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RESEARCH PAPER

Characterization of landscape features associated with mosquito breeding in urban Cairo using remote sensing

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Abstract Problems of mosquito vectors proliferation have been increasing in Cairo in conjunction with urbanization and industrialization where several anopheline and culicine species have been collected. The present study was carried out to characterize the landscape variables potentially associated with mosquito breeding in a subset of urban Cairo. The study compared the capabilities of two satellite sensors, namely Landsat TM5 and Ikonos; in such endeavor. The study area encompassed 18 urban districts of Cairo. Mosquito breeding habitats were characterized within the district level using integrated remote sensing and geographic information system (GIS) analyses. Different environmental variables derived from both satellite imageries were used to characterize landscapes of districts where mosquito breeding habitats occur. These variables include urbanization level, Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), wetness, and Band 2/Band 4 (B2/B4) ratios. The majority of mosquito breeding sites (93.5%) were found in slum areas. For both sensors, districts where breeding sites occurred were characterized by significantly higher mean of soil percentage and lower mean of majority wetness. At this level of characterization, Landsat TM5 would be adequate for the major identification of habitat areas. For targeting mosquito larval control however, Ikonos would provide better inputs as it allowed a better classification of small land cover classes including water.

1. Introduction

Vector-borne diseases are becoming one of the major public health problems associated with rapid urbanization in many tropical countries (Knudsen and Slooff, 1992). Cairo is among the mega cities of the world where its population rose from 6.1 million in 1975 to 16.5 in 2000 (2.7% growth rate); and reached 18 million in 2006 (CAPMAS, 2006). Problems of mosquito vectors proliferation have been increasing in Cairo in conjunction with urbanization and industrialization that took place in the second half of the last century (Ossman, 2001). In recent

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years, several mosquito species have been collected from urban Cairo, of which many are vectors of diseases (e.g. Abdel-Megeed et al., 2003; Morsy et al., 2004; Ammar et al., 2012).

One of the challenges facing health authorities in urban areas is locating and surveying breeding habitats of mosquitoes for control measures. Modern technologies such as Geographic Information Systems (GIS) and remote sensing have been progressively used by health authorities to assist in these operations (Beck et al., 2000). Satellite remote sensing is increasingly being applied to locate and characterize breeding habitats of a variety of vectors especially mosquitoes (e.g. Impoinvil et al., 2008; Severini et al., 2008). The availability of low-cost, medium-resolution imageries; such as Landsat Thematic Mapper (TM5), and of commercial imaging satellites; such as Ikonos and QuickBird, offer new opportunities to assess urban habitats for disease vectors by providing very high spatial resolutions appropriate for mapping urban variables that may indicate the presence of vector habitats (e.g. Jensen and Cowen, 1999; Rongnoparut et al., 2005; Mushinzimana et al., 2006; Jacob et al., 2006; Bogh et al., 2007).

The present study was carried out to evaluate the utility of two remote sensing sensors; namely Landsat TM5 and Ikonos; to characterize mosquito breeding habitats in urban Cairo.

2. Materials and methods

2.1. Study area

The present study was carried out in a subset of Cairo Governorate covering a total area of 135 km^2 (Upper Left: 31° 12′ 40.5″ E, 30° 05′ 07″ N-Lower Right: 31° 20′ 57.58″ E, 29° 59′ 14.76″ N) and including 18 districts. Annual rainfall is low with a long-term average of 25 mm/year. Daily air temperatures vary between 35 °C and 38 °C in summer and 10–20 °C in winter (Egyptian Meteorological Authority, 1996).

2.2. Mosquito breeding habitats

Data concerning mosquito breeding habitats (31 sites) encountered within this area were collected by the senior author of this manuscript during the period April–September 2005. During this period, most breeding habitats were visited twice. Breeding habitats positive for mosquitoes were geo-referenced using a hand-held GPS unit; and their type, mosquito species present and their surroundings were described. Collected mosquito larvae were transported to the laboratory where they were taxonomically identified using the keys of Harbach (1985), Harbach (1988) and Glick (1992).

2.3. GIS database

A GIS-ready layer of Cairo districts' boundaries was purchased scale 1:50000. The 18 districts of the study area were selected and converted into a shape file using Arc GIS to produce the district map. Geographic coordinates of mosquito breeding sites were also converted into GIS format and were represented by a-point coverage.

2.4. Remote sensing data acquisition

Images of the study area were obtained from two satellite sensors; Landsat TM5 and Ikonos satellites. The Landsat TM5 image was acquired on 12 July 2005 while the Ikonos scenes were acquired on 8 May 2003; as no suitable images (with no artifacts and low or no cloud cover) were commercially available for the similar dates.

