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# Potential Establishment, Prevalence of Dengue Vector, *Aedes* sp. and its Risk Map in Hurghada Region, Red Sea, Egypt

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## ABSTRACT

Rising temperatures are predicted to expand the range of *Aedes aegypti* and *Aedes albopictus*, potentially leading to new areas vulnerable to dengue outbreaks. The recent arrival of *Aedes aegypti* in Upper Egypt underscores this emerging threat, with documented outbreaks in the Red Sea Governorate (2017) serving as evidence. To address this, a cross-sectional surveillance study was conducted during the summer of 2023 in Hurghada City, Egypt, to identify established dengue vectors and their breeding sites. The presence of *Aedes aegypti* was confirmed, and entomological indices were calculated to assess vector distribution. Risk maps were generated to evaluate potential risks across the city. The study confirms the establishment of *Aedes aegypti* in Hurghada and provides valuable data for assessing future vector distribution and potential dengue outbreaks. These findings contribute to understanding how global warming and socioeconomic factors influence dengue transmission and will aid in developing effective control measures to prevent future outbreaks in Hurghada.

## INTRODUCTION

Mosquito-borne diseases, particularly those transmitted by *Aedes* vectors, are a growing public health concern worldwide **(Kilpatrick *et al.*, 2012; Campbell *et al.*, 2015)**. The geographic expansion of these vectors in tropical and subtropical regions intensifies the burden of diseases like dengue, malaria, and yellow fever **(WHO, 2009, 2010)**. Understanding the geographical distribution of dengue and its vectors is crucial for several reasons. First, it allows for a better assessment of dengue's contribution to global mortality rates **(Hales *et al.*, 2002; Kilpatrick, 2012)**. Second, it informs decisions regarding the allocation of limited resources for dengue control efforts **(Hales *et al.*, 2002)**. Third, it facilitates the evaluation of the international consequences of these distribution changes **(Hales *et al.*, 2002)**.

Many researches **(Heikal *et al.*, 2011; Shoukry *et al.*, 2012)** examined the resurgence of the *Ae. aegypti* vector but did not support additional evidence of its presence in Egypt. The Ministry of Health in Upper Egypt verified the occurrence of 101 dengue cases in Qena Governorate in October 2017 **(Abdelkader, 2018)**. Moreover, the city of Qusair (Red Sea Governorate) reported the first occurrence of *Ae. aegypti* and the resurgence of the dengue outbreak with over 680 patients **(Abozeid *et al.*, 2018)**.

**Heikal *et al.* (2011)** in Aswan, Egypt, reported the resurgence of *Ae. aegypti*, the dengue fever vector that was previously found in Africa. This indicates the need to be vigilant about this potential hazard to public health. According to **El Bahnasawy *et al.* (2011)**, the Egyptian health authorities need to be aware of the existence of *Ae. aegypti* and endemic DF in the adjacent regional nations. According to **Shoukry *et al.* (2012)**, *Ae. aegypti* in Toshka is a crucial indicator of dengue and other Sudanese *Aedes*-borne infections. *Ae. aegypti* was found in both immature and adult stages by **Saleh (2012)** in the Aswan district. The range and greatest risk of establishment were plotted for *Ae. aegypti* and *Ae. albopictus* by **Ducheyne *et al.* (2018)** for the WHO/EMR. They went on to say that this needed to raise awareness and readiness.

There have been cases of dengue fever reported in Egypt in the past; the most recent outbreak occurred in Dairut in 2015. However, there is no information available regarding outbreaks in the Red Sea coastal communities such as Hurghada, Sharm El-Sheikh, and Dahab, which have become popular vacation spots for Russian nationals **(WHO, 2017)**. Germany reported 36 cases of dengue virus (DENV) infections in 2023 following exposure in Egypt, up from zero to eight cases in 2017–2022. Nearly 50% of the patients had stayed in private homes, with over 90% of them having visited the Red Sea Coast, primarily Hurghada **(Frank *et al.*, 2024)**.

For the purpose of developing efficient vector control plans and early warning systems for the prevention of dengue epidemics, mapping the spatial distribution of the dengue vector *Ae. aegypti* and precisely estimating its abundance are essential **(Rahman *et al.*, 2021)**.

Climate change significantly impacts mosquitoes due to their cold-blooded nature **(Campbell *et al.*, 2015)**. Studying how these changes affect mosquito behavior allows us to predict seasonal and geographic shifts in disease outbreaks, thereby enabling us to prepare for future outbreaks linked to climate variations **(Campbell *et al.*, 2015)**. Dengue fever poses a significant global health threat, with an estimated 2.5 billion people, or 40% of the world's population, living at risk **(Fonseca & Fonseca, 2002; Hales *et al.*, 2002; Renganathan *et al.*, 2003; Beatty *et al.*, 2007)**. Globally, an estimated 50 million new cases and 24,000 deaths are reported annually.

This study focuses on the recent emergence of dengue fever and its vector, *Aedes aegypti*, in Hurghada, Egypt. In October 2015, an outbreak of dengue fever was reported in a village in Assiut Governorate, Egypt **(Abozeid *et al.*, 2018; Mohammed *et al.*,**

**2019; Mostafa *et al.*, 2019)**. Notably, the Egyptian Ministry of Health confirmed the introduction of *Aedes aegypti*, a primary dengue vector, into Upper Egypt.

Our study aimed to identify and monitor the dengue vector(s) in Hurghada City, Egypt, investigating mosquito breeding sites and feeding behavior, and developing predictive maps to assess the potential future expansion of this vector.

## MATERIALS AND METHODS

### 1. Study area

Hurghada, the capital city of Egypt's Red Sea Governorate, is a popular tourist destination stretching 40 kilometers along the western coast of the Red Sea (Fig. 1). Nestled between the Red Sea mountains and turquoise waters, Hurghada is bordered by Ras Ghareb to the north and Safaga to the south. The coastline near Hurghada is dotted with several islands, including Giftun and Umm Qamar. Popular resort areas like El Gouna, Sahl Hasheesh, Soma Bay, and Makadi Bay are also found within this region. Hurghada experiences a moderate climate year-round, characterized by a desert climate with significant temperature variations between day and night. Minimum temperatures can reach 18°C (64°F), while highs can climb to 42°C (108°F).

Five specific locations were chosen for this study due to their reported high incidence of dengue fever between 2016 and 2018. These sites are designated as AL-Salam, Al-Arab, Zirzara 1, Zirzara 2, and Michelin, and their coordinates are 25° 15' 26.57" N, 33° 48' 46.48" E.

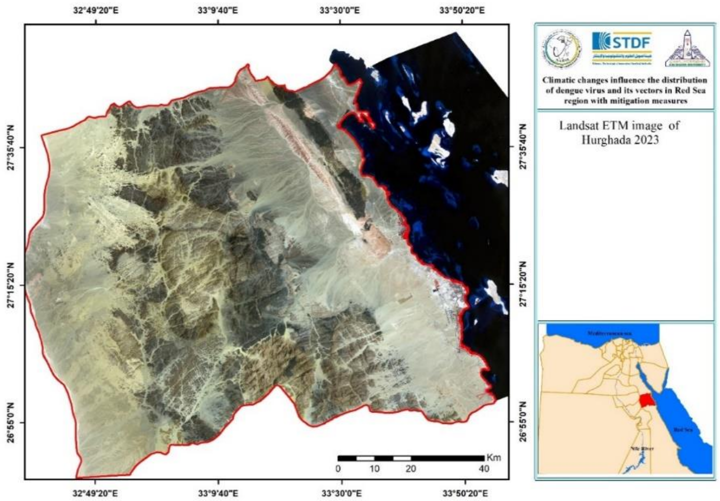

**Fig. 1.** Landsat ETM for Hurghada 2023

## 2. Collection, abundance, and identification of *Aedes* mosquitoes

### *2.1. Larval collection*

A preliminary survey was conducted within the chosen locations (AL-Salam, Al-Arab, Zirzara 1, Zirzara 2, and Michelin). Approximately 20 houses were randomly selected in each location to assess the presence of *Aedes* species mosquitoes. To identify immature mosquito stages (eggs, larvae, pupae), standard sampling methods were employed. Small containers were emptied into a white enamel pan for thorough visual inspection. Any suspected larvae were collected using Dippers for further identification. Containers that were too large to be emptied were inspected for the presence of larvae using a flashlight for illumination. Any suspected larvae were collected using Dippers. Dippers should be constructed of plastic with long handles to minimize disturbance and maximize sample collection efficiency.

