Original Research Article

Assessing and monitoring spatiotemporal distribution of mosquito habitats, Suez Canal Zone

ABSTRACT

This study aims to predict the potential mosquito larval habitats and monitoring the environmental factors associated with mosquito habitatsto assess the spatiotemporal distribution in Suez Canal Zone,during the period of November 2014 - April 2016 by integrating remote sensing and GIS techniques. Larvae were collected using a standard dipping with a small ladle from all accessible breeding habitats. Environmental factors Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI) and Land Surface Temperature (LST)associated with mosquitoes breeding habitats werederived from multispectral images. Results showed that, the maximum predicted area in Port Said governorate (Sector A)was detected at April 2016 recording 134.37 km^2,while in Ismailia (Sector B) and Suez Governorates (Sector C) at October 2015 (295.27 km^2, 74.37 km^2 respectively). Total predicted area in Suez Canal Zone, in the whole study period, could be ordered as following; Ismailia (1196.91 km^2, 70 %), Port Said (254.61 km^2, 17%) and Suez (213.9 km^2, 13%).Significant positive correlations were found between the total predicted area in Sector A, B and C with the studied environmental variables. The strongest positive correlation was observed in Ismailia (Sector B). The present study provides the baseline information for decision makers to take necessary optimal control strategies to mitigate mosquito nuisance, proliferation and potential diseases transmission.

Keywords:*Assessing, monitoring, spatiotemporal distribution, mosquito habitats, Suez Canal Zone.*

INTRODUCTION

Mosquitoes are among the most sensitive insects to environmental change; their survival, density and distribution are dramatically influenced by small changes in environmental conditions, such as temperature, humidity and the availability of suitable

larval habitats [1-4]. More than a half of the world's population lives under permanent risk of diseases transmitted by mosquitoes [5].

Mosquitoes prefer an environment with certain resources (food, shelter, favorable temperature and suitable humidity) in sufficient quantity and at appropriate time for survival and development [6]. The Rapid environmental modification due to agricultural activities, water resources development projects and urbanization has been observed to contribute to spread the breeding of various species of mosquito that most often transmit pathogens to humans [7-10]. The most direct effect of urbanization is the creation of habitat (e.g., artificial containers, storm water pools) that supports growth and development of immature stages of some mosquito species [11]. Population growth within cities can also result in higher population densities of human blood meals and increased biting and pathogen transmission rates [9,10].

The optimum temperature for mosquitoes is 25-27°C and the maximum temperature for both vectors and parasites is 40°C [12]. Normalized Difference Vegetation Index (NDVI) is positively related to vegetation biomass and is also affected by vegetation compositionand has been identified as a significant predictor of mosquito distribution and populations [13-16].

The study area has an old history of mosquito borne diseases; Rift Valley Fever [17] and malaria [18] transmitted by *Cx. pipiens*[19,20] and *An. pharonsis*[21], respectively.

Presently, remote sensing techniques are widely used to employ optimal techniques to create an environmentallyfriendly approaches strategy to control nuisance mosquitoes and mosquito-borne diseases [22]. Remote sensing data provide a cost-effective source of environmental data related to vector distribution and abundance, which have been incorporated in a GIS environment (Modeling) to predictmosquito larval habitats[23].

The integration between Remote Sensing (RS) and Geographic Information Systems (GIS) have proven to be rapid and accurate tools in the large-scale geospatial mapping, that is difficult or impossible for using field survey, to identify the potential larval habitats and monitoring of some environmental factors affecting the distribution and biological productivity of mosquito habitats[24].

The appropriate information for the vector-borne disease and vector abundance associated with geographically and environmental-specific variables contribute to mapping the area under risk of the disease transmission [25].Remote sensing and GIS have greatly expanded opportunities for data collection, integration, analysis, modeling and map production [26-29,7, 30-32].

MATERIAL AND METHODS

Study Area

The Suez Canal is located in the northeast of Egypt and extends from Port Said, in the North, to Port Taufiq, near Suez, in the South. It connects the Mediterranean Sea to the Gulf of Suez and thus to the Red Sea, as shown in Figure (1). The canal is about 160 km long. The Canal comprises two parts, north and south of the Great Bitter Lake, linking the Mediterranean Sea to the Gulf of Suez on the Red Sea. The study area, representing in the western bank of the Suez Canal from Port Said on the northern extremity to Suez, includes a parts of three governorates; Port Said, Ismailia and Suez. It occupies an area of 7523.008 km^2 and lies between latitude 29 ^{o} 30' N to 31 ^{o} 30' N and longitude 32 ^{o} 10' E to 32 ^{o} 40' E. It is bordered on the north by the Mediterranean Sea, west and south by eastern desert, and from the northern east by a part Sinai Peninsula. According to the Central Authority for Public Mobilization and Statistics (CAPMAS) the population of Suez Canal region reached 2.1 million people in 2009.