The Landsat TM5 scene (Path/Row: 176/39) has a 30 m multispectral resolution. A subset of the scene for 135 km^2 study area was extracted from the image. The Ikonos image with 1 m panchromatic and 4 m multispectral resolution was comprised of two separate scenes. A mosaic of the two Ikonos scenes was produced using ERDAS (Earth Resources Data Analysis System) Imagine version 8.7. Both Landsat TM5 and Ikonos images were geo-referenced to a UTM projection (zone 36 North) with a WGS-84 datum using known ground control points collected in the field with hand-held GPS units.

2.5. Image analysis

Different environmental variables were used to indicate and identify mosquito breeding habitats. These variables include urbanization level, Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), wetness, and B2/B4 band ratios. All variables were derived from both Landsat TM5 and Ikonos imageries, except the urbanization level was generated from Ikonos merged imagery. Ikonos merged imagery at 1 m resolution multispectral was generated by merging 1 m resolution panchromatic image with the 4 m resolution multispectral bands.

2.5.1. Districts' urbanization level

The study area was stratified into two main strata namely; planned and slum using Ikonos imagery. According to this stratification, planned areas were characterized by a network of hierarchical roads, the presence of basic services, infrastructures, and green areas. Slum areas were characterized by irregular settlements, partial construction or uncompleted buildings, disorganized network of roads, extremely narrow streets with many dead ends, absence of services and infrastructures, crowding and high population density. Visual interpretation was performed on the merged data by digitizing and tracing different urban strata using ERDAS Imagine. The district map was overlaid onto the urban stratification map to produce the urbanization level map. According to the percentage of different strata within each district, the 18 districts were categorized into four urban categories as follows: planned ($\geqslant$75% planned), slum ($\geqslant$75% slum), planned with minor slum (60–75% planned) and slum with minor planned (60–75% slum).

2.5.2. Land use land cover (LULC) classification

Supervised classification was performed to cluster pixels in the image into four classes namely: water, vegetation, urban and soil. This was done by defining areas of interest (AOI) that represented each of the four land cover classes in the output image. The maximum likelihood classification was performed to assign each pixel in the image to the class that has the highest probability.

2.5.3. NDVI

NDVI is calculated as a ratio between measured reflectivity in the red (0.63–0.69 μm) and NIR (0.76–0.90 μm) portions. These two spectral bands were chosen because they are most affected by the absorption of chlorophyll in leafy green vegetation and by the density of green vegetation on the surface. NDVI was calculated as: $NDVI = (NIR - R)/(NIR + R)$. To aid with interpretation, NDVI values were then scaled to a range of 8 bit image as follows: $scale\ NDVI = 100(NDVI + 1)$.

2.5.4. Wetness

Wetness is one of the spectral quantitative indices that represent land surface moisture content. Wetness values were derived from the "Tasselled Cap" function in ERDAS Imagine.

2.5.5. Band 2/Band 4 pixel ratio (B2/B4)

Band ratio of Green (B2) and NIR (B4) is expected to be high in vegetation because they are most affected by the absorption of chlorophyll in leafy green vegetation and by the density of green vegetation on the surface. In order to maximize the range of B2/B4 values, the output values were scaled using the equation: $scale\ B2/B4 = 100(B2/B4 + 1)$. This scaling converts floating numbers into pixel values that are appropriate on a dark-and-white display.

Accordingly, a set of 13 predictive variables was calculated for each district namely: proportion of each landscape element occupied (water, vegetation, urban, and soil), minimum, maximum, and majority scaled NDVI, minimum, maximum, and majority wetness, and minimum, maximum, and majority scaled B2/B4.

2.6. Characterization of mosquito breeding habitats on the district level

The district boundaries' map was overlaid on the Landsat TM5 and Ikonos LULC maps in order to test the relationship between the presence of breeding sites and the LULC map. The proportion of each LULC class within each district was calculated for both satellite imageries using summary function in ERDAS Imagine. The Zonal Statistics function was used to calculate the minimum, maximum, and majority of scaled NDVI, wetness, and scaled B2/B4 per district for Landsat TM5 and Ikonos data.

2.7. Statistical analysis

All analyses were performed using SPSS (version 13.0 for Windows). Pearson correlation coefficient was used to study the relation between the number of breeding sites and the environmental variables derived from both Landsat TM5 and Ikonos imageries. Discriminant analysis which incorporated environmental conditions obtained from Landsat TM5 and Ikonos data was used to distinguish between districts with or with no breeding sites.