Three entomological indices were employed to assess the mosquito population density and distribution, following the methods outlined by **Sharma *et al.*** (2005).

**House index (HI):** The percentage of houses infested with immature *Aedes* mosquitoes. The house index was calculated by dividing the number of houses infested with any stage of immature *Aedes* mosquitoes (eggs, larvae, pupae) by the total number of houses inspected and then multiplying by 100.

**Container index (CI):** The percentage of water-holding containers containing immature *Aedes* mosquitoes. CI was calculated by dividing the number of water-holding containers with positive findings for immature *Aedes* mosquitoes (eggs, larvae, pupae) by the total number of inspected water-holding containers and then multiplying by 100.

**Breteau index (BI):** The number of positive containers per 100 inspected houses. BI was calculated by dividing the number of containers with positive findings for immature *Aedes* mosquitoes by the total number of inspected houses and then multiplying by 100.

### *2.2. Adult collection*

For Adult mosquito collection, we employed two methods: light traps and aspirators.

**CDC light traps:** These traps were strategically positioned in suitable locations before sunrise and retrieved after sunset to target host-seeking female mosquitoes. Captured mosquitoes were collected from the traps.

**Aspirators:** This method targeted resting females and those hovering near breeding containers. Mosquitoes were carefully collected using aspirators designed for minimal harm to the specimens.

Following collection, all adult mosquitoes were safely frozen overnight to halt biological processes and facilitate later identification. Before handling and identification, mosquitoes were carefully thawed to minimize damage to their delicate body structures

**(Upton, 1991)**. Subsequently, a morphological examination was performed to determine sex and identify mosquito species.

### *2.3. Taxonomic identification of collected larvae and adults*

The morphological identification of larvae and adults was performed using established keys from **Reinert (2000)** and **Rueda (2004)**.

## 3. Mapping of mosquito population

We used a handheld GPS device to record the locations of mosquito breeding sites (areas with larvae and adult mosquitoes). These locations were stored in a specific format (WGS_1984_UTM_Zone_36N) and analyzed using MapSource® software **(Garmin, 2006)**. We also obtained a satellite image of the study area (Hurghada and surroundings) from Landsat 8, dated May 18, 2022. From these images, we identified and digitized features like water bodies, forests, vegetation, roads, and residential areas. We then used another software, ArcGIS 10.2 **(ESRI, 2006)** to combine the mosquito location data with these features in a digital map (GIS database). This allowed us to analyze the distribution of mosquito breeding sites within the study area. Finally, we overlaid the image with the different layers of information (features and mosquito data) to visualize everything together in the same coordinate system **(WGS, 1984)**.

ENVI 5.3 and ArcGIS 10.2 programs were used to process the satellite images, a preliminary treatment that includes atmospheric correction and spectral correction, then producing a mosaic consisting of two satellite visuals covering the study area of the type of the American satellite (Landsat-8) captured in 2022 by the space-wave sensor visible spectrum (OLI) and thermal spectrum sensor (TIRS).

A three-dimensional Digital Elevation Model (DEM) was produced for the Hurghada region using the Shuttle Radar Topography Mission (SRTM) satellite image to produce a map of surface drainage channels, while the Modified Normalized Difference Water Index (MNDWI) was calculated to determine the surface water areas from the following mathematical equation:

$$\text{MNDWI} = (\text{Green Band} - \text{MIR Band}) / (\text{Green Band} + \text{MIR Band})$$

Whereas the Green Band represents band 6, while the MIR Band represents band 3 for the LANDSAT 8-OLI satellite.

Fig. (2) shows map of drainage (Stream) and Fig. (3) shows a map of drainage and surface water bodies, explaining their spatial distribution.

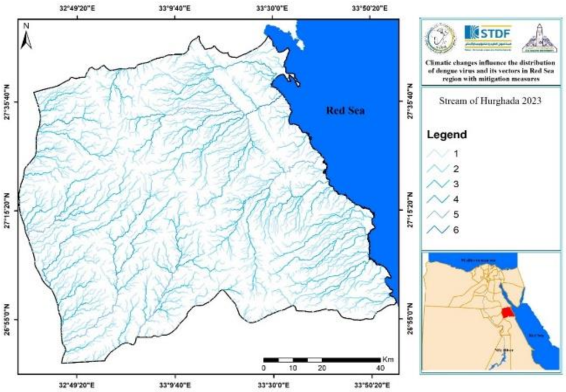

**Fig. 2.** Map of drainage (Stream)

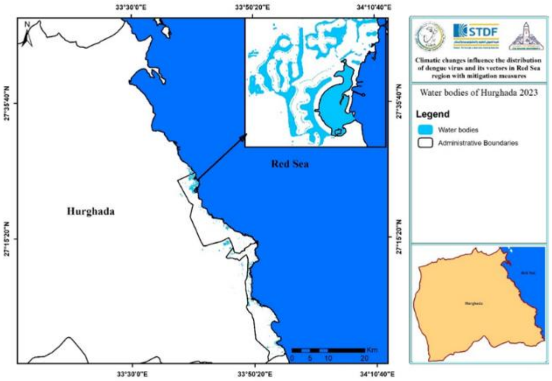

**Fig. 3.** Map of surface water bodies of Hurghada

The thermal band filter represented in Band 10 of the Landsat-8 satellite (TIRS) was used to produce land surface temperature (LST) maps of the study area, as shown in Fig. (4).

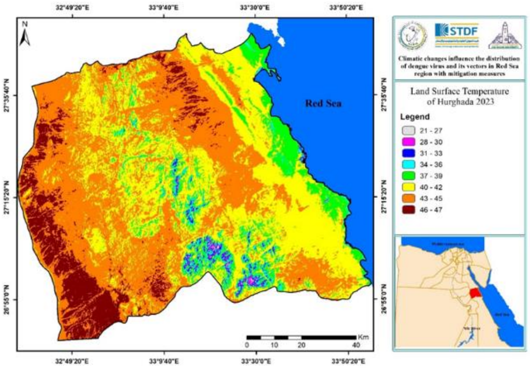

**Fig. 4.** Land surface temperature of Hurghada

Landsat-8 (OLI) satellite image captured in 2023 was used to determine the vegetation cover densities of the study area, as shown in Fig. (5), where the normalized differences vegetation index (NDVI) was calculated through the following mathematical model:

NDVI= (NIR Band-R Band)/ (NIR Band+ R Band)

Whereas, infrared (NIR) rays are represented in the spectral filter of satellite image (band 5) and visible (red) rays are represented in the spectral filter (band 4).

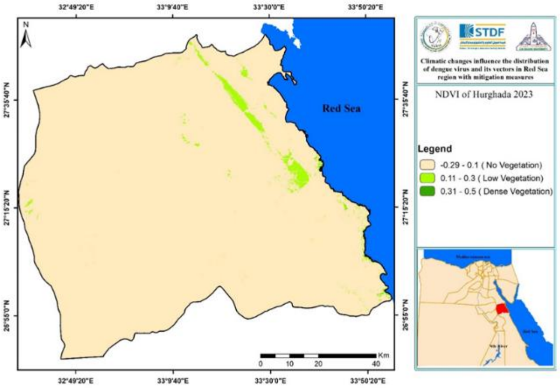

**Fig. 5.** Vegetation cover map (Normalized difference vegetation index) for Hurghada

The satellite images were processed to produce maps of urban areas of Hurghada, as shown in Fig. (6).

