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Spatial- temporal statistical analysis of the relationship between climate factors and the biodiversity of *Aedes Albopictus* Mosquito over Northern Libya

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ABSTRACT

Climate scientists are looking to build the largest climate models and compile data on the Earth's surface, including the impact of climate factors over time on the biodiversity of the *Aedes albopictus* Mosquito. In our study, it became clear that there are relationships between the spread of *Aedes albopictus* Mosquito and different climate factors. A strong inverse relationship was found between mosquitoes and temperature, with a correlation coefficient of -0.76., while the relationship with relative humidity and Precipitation reached 0.533 and 0.518, respectively. When spatially analyzing the Moran's I and LISA variables, it was found that there are hot spots concentrated in the AL Jabal al Akhdar region and cold spots in Sirt and Mizdah for the significance level P<0.05, and a local Geary analysis identified the dependent and independent places of climate variables and their impact on mosquito numbers and determined the significance level. During 2025-2080, mosquito numbers are decreasing due to rising temperatures according to climate scenarios.

Keywords: Mosquito *Aedes albopictus*, Temperature, North Libya, relative humidity, Precipitation

1. INTRODUCTION

Since mosquitoes carry parasites that cause serious diseases in both humans and animals, their diversity and abundance in a given location are crucial factors. Consequently, species could become efficient vectors if favorable microclimatic changes occur (Manas, 2023; Bhattacharyya et al., 2014; Handi and Oleg, 2020). And of significant factors, such as environmental conditions and climate change, contribute to the widespread spread of viral infections carried by mosquitoes.

International travel and trade, population increase, and urbanization a few examples are (Kovats et al., 2001; Moritz et al., 2015; Kumar et al., 2018; Lowe et al., 2020; Andrew et al., 2006; Andrea et al., 2014; Rachel et al., 2021). Mosquitoes are considered one of the most dangerous living organisms in the world and pose a serious threat to public health, Teklehaimanot and Pushpa, (1999), Elisabet et al., (2012) and many species of mosquitoes find ideal breeding grounds near the coastal lands of the Mediterranean Sea.

The impact of climate change on mosquito numbers is important in the field of scientific research Patz et al., (2000) and by controlling mosquito survival, reproductive potential, and vectorial competence, key climatic factors like temperature, humidity, and Precipitation patterns have a substantial impact on mosquito population dynamics (Ahmed et al., 2019). To accurately forecast spikes in mosquito populations, evaluate the risks of disease transmission, and create focused and efficient vector control plans for Mediterranean wetlands, a comprehensive understanding of these climatic impacts is essential (David et al., 2024). Climate changes in temperature and rainfall have a significant impact on the mosquito life cycle. Juliano, (2007), where rainfall cause water bodies that are perfect for egg and larval reproduction, but intense rainfall can remove these stages, reducing the likelihood of survival.

Given that climate change may influence the distribution and density of mosquito populations in different places, these impacts are especially significant when it comes to diseases spread by mosquitoes Patz et al., (1998), and the abundance of mosquitoes depends on the geographical area Reisen et al., (2006), David et al., (2024), where way that different species react to climate variables including temperature, humidity, and Precipitation varies. Globally important species like *Aedes aegypti* and *Aedes albopictus* are the main focus of most models (Medlock et al., 2012). In Spain, the annual quantity of *Ochlerotatus detritus* and *Culex pipiens* was positively correlated with winter rainfall. Furthermore, shown that the yearly mean temperature had a positive correlation with *Ochlerotatus caspius* abundance, while the maximum yearly temperature had a non-linear relationship with Cx. pipiens population density.

Utilizing climate change scenarios A2 and B2 for rainfall and temperature between 2011 and 2100 (David et al., 2024; Yuan et al., 2024). A study conducted on Reunion Island projected the effects of climate change on *Aedes albopictus* populations from 2070 to 2100 under several scenarios of greenhouse gas emissions using a high-resolution regional climate model. The main conclusions are that variations in temperature and Precipitation will affect *Aedes albopictus* abundance depending on location and elevation. Lamy et al., (2023), and previous studies have used climate models based on environmental variables to determine the distribution of invasive mosquito species.

