticed a temperature range of 21-32°C for *Cx. pipiens* and *Cu*. *Longiareolata* at some breeding sites in Egypt, contradicting the values recorded in the current study. It is worthy to mention that, temperatures below 14°C and below 30°C reduce the larval development rate of many species **(Muirhead-Thomson, 1951; Clements, 1992)**.

Concerning the total dissolved solids (TDS), values ranged from 551–1103mg/ l; TDS was considered the most reliable factor recording significant correlations (P< 0.05) among mosquito breeding habitats. The obtained results agree with those of **Tadesse *et al*. (2011)** in Ethiopia.

CONCLUSION

This study reported that *Cx. antennatus*, *Cu. pipiens*, *Cx. perexiguus* and *Cx. tritaeniorhynchus* were detected during a survey in El Gharbia Governorate, and the most common species was *Culex pipiens*. The combination of field data and a geographic information system (GIS) can be utilized to quickly and effectively identify some environmental elements that influence the growth of mosquitoes, which could be used to provide comprehensive data to aid effective vector control programmers.

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