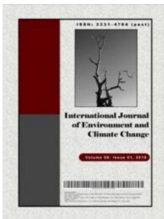

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Mosquito Larval Species and Geographical Information System (GIS) Mapping of Environmental Vulnerable Areas, Dakhla Oasis, Egypt

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Authors' contributions

This work was carried out in collaboration among all authors. Author MMS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors AME and ESM managed the analyses of the study. Author MMS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This paper investigates the spatial distribution of mosquito breeding sites within the Dakhla oasis of the Western Desert of Egypt.
Study Design: GIS spatial analysis was used to map the area under risk of mosquito proliferation.
Place and Duration of Study: Dakhla oases, during September 2009 to October 2010.
Methodology: Landsat images, synchronized with mosquito larval survey, were processed to identify the vegetation status of the study area. Twenty-two locations distributed in Dakhla oasis were investigated as nine mosquito species were collected from drains, paddle fields, and waterlogged areas.
Results: Results showed that the main vector of Malaria disease (*Anopheles pharoensis* and *Anopheles sergentii*), as well as the *Culex pipiens*, which is the main vector of filarial disease are abundant. Further, the geo-environmental setting and the discharge of increasing cultivated areas develop considerable waterlogging and pond areas, which are favorable breeding sites of mosquito. In Dakhla oases, the produced risk map showed that a large part of urban and cultivated regions were at risk of mosquito spread.
Conclusion: It was concluded that mosquito larval populations fluctuated with the dynamics of vegetation cover in Dakhla. Multi-year data of mosquito collections are still required to provide a better characterization of the abundance of these insects from year to year which can potentially provide predictive capability of their population density based on remotely sensed ecological measurements.

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Keywords: Environmental risk; mosquito; GIS; Dakhla.

1. INTRODUCTION

The vector borne diseases (particularly Malaria, Filaria, Rift Valley Fever and West Nile Virus) are abundant and widely distributed in the realm of the Nile delta and valley supported by the development of dense network (i.e. channels) for irrigation and drainage as well as cultivation areas [1,2]. The abundance of mosquitoes significantly increases in areas dominated by quiescent body of water and shallow areas such as backwaters, isolated pools, and marshy areas of rivers and channels [3]. However, the Saharan oases are isolated and remote from the heavily inhabited Nile valley and deltas, the vector borne diseases have also been recorded [4]. The recent fundamental changes in landuse and landcover in the oases may have created favorable conditions for large scale breeding for the mosquitoes. The increasing human migration from areas, such as the Nile delta and valley into the oases may be also fraught with general health hazards where infected people could have been settled in these new areas. This in turn may develop epidimecity of the infectious diseases [5,6,7,8].

The hydrological conditions within the Saharan oases vary completely than their counterparts of the Nile Delta and Valley. The velocities of water flow in the oases is very low compared to the Nile delta channels, where the former is developed in terminal closed basin while the latter is driven by open channel flow conditions. Consequently, the quality of water, salt concentration by evaporation from channels and the main ponds, pH and other physical characteristics are accordingly different. Therefore, the species composition (diversity) of mosquitoes as well as its distribution and spread with disease transmission, which is correlated with water characteristics could be affected by the dynamics of hydrological processes in oases environment [9,10].

Geospatial mapping is facilitating the control practice of mosquito breeding habitats, [11,12,13]. GIS is considered as a good tool for mosquito mapping and identifying environmental indicators of filaria transmission [14]. Remote sensing and GIS used for Mosquito larval habitat mapping as well as monitoring the filarial infection regions [15].