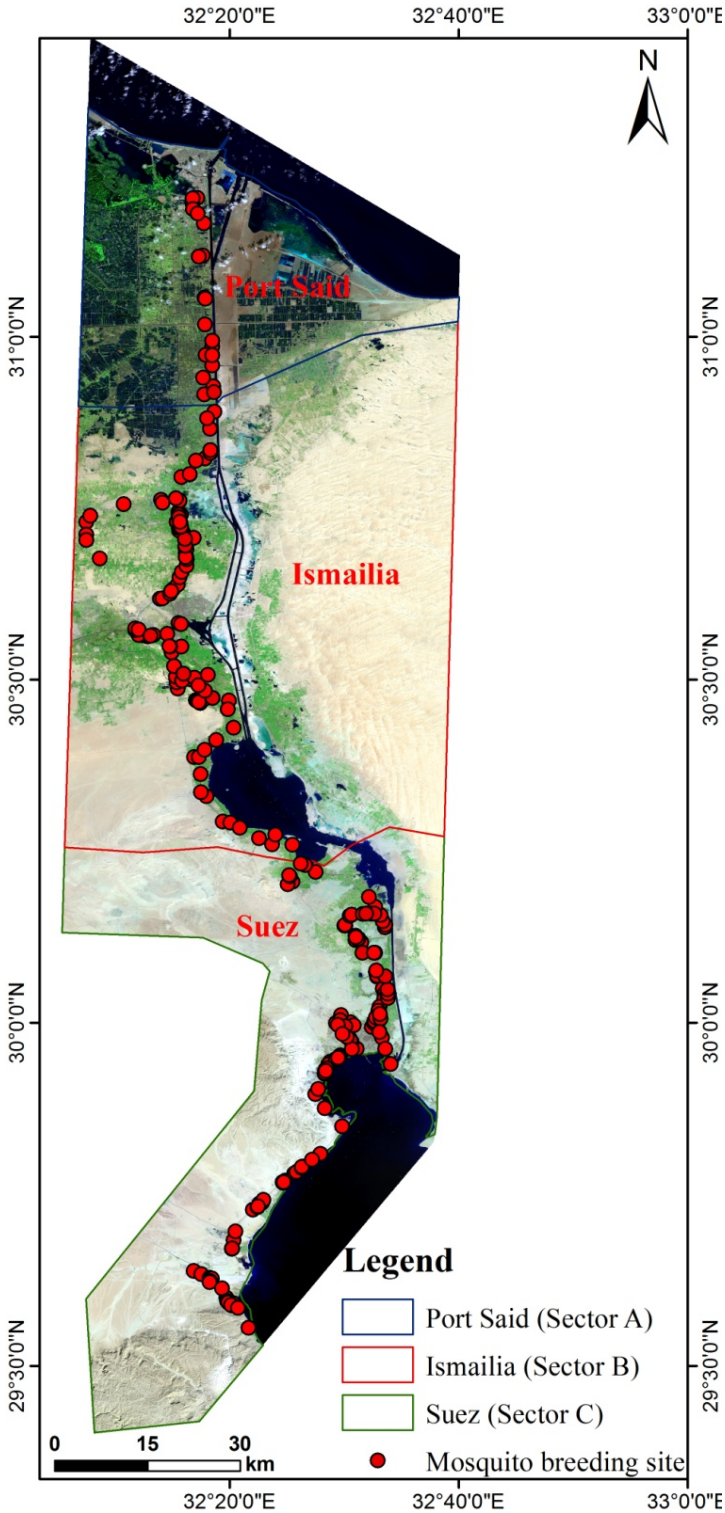


Figure (1) : Map of the study area

Mosquito larval surveys

Entomological surveyswere conducted of all accessible breeding sites as illustrated in Figure (1)for sixseparate months in two consecutive years, 2014-2015and 2015-2016 (November 2014; January, April, October 2015; February, April 2016).Mosquito's larvae were collected by a standard dipping using a small ladle (10.5 cm in diameter with a 90 cmwooden handle), from stagnant aquatic habitats. Different numbers of dips were taken based on the size of the breeding site, water level and the availability of larvae. From each breeding site, 2-10 dips were taken.

Collected larvae were placed in labeled glass vials containing a fixative solution (70% Ethyl Alcohol), the larvae were permanently prepared on slides and taxonomically identification using the Keys of Harbach [33] and Glick [34]. Procedures and precautions, regarding larval collection and transportation, were carried out according to WHO [35] guidelines.

Spectral Data Acquisition and Processing

Space-borne multispectral Landsat8-OLI images were freely acquired from *http://glovis.usgs.gov/.*Multi-dated six images were downloaded and used in this study during the period 2014-2016. The study area is located within two different scenes (i.e. path 176, rows 38 and 39) and downloaded as raw data (i.e. digital number; DN). These images have been radiometrically corrected to spectral radiance. The spectral radiance then corrected for atmospheric effect to obtain surface reflectance values, followed by a geo-referenced mosaicking. The corrected image was subset to the study area.

To determine the preferable predictor of habitat type; Normalized difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI) and Land Surface Temperature (LST) were obtained. NDVI is able to respond to changes in green biomass, chlorophyll content and canopy water stress. It is important in predicting surface characteristics when the vegetation cover is not too dense or too sparse [36]. NDVI is determined using the red and near-infrared (NIR) bands of a given image [37]and is expressed as follows:

$$NDVI= (NIR-RED)/(NIR+RED)$$

Second studied index is NDMI which is correlated with soil moisture. It contrasts near-infrared (NIR) band, which is sensitive to reflectance of leaf chlorophyll and to mid-infrared (SWIR1). Values higher than 0.1 indicate to high humidity level, while low levels (close to -1) signify low humidity content [38]. NDMI is expressed as follows:

$$NDMI= (NIR-SWIR)/(NIR+SWIR)$$

Finally, LST is an important parameter in physics of earth surface through process of energy and water exchange with atmosphere. This process plays an important role in wide fields of scientific studies; as hydrology, ecology and global change researches. Thermal infrared remote sensing (i.e. Thermal bands) provides a unique method for obtaining information on LST in global and regional scales where most of the sensor's detected energy is directly emitted by land surface [39].Following expressions were followed to convert DN values to Temperature (Celsius) for Landsat-8; band 10 [38]:

$$L\lambda= Gain*DN+Bias= ((Lmax-Lmin)/255)*DN+Bias$$

$$Reflectance= 0.00033420 * (DN \text{ of } B10 \text{ of landsat8})$$

$$Temperature\ (Kelvin) =1321.08 / \log (774.89 / B10)$$

$$Temperature\ (Celsius) = Temperature\ in\ Kelvin -273.15$$

Where, Lλ: spectral radiance at the sensor (Wm-2sr-1μm-1), Bias: Lmin

Statistical analysis

The density of mosquito larvae in each breeding habitat was calculated using the following formula of Banaszak and Winiewski[40]:

$$D = l / L \cdot 100\%$$

Where D is density, l is number of specimens of each mosquito species, and L is number of all specimens. Means were calculated for environmental factors (NDVI, NDMIand LST) and larval densities of the collected mosquito species at each breeding habitat. Correlation coefficient was calculated to study the relationships between environmental factors and the total predicted area.

RESULTS AND DISCUSSION

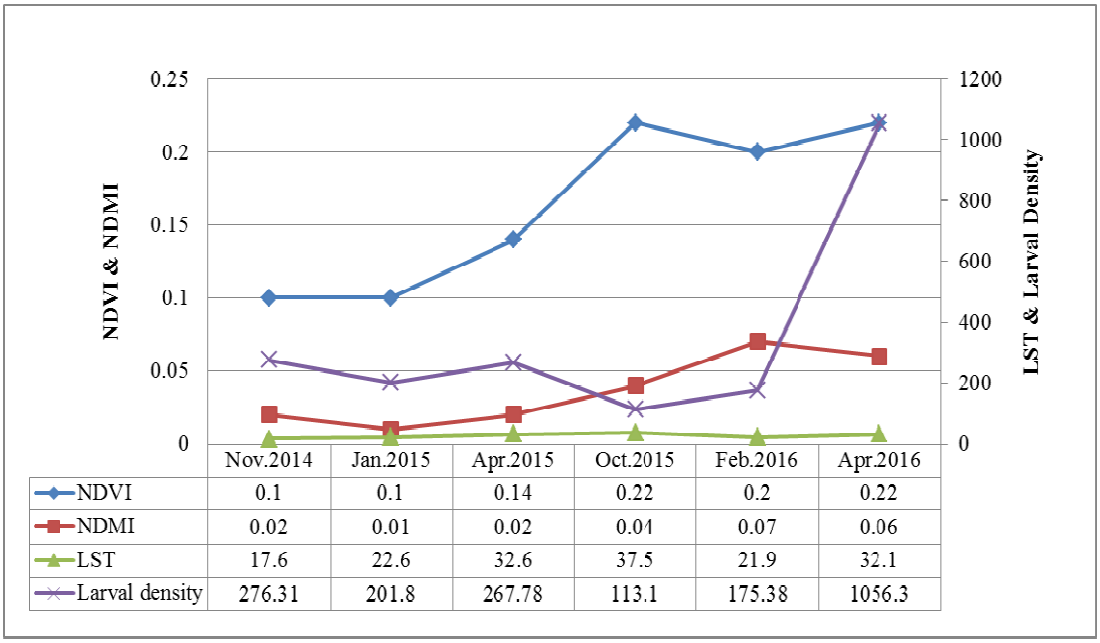
Monitoringenvironmental variables and larval density

During the study period, a total number of 14806 mosquito larvae was collected from 155 sites out of 300 total breeding sites.Three different parameters,derived from satellite images,were successfully selected to characterize mosquito breeding sites in Suez Canal Zone including vegetation cover, moisture content and temperature which have a great effect and exhibited Signing relationships with mosquito proliferation [32,41].

Consequently, Landsat-8 images were processed to monitor and assess spatiotemporal changes in NDVI, NMDI and LST at mosquito proliferation sites. Mean NDVI showed a slight fluctuation in mosquito breeding sites during the whole period of study as illustrated in Figure (2). It ranged from 0.1 to 0.2 which ensure the necessity of vegetation even sparse for mosquito breeding and proliferation. Considering that vegetation cover provides shelter for mosquitoes and favors their proliferation [42,43], where most sites recorded positive values of NDVI. Agricultural areas represent humid environment that can sustain both immature and adult mosquitoes [44].Urban irrigated agriculture created suitable breeding habitats for mosquito vectors [45,46].The lowest mean value was observed at November 2014, January 2015 and April 2015, while the highest levels were recorded at October 2015, February 2016.On the other hand, mean NDMI showed positive values in all months which confirm that breeding sites exhibited high levels of moisture ranging from 0.01 to 0.07. Mean LST indicated a remarkable variation during the study period fluctuating from 17.6 ºC to 37.5 ºC. In response to changes climatic conditions and seasonal changes, optimal LSTlevels vary in breeding sites,highest level at warmest month; October 2016 (31.5–43.4 ºC) with a mean of 37.5 ºC. The optimum temperature for mosquito proliferation usually ranges from 27to 37 ºC.However, it could survive at temperature 40 ºC or more as reported in Suez Canal zone at October 2015.