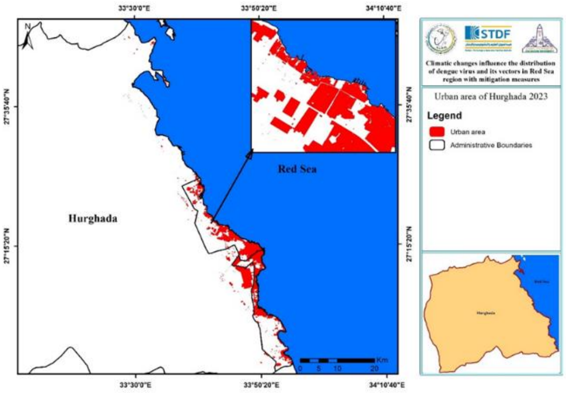

**Fig. 6.** Map of urban areas of Hurghada

ArcGIS 10.41 program was used to build a cartographic model to locate and map sites suitable for different degrees of breeding and spread of *Aedes* mosquitoes during the entomological survey 3-5/2023. The model was built (Fig. 7), based on previous data extracted from satellite images, including eight layers of geographic information as follows: A vegetation cover map, map of drainage and surface water bodies, a map of land surface temperatures that range between more than 10ºC and less than 40ºC, stream, normalized difference vegetation index, normalized difference water index, normalized difference moisture index, urban areas map.

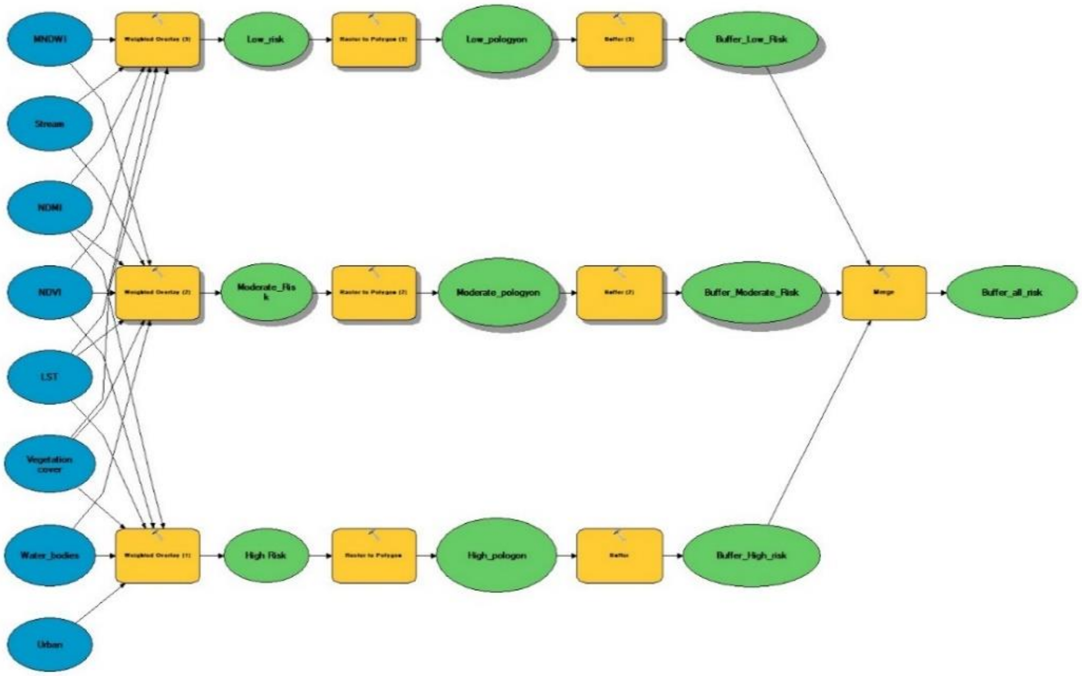

**Fig. 7.** Cartographic model for determination risk sites of breeding mosquitoes, *Ae.* sp. in 2023

## 4. Sites exposed to risk by breeding mosquitoes

Three major degrees of risk were identified and mapped according to the degree and percent of variables favored for breeding are linked as follows:

### *4.1. High-risk areas*

The cartographic model was used to generate risk maps of mosquito breeding sites, high-risk areas were identified having the highest percent of the six important factors (Vegetation cover, drainage, surface water bodies, land surface temperatures that range between more than 10ºC and less than 40ºC, normalized difference vegetation index, normalized difference moisture index and urban.

### *4.2. Moderate risk areas*

This degree of risk was produced through the use of the following factors: Vegetation cover, drainage, surface water bodies, land surface temperatures that range between more than 10ºC and less than 40ºC, stream, normalized difference vegetation index, normalized difference water index, and normalized difference moisture index. Urban areas were excluded from the production of moderate-risk areas, which reduce the degree of risk of mosquito spread as a result of the absence of the vertebrate host (human).

### *4.3. Limited risk areas*

Produced by applying the cartographic model based on the presence of vegetation cover, land surface temperatures that range between more than 10ºC and less than 40ºC, stream, normalized difference vegetation index, normalized difference water index, and normalized difference moisture index.

### 5. Determination of the range of mosquito activity

The mosquito activity range (buffer zone) was determined for producing the hazard map. Geographic information systems (ArcGIS 10.41 program) were used to calculate the areas of risk for the spread of mosquitoes in Hurghada in 2023.

### 6. The spatial and relative distribution of urban areas at different levels of risk of *Aedes* spread

To clarify and define the relationship between urban areas and the range of different risk degrees for *Aedes* mosquito spread during 2023, the newly produced urban maps were used, using Landsat-8 satellite images, where the layer of urban areas was dropped on the thematic maps that represent the range of mosquito activity produced from the cartographic model.

### 7. Mosquito samples collection sites and their relation with mosquito activity range

Risk maps were generated based on criteria and layers selected to suit the prevalence of *Aedes* vectors. To verify the accuracy of these risk maps, which indicate areas and degrees of mosquito infestation risk, field entomological survey points were visited. The field teams confirmed the presence of both male and female *Aedes* mosquitoes and identified larvae locations at these survey points. These findings were then overlaid on thematic maps representing mosquito activity ranges. This overlay was projected onto maps produced from the cartographic model to illustrate the relationship between the number of mosquito collection sites and the varying degrees of risk throughout the year 2023.

## RESULTS

Following the classification of **Rueda (2004)**, all collected mosquito specimens were classified under two genera. The first was identified as genus *Culex* with two species (*pipiens* and *quinquefasciatus*) while the second identified genus was *Aedes* with one identified species, *aegypti*. Numbers of *Aedes aegypti* collected in each location were recorded for further estimations and comparisons of population densities over these locations.

## 1. Morphological characterization and identification of *Aedes aegypti*

### *1.1. Larval characterization*

According to **Rueda (2004)**, examining the mosquito larva's head under a microscope revealed several unique features. One hair (seta 4-C) had many branches, and another (seta 5-C) was single and positioned alongside another hair (7-C). Additionally, two specific hairs (4 and 6-C) were located noticeably in front of another (7-C).

The plates on the thorax had specific hairs (9-12-M and T) with strong, hooked spines. The last segment of the abdomen had a row of comb-like scales, each with small side projections. Another hair (4-X) had five pairs of smaller hairs.

These characteristics, especially the two spines on each side of the thorax and the single row of comb scales on the abdomen help distinguish *Ae. aegypti* larvae from other *Aedes* species. Additionally, *Ae. aegypti* has a specific spine (medial) with smaller spines at its tip (Fig. 8), which is absent in *Ae. albopictus*, another mosquito that transmits the dengue virus.