To characterize environmental variation across the study region, the Normalized Difference Vegetation Index (NDVI) was used. NDVI is a measure of photosynthetic activity; its variation reflects the spatial and temporal dynamics of vegetation that indirectly influence mosquito reproduction and development [16]. Many malaria studies have employed vegetation indices, particularly the NDVI, in order to distinguish and detect areas under risk to mosquito-borne diseases [17,18,19,20]. NDVI is well establish and has been in use for more than 44 years, when it was first developed by Rouse with others, 1974 [21]. Many remote-sensing satellites possess bands in the red and near infrared (NIR) that allow calculation of NDVI. Negative values of NDVI (values approaching -1) correspond to water, snow, ice and some dark surfaces such as burn scars. Positive values (approaching +1) are associated with photosynthetically active trees, shrub, grassland, and other forms of vegetation. Brown and others [17], established NDVI as a practical component in the prediction of mosquito habitat and malaria outbreaks through comparative modeling of three satellite sensor scenes (Hyperion, ASTER and Landsat-TM) at three scales (pixel, wetland perimeter, and wetland area). The green vegetation is associated with higher amounts of precipitation thus a more favorable environment for mosquito habitats [17]. The hierarchical logistic regression models supported the relation between vegetation, amount of rain and mosquito breeding sites, by showing higher NDVI values positively associated with presence of *An. punctipennis* larvae. This association, shown in past research as well, has been integral in the predictive modeling of malaria [22,23,24]. Positive association between NDVI and mosquito population rates investigated in West and Central Africa [18]. Their results also showed precipitation as statistically significant in mosquito population rates. Associations between NDVI and precipitation found in semi-arid environments have made this a powerful index for researchers to investigate and model malaria distribution in space and time. Kerr with others [25] acknowledged the contribution NDVI has made to disease studies. An important component of strategic prevention and control plans mosquito-borne diseases is forecasting the distribution, timing, and abundance of mosquito vector populations. Populations of many medically important mosquito species are closely tied to climate, and historical climate-population associations used to predict future population dynamics. The instances of mosquito's population changes appear to be direct responses to satellite-derived index of climate (Normalized Difference Vegetation Index, NDVI), [26]. These preliminary findings are important first steps in developing an automated, climate-driven, early warning system to flag regions at elevated risk of mosquito-borne disease transmission.

The aim of this paper is to use GIS spatial analysis and remote sensing data to assess the distribution and spread of mosquito larvae and the area under risk of proliferation in the Dakhla oases in order to implement the optimum pest-control strategies.

2. MATERIALS AND METHODS

2.1 Study Area

Geographically, the Western Desert, including the Mediterranean littoral zone and the New Valley, comprises 68% of Egypt's total area. The New Valley consists of three oases; Kharga, Dakhla, and Farafra. Dakhla is the biggest oasis in the Western Desert and lies farthest away from the main settlements of Egypt with about 75,000 inhabitants (2003 estimate) who live in 17 different settlements. The whole depression of the Dakhla oasis comprises a number of smaller oases, separated by hills or desert, but never far in between [27].

The Dakhla oasis is located in the South Western Desert of Egypt, 120 km west of the Kharga oasis, about 300 km west of the Nile valley and about 300 km southeast of Farafra oasis, between longitudes 28°15` - 29°40` E and latitudes 25°00` - 26°00` N. The oasis is about 155 km long from southeast to northwest, with a maximum width of about 60 km. Present study represents part of Dakhla Oasis as illustrated in Fig. 1.

Dakhla is situated above sea level, as high as an average of 122 meters. Altitudes range from 110 to 140 m above sea level [28]. Originally, Dakhla was fed by about 520 springs and ponds, but in modern times many have dried out, and others only work with electric pumps. The economy of Dakhla is based on agriculture, production of handicrafts, and some tourism. Before the roads were constructed, Dakhla must have felt like a planet of its own, where only a few inhabitants ever came as far as the neighboring oases Kharga and Farafra.

As to climate, the Dakhla oasis belongs to the rainless part of Egypt [29]. The hottest months are June, July, and August (with a mean maximum temperature of 37.7°C). The coldest month is January (with a mean minimum temperature of 4.0°C).