Mosquito breeding habitats in Suez Canal Zone were surveyed and monitored during the whole study period. Mosquito larvae were collected from breeding sites for calculating and monitoring temporal changes in larval density. The highest mean of larval

density (1056.3) was recorded at April 2016,as a similarfinding of Hanafi-Bojd et al.[30],associated with mean values of NDVI of 0.2, NDMI of 0.06 and LST of 32.1 ºCwhich represent the optimal conditions for mosquito proliferation in Suez Canal Zone. Conversely, least mosquito larval density (113.1) was recorded during October 2015 in association with NDVI of 0.2, NDMI of 0.04 and LST of 37.5ºC (Figure2).



	Nov.2014	Jan.2015	Apr.2015	Oct.2015	Feb.2016	Apr.2016
NDVI	0.1	0.1	0.14	0.22	0.2	0.22
NDMI	0.02	0.01	0.02	0.04	0.07	0.06
LST	17.6	22.6	32.6	37.5	21.9	32.1
Larval density	276.31	201.8	267.78	113.1	175.38	1056.3

Figure(2): Mosquito habitat characteristics (mean) at different months and Mean Larval density at Suez Canal Zone

Monitoring spatiotemporal changes in mosquito proliferation sites

Mosquito breeding sites were geographically identified and linked with previous factors which have been assessed and modeled to predict the potential larval habitats in Suez Canal Zone. The prediction maps were used to assess the spatiotemporal changes in breeding habitats in the three Governorates of Suez Canal Zone; Port Said (Sector A), Ismailia (Sector B) and Suez (Sector C).

Figure 3 and 4show the spatiotemporal distribution of mosquito breeding habitats in Port Said (Sector A). The maximum predicted area was detected in April 2016 recording 134.37 km^2. A remarkable increase in the predicted area was found associated with high temperature levels. The total predicted area remarked a continuous increase during the

whole period of study from November 2014 to April 2016 except in February 2016 which recorded low prediction (22.16 km^2). On the other hand, no predicted area was detected in November 2014 which showed the least recorded LST (17.6 ºC). It was generally noticed that the majority of the predicted area was located along the western banks of the Suez Canal. This area is characterized by vegetation and urbanized zones which create habitats suitable for mosquito breeding. Also, some area was predicted in the south eastern parts of the Sector. These areas include, among their land cover classes, natural vegetation and drainage canals adjacent to the fish farms which are favored for mosquito breeding and represent suitable locations for proliferation. Some localities are unsuitable habitats for mosquito breeding such as; Suez Canal itself where running water, desert land, fish farm so non-predicted results were found in this area.

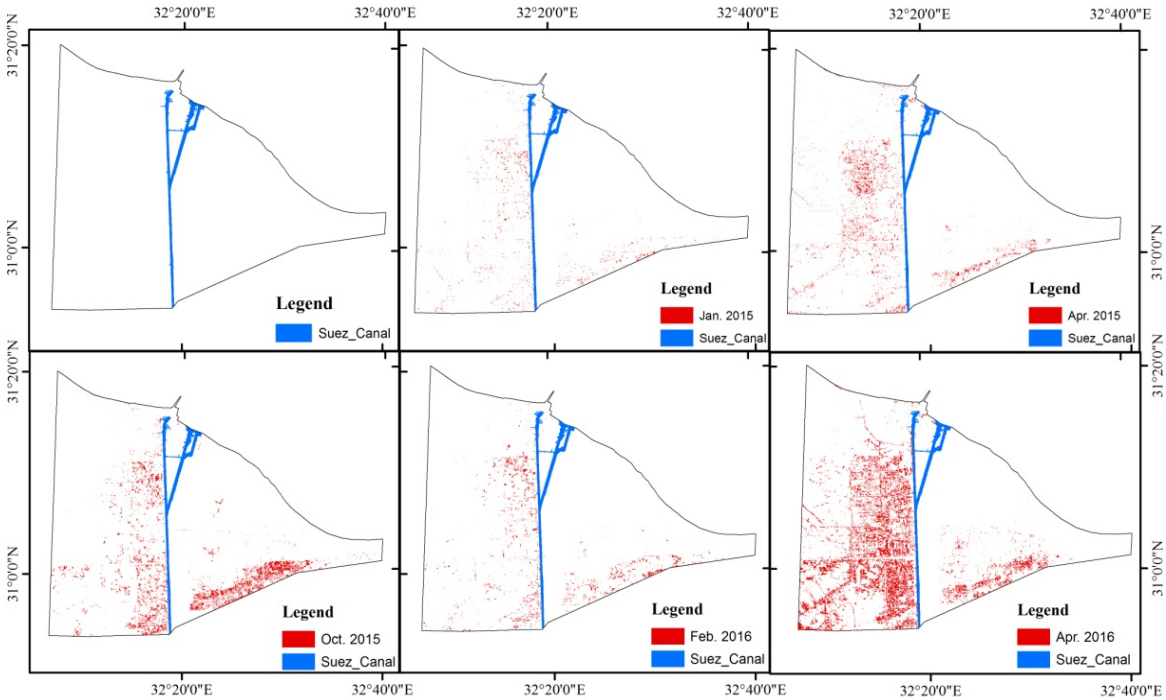


Figure (3):Spatiotemporal distribution of mosquito breeding habitats in Port Said Governorate (Sector A).