The presence of these species has been recorded, (Matteo et al., 2016; Kurucz et al., 2020; Justin and Hugh, 2022). In addition, other indicators of mosquito presence, such as vegetation cover, population expansion, and land-sea transport, have been used. These studies have relied on meteorological factors such as temperature, Precipitation, and humidity (Cunze et al., 2016; Daniele et al., 2022). To obtain a suitable environment to simulate the spatial and temporal abundance of mosquito species, it is necessary to select appropriate environmental predictors. It has been found that the abundance of mosquito species depends on the environment and its climatic conditions (Antoinette et al., 2023).

Study Area

The study area is in northern Libya and includes 24 regions with topography diverse, as shown in (Figure 1).

Data Source

Using the climate scenario RCP 85 (Representative Concentration Pathway), daily counts of *Aedes albopictus* mosquito were used in the study, along with the year average and data temperature (C^0). Obtained from Climate Data Store Climate Data Store. From world Data Center, we obtained the relative humidity and Precipitation data for the IPCC RCP 8.5 scenario.

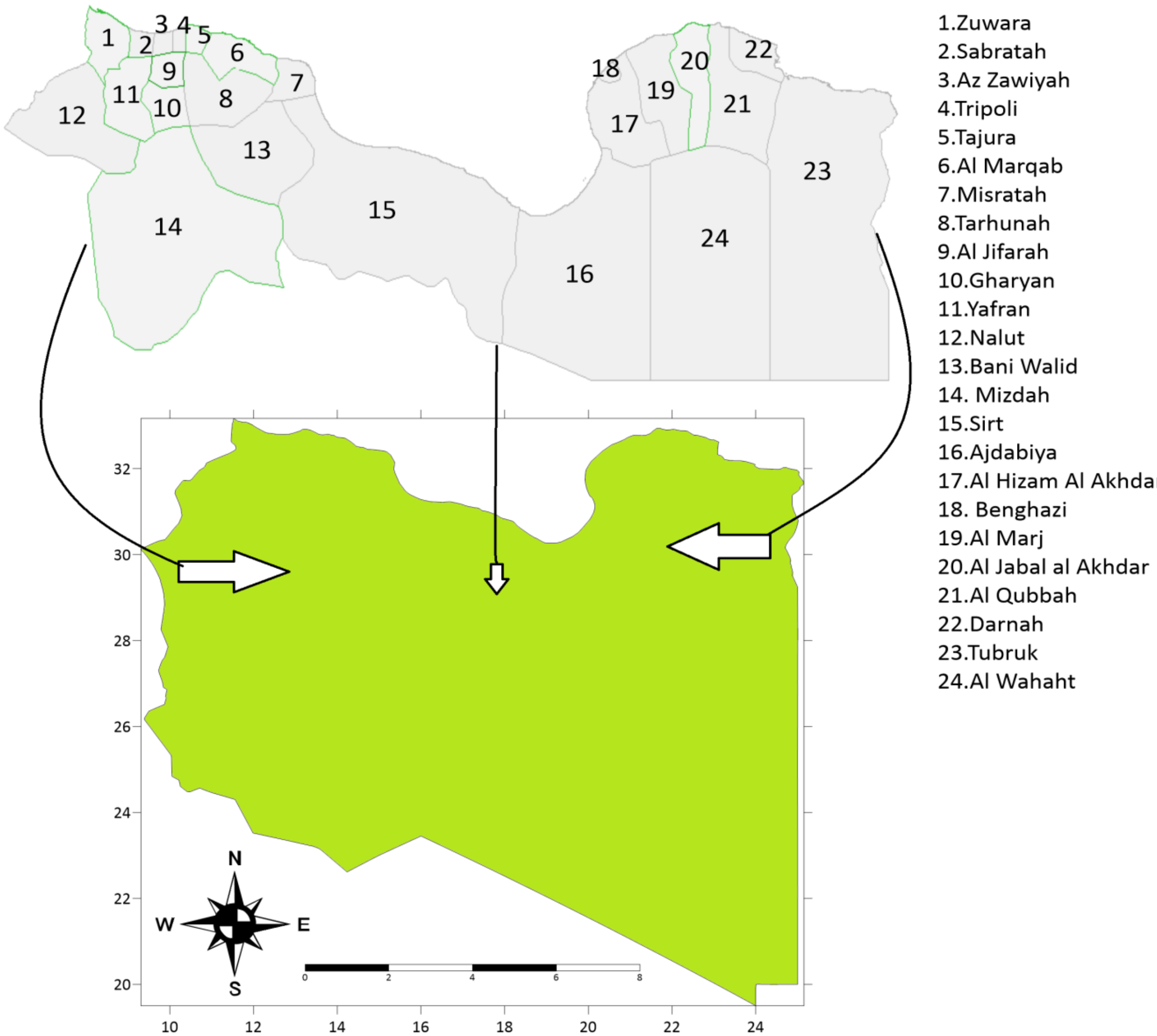

Figure 1 Study Area

Distribution of *Aedes Albopictus* Mosquito and Climate Factors for Regions:

Due to climate changes occurring in the Mediterranean basin and movement across it, it is considered a vector for mosquitoes. Through the geographical distribution of mosquito spread for the periods 2006-2024 and 2025-2080, it was found that mosquitoes multiplied in the period 2006-2024 in the eastern regions for Libya, including Al-Qubbah, Dernah, and AL Jabal alAkhdar, and in the western region in Gharyan. While during the period 2025-2080, it was found that the number of mosquitoes was decreasing, and this was more evident in the east than the west, as shown in Figure 2, coinciding with climatic factors, such as an increase in Precipitation and consequently an increase in humidity and a decrease in temperature in the same regions. This results in an increase or decrease in the number of mosquitoes over time with the change in climatic factors.

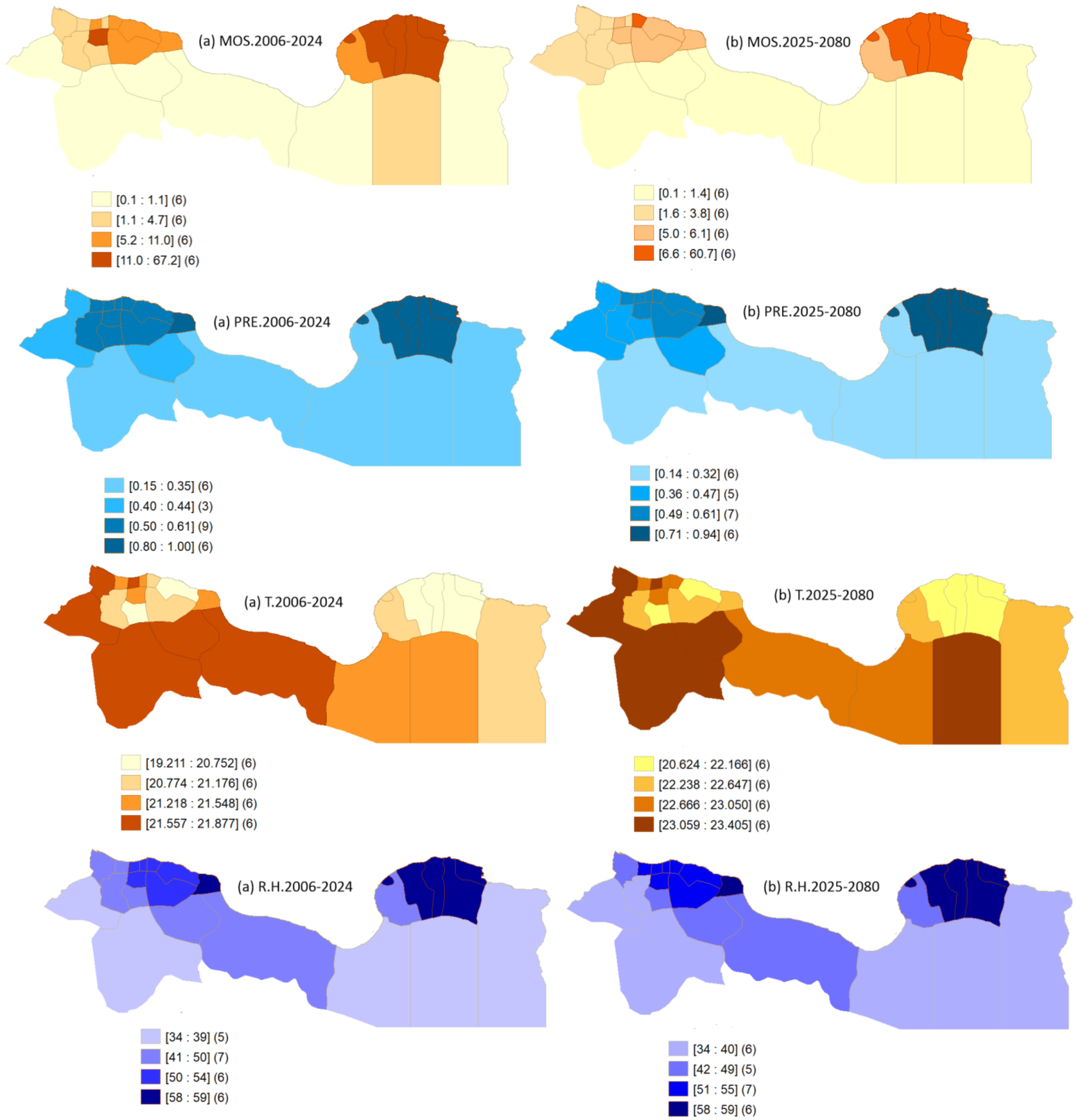

Figure 2 Spatial distribution of Mosquito numbers, Precipitation (mm/day), Temperature (T C^{O}), and Relative humidity (%) for the period (a) 2006-2024 and period (b) 2025-2080.

2. MATERIALS AND METHOD

Statistical analysis

Statistical analysis of data from 2006-2024 was used to determine the strength of the relationship between mosquito numbers, temperature, relative humidity and rainfall, through the Pearson correlation coefficient between variables X and Y calculated from.

$$r = \frac{\sum_{i=0}^{n}(y_i - \bar{y})(x_i - \bar{x})/n}{\sqrt{\frac{\sum_{i=0}^{n}(y_i - \bar{y})^2}{n}}\sqrt{\frac{\sum_{i=0}^{n}(x_i - \bar{x})^2}{n}}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Local Spatial Autocorrelation

Using spatial correlation and comparing its equations with the correlation over time based on Pearson's first relation and Moran's I, as follows:

$$I = \frac{N \sum_{i=0}^{n} \sum_{j=0}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\left(\sum_{i=0}^{n} \sum_{j=0}^{n} w_{ij}\right) \sum_{i=0}^{n} (x_i - \bar{x})^2} \quad \text{.............................(2)}$$

Where: N is the number of observations (points or polygons), $\bar{x}$ is the mean of the variable, x_i is the variable value at a particular location, x_j is the variable value at another location, wij is a weight indexing location of i relative to j (Guofeng, 2020).