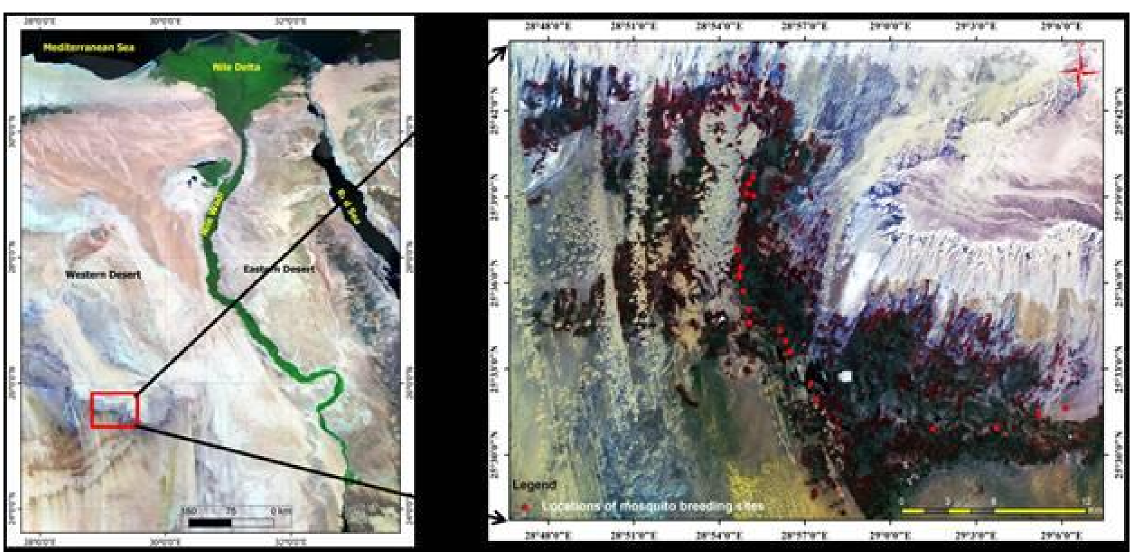

Fig. 1. Location map of study area (Dakhla oasis) & sampling sites

2.2 Field Surveys and Collection of Mosquitoes

Entomological surveys and sampling were carried out in cultivated areas as well as urban areas to update and identify the distribution of mosquito fauna of some new water resources and irrigated fields as well as stagnant and small collected water originated as a result of flooding irrigation [30]. During this investigation, surveys were carried out during September 2009 to October 2010. Field surveys were carried out in 22 localities distributed in Dakhla oasis. The collection sites were selected to represent areas surrounding irrigated rice field, where few data are available.

In all breeding places, larval collections were carried out by dipping in water collections (using small ladle). Collected larvae were transported to the laboratory in a fixative solution (containing 70% Ethyl Alcohol). The procedures and precautions regarding larval collection and transportation according to World Health Organization [31] were followed each time. Each surveyed site was geo-referenced using a hand-held Global Positioning System (GPS) devise (Magellan 320, USA). In the laboratory all specimens (4th larval instars) were identified using the Keys of [32,33].

2.3 Remote Sensing Data Processing & GIS Analyses

Remote sensing data are useful to identify conditions favorable for larval mosquito development, due to their preference for vegetated and humid areas. The distribution of mosquitoes is partly related to land use factors such as the presence or absence of wetlands, the type of surrounding vegetation, elevation and agricultural land use [34]. Many of these environmental factors can be mapped using remotely sensed data, and the normalized difference vegetation index (NDVI) can be used to explore or explain the relationship between mosquito population densities and vegetation/water seasonal patterns. Little is known about the use of remotely sensed data to estimate mosquito distributions in the Egypt, except the initial work of [35].

This unique spectral response of vegetation makes it possible to differentiate vegetation from other surface materials remotely. Derived NDVI values range between -1 to +1, with values below zero indicating absence of vegetation and those above zero showing increasing amounts of green vegetation. Green vegetation dynamics are a major determinant of the life cycles of insects in a wide range of environments [36,37].

After mosquito larval species identification, a map for each species was produced using Inverse Distance Weighting (IDW) in ArcGIS V 10.1 Environment. The species density is geographically represented in each map individually. These maps were then overlapped to create a risk map. Simply each species was inserted as input criteria in a simple cartographic GIS model to identify the highly vulnerable areas to mosquito proliferation and thus to diseases transmission.