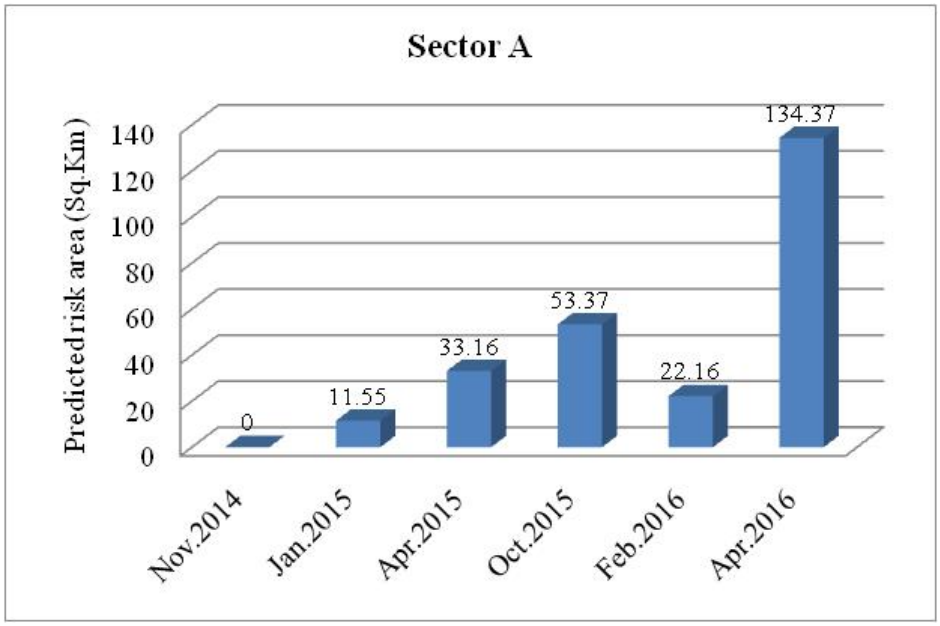


Figure (4):Predicted risk area in Port Said Governorate (Sector A)

Figure 5 and 6 illustrate the predicted area for mosquito proliferation in Ismailia governorate (Sector B) ranged from 64.8 km^2 in November 2014 to 295.27 km^2 in October 2015. Nearly same prediction was recorded in January 2015 and April 2015 (182.84 and 165.31 km^2) as well as in February 2016 and April 2016 (244.62 and 244.07 km^2). The predicted area was mainly distributed in the western region of sector B particularity in the agricultural land. Moreover, mosquito breeding sites were predicted in the eastern parts adjacent to the Suez Canal particularly in the seepage regions. It was also found that the northern parts of Bitter Lakes exhibited a favorable habitat for mosquito breeding during the whole period of study.

Ismailia governorate is characterized by the variable land uses; old vegetation, newly reclaimed areas particularly western parts (i.e. El-Salihia El-Gedida), desert land, denselyresidential areas, rural area, irrigation and drainage canals and recreational areas. The interaction between these land uses increase the suitability for mosquito breeding and induce proliferation which magnifies the risk from mosquito transmitted diseases,similar to the previous observation by Kenawy and El Said [47].

Ismailia governorate, as confirmed by several studies, has an old history of mosquito transmitted diseases due to the previous factors which magnifies the risk and nuisance from mosquito diseases and bites.