3. Results

During the present study, eleven mosquito species were collected (Table 1). These include four *Anopheles (pharoensis; multicolor; tenebrosus* and *sergentii)*, five *Culex (antennatus; pipiens; poicilipes; perexiguus* and *pusillus)*, and one of both *Culesita* (*longiareolata*) and *Ochlerotatus* (*caspius*) species. The most prevalent species were *Cx. pipiens*, *Cx. perexiguus* and *An. multicolor*, respectively.

Many of the positive mosquito breeding habitats were found in slum areas, others were adjacent to bare soil or located in water bodies present within desert area. A number of 12 out of the 31 sites (38.71%) were shaded with emergent vegetation, 7 sites (22.58%) were shaded with low density of vegetation, 6 sites (19.34%) had no vegetation, 3 sites

Table 1 Mosquito species collected from each breeding site during the present study.

Breeding site location	Mosquito species collected	Breeding site location	Mosquito species collected
El-Mokatum 1	*Cx. pipiens* + *Cx. antennatus*	Manshit Naser 3	*Cx. pipiens* + *Culiseta longiareolata*
El-Mokatum- Ain Mousa 1	*Cx. pipiens*	El-Dowaka	*Cx. pipiens* + *Culiseta longiareolata* + *Cx. perexiguus*
El-Mokatum- Ain Mousa 2	*An. multicolor* + *Oc. caspius*	Ain El Seera 4	*Cx. pipiens* + *Cx. perexiguus*
Ain El Seera 1	*Cx. pipiens*	Ain El Seera 5	*Cx. pipiens* + *Cx. perexiguus*
Ain El Seera 2	*An. multicolor* + *An. sergenti*	El khaialla 1	*Cx. perexiguus*
Ain El Seera 3	*Cx. pipiens* + *Cx. perexiguus*	El khaialla 2	*Oc. caspius*
El Fostat City 1	*An. tenebrosus*	El khaialla Batn El Bakara 3	*Cx. perexiguus*
El Fostat City 2	*An. multicolor* + *Cx. pusillus*	El khaialla Batn El Bakara 4	*Oc. caspius* + *An. multicolor* + *Cx. poicilipes*
El khaialla 1	*Oc. caspius*	El-Mokatum Ain Mousa 1	*An. multicolor*
El khaialla 2	*Oc. caspius*	El-Mokatum Ain Mousa 2	*An. multicolor*
El khaialla 3	*Oc.caspius* + *Cx.pusillus*	El-Mokatum- Ain Mousa 3	*Cx. poicilipes*
El khaialla- mdafen El Emam El Lithy	*Cx. pusillus*	El-Mokatum 2	*An. pharoensis* + *Cx. perexiguus*
El khaialla- Batn El Bakara 1	*Oc.caspius* + *Cx. pusillus* + *An. multicolor*	Manshit Naser 4	*Cx. pipiens* + *Culiseta longiareolata*
El khaialla- Batn El Bakara 2	*Cx.pipiens* + *Cx.perexiguus* + *Cx. antennatus*	Manshit Naser 5	*Cx. pipiens* + *Culiseta longiareolata*
Manshit Naser 1	*Cx. pipiens*	Manshit Naser 6	*Cx. pipiens* + *Culiseta longiareolata*
Manshit Naser 2	*Cx. pipiens* + *Culiseta longiareolata*		

Table 2 Medical importance of mosquitoes collected during the present study.

Mosquito genera	Mosquito species	Medical importance
Anopheles	*sergentii*	Malaria
	pharoensis	Malaria
	multicolor	–
	tenebrosus	–
Culex	*pipiens*	Human filariasis, Rift Valley fever & West Nile virus
	perexiguus	West Nile
	antennatus	Human filariasis & Rift Valley fever
	pusillus	–
	poicilipes	–
Culesita	*longiareolata*	–
Ochlerotatus	*caspius*	–

(9.68%) were covered by solid wastes, while 2 sites (6.45%) were in small water patches/pockets and 1 site (3.23%) was located inside a building (cryptic breeding).

Some of the collected mosquito species are known vectors of serious diseases of man and animals. The medical importance of the collected species is shown in Table 2.

3.1. Urbanization level of districts

According to urban categorization, seven districts (38.9%) were classified as planned, three districts (16.7%) were classified as planned with minor slum, six districts (33.3%) were classified as slum with minor planned, and two districts (11.1%) were classified as slum (Table 3). By overlaying the 31 breeding sites on the district map; it was found that these sites were located within three districts out of the 18 located within the study area. These districts were El Khalifa, Misr El Qadima, and Monshaet Nasser. These districts varied between slum, slum with minor planned and planned with minor

Table 3 Classification of districts according to urbanization level.