Bivariate Local Moran's I (Bivariate LISA)

Using the spatial correlation of the two variables, use the Bivariate Local Moran relationship for dispersion as well as LISA to identify high-value locations with similar neighbors called Hot Spots (High/High), Cold Spots: low-value areas with similar neighbors (Low/Low) & spatial outliers: high-value locations with low-value neighbors (High/Low) and low-value locations with high-value neighbors (Low/High), and the significance level of the P- Value, from the following relationship (Guofeng, 2020):

$$I_i^B = c x_i \sum_j w_{ij} \, y_j \quad \text{..(3)}$$

Multivariate Local Geary

Using the Multivariate Local Geary, identify the dependent and independent locations points and adjust the p- values for significance (i.e. 0.05, 0.01, 0.001, or 0.0001). It is defined by the following relationship: .

$$C_i^M = \sum_{h=1}^{k} \sum_j w_{ij} \, (x_{hi} - x_{hj})^2 \text{..(4)}$$

3. RESULTS AND DISCUSSION

Mosquito biodiversity depends on several climatic factors, and spatial variation, the impact of which is significant. When analyzing the results, it became clear that the change in climate factors with mosquito distribution during the period 2006-2024. Showed the strength of the direction of the relationship between them, as shown in the (Table 1).

Table 1 Correlations

		Mos. Rate	PRE	R.H	T
Mos. Rate	Pearson Correlation	1	.518**	.533**	-.760**
	Sig. (2-tailed)	-	.000	.000	.000
	N	456	437	456	456

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

The results of the correlation analysis showed a moderate to strong inverse relationship between temperature and mosquito rate. At the same time there was a moderate direct relationship between mosquito rate and humidity and Precipitation rates. This means that areas with a moderate and humid climate are more susceptible to mosquito - spread than areas with very high temperatures. To compare the mosquito count rate between different regions, One-Way ANOVA will be used (Table 2).