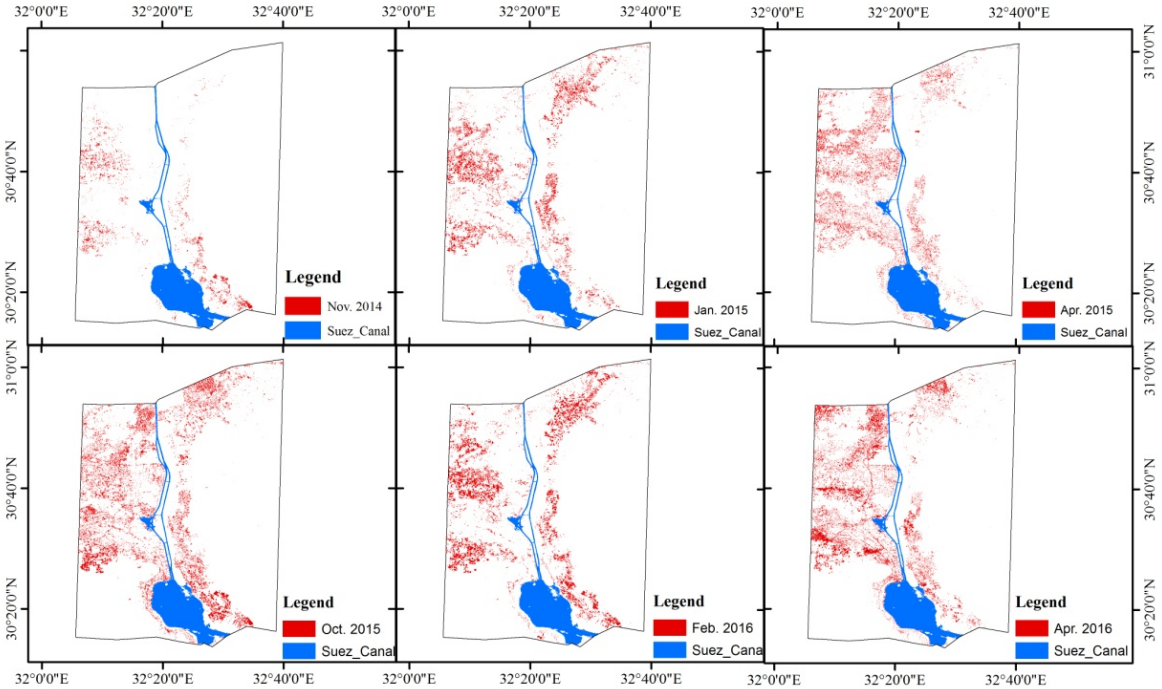


Figure (5):Spatiotemporal distribution of mosquito breeding habitats in Ismailia Governorate (Sector B)

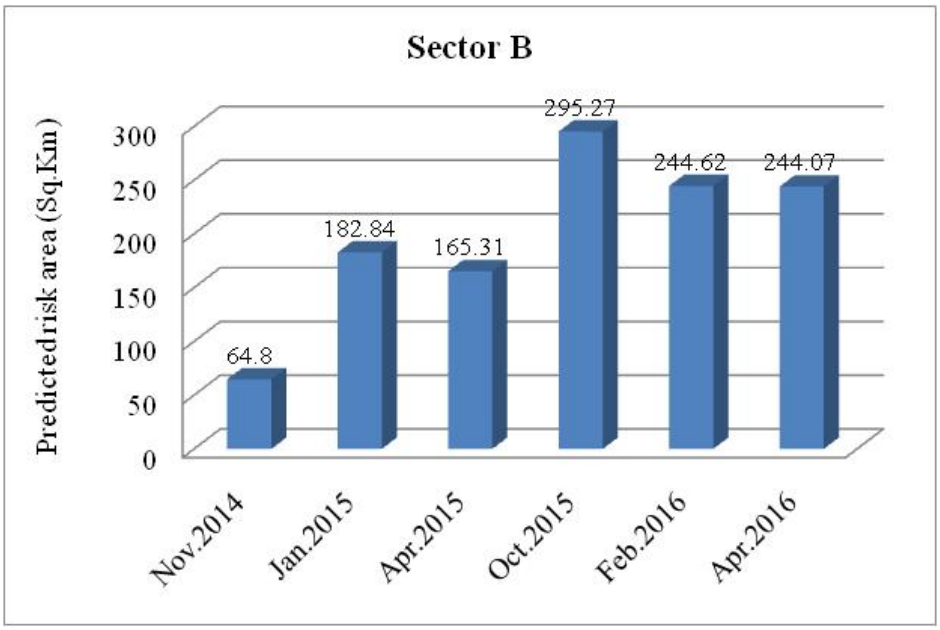


Figure (6):Predicted risk area inIsmailia Governorate (Sector B)

The predicted area in Suez Governorate (Sector C) showed a noticeable decrease from October 2015 (74.37 km^2) to April 2016 (26.5 km^2), while a mild fluctuation was observed in November 2014 (14.68 km^2), January 2015 (27.46 km^2) and April 2015 (15.75 km^2). The same maximum and minimum levels were observed in Suez as Ismailia; minimum prediction in November 2014 and maximum in October 2015 due to the similarity of climatic conditions in the two sectors. The whole eastern area of sector C, in disperse parts, showed a prediction for mosquito during the whole months. The prediction in the western parts of Sector C is extensively distributed close to Suez Canal and Gulf of Suez in its northern parts (Red Sea) as illustrated in Figure (7,8). No predicted area is observed in the extreme south of Sector C due to the inappropriate conditions; high temperature levels, no water bodies, no vegetation.