3. RESULTS AND DISCUSSION

3.1 Mosquitoes Identification & Characterization of Breeding Sites

The mosquito species encountered at Dakhla oasis are shown in Table 1 & 2 and Fig. 2. Nine mosquito species were encountered in the different localities surveyed of which three are anophelines and six are culicines. *An. sergentii* was found to be the most predominant anopheline species. It was present in all the localities surveyed. *An. pharoensis* was found to be somewhat less abundant. It was found in 13 localities out of the 22 surveyed sites. *An. multicolor* was found to be less abundant than *An. sergenti* and An. pharoensis since it was found only in 10 localities. *Cx. univittatus*, *Ochlerotatus caspius* and *Cx. theileri* were predominant culicines. During the rice irrigation phase in Dakhla oases, the type of water storage observed during this study was cement drainage and wide deep. Some of water was found on the other side of drainage. This leads to increase vegetation density that provides resting and nectar meals for mosquitoes as well as providing shading from direct sunlight. Small and shallow water pools, often formed from cow or human foot prints are also implicated. Therefore, it provides favorable breeding sites for mosquito larvae especially *An. pharoensis*, *An. sergentii* and *Cx. pipiens*. These findings are in accordance with many authors [4,38,39,40], who recorded the same species in Dakhla oasis.

Table 1. Mosquito species density (No. of mosquito larvae/ No. of dips)

Sites	*An. pharoensis*	*An. sergentii*	*An. multicolor*	*Cx. pipiens*	*Cx. Antennatus*
1	5	3	0	10	2
2	0	7	10	0	0
3	10	2	1	15	0
4	9	1	0	12	0
5	0	3	7	5	0
6	2	1	0	11	0
7	14	8	2	22	0
8	2	5	0	0	0
9	9	2	1	18	0
10	0	11	0	5	0
11	17	3	1	18	0
12	0	2	0	11	0
13	8	2	3	9	0
14	12	8	0	0	0
15	0	8	0	0	0
16	7	2	1	15	0
17	11	8	0	25	0
18	5	2	2	9	0
19	0	5	0	11	0
20	9	4	0	8	4
21	0	3	1	8	0
22	2	12	0	17	5
Identified mosquito larval species					

Table 2. Correlation coefficient between mosquito larval species densities

		Cx. antennatus	*Cx. pipiens*	*An .multicolor*	*An. sergentii*	*An. pharoensis*
Cx. antennatus	Pearson Correlation	1	.110	-.200-	.329	-.033-
	Sig. (2-tailed)		.626	.372	.135	.885
	N	22	22	22	22	22
Cx. pipiens	Pearson Correlation	.110	1	-.277-	-.081-	.555**
	Sig. (2-tailed)	.626		.212	.719	.007
	N	22	22	22	22	22
An. multicolor	Pearson Correlation	-.200-	-.277-	1	-.032-	-.199-
	Sig. (2-tailed)	.372	.212		.889	.374
	N	22	22	22	22	22
An. sergentii	Pearson Correlation	.329	-.081-	-.032-	1	-.122-
	Sig. (2-tailed)	.135	.719	.889		.588
	N	22	22	22	22	22
An. pharoensis	Pearson Correlation	-.033-	.555**	-.199-	-.122-	1
	Sig. (2-tailed)	.885	.007	.374	.588	
	N	22	22	22	22	22

***. Correlation is significant at the 0.01 level (2-tailed).*

Investigations showed that breeding sites were characterized by turbid water and stagnant with green algae. Some of mosquito species collected in Dakhla oases are recorded as vectors of diseases in Egypt. The major recorded larval breeding sites were the rice paddies when flooded by irrigation water. This implies that irrigation activity and land scape by human activity are the principal contributors to the prevalence of a large mosquito population most of the year in the irrigation scheme [41].

Our suggestion management strategy would be to spray insecticides into floodwaters. This measure may be prohibitively expensive; In this case, it is preferable to try to get rid of water pools by discharging them to water banks. Mosquitoes have a flight range of about 2 km upwind as verified in the study carried out by [41] using mark-release recapture method. If all houses were to be built more than 2 km upwind from the nearest paddy, this would reduce the number of mosquitoes visiting houses significantly, and hence, reduce the incidence of vector borne diseases and the vectorial capacity of mosquitoes. This is the management strategy that we favor. It is expensive for existing irrigation schemes, but should prove feasible for the ones planned in future. On the other hand, it should be noted that the livestock population in Dakhla oases Irrigation Scheme is high, every household owning cattle, sheep, goats, poultry, and occasionally dogs, donkeys and cats. These animals also act as mosquito hosts or as a source of alternative blood meal, with cattle being major hosts for anopheline species and birds for culicines. The management of the irrigation scheme should take this into consideration by advising that livestock should also be kept further off the breeding sites in the paddies. Among the mosquito species observed, two species, *An*. *sergenti* and *An*. *pharoensis* are the most significant as malaria vectors [42,43,44,45], and *Cx*. *pipiens* is important proven species for transmission of filarial disease [46].