Null hypothesis H_0 : There are no significant differences between regions in terms of mosquito count rate

Alternative hypothesis H_1 : There are differences between regions in terms of mosquito count rate

Table 2 ANOVA

Mos. Rate					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	94761.857	23	4120.081	13335.983	.000
Within Groups	133.155	431	.309	-	-

Total	94895.013	454	-	-	-

Since P-Value = 0.000 < α = 0.05, this indicates a significant difference between the regions regarding the rate of mosquito numbers. To know which regions specifically differ from each other, we drawn a boxplot (Figure 3) and a curve to see the regions with the highest rate of mosquitoes:

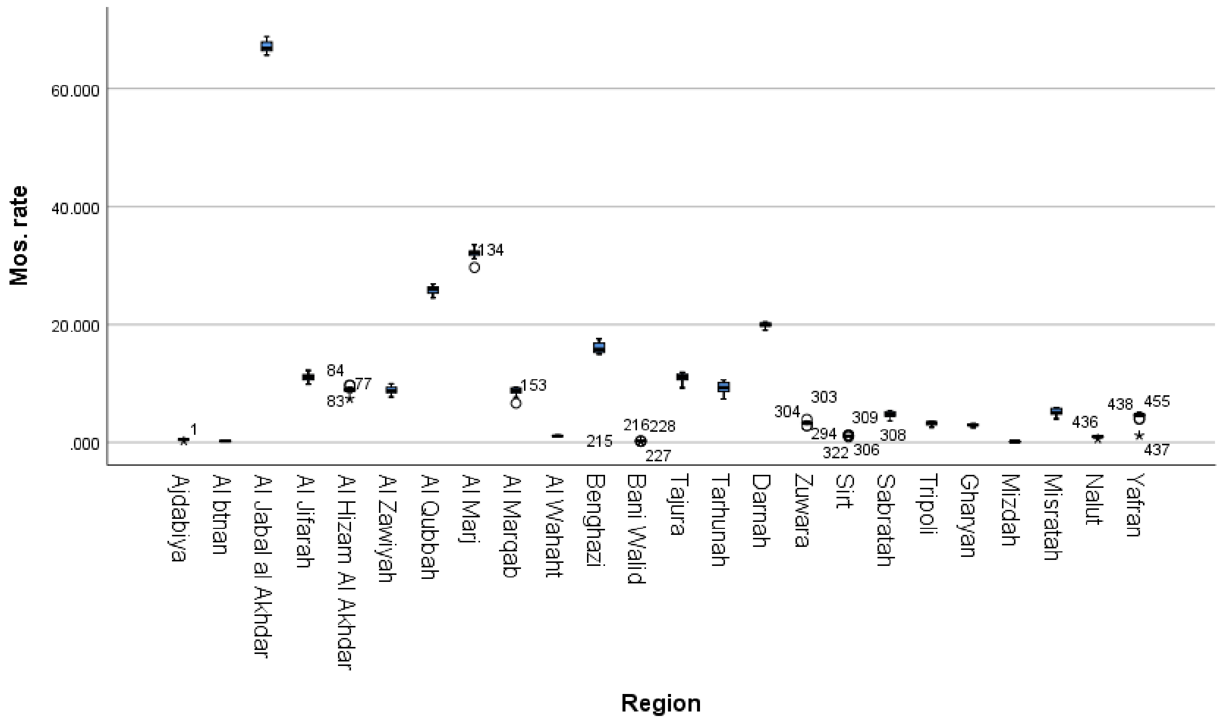

Figure 3 Schematic of the boxplot

The height of the box in the AL Jabal al Akhdar area and then Al Marj indicates that the mosquito rate in this area has a wide variation, followed by the Al Qubah and Darnah areas. The reason may be that these areas are a suitable environment for mosquito growth due to climate changes or changes in temperature and humidity over time. As for the rest of the areas, the mosquito rate in them is between medium and low, especially the areas far from the sea, which are considered a relatively stable environment with low mosquito rates. A multiple Regression analysis will be conducted for the period 2006-2024 and 2025-2080 to determine the extent of the effect of rainfall, humidity, and temperature on the growth rate (Table 3).

Table 3 Model Summary

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
2006-2024	.784a	.615	.612	9.154173
2025-2080	.661a	.437	.435	10.020774856

a. Predictors: (Constant), T, R.H, PRE

b. Dependent Variable: Mos. Rate

In the period 2006-2024, we find that R^2 = 0.615, and the period 2025-2080 R^2 = 0.437, which means 61.5% and 43.7% for the two periods respectively. The variation in mosquito numbers explained by humidity, rainfall and temperature, and R = 0.784 and R = 0.661 for the two periods respectively, indicating a strong association between the dependent and independent variables, and the independent variables, indicating that the number of mosquitoes is decreasing over time.