Urban type	District name
Planned	El Daher, Zamalek, Qasr El Nil, Shoubra, Al Azbakiya, Al Wayly, Abdeen
Planned with minor slum	Nasr City - Qism2, Rod El Farag, Sayeda Zeinab
Slum with minor planned	El Khalifa, El Gamaliya, Bab El Shaariya, Boulaq, Misr El Qadima, El Mosky
Slum	Monshaet Nasser, El Darb El Ahmar

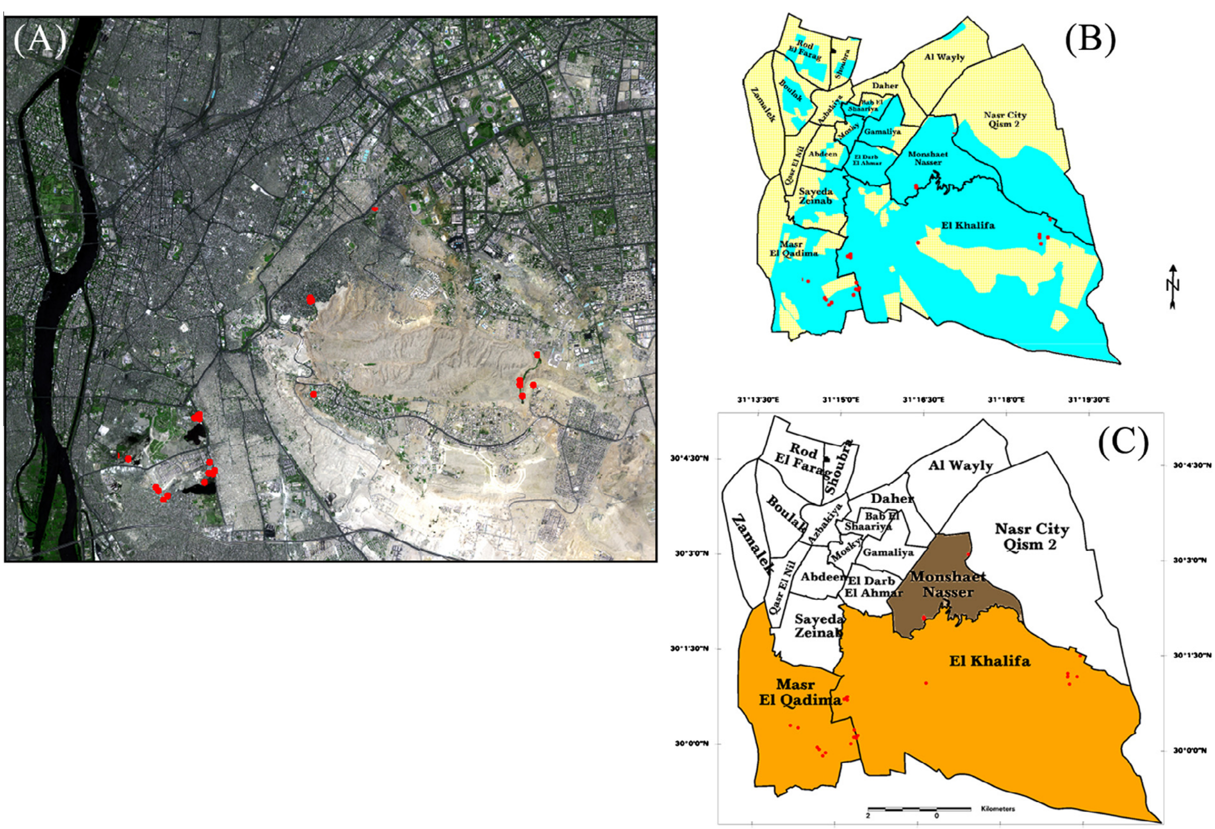

Figure 1 Mosquito breeding sites (●) overlaid on: (A) Ikonos merged image; (B) Urban strata classified as planned (■) and slum (■); (C) Urban stratification map of positive districts categorized as slum (■) and slum with minor planned (■), and negative districts (□).

Table 4 Discriminant analysis group statistics of predictive variables derived from Landsat TM5 data according to the presence or absence of breeding sites within districts.