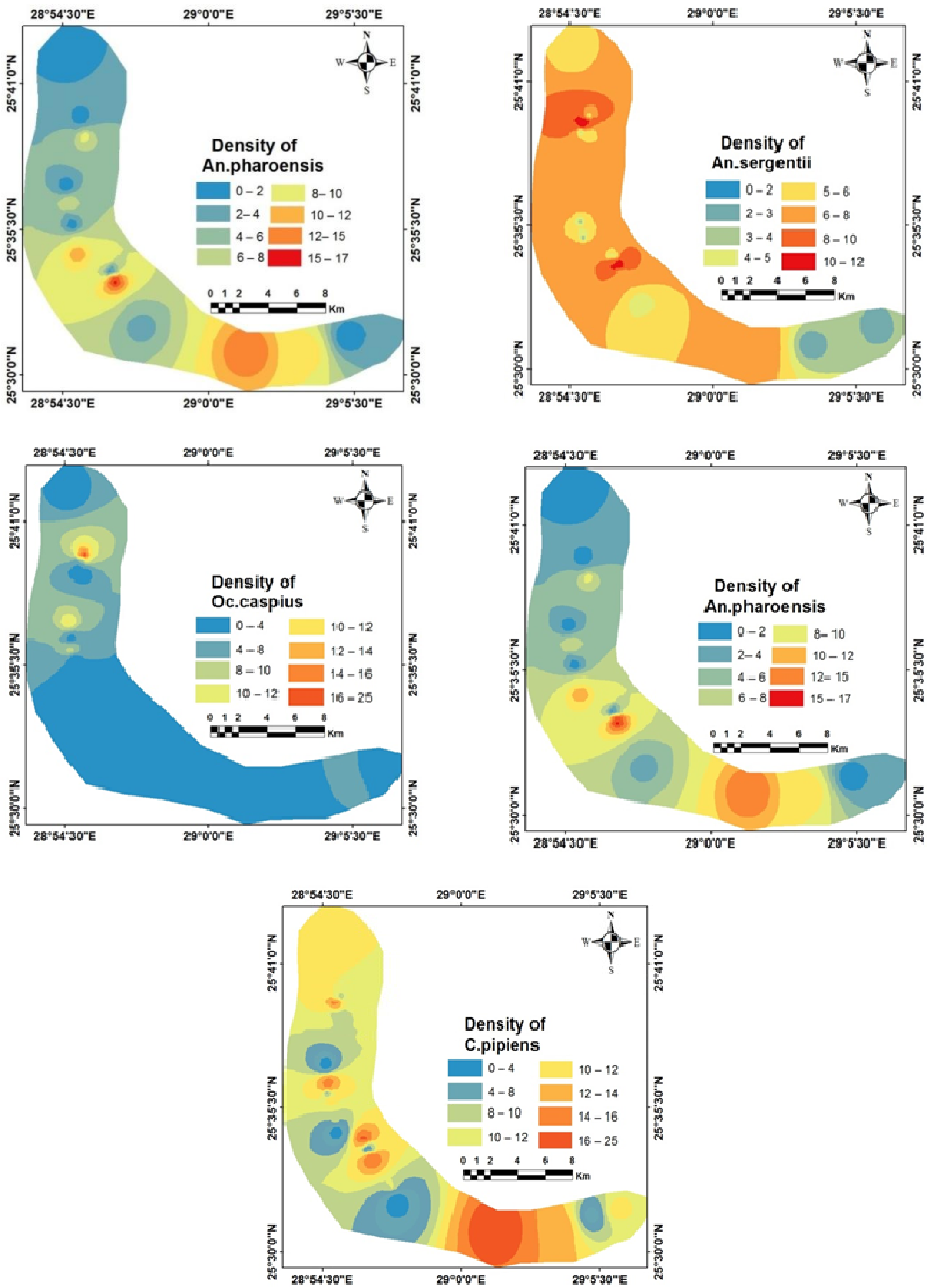

Fig. 2. Spatial distribution of mosquito larval species densities

The presence of *Cx. pipiens* in the study area is epidemiologically important since *Cx. pipiens* was reported as the main vector of RVF virus; *Bencroftian filariasis* and West Nile virus