Table 4 Coefficients[a]

Model 2006-2024	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	235.535	16.231	-	14.511	.000
PRE	7.605	2.168	.127	3.509	.000
R.H	.254	.056	.162	4.506	.000
T	-11.512	.703	-.610	-16.388	.000
2025-2080	B	Std. Error	Beta	t	Sig.
(Constant)	83.512	7.288	-	11.458	.000
PRE	15.059	1.558	.278	9.663	.000
R.H	.307	.044	.201	6.915	.000
T	-4.325	.290	-.359	-14.923	.000

a. Dependent Variable: mosquito rate

This indicates that all variables have a significant effect on the mosquito rate. In general, temperature is the most influential factor affecting the mosquito rate, i.e. high temperature reduce the reproduction and spread of mosquitoes (Table 4).

Spatial analysis

The GeoDa software was used to understand the geographic distribution of mosquito rates and climatic factors. Using the Bivariate local Moran's I and the Bivariate LISA, it is noted from Table 5 there is relationship between the two variables, Mosquito- numbers and local Moran's I Precipitation for the periods 2006-2024 and 2025-2080. Figure 4 shows the hot spots in the AL Jabal al Akhdar region and the cold spots in the Mizdah and Sirt regions, and the LISA index shows the spatial correlation increases strongly in the AL Jabal al Akhdar region and then in the Sirt and Mizdah regions at the significance level P-Value < 0.05.

Table 5 Bivariate Local Moran's I (Bivariate LISA) for Precipitation and Mosquito

PRE and MOS 2006-2024	Moran's I	Bivariate LISA	P-Value
Al Jabal al Akhdar	0.637	0.857	0.027
Sirt	-0.597	0.6097	0.024
Mizdah	-0.483	0.359	0.037
Region All	0.172	-	-
PRE and MOS 2025-2080	Moran's I	Bivariate LISA	P-Value
Al Jabal al Akhdar	0.665	0.893	0.012
Sirt	-0.507	0.551	0.031
Mizdah	-0.435	0.331	0.049
Region All	0.172	-	-

While the spatial relationship between mosquito numbers and temperature, the Table 6 shows that the relationship is strongly inverse in the AL Jabal al Akhdar region and the inverse relationship decreases in the Sirt and Mizdah regions, and the spots are Cold-Hot in the AL Jabal al Akhdar and Hot-Cold in both Sirt and Mizdah, at the significance level P < 0.05 (Table 6 and Figure 5). The relationship between humidity and mosquito numbers is noticeable, as hot spots appear in eastern Libya in the Al Jabal al Akhdar region. In contrast, cold spots appear in western Libya, represented by Sirt and Mizdah, where the spread there is less (Table 7 and Figure 6). Their presence is indeed in these areas, which are considered valley courses and are dry due to climate change. However, during the rainy season, these areas become, due to the valleys, suitable areas for mosquito breeding, and in return, there is an increase in humidity and a decrease in temperature, as shown by the same significant value P < 0.05.