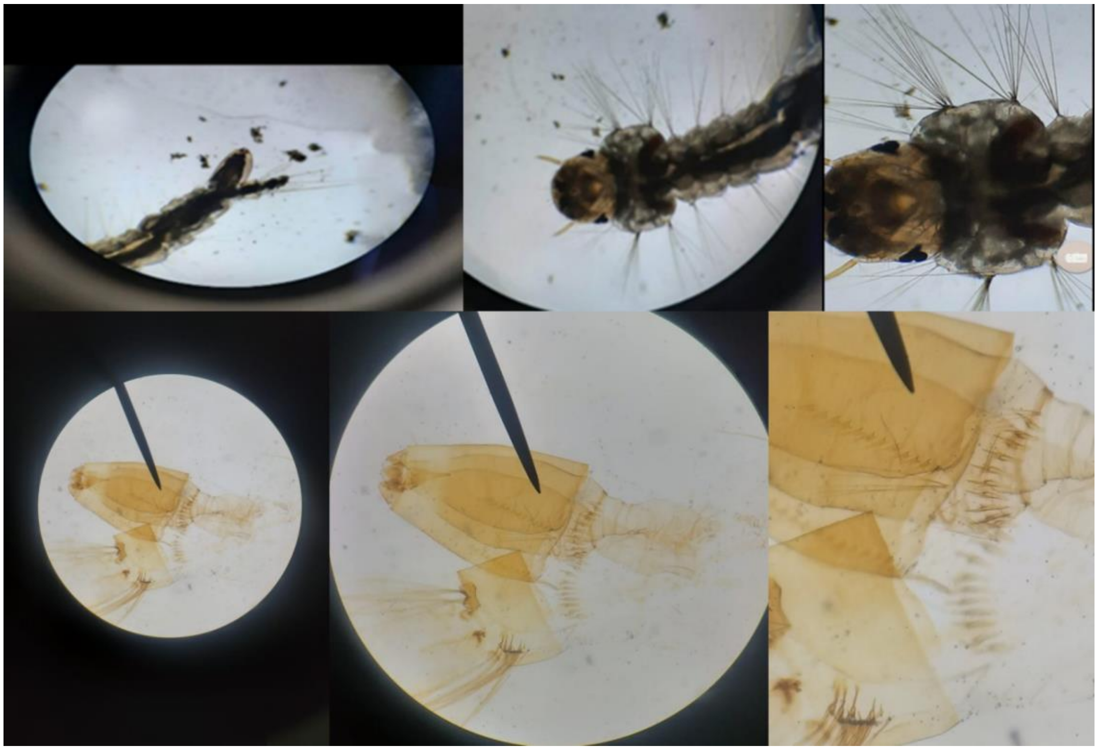

**Fig. 8.** *Aedes aegypti* larvae collected from Hurghada region in 2023

### *1.2. Description of adult Aedes aegypti*

All adult *Ae.* specimens are dark-colored with striking white markings and banded legs (Fig. 9). Their long, thin mouthpart (proboscis) is black, while their mouth-feelers (palps) are white. The top of their thorax (scutum) has a distinctive lyre-shaped pattern formed by white scales. This pattern contrasts with the rest of their body, which is covered in narrow, dark scales. Their wings are also dark and scaled. The hind legs are interesting, the thigh (femur) is light-colored for most of its length, with dark scales only on the very tip both on top (dorsally) and underneath (ventrally). The feet (tarsi) have alternating light and dark bands, with the base of each segment (except the last) being light and the last segment entirely light. Their abdomen has white patches or bands of scales running down the middle (median) and on the sides (lateral). The underside (sternites) is light-colored with darker bands near the tips of some segments **(Russel, 1996; Rueda, 2004)**.

**Fig. 9.** Adult *Aedes aegypti* collected from Hurghada region in 2023

## 2. Cross-sectional surveillance of *Aedes* sp. over the study area

Larval and adult mosquito densities were quantified for each collected species in all surveyed locations. Data specific to *Aedes aegypti* were then employed to calculate entomological indices, allowing for the estimation of abundance and identification of potential habitat preferences.

### *2.1. Aedes aegypti larval presence and abundance in Hurghada households*

Eight hundred and eighteen larvae were collected from 100 inspected houses. *Culex* larvae were dominant with a percentage of 58.6% of the total collected larvae, while *Aedes aegypti* recorded 41.3%. The Al-Arab region was the highest infested area, as shown in Table (1).

**Table 1.** Mosquito genera collected from different locations within Hurghada during 2023

| **The examined location** | Number of collected mosquito larvae | | |
|---|---|---|---|
| | *Culex pipiens* | *Culex quinquefasciatus* | *Aedes aegypti* |
| Zirzara 1 | 80 | - | 31 |
| Zirzara 2 | 34 | 6 | 27 |
| Al-Salam | 128 | 22 | 100 |
| Al-Arab | 160 | 40 | 180 |
| Michelin | 10 | - | - |
| Total | **412** | **68** | **338** |

| | |
|---|---|
| | 818 |

In entomological surveys where dengue fever was expected, **Mostafa *et al.* (2019)** selected four cities: Hurghada, Safaga, Al-Kuseer, and Ras Ghareb. They discovered that the survey yielded a total number of immature stages of *Aedes aegypti* of 92.22% (960/1041), or 92.5% (888/960) for larvae and 7.5% (72/960) for pupa.

### *2.2. Entomological indices for Aedes aegypti larval incidence in Hurghada households*

A total of 169 containers {Zirzara 1 (26), Zirzara 2 (13), Al-Salam (50), Al-Arab (60), Michelin (20)} were investigated. A total of 32 containers were found positive as larval breeding places for *Aedes aegypti,* as shown in Table (2).

**Table 2.** Prevalence of *Ae. aegypti* larvae based on the house index (HI), container index (CI), and breteau index (BI).

| | **House index** | | | **Container index** | | | **Breteau index** | | |
|---|---|---|---|---|---|---|---|---|---|
| **District** | **Total inspected houses** | **Positive houses** | **HI** | **TEC** | **TPC** | **CI** | **Positive inspected containers** | **Total inspected houses** | **BI** |
| Zirzara 1 | 20 | 2 | 10 % | 26 | 4 | 15.3 % | 4 | 25 | 18.18 % |
| Zirzara 2 | 20 | 2 | 10 % | 13 | 2 | 15.3 % | 2 | 15 | 9.09% |
| Al-Salam | 20 | 3 | 15 % | 50 | 12 | 24% | 14 | 30 | 63.64 % |
| Al-Arab | 20 | 7 | 35 % | 60 | 14 | 23.3 % | 12 | 25 | 54.55 % |
| Michelin | 20 | 0 | 0% | 20 | 0 | 0 % | 0 | 20 | 0.00 |

TEC: Total examined containers

TPC: Total positive containers

CI= (number of positive containers ÷ total inspected containers) ×100

BI = (number of positive containers ÷ 100 inspected containers) ×100

The most positive houses were recorded in the Al-Arab region, with HI % (35). Zirzara 1, Zirzara 2, and Al-Salam recorded moderate preferring breeding sites, with HI (10, 10 and 15 % respectively).

According to the CI index, Al-Salam and Al-Arab proved to contain highly susceptible containers for *Ae. aegypti* breeding (CI%: 24, 23.3 respectively)

During the study period, 120 houses were visited, and 32 containers were found positive for *Ae*. aegypti larval incidence. The highest values of BI were recorded for Al-

Salam (63.64%), followed by Al-Arab (54.55%) and Zirzara 1 (18.18%) while Zirzara (2) recorded the lowest BI value (9.09%). Michelin was found free of *Ae. aegypti*.

### *2.3. Breeding site preferences of Aedes aegypti in Hurghada, Egypt, based on container material preferences*

In Table (3), we found that, out of 169 inspected containers, 32 containers were found positive to carry *Ae. aegypti* larvae. The iron containers recorded the highest percentage of larval incidence. Iron and polyethylene containers were the most preferable sites for larval breeding. However, iron containers were more susceptible to *Ae. aegypti* larval presence, with a larval incidence percentage of 57.7%, followed by plastic containers with a larval incidence percentage of 38.1%, and the lowest incidence was recorded for Barrel containers 4.1% (Table 3).