[46,47,48,49]. This information is critical and draws attention to potential transmission risk of several mosquitos borne diseases in this area when infected hosts are introduced. Thus, this area may form a focus of many parasites infection along the western border of Egypt. Indoor mosquito collections in irrigated and non-irrigated areas using human bait and light traps is of great importance to reduce mosquito densities, thus reducing the chance of disease transmission by mosquitoes [50]. They found that Catches inside houses using human bait and modified CDC light traps indicated that in the rice field environments numbers of the main malaria vectors of the area were higher than in non-irrigated areas, and that their breeding extended over some 6 months of the year. Abundance of these mosquitoes in dwellings was closely linked to the conditions in nearby rice fields, and the 2 main population peaks of *An*. *gambiae* were connected with hand transplanting of young rice from nurseries to the main fields. On the non-irrigated plain, prevalence of the major anopheline species followed a more classical pattern, being closely linked to local rainfall, and the predominant mosquito species were found to be those breeding in semi-permanent swamps and water holes. Several investigators in other parts of the world have adopted similar approaches with successful results. In order to distinguishing between high and low anopheline-producing rice fields through the use of remote sensing and GIS, Wood with others, were able to predict high mosquito densities 2 months earlier, thus informing control activities [51].

3.2 Vegetation Density in Mosquito Breeding Sites

Remote sensing data are commonly used to identify ecological conditions associated with vector-borne diseases especially mosquito vectors [34,52]. Measurements in the visible red and near infrared bands are of specific relevance to ecology. The spectral signature of plant canopies is characterized by a strong chlorophyll absorption in the red portion of the spectrum and a very high reflectance in the near infrared portion. This unique spectral response of vegetation makes it possible to differentiate vegetation from other surface materials remotely. From Fig. 3, Normalized Differences Vegetation Index (NDVI) of El-Dakhla oases ranged from high to non-vegetation (i.e. from -1 to +1). Most breeding sites located in moderate density of hydrology. Derived NDVI values range between -1 to +1, with values below zero indicating absence of vegetation and those above zero showing increasing amounts of green vegetation. Green vegetation dynamics are a major determinant of the life cycles of insects in a wide range of environments [36,53]. Thus data on NDVI values and NDVI anomalies may be useful to predict the potential geographical distribution of mosquito vectors and related species in Egypt.

3.3 Risk of Mosquitoes Transmitting Diseases

Using GIS spatial analysis functions areas at risk of mosquito attacks and disease transmission within the study area were identified and mapped. In this particular case, the risk map showed that a large part of urban and cultivated lands at the study area would be at risk since it would be located within the buffer zone (Fig. 4).

Results showed that, the remote sensing technology is a highly-effective tool for assessing current and future prevalence of insect borne diseases as well as endemic and epidemic diseases. GIS can be used effectively to help track, monitor and combat the spread of a disease (RVF, Filaria, Malaria and West Nile Virus).

Arboviruses transmitted in rice field ecosystems are maintained primarily in zoonotic cycles of continuous transmission or transovarially and constitute a constant threat. Infection with arboviruses associated with rice field ecosystems results in a spectrum of human disease ranging from subclinical infection to acute encephalitis. Limited data indicate substantial levels of arbovirus transmission in several areas. Epidemics of viruses, which are normally endemic, probably result from a buildup in vector population density as a result of weather (principally high summer temperature), agricultural practices, and water management. Reduction of vector density in rice fields [45] at the appropriate time is a requirement for disease control. Reducing vector biting by house screening, use of bed nets, repellents, and health education may play an important role in reduction of disease transmission.