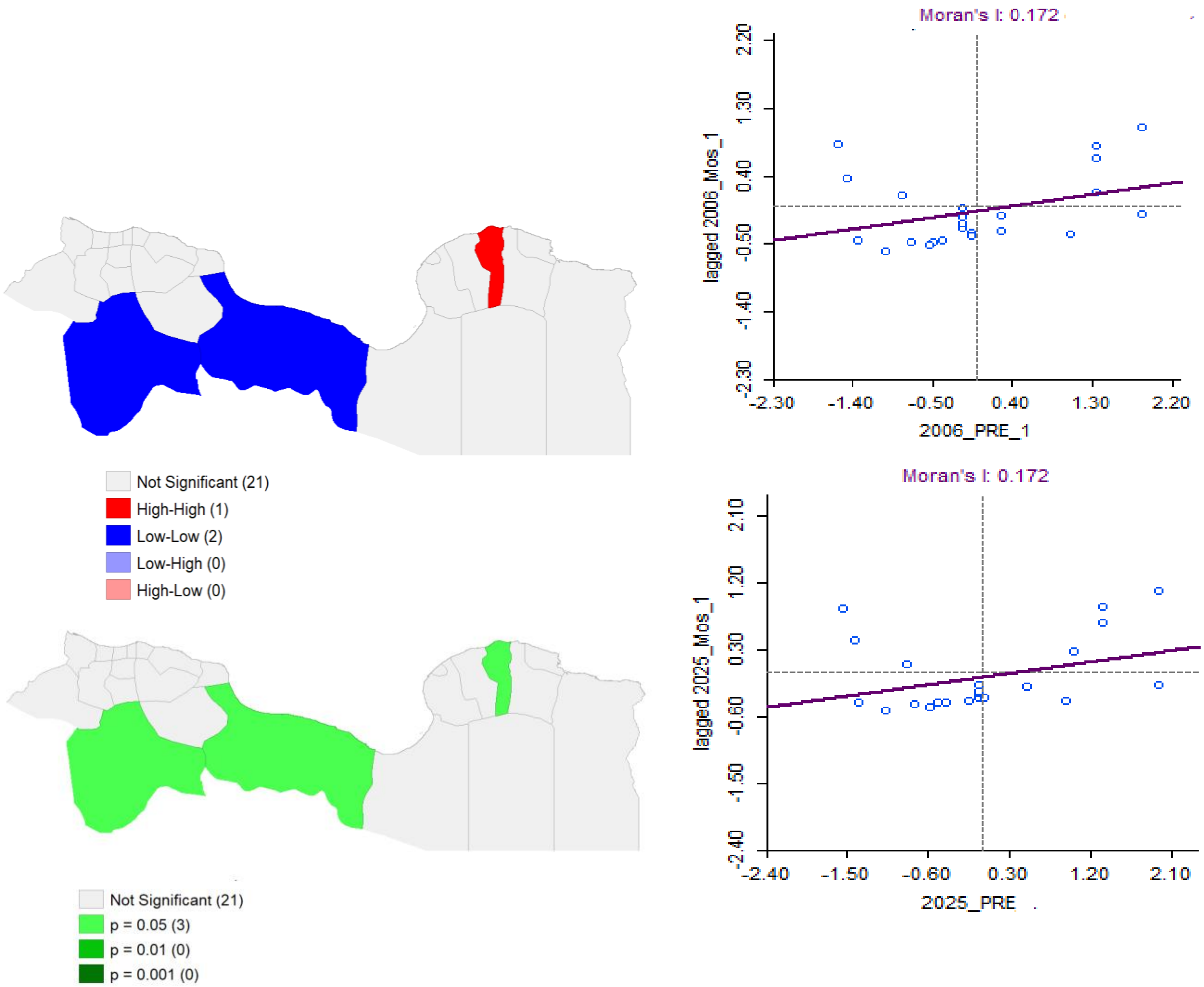

Figure 4 Bivariate Local Moran's I (Bivariate LISA) values for Precipitation and Mosquito for period 2006-2024 and 2025-2080.

Table 6 Bivariate Local Moran's I (Bivariate LISA) for Temperature and Mosquito

T and MOS 2006-2024	**Moran's I**	**Bivariate LISA**	**P-Value**
Al Jabal al Akhdar	0.637	-1.497	0.027
Sirt	-0.597	-0.454	0.024
Mizdah	-0.483	-0.392	0.037
Region All	-0.301	-	-
T and MOS 2025-2080	Moran's I	Bivariate LISA	P-Value
Al Jabal al Akhdar	0.665	-1.562	0.012
Sirt	-0.507	-0.355	0.031
Mizdah	-0.435	-0.403	0.049
Region All	-0.308	-	-

From the local Jerry group, identify the dependent and independent places of climate variables and the extent of their impact on the number of mosquitoes and determine the level of importance through Figure 7 explains the relative humidity and the number of mosquitoes. the dependent places are clear in the areas of Mizdah, Yafran, Al-Jifarah, Az-Zawiyah, Tripoli, Tajura, and Al-Marqab with a level of importance of P = 0.05, and since the dependent places are the same for the periods 2006-2024 and 2025-2080. While in the amounts of Precipitation and the numbers of mosquitoes during the period 2006-2024, the places affiliated to the west of north Libya (Nalut, Zuwara, Yafran, Sabratah, Al-Jifarah, Tajura) are concentrated with a significance level of P = 0.05, while Az-Zawiyah, Tarhunah with a significance level of P = 0.01 and Jfara with a significance level of P = 0.001, and in the northeast in Ajdabiya and the AL-Qubbah area, this spatial unit is independent with a significance level of P = 0.05.