**Table 3.** Breeding prevalence and abundance of *Aedes aegypti* larvae based on type and structure of breeding containers

| **Type of container** | **Al-Salam** | **El-Arab** | **Zirzara 1** | **Zirzara 2** | **Michlin** | **Total no. of *Aedes* larvae** | **Larval incidence%** |
|---|---|---|---|---|---|---|---|
| Iron | 95 | 81 | 12 | 7 | - | 195 | 57,7 |
| Plastics | 30 | 79 | 14 | 6 | - | 129 | 38,1 |
| Barrel | - | 14 | - | - | - | 14 | 4,1 |

### *2.4. Breeding site preferences of Aedes aegypti in Hurghada, Egypt, based on indoor and outdoor preferences*

*Aedes aegypti* larvae were collected from both indoor and outdoor containers in each location. The data on this collection, categorized by container position (indoor or outdoor), are presented in Table (4) to estimate indoor and outdoor breeding preferences for *Ae. aegypti*.

**Table 4.** Larval breeding preference of *Aedes aegypti* larvae during 2023 in different locations in Hurghada City based on indoor or outdoor containers

| **Position of water container (District)** | **Total number of collected *Ae. aegypti* larvae at each location** | | | | | | **Incidence %** |
|---|---|---|---|---|---|---|---|
| | **Al-Salam** | **Al - Arab** | **Zirzara 1** | **Zirzara 2** | **Michlin** | **Total** | |
| Out-door | 74 | 43 | 11 | - | - | 128 | 37.8% |
| In-door | 100 | 82 | 15 | 13 | - | 210 | 62,1% |
| Total **Larval population** | 174 | 125 | 26 | 13 | - | 338 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Breeding preference** | 36,9% | 47,3% | 7,7% | 3,8% | - | | |

Table (4) shows a higher percentage of *Aedes aegypti* larvae collected from indoor containers (62.1%) compared to outdoor containers (37.8%).

### 3. Adult *Aedes aegypti* bionomics in Hurghada City

Indoor resting *Aedes aegypti* adults were collected before sunset and after sunrise from the above-mentioned spots with the help of aspirators, while CDC light traps were used to collect outdoor flying adults. Table (5) shows the preference of *Ae. aegypti* based on indoor or outdoor sites.

**Table 5.** Distribution of Adult *Aedes aegypti* in Hurghada City, Egypt, during winter 2023

| **Date** | **Al-Salam** | | **Al-Arab** | | **Zirzara 1** | | **Zirzara 2** | | **Michelin** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **T** | **/House** | **T** | **/House** | **T** | **/House** | **T** | **/House** | **T** | **/House** |
| 12-2022 | | | | | | | | | | |
| Out-door | 22 | 5.2 | 20 | 5 | - | - | 4 | 1 | - | - |
| In-door | 33 | 8.2 | 43 | 10.2 | 12 | 3 | 6 | 2.5 | - | - |
| 1-2023 | | | | | | | | | | |
| Out-door | 22 | 5 | 12 | 3 | 2 | 0.5 | - | - | - | - |
| In-door | 26 | 6 | 18 | 4.5 | 8 | 2 | 6 | 1.5 | - | - |
| 2-2023 | | | | | | | | | | |
| Out-door | 24 | 12 | 20 | 5 | 3 | 0.7 | 8 | 2 | 4 | 1 |
| In-door | 30 | 7.5 | 40 | 10 | 5 | 1.2 | 8 | 2 | 1 | 0.25 |
| 4-2023 | | | | | | | | | | |
| Out-door | 12 | 3 | 12 | 3 | 5 | 1.2 | 5 | 1.2 | 4 | 1 |
| In-door | 32 | 8 | 20 | 5 | 8 | 2 | 8 | 2 | 2 | 0.5 |
| Total | 201 | | 185 | | 43 | | 45 | | 11 | |
| Out-door | 80 | 25.2 | 64 | 16 | 10 | 2.4 | 17 | 4.2 | 8 | 2 |
| In-door | 121 | 29.7 | 121 | 29.7 | 33 | 8.2 | 28 | 8 | 3 | 0.75 |
| Out-door collection % | 39.8% | | 34.5% | | 23.3% | | 37.8% | | 72.7% | |
| In-door collection % | 60.2% | | 65.5% | | 76.7% | | 62.2% | | 27.3% | |

T = Total no. of collected adult *Aedes aegypti*

Percent occurrence of adult *Aedes aegypti* shows the preference of adults to stay indoors, resting and laying their eggs inside houses. However, in Table (5), Michlin region recorded outdoor preference rather than indoor. This is because the degree of urbanization is higher in this area and dwellers are more aware of the disease with a satisfactory level of education.

## 4. GIS and risk maps

Macroclimate is an important factor in predicting the range of *Aedes* mosquito distribution and as climate change, a great threat grows to expand the area hospitalized by this species.

Results show that water bodies occupy an area of 5km$^2$, which is 0.05% of the area of the total study area (9451 m$^2$), and areas with surface temperatures ranging between more than 10ºC and less than 40ºC were identified, which represents the optimum temperature for the breeding and spread of *Aedes* mosquitoes in Hurghada, with the exclusion of places characterized by temperatures less than and equal to 10ºC and more than and equal to 40ºC because they are not suitable for the breeding and spread of *Aedes aegypti* mosquitoes.

In order to predict mosquito distribution maps according to specific roles to each degree of risk, the risk maps are created using specific data layers (vegetation cover, drainage, surface water bodies, land surface temperatures, stream, normalized difference vegetation index, normalized difference moisture index, and urban), which interact with one another by weighing each layer, as shown below.

A classification of the vegetation cover density was done into three sections (Table 6), a section that does not contain plants and represents a large percentage of the study area, which was found to be associated with a large percentage of desert areas and urban areas, which are completely devoid of vegetation cover and occupies an area of 934 km$^2$ (98.8%), and another section representing the seasonal natural vegetation with a low density, and the high-density vegetation (Landscape and agricultural land) was the least present in the study area, as it occupied an area of 11km$^2$, equivalent to 0.116% of the total area of the study area.

**Table 6.** Areas of vegetation cover in Hurghada during 2023

| **Vegetation cover** | **Area/ km$^2$** | **Percentage (%)** |
|---|---|---|
| Arid land | 9342 | 98.8 |
| Vegetation cover | 11 | 0.116 |
| Total area | 9353 | 98.96 |

It was found that urbanization occupies an area of 93km$^2$, which represents 0.995% of the total area, centralized in the Kesm Awal and Kesm Than in Hurghada.

Dengue risk in urban contexts of Argentina's subtropical regions has advanced thanks to models of the vector mosquito species, *Aedes aegypti* and *Ae. albopictus*, and environmental variables assessed through remote sensing. The supervised classification of Sentinel-2 photos and computed spectral indices allowed for the determination of the percentage of each landscape cover type, including water, urban areas, bare soil, low vegetation, and high vegetation. According to **Martín *et al.* (2023)**, the model's output indicated that the relationship between the NDVI minimum and maximum values and *Ae. aegypti* larvae abundance was more accurately represented.

### *4.1. Sites exposed to risk by breeding mosquitoes*

By using a cartographic model, three major degrees of risk are identified and mapped according to the degree and percent of variables favored for breeding and are linked as follows:

#### 4.1.1. High-risk areas

In the cartographic model used to generate risk maps of mosquito breeding, high-risk areas were identified that have the highest percent of the six important layers (Vegetation cover, drainage, surface water bodies, land surface tempreatures that range between more than 10ºC and less than 40ºC, normalized difference vegetation index, normalized difference moisture index and urban). They are often concentrated where urban areas are more concentrated and dense, which increases the risk of outbreaks of diseases transmitted by mosquitoes. These areas occupy 1km$^2$ of the total area. The study area is 9451km$^2$.