Landsat TM5 derived variables	Positive districts (mean ± SD)	Negative districts (mean ± SD)	$F_{1,16}$	P value
Water percentage	0.59 ± 0.82	0.18 ± 0.24	3.23	0.09
Vegetation percentage	10.74 ± 8.94	18.20 ± 14.59	0.71	0.41
Urban percentage	63.32 ± 29.30	78.09 ± 22.86	0.97	0.34
Soil percentage	24.27 ± 32.46	1.48 ± 5.09	8.42	0.01
Minimum scaled NDVI	82.33 ± 4.93	86.53 ± 2.20	6.06	0.03
Maximum scaled NDVI	131.33 ± 5.51	126.07 ± 10.65	0.67	0.42
Majority scaled NDVI	96.67 ± 2.89	95.80 ± 2.81	0.24	0.63
Minimum wetness	72.67 ± 13.05	121.80 ± 24.47	11.07	0.00
Maximum wetness	233.00 ± 20.81	225.33 ± 14.59	0.61	0.45
Majority wetness	151.67 ± 18.82	182.33 ± 6.69	28.16	0.00
Minimum scaled B2/B4	117.33 ± 30.02	136.80 ± 28.88	1.13	0.31
Maximum scaled B2/B4	229.00 ± 20.08	215.20 ± 12.99	2.40	0.14
Majority scaled B2/B4	153.33 ± 46.29	165.93 ± 41.29	0.23	0.64

Table 5 Discriminant analysis group statistics of predictive variables derived from Ikonos data according to the presence or absence of breeding sites within districts.

Ikonos derived variables	Positive Districts (mean ± SD)	Negative Districts (mean ± SD)	$F_{1,16}$	P value
Water percentage	0.55 ± 0.74	0.04 ± 0.07	8.96	0.01
Vegetation percentage	7.88 ± 4.35	11.58 ± 8.02	0.59	0.46
Urban percentage	75.53 ± 14.45	83.78 ± 15.00	0.76	0.40
Soil percentage	13.23 ± 17.60	1.08 ± 3.17	7.76	0.01
Minimum scaled NDVI	61.67 ± 8.33	63.47 ± 7.81	0.13	0.72
Maximum scaled NDVI	153.33 ± 3.06	152.80 ± 4.49	0.04	0.85
Majority scaled NDVI	96.67 ± 0.58	96.47 ± 1.89	0.03	0.86
Minimum wetness	33.67 ± 4.16	47.47 ± 15.43	2.26	0.15
Maximum wetness	201.33 ± 38.55	196.00 ± 36.05	0.05	0.82
Majority wetness	91.00 ± 9.54	100.60 ± 2.35	14.20	0.00
Minimum scaled B2/B4	114.67 ± 25.40	126.87 ± 22.96	0.69	0.42
Maximum scaled B2/B4	255.00 ± 0.00	255.00 ± 0.00	Constant	
Majority scaled B2/B4	170.67 ± 61.23	183.67 ± 52.33	0.15	0.71

slum urban categories. 24 breeding sites (77.4%) were located in the slum with minor planned category, and seven breeding sites (22.6%) were located in the slum (Fig. 1).

3.2. Characterization of mosquito breeding habitats on the district Level

In order to identify the combination of variables that best characterize the presence of breeding sites within study districts, the environmental variables (LULC, scaled NDVI, wetness, and scaled B2/B4) derived from Landsat TM5 and Ikonos were calculated for each district in relation to the occurrence of breeding sites. For Landsat TM5, the relation between the number of breeding sites and the predictive variables revealed that soil percentage (r = 0.740, P = 0.0001) and maximum scaled B2/B4 (r = 0.491, P = 0.038) were positively correlated with the number of breeding sites. While, minimum scaled NDVI (r = −0.670, P = 0.002), minimum wetness (r = −0.649, P = 0.0001), and majority wetness (r = −0.860, P = 0.0001) were negatively correlated with the number of breeding sites. For Ikonos data, water percentage (r = 0.646, P = 0.004) and soil percentage (r = 0.709, P = 0.001) were positively correlated to the number of breeding sites. Whereas only majority wetness was negatively correlated (r = −0.799, P = 0.0001).