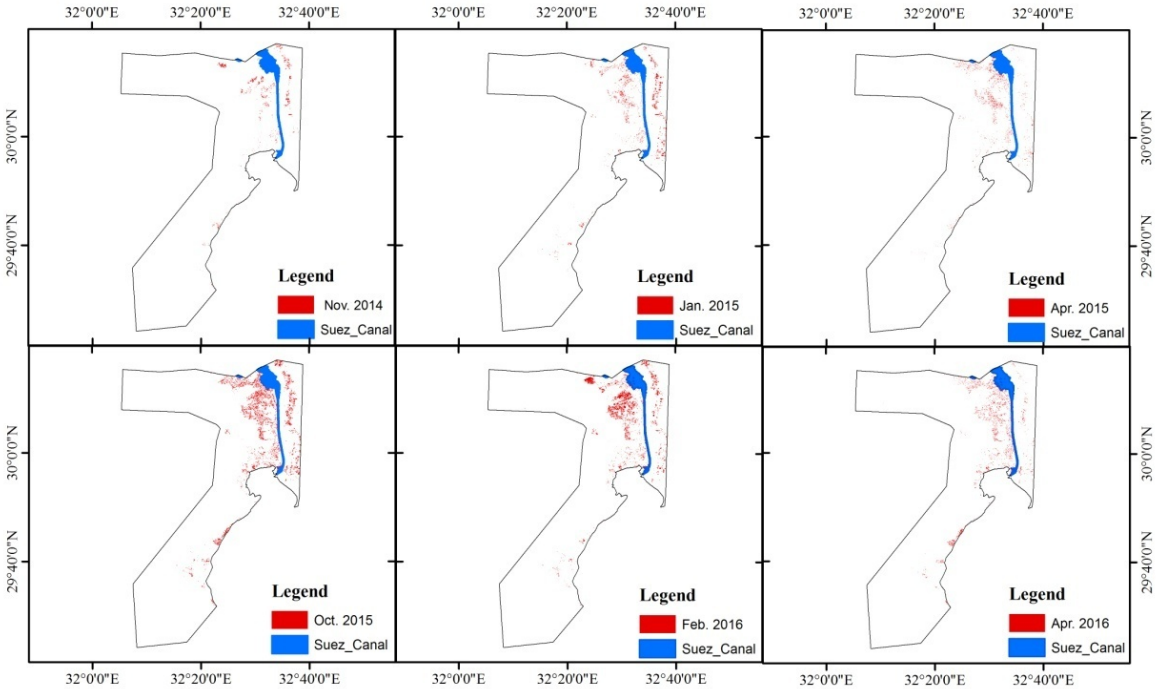


Figure (7): Spatiotemporal distribution of mosquito breeding habitatsin Suez Governorate (Sector C)

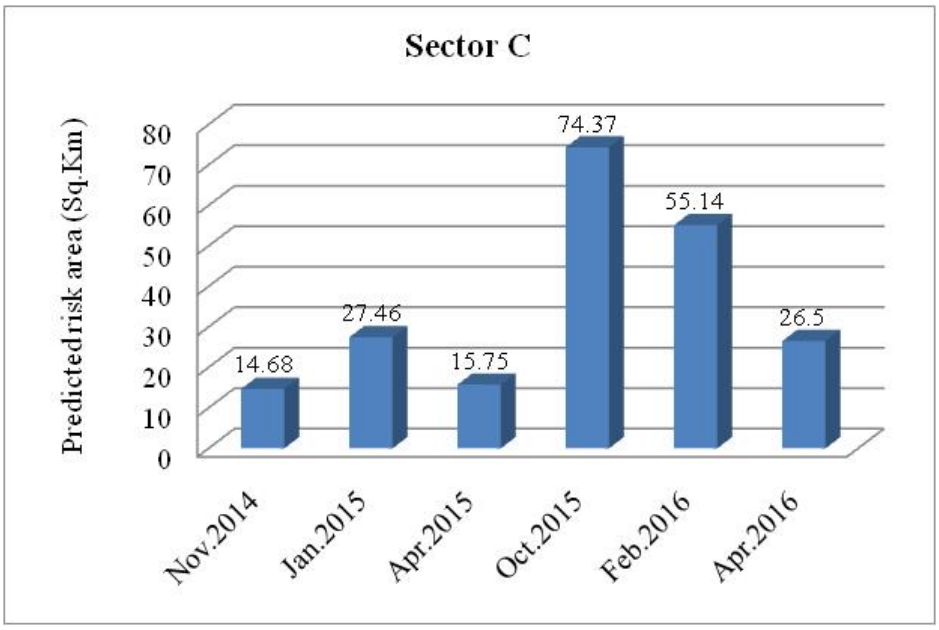


Figure (8): Predicted risk area in Suez Governorate (Sector C)

As illustrated in Figure 9, the total predicted area in Suez Canal Zone ranged from 79.52 km^2 (1.06 %) in November 2014 to 423.31 km^2 (5.63 %) in October 2015. Temporal distribution of the total predicted area is similar to the trend recorded in Sector B (Ismailia). Total predicted area in Suez Canal Zone, in the whole study period, could be ordered as following; Ismailia (1196.91 km^2, 70 %), Port Said (254.61 km^2, 15 %) and Suez (213.9 km^2, 13 %) (Figure 10). This confirms the necessity of starting mosquito control strategies starting by Ismailia which is the highly vulnerable Suez Canal governorate for mosquito proliferations. Mitigation processes should also include Port Said and Suez to minimize the probability of diseases transmission.

The results indicated that the higher predicted risk area observed in the October 2015 and April 2016 because of increasing preferable sites for mosquitobreeding, human activities etc.