#### 4.1.2. Moderate risk areas

This degree of risk was produced through the use of the following layers: Vegetation cover, drainage, surface water bodies, land surface temperatures that range between more than 10ºC and less than 40ºC, stream, normalized difference vegetation index, normalized difference water index, normalized difference moisture index. Urban areas were excluded from the production of moderate-risk areas, which reduce the degree of risk of mosquito-spread as a result of the absence of a disease-transmitting host (human). Due to the abundance of oviposition sites in metropolitan areas, *Aedes aegypti* thrives there. As a result, human activities (such as storing water outside) have a major influence on this species' range, and this should be the main target of management measures **(Jansen & Beebe, 2010)**. Furthermore, *Ae. aegypti* is more prevalent in urban areas with large densities **(Hahn *et al.,* 2016)**. Moderate risk areas are scattered throughout the study area occupying an area of 5km$^2$ of the total area of the study area.

#### 4.1.3. Limited risk areas

Limited risk areas are produced by applying the cartographic model based on the presence of these layers, vegetation cover, drainage, surface water bodies, land surface temperatures that range between more than 10ºC and less than 40ºC, stream, normalized difference vegetation index, normalized difference water index, normalized difference moisture index. Limited risk areas are distributed in east areas, and occupy an area of 8km$^2$ of the study area (9451km$^2$).

Within a 15 × 15km area, these criteria are used to assess the abundance of *Aedes* and *Culex* mosquitoes close to cattle populations. Yet another use of remotely sensed data modeling ecological parameters like temperature, precipitation, and vegetation cover was made. According to **Kazansky *et al.* (2016)**, these criteria are used to assess the abundance of *Aedes* and *Culex* mosquitoes close to cattle populations within a 15 × 15km area.

According to **Lacaux *et al.* (2007)**, the turbidity of transient, relatively small ponds and the dynamic vegetation cover are related to the mosquito abundance in the Ferlo region of Senegal.

In rural areas, *Ae. aegypti* was the most prevalent species (68.56%). Because urbanization fosters the survival of *Aedes* species and the development of the dengue, chikungunya, and zika viruses, it is frequently linked to the emergence and spread of vector-borne diseases. According to **Djiappi-Tchamen *et al.* (2021)**, this systematic study investigated the connection between urbanization and the onset and spread of diseases and epidemics carried by *Aedes* mosquitoes.

In Jaffna City, northern Sri Lanka, where the arboviral illnesses dengue and chikungunya are endemic, *Aedes aegypti* mosquitoes were discovered growing in the water in open public drains (drain-water, DW) **(Surendran *et al.*, 2019)**.

According to **Dickens *et al.* (2018)**, the two most reliable and powerful global predictors of the presence of *Ae. aegypti* and *Ae. albopictus* were absolute humidity and annual minimum temperatures. These factors should be taken into account in control efforts and future distribution estimates.

Fig. (10) shows a map of the different degrees of risk for mosquito invasion, where it was found that the vast majority of the study area (99.8%) was not exposed to the risk of mosquito expansion, concerning the degrees of risk of breeding. The results presented in Fig. (10) and Table (7) indicate that the area classified as low risk covers 8 km² of the total area. In contrast, areas identified as high risk and moderate risk encompass 1 and 5km², respectively.

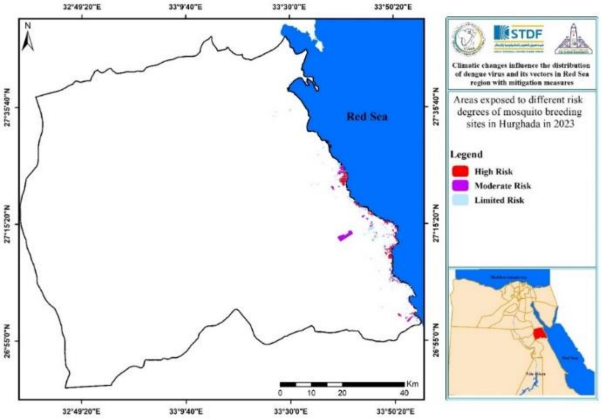

**Fig. 10.** Collected map of areas exposed to different risk degrees of *Aedes* mosquito breeding sites in Hurghada in 2023

**Table 7.** Areas exposed to different risk degrees of *Aedes* mosquito breeding sites in Hurghada in 2023

| **Mosquito breeding risk degree** | **Area/ km$^2$** |
|---|---|
| High risk | 1 |
| Moderate risk | 5 |
| Limited risk | 8 |
| No risk | 9437 |
| Total area | 9451 |

### *4.2. The range of mosquito activity*

Through previous studies, it was found that the average flight range of the adult *Aedes* mosquitoes was about 2km in natural conditions around the breeding area. Accordingly, maps were produced that define the surrounding areas (buffer zone) in which mosquitoes spread using satellite data for the year 2023 (Fig. 11). Therefore, the mosquito activity range (buffer zone) was determined for producing the hazard map.

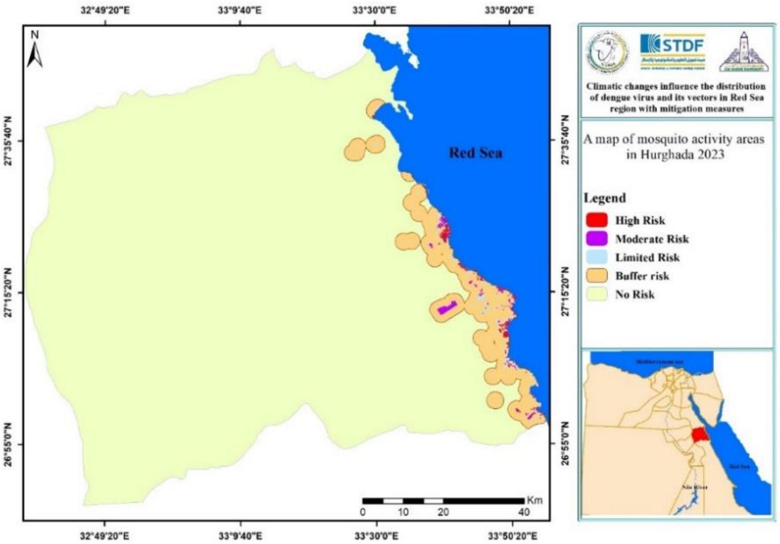

**Fig. 11.** A map of mosquito activity areas in Hurghada 2023

Geographic information systems (ArcGIS 10.41 program) were used to calculate the areas of risk for the spread of mosquitoes in Hurghada during 2023. The area of mosquito spread and activity was 563km$^2$, or 6% of the study area (9451km$^2$), while the areas not exposed to mosquitoes occupied 8888km$^2$, or 94% of the total studied area.

The areas of high risk for the spread of mosquitoes through satellite data for the year 2023 with a buffer zone are mostly concentrated east of Hurghada and occupy an area of 224km$^2$, or 2.37% of the total area of Hurghada, which amounts to 4951km$^2$, as shown in Table (8). The areas exposed to a moderate degree of danger of mosquito-spread in Hurghada for the year 2023, with the inclusion of the buffer zone, occupy an area of 323km$^2$ of the total area of the study area, which is 4951km$^2$, as shown in Table (8). The areas of limited risk for the spread of mosquitoes amounted to 513km$^2$, which reached 9451km$^2$.

The results show that the area outside the range of mosquito-spread is 8888km$^2$ (94%), as the area of limited risks reaches 513km$^2$, while the high and moderate risk areas are 224 and 323km$^2$ respectively, as shown in Table (8) and Fig. (12).