The 18 study districts were classified into two groups according to the presence or absence of breeding sites. Discriminant Analysis showed that 16.7% (3/18 districts) and 83.3% (15/18 districts) were classified as ***positive*** and ***negative*** groups respectively. The group statistics of district classifications according to the presence/absence of breeding sites for Landsat TM5 data revealed that positive districts were characterized by significantly higher mean of soil percentages (24.273 ± 32.460; P = 0.01); significantly lower mean of minimum scaled NDVI (2482.333 ± 4.933; P = 0.03), minimum wetness (72.667 ± 13.051; P = 0.0001), and majority wetness (151.667 ± 18.824; P = 0.0001) than negative districts (Table 4). For Ikonos derived data, the positive districts were characterized by significantly higher mean of water percentage (0.550 ± 0.739; P = 0.01) and soil percentage (13.233 ± 17.604; P = 0.01). They were also characterized by significantly lower mean of majority wetness (91.000 ± 9.539; P = 0.0001) than negative districts (Table 5). According to the stepwise discriminant analysis of Landsat TM5 data, only majority wetness ($F_{1,16}$ = 28.157, P = 0.0001) was retained in the final model to discriminate between positive and negative districts. The sensitivity and specificity of the model reached 100% as it was able to correctly discriminate between both groups. The overall accuracy of discrimination reached 100%. For Ikonos data, two variables elucidated the discrimination between the presence and absence of breeding sites on the district level. These variables were majority wetness ($F_{1,16}$ = 14.200, P = 0.002) and water percentage ($F_{2,15}$ = 14.434, P = 0.0001). The standardized canonical coefficients revealed that majority wetness had a larger contribution in discriminating between district groups (0.943) than water percentage (−0.851). The sensitivity of the model reached 66.7% as it was able to correctly categorize two out of three districts where breeding sites were found. However, the specificity of the analysis reached 100% as it was able to categorize all districts where no breeding sites were found. The total accuracy of the model reached 94.4%.

4. Discussion

The study of urban areas using satellite sensors of high spatial resolution poses special problems due to urban structural heterogeneity and complexity (Gamba et al., 2003; Small, 2003). In the present investigation, Ikonos merged imagery was used in the urban categorization process while Landsat TM5 and Ikonos multispectral were used for the characterization of mosquito breeding habitats. The high spatial resolution of Ikonos data was appropriate for the identification of city blocks, individual roads, roadways, and buildings. This corroborates the findings of Jensen and Cowen (1999). Fifty percent of the study area was categorized as slum; where the absence of services and infrastructures created conditions suitable for mosquito breeding. Over 90% of the breeding sites were found in these slum areas. The unique hydrological conditions of Cairo have also contributed to the vector problem as the high water table (water logging) and presence of natural springs (e.g. Ain Mousa, Ain El Sira, El Khayala) were observed to create favorable conditions for mosquitoes (El Shewiy, 1996).

For both Landsat TM5 and Ikonos, the districts positive for mosquito habitats were characterized by higher mean of soil percentage and lower mean of majority wetness. The finding of significantly higher number of breeding habitats in districts with higher soil percentages seems related to the landscape features of such land cover. Soil land cover represents vacant lands and slum areas around the boundaries of urban settings (e.g. El Khalifa district which had the highest percentage (42%) of breeding sites). These landscapes are poorly managed with sub-standard intervention that would lead to leaking infrastructure, accumulation of waste and emergence of marginal vegetation. These findings are consistent with previous work of Klinkenberg et al. (2008) who reported that unplanned urban expansion outpacing infrastructure development created breeding conditions, while the proper construction of drains and sewage systems would reduce the amount of open drains proliferating high nuisance of mosquito breeding sites. In addition to factors related to soil land cover, both man-made and natural phenomena have contributed to the genesis of more breeding habitats in our study area. These included high water table and the presence of natural water springs (e.g. Ain Mousa). High water table is a well documented problem in Cairo which is exaggerated in poorly managed lands especially in the study area (El Shewiy, 1996). Both types of sensors showed a significantly lower number of breeding habitats in districts with the majority wetness. This was described according to the mosquito larvae ecology, they are usually found at the water's surface and frequently next to vegetation or surface debris. In larger pools and ponds, they are usually near the margins, not in open, deep water (O'Malley, 1995).

For Landsat TM5, districts positive for mosquito breeding habitats were also characterized by lower wetness and vegetation vigor (measured as NDVI). This finding is closely associated with the soil land cover. As previously mentioned, in such land cover only marginal vegetation grows in response to leaking infrastructure or high water table. In contrast, truly urban environs are characterized by well managed soft landscaping in the form of large greenery, ornamental vegetation and open parks. These soft landscapes are watered daily and are well managed. This results in higher vegetation vigor, therefore higher NDVI and wetness values (Schmidt-Vogt, 1999). In addition, in such urban areas several hard landscape features; such as swimming pools and fountains; are numerous in comparison to areas with vacant lands with a resultant higher wetness. Here it should be also noted that NDVI is usually taken as a measure of vegetation vigor and health, denoting both green areas and soil moisture (Tucker, 1979). Accordingly, it seems that mosquito breeding habitats in urban Cairo are favored in un-developed or poorly planned areas characterized by marginal vegetation cover and associated lower moisture. Eisele et al. (2003) also found that urban areas in Kisumu and Malindi with lower NDVI may likely represent areas with high household and population density, such as slums constructed mostly of wood and sheet metal, and urban business districts, such as parking lots and buildings constructed mostly of concrete. Thus areas of low NDVI may also be important in terms of mosquito habitat development.