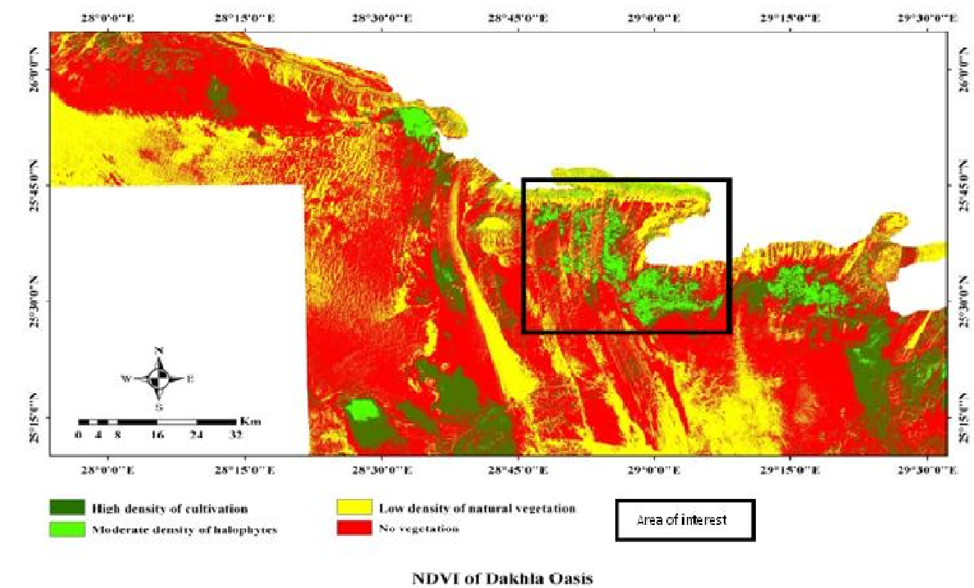

Fig. 3. Normalized differences vegetation index (NDVI) of El-Dakhla oases

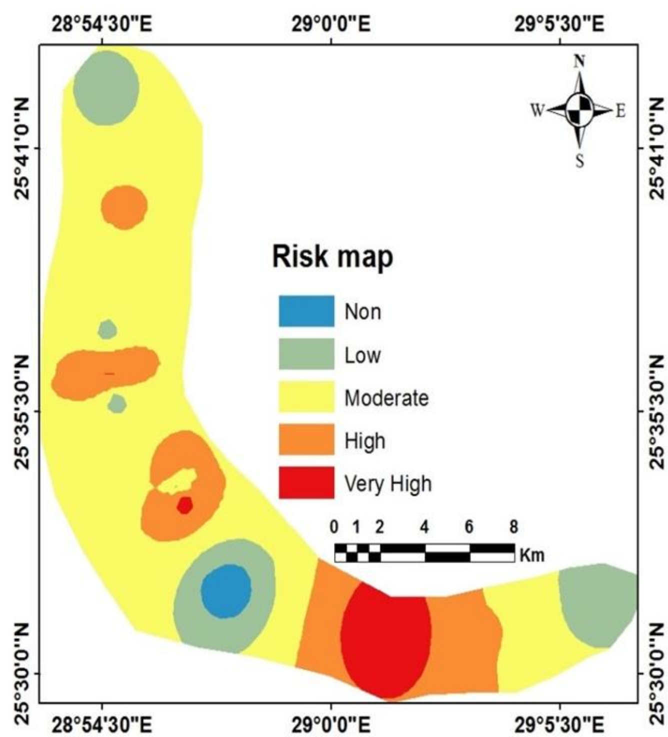

Fig. 4. Mosquito species inserted as input criteria in a simple cartographic GIS model to identify the highly vulnerable areas to mosquito proliferation risk map in Dakhla oases

4. CONCLUSION

The species composition of mosquito larvae varied in different habitats at various geographical locations in El-Dakhla Oases. However, the higher numbers of species were collected from the rice paddies and streams (particularly margins, inlets and pool). Only *An.*

pharoensis, *An*. *sergentii*, *An*. *multicolor*, *Cx*. *pipiens*, *Cx*. *antennatus*, *Cx*. *univittatus*, *Cx*. *theileri*, *Cx*. *deserticola* and *Oc*. caspius, larvae were collected from all 22 habitat groups surveyed. Mosquito larval populations fluctuated or increased with the seasonal dynamics of vegetation for 2009, as observed in El-Dakhla. Multi-year data of mosquito collections are required to provide a better characterization of the abundance of these insects from year to year which can potentially provide predictive capability of their population density based on remotely sensed ecological measurements.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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