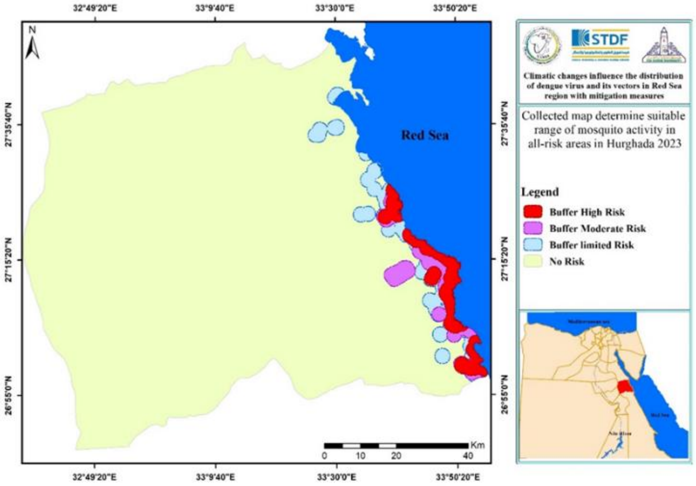

**Fig. 12.** Collected map determine suitable range of mosquito activity in all-risk areas in Hurghada 2023

**Table 8.** The space areas (suitable range) exposed to different risk degrees of mosquito-spread in Hurghada during 2023

| **Mosquito prevalence risk degree** | **Area/ km$^2$** |
|---|---|
| High risk | 224 |
| Moderate risk | 323 |
| Limited risk | 513 |
| No risk | 8888 |
| Total area | 9451 |

### *4.3. The spatial and relative distribution of urban at different levels of risk of Aedes spread*

The results in Fig. (13) and Table (9) show the urban areas that fall within the scope of the high-risk areas, which occupy an area of 77km$^2$, of the total area of urban areas (93km$^2$). Urban areas that fall within the range of mosquito prevalence to a moderate degree of risk are 11km$^2$, and urban areas that fall within the range of mosquito prevalence limited degree of risk occupy 4km$^2$, while it was found that urban areas that do not fall within the range of mosquito-spread 1km$^2$ of the total area of urban areas in Hurghada.

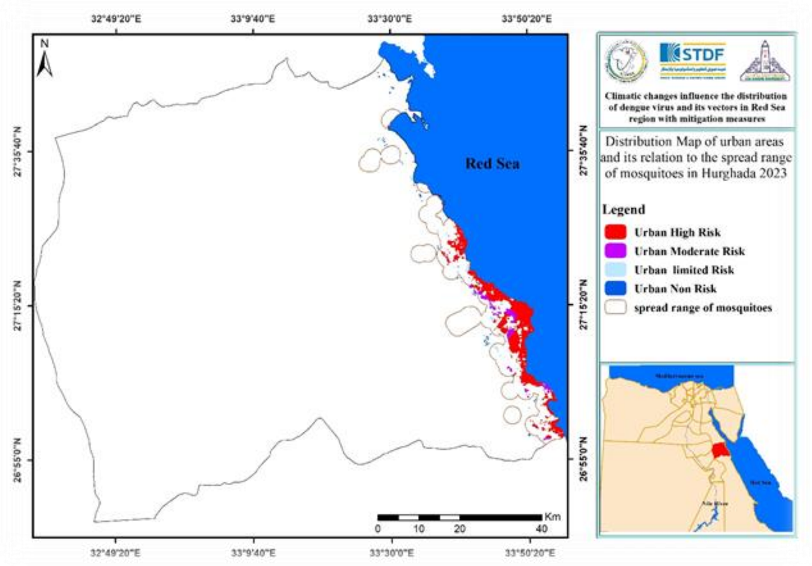

**Fig. 13.** Distribution map of urban areas and its relation with the spread range of mosquitoes in Hurghada during 2023

**Table 9.** Calculation of urban areas exposed to different risk degrees of mosquito-spread in Hurghada 2023

| Urban areas exposed to different risk degrees of mosquito-spread | **Area/ km$^2$** | **Percentage (%)** |
|---|---|---|
| **High risk** | 77 | 82.8 |
| **Moderate risk** | 11 | 11.8 |
| **Limited risk** | 4 | 4.3 |
| **No risk** | 1 | 1.1 |
| **Total urban area** | 93 | 100 |

### *4.4. Mosquito samples collection sites and their relation to mosquito activity range (Collection sites for Aedes mosquitoes)*

Results show the locations of mosquito collection sites through the field and their relationship with the range of mosquito spread for Hurghada during 2023, as shown in Fig. (14). It was found that the total number of mosquito sites within the range of the predicted area is at risk of mosquito-spread.

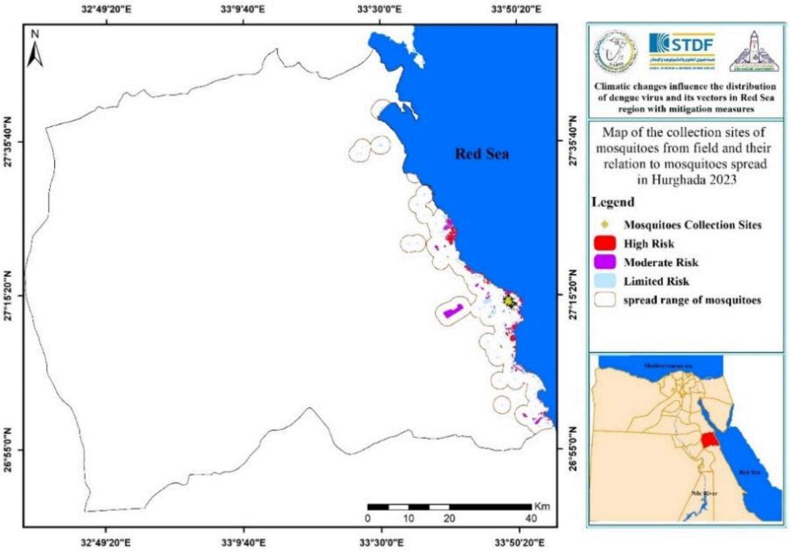

**Fig. 14.** Map of the collection sites of mosquitoes from the field and their relation to mosquitoes spread in Hurghada in 2023

## DISCUSSION

*Aedes aegypti*, a day-biting mosquito exhibiting high adaptation to urban environments, serves as the primary vector for dengue transmission. While *Aedes albopictus* can also transmit the virus, its role is secondary. *Aedes aegypti* demonstrates a cosmopolitan distribution, spanning latitudes between 35°N and 35°S. This geographic range aligns closely with the 10°C winter isotherm, suggesting this temperature might be a critical factor limiting the species' overwintering success **(Ahmed *et al.*, 2007)**. *Aedes aegypti* exhibits high adaptability to urban environments, exploiting stagnant water in artificial containers, including discarded materials and tires, for larval development. Following a blood meal from a viremic host, female *Ae. aegypti* can transmit the virus after an incubation period of 4-10 days. This infectious capacity persists throughout their lifespan. *Ae. aegypti* females demonstrate crepuscular feeding behavior, primarily targeting humans during dawn and dusk. Their propensity for multiple feeding events in a short timeframe facilitates efficient viral transmission within households **(Fonseca & Fonseca, 2002)**.

The prevention and control decision of dengue outbreaks depends on the surveillance of cases and abundance of its vectors. In the absence of a vaccine for dengue treatment, early detection of vector abundance and movement is considered indispensable to prevent disease incidence **(WHO, 2009; Kamal *et al.*, 2018)**.

A bionomic investigation of *Aedes aegypti* was conducted in the Red Sea region in 2023. This study aimed to elucidate the seasonal abundance and identify breeding habitats of both larval and adult stages. The data were analyzed to determine potential correlations between mosquito populations and dengue virus outbreaks. Indoor larval surveys were specifically chosen as the sampling method within five high-risk areas known for dengue prevalence.

Bionomic studies revealed the dominance of *Culex* spp. during this survey; this may be attributed to the high resistance of *Culex* complex to the daily sprayed insecticides by municipal, but we think this situation will be altered after increasing *Aedes* sp. resistance after frequent insecticide spraying.

It seems that the breeding of *Aedes aegypti* takes place more in artificial containers, (collecting water reservoirs) than in natural containers. Stagnant water appeared to be the most suspected breeding type for mosquitoes. Iron water tanks, especially discarded ones with stagnant water, were found the most suitable breeding places.