When Ikonos was applied, mosquito breeding habitats were shown to be associated with a higher water land cover. Abdel-Megeed et al. (2003) found that seepage water pools and tap water pool where mosquitoes breed ranged between 10–400 m^2 and 0.5–8 m^2 in Misr El Qadima, Mar Girgis Zone, Cairo. Landsat TM5 imagery lacks the ability to detect land cover classes that are less than 30×30 m in size, while they can be detected by the high spatial resolution of Ikonos data (Masuoka et al., 2003). This might explain the positive correlation to the water percentage. In this regard, the association of higher breeding potential to lower moisture seems to be related more to the lower moisture content of vegetation and the effect of bare soil on producing less wetness; rather than a direct relation to the number of water features themselves.

The accuracy of the discrimination model showed that the sensitivity and specificity for Landsat TM5 reached 100%. While the sensitivity and specificity for Ikonos reached 66.7% and 100% respectively. Despite the difference in the spatial resolution between Landsat TM5 and Ikonos satellite images, both sensors produced environmental variables that are adequate for characterizing mosquito breeding habitats on the district level. Similar results were reached by Stoops et al. (2008) while using high resolution satellite images to identify the presence of *Anopheles* larval breeding sites in Indonesia.

The two types of sensors could be used together in planning and implementing a mosquito control program. But at this level of characterization, Landsat TM5 in conjunction with information on the location and number of breeding sites in a geographic information system (GIS) would be adequate for the major characterization of mosquito breeding habitats. However, for targeting mosquito larval control, Ikonos would provide better inputs as it allowed a better classification of small land cover classes including water (Masuoka et al., 2003). In addition, Landsat TM5 images are easily available at low cost in digital formats and a single scene covers a large area (swath width = 185 km), while Ikonos images have the best spatial resolution for identification but they are more costly and often the availability of images is limited in areas where cloud coverage is significant and frequent.

5. Conclusion

The present study was carried out to characterize the landscape variables associated with mosquito breeding habitats in urban Cairo using Landsat TM5 and Ikonos satellite sensor data. The landscape elements associated with mosquito breeding; and subsequently with disease risk; were higher percentage of soil and lower means of wetness. Our analyses also indicated that over 90% of mosquito breeding sites were found in slum areas and therefore, people living in such areas would be at a higher risk of transmission of mosquito-borne diseases such as malaria; filariasis; Rift Valley fever and West Nile. Our results demonstrated the capability of remote sensing to characterize landscape determinants of mosquito habitats in urban settings. This tool can be deployed to assist mosquito control efforts using high resolution satellite sensors.

References

Abdel-Megeed, M.I., Moustafa, A.Z., Washahy, K., Selim, N.A., 2003. Toxicity of certain insecticides against mosquito larvae *Culex pipiens* (Diptera: Culicidae). J. Environ. Sci. 6 (2), 575–591.

Ammar, S.E., Kenawy, M.A., Abdel-Rahman, H.A., Gad, A.M., Hamed, A.F., 2012. Ecology of the mosquito larvae in urban environments of Cairo Governorate. Egypt. J. Egypt Soc. Parasitol. 42 (1), 191–202.

Beck, L.R., Lobitz, B.M., Wood, B.L., 2000. Remote sensing and human health: new sensors and new opportunities. Emerg. Infect. Dis. 6, 217–226.

Bogh, C., Lindsay, S.W., Clarke, S.E., Dean, A., Jawara, M., Pinder, M., Thomas, C.J., 2007. High spatial resolution mapping of malaria transmission risk in the Gambia, west Africa, using Landsat TM satellite imagery. Am. J. Trop. Med. Hyg. 76 (5), 875–881.

CAPMAS, 2006. Central agency for public mobilization and statistics. CAPMAS web site: <http://www.msrintranet.capmas.gov.eg>.

Egyptian Meteorological Authority, 1996. The Climatic Atlas of Egypt. Cairo.

Eisele, T., Keating, J., Swalm, C., Mbogo, C., Githeko, A., Regens, J., Githure, J., Andrews, L., Beier, J., 2003. Linking field-based ecological data with remotely sensed data using a geographic information system in two malaria endemic urban areas of Kenya. Malaria J. 2, 44.

El Shewiy, M., 1996. Environmental problems related to groundwater conditions within Greater Cairo, Institute of environment studies and research. Unpublished thesis, Ain Shams University, Cairo, Egypt.