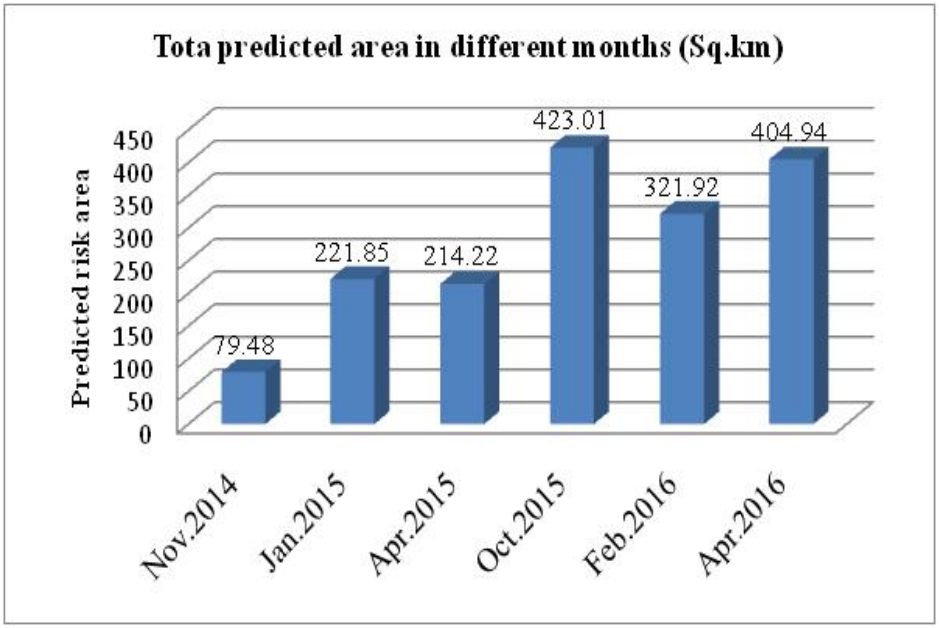


Figure (9): Temporal distribution of the total predicted area in Suez Canal Zone

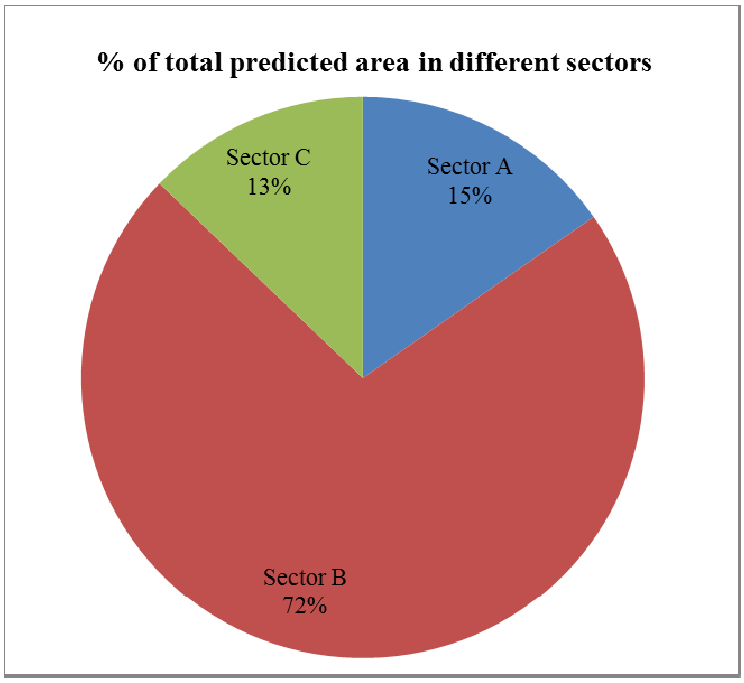


Figure (10): Total predicted area in different sectors of Suez Canal Zone

In this study, three environmental parameters were utilized to model and monitor the spatiotemporal distribution of mosquito breeding habitats along Suez Canal Zone. To study the relationships between these variables and the total predicted area, a correlation coefficient was calculated (Table 1). Significant positive correlations were found between the total predicted area in Sector A, B and C with the studied environmental variables. The strongest positive correlation was observed in Ismailia (Sector B); NDVI (0.86), NDMI (0.62) and LST (0.69) which confirm the previous findings that Ismailia Governorate is the highly vulnerable area to mosquito proliferations and probability of transmitted diseases.

Table (1): Correlation coefficient between predicted area in different sectors and environmental factors

	Sector A	*Sector B*	*Sector C*	*NDVI*	*NDMI*	*LST*
Sector A	1.00					
Sector B	0.55	1.00				
Sector C	0.09	0.81	1.00			
NDVI	**0.72**	**0.86**	**0.69**	1.00		
NDMI	**0.54**	**0.62**	**0.51**	0.85	1.00	
LST	**0.62**	**0.69**	**0.41**	0.65	0.18	1.00

Validation of the resulted maps

The present study was based on utilizing the spectral derived parameters (NDVI, NDMI and LST) to predict habitat suitability for mosquito proliferation through a simple GIS model. This model incorporates these parameters, considering their values at mosquito breeding sites, to predict the area under risk of mosquito breeding. This model was generated based on results of six field trips where 155 different breeding sites were identified and investigated. The current study considers the validation process as one of the main steps in the accuracy assessment of the generated models. To validate the generated model and the resulted maps, more than 100 sites located within the predicted area were visited and validated. The model gave satisfactory results in identifying the correct habitats and in excluding the unsuitable sites. More than 80% of visited sites were confirmed as positive sites for mosquito breeding and proliferation.

CONCLUSION

In the present study, the spatiotemporal distribution of mosquito larval habitats was assessed and mapped in Suez Canal Zone using geospatial techniques during the period November 2014-April 2016. It could be concluded that the spatiotemporal distribution of mosquito breeding sitesvaried in correspondence with the changes in environmental factors (i.e. vegetation, moisture and temperature). The GIS generated models showed that the highest predicted habitats/areaswere observed in Ismailia governorate.Results showed that there are significant positive correlations between the total predicted area in Port Said/Ismailia/Suez Governoratesand the studied environmental variables.The abundance of mosquito species in Suez Canal zone requires a wide vector control program based on detailed biological and ecological information. Hence, the results of the study provides the baseline information for decision makers to initiate necessary optimal control strategies to mitigate mosquito nuisance, proliferation and potential diseases transmission

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