Inappropriately disposed household items, including buckets, jars, tins, pots, plastic bowls and bottles, cans, and discarded appliances, were observed scattered in front of residences within the study areas. These discarded items may serve as potential breeding sites for *Aedes aegypti* mosquito larvae.

The investigated areas experience limitations in regular water access, leading to the common practice of utilizing large drums for water storage. Unfortunately, such containers, if not adequately maintained, can also become suitable breeding grounds for *Aedes aegypti* larvae. It was also realized that uncovered containers used as water reservoirs were very suitable for mosquito breeding.

Concerning entomological indices, the high values of CI and BI (Tables 2), put Al-Salam and Al-Arab regions at a high-risk level for possible transmission of dengue. (BI>20, highly risk). This assumption is confirmed by the percentage values of breeding preference of both districts (Table 4). Some factors appeared to be responsible for the emergence of dengue fever in Upper Egypt, such as:

Unplanned urbanization created ideal conditions for increased transmission of mosquito-borne diseases in these areas which were established to serve tourism in Hurghada.

The substandard housing, crowding, and deterioration in water, sewer, and waste management systems in these low socio-economic societies could be considered.

The lack of effective mosquito control measures in infected areas and depending on chemical control measures only will create resistance very soon.

The prevalence occurrence of adults is estimated by measuring the number of collected adults per positive house, In the highly infested areas such as AL-Arab and Al-Salam indoor occurrence was preferable (Table 5). The % of occurrence is proportional to the % of container indices **(Muir *et al.*, 1998; Kamal *et al.*, 2018)**. The factor limiting the prevalence behavior of adults is the water containers (covered or uncovered, the type of water tanks, stagnant type). In semi-urbanized areas such as Michelin, outdoor biting behavior is dominant.

A portion of the behavioral variation can be explained by the existence of distinct sibling species. Nonetheless, variations among members of the same species highlight how important environmental conditions are in dictating each species' presence, distribution, seasonality, and behavior regulations **(Obsomer *et al.*, 2007)**.

Aquatic habitat appropriateness for *Aedes aegypti* larvae is influenced by environmental factors **(Zhou *et al.*, 2007)**.

A similar methodology was used in Hurghada for this investigation. Pools and houses were thought to be possible residences for *Aedes* larvae. All habitat categories contained *Aedes aegypti* larvae, indicating their remarkable degree of adaptability to the various environmental conditions present in the sampling regions.

Our analysis revealed a significant negative correlation between the distribution of *Aedes aegypti* breeding sites and the distance to the nearest residence. This suggests a potential preference for oviposition (egg-laying) in peridomestic habitats by *Aedes aegypti* mosquitoes. These findings corroborate similar observations reported by **Rohani *et al.* (2010)** in Pos Senderot, Pahang. Proximity to mosquito breeding sites is the primary factor for dengue risk mapping. This is because the spatial overlap between oviposition habitats and human settlements maximizes vector transmission potential **(Menach *et al.*, 2005)**.

Prior investigations have demonstrated a significant association between mosquito flight range and both temporal (time-based) and environmental factors, including wind vector (direction and speed), physical obstacles (e.g., hills, trees), proximity to breeding sites, and distance from human settlements **(Charoenpanyanet & Chen, 2008)**.

As mentioned by **Bergquist (2001)**, geographic information systems (GIS) and remote sensing (RS) technologies serve as powerful tools for investigating the spatial and temporal dynamics of vector-borne diseases.

**Kistemann *et al.* (2002)**, reported that remote sensing (RS) has proved to be a prominent tool in investigating areas at risk of malaria transmission. The growing success of RS techniques in mapping mosquito habitats across North America established a robust foundation for applying these approaches to satellite-based sensor mapping of remote tropical regions. These regions often face considerably greater logistical challenges and public health burdens related to malaria control **(Hay *et al.*, 1998)**.

**Cano *et al.* (2006)** were able to characterize the spatial distribution of a vector-borne disease by investigating the geographic overlap between the distributions of its competent vectors and susceptible vertebrate hosts.

It is noteworthy that controlling mosquitoes in the study area without such a study will require conducting control in an area of 9451km2. The current study contributes to reducing the control areas to an area of 563km2, 6% of the total area, which saves a lot of expenses and costs of pesticides used in control in addition to preserving the environment from water, air, and soil pollutants added by the residues of these pesticides. The current study also contributes to supporting decision-makers in accurately identifying control areas on accurate and modern scientific foundations.

Urbanization plays an essential function in vector control since it can result in more mosquito breeding grounds due to poor waste disposal practices, clogged drainage systems, and man-made water storage containers. Although our primary goal was to use satellite data to analyze possible breeding sites **(Medeiros-Sousa *et al.*, 2017)** speculating that some features of urbanization, such as land cover connected to human settlements, may have been indirectly captured by the data.

It is recommended in subsequent studies to consider the area inhabited by people and animals, as these are the areas targeted for conservation, and therefore control expenses will be saved in areas whose environment may be suitable for mosquito breeding, but which do not represent any risks to living organisms.

The World Health Organization (WHO) and the Ministry of Health and Population (MoHP) in Egypt worked together to assess the needs for vector control and create an action plan that would increase national capability in integrated vector management, vector mapping, resistance monitoring, and responsible pesticide use for public health. In order to improve vector risk surveillance and vector mapping in high-risk areas, MOHP receives technical support from the WHO.

Many chemicals, biological, mechanical, and pharmaceutical control techniques are employed to minimize the human-to-mosquito transmission of these diseases. The quick global spread of extremely invasive mosquitoes, the emergence of resistance in a number of mosquito species, and the recent outbreaks of novel arthropod-borne viruses present significant and pressing problems for these various techniques. Thus, one of the current strategies is to use the concepts of nanobiotechnology to the management of mosquito vectors. The green synthesis of nanoparticles using active toxic agents from plant extracts, which has been around since ancient times, is a single-step, environmentally friendly, biodegradable method that does not require the use of toxic chemicals. **Onen *et al.* (2023)** reported that this method exhibits antagonistic responses and broad-spectrum target-specific activities against various species of vector mosquitoes.

When discussing the possible drawbacks of the study's reliance on satellite data, which may have an impact on the precision of risk maps; the following pertinent drawbacks may be relevant: Resolution: *Aedes aegypti* prefers tiny bodies of water for reproduction; details at ground level may not be captured by satellite images. Spectral limitations: Cloud cover and satellite data alone can make it difficult to distinguish between various land cover types that may affect mosquito breeding places. Having cloud cover can greatly impede the capacity to obtain sharp satellite photos **(Louis *et al.*, 2014)**.

The following methods can be used to alleviate the limitations: using high-resolution data (Landsat 8) to help with the resolution limitations; combining data to create a more comprehensive picture by integrating satellite data with other sources, such as ground surveys, and accuracy assessment, which involves validating the satellite-derived risk map with ground data.

Although satellite data have limits, these data are nevertheless a useful tool for risk mapping on a wide scale. Our study offers important insights on the possible establishment and prevalence of *Aedes* sp. in the Hurghada region.

Dengue risk maps are a valuable tool for local public health officials. Our study provides a preliminary risk map for Hurghada region based on satellite data. This map can help identify areas with higher potential for mosquito breeding, allowing for targeted interventions such as spraying and larvicide application.

## CONCLUSION

Updating the current distribution of *Aedes* sp. and anticipating their future incidence was achieved by detecting and specifying the indoor and outdoor breeding places of larval and adult stages of *Aedes* vector. *Aedes* entomological indices were calculated. Satellite data can be a valuable tool in creating a dengue warning system. Unlike traditional methods, these satellites can collect environmental information over large areas frequently and consistently. These data, combined with information from other sources, help predict the risk of dengue outbreaks in specific regions.

## ETHICAL APPROVAL

This research was approved by the Research Ethics Committee of Faculty of Science, Ain Shams University, Cairo, Egypt (approval code: ASU-SCI/ENTO/2024/3/2).

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