Gamba, P., Benediktsson, J.A., Wilkinson, G., 2003. Foreword to the special issue on urban remote sensing by satellite. IEEE Trans. Geosci. Remote Sensing 41, 1903–1906.

Glick, J.I., 1992. Illustrated key to the female anopheles of Southwestern Asia and Egypt (Diptera: Culicidae). Mosq. Syst. 24, 125–153.

Harbach, R.E., 1985. Pictorial keys to the genera of mosquitoes, subgenera of Culex and the species of Culex (Culex) occurring in Southwestern Asia and Egypt, with a note on the subgeneric placement of Culex deserticola (Diptera: Culicidae). Mosq. Syst. 17 (2), 83–107.

Harbach, R.E., 1988. Mosquitoes of the subgenus Culex in Southwestern Asia and Egypt (Diptera: Culicidae). Contr. Am. Entomol. Inst. (Ann Arbor) 24 (1), 1–240.

Impoinvil, D.E., Mbogo, C.M., Keating, J., Beier, J.C., 2008. The role of unused swimming pools as a habitat for *Anopheles* immature stages in urban Malindi. Kenya J. Am. Mosq. Control Assoc. 24 (3), 457–459.

Jacob, B.G., Shililu, J., Muturi, E.J., Mwangangi, J.M., Muriu, S.M., Funes, J., Githure, J., Regens, J.L., Novak, R.J., 2006. Spatially targeting *Culex quinquefasciatus* aquatic habitats on modified land cover for implementing an integrated vector management (IVM) program in three villages within the Mwea Rice Scheme. Kenya Int. J. Health Geogr. 9, 5–18.

Jensen, J.R., Cowen, D.C., 1999. Remote sensing of urban suburban infrastructure and socio-economic attributes. Photogrammetric Eng. Remote Sensing 65, 611–622.

Klinkenberg, E., McCall, P., Wilson, M.D., Amerasinghe, F.P., Donnelly, M.J., 2008. Impact of urban agriculture on malaria vectors in Accra. Ghana Malaria J. 7, 151.

Knudsen, A.B., Slooff, R., 1992. Vector-borne disease problems in rapid urbanization: new approaches to vector control. Bull. World Health Organ. 70, 1–6.

Masuoka, P.M., Claborn, D.M., Andre, R.G., Nigro, J., Gordon, S.W., Klein, T.A., Kim, H., 2003. Use of Ikonos and Landsat for malaria control in the Republic of Korea. Remote Sensing Environ. 88, 187–194.

Morsy, Tosson A., Khalil, Nabawia M., Habib, Faiza S.M., El-Laboudy, Noha A., 2004. Seasonal distribution of Culicini larvae in Greater Cairo. J. Egypt Soc. Parasitol. 34 (1), 143–152.

Mushinzimana, E., Munga, S., Minakawa, N., Li, L., Feng, C.C., Bian, L., Kitron, U., Schmidt, C., Beck, L., Zhou, G., Githeko, A.K., Yan, G., 2006. Landscape determinants and remote sensing of anopheline mosquito larval habitats in the Western Kenya highlands. Malaria J. 16, 5–13.

O'Malley, C., 1995. Seven ways to a successful dipping career. Wing Beats 6 (4), 23–24.

Ossman, A.S., 2001. Policies of Directing Cairo Urban Expansion. Ph.D. Unpublished thesis, Ain Shams University, Faculty of Engineering, Department of Urban Planning.

Rongnoparut, P., Ugsang, D.M., Baimai, V., Honda, K., Sithiprasasna, R., 2005. Use of a remote sensing-based geographic information system in the characterizing spatial patterns for *Anopheles minimus* A and C breeding habitats in Western Thailand. Southeast Asian J. Trop. Med. Public Health 36 (5), 1145–1152.

Schmidt-Vogt, D., 1999. Swidden farming and fallow vegetation in Northern Thailand. Geological Research, vol. 8. Franz Steiner Verlag, Stuttgart, Germany.

Severini, F., Di Luca, M., Toma, L., Romi, R., 2008. *Aedes albopictus* in Rome: results and perspectives after 10 years of monitoring. Parassitologia 50 (1–2), 121–123.

Small, C., 2003. High spatial resolution spectral mixture analysis of urban reflectance. Remote Sensing Environ. 88, 170–186.

Stoops, C.A., Gionar, Y.R., Shinta, Sismadi.P., Rachmat, A., Elyazar, I.F., Sukowati, S., 2008. Remotely-sensed land use patterns and the presence of anopheles larvae (Diptera: Culicidae) in Sukabumi, West Java. Indones. J. Vector Ecol. 33 (1), 30–39.

Tucker, C.J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing Environ. 8, 127–150.