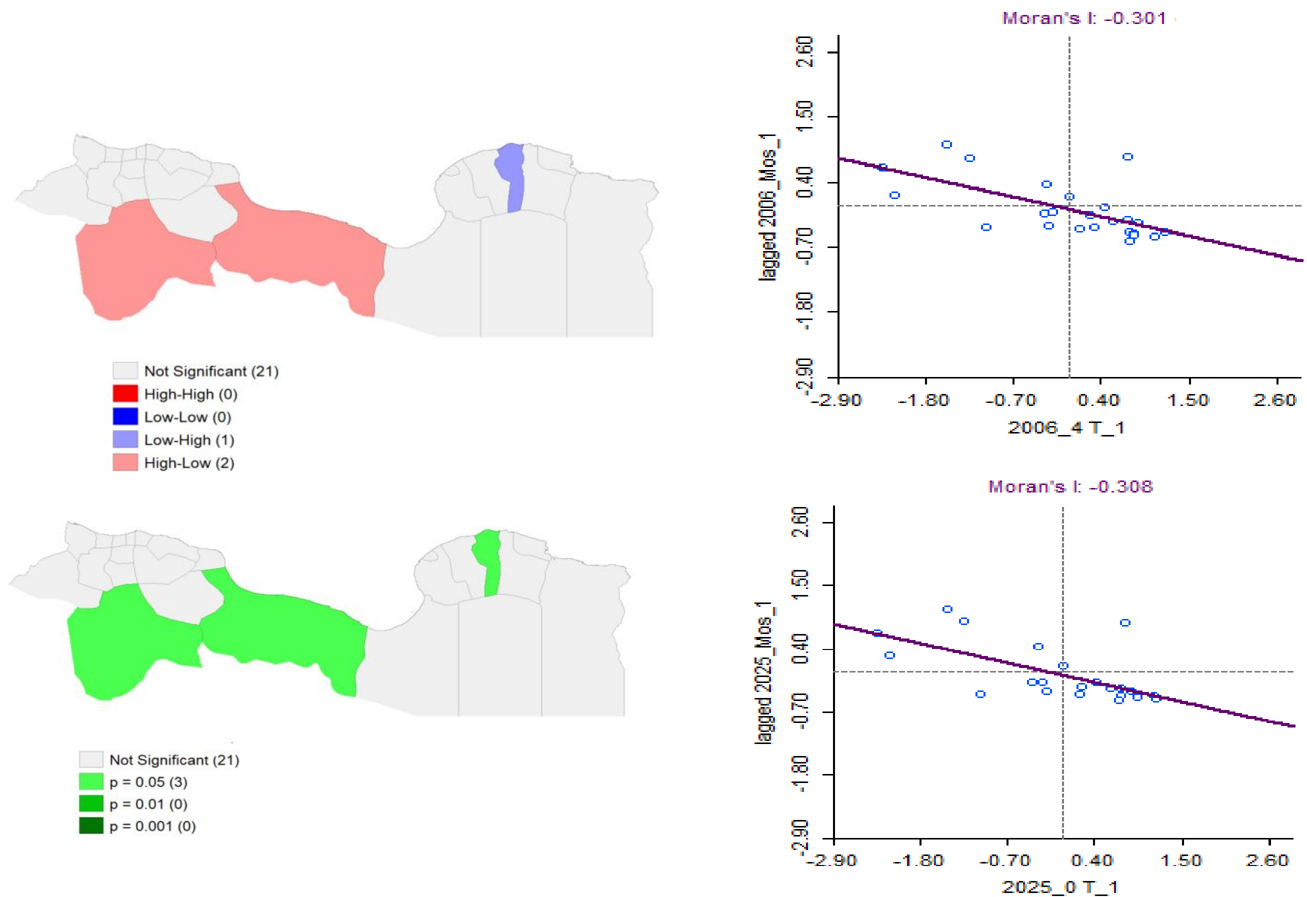

Figure 5 Bivariate Local Moran's I (Bivariate LISA) values for Temperature and Mosquito for period 2006-2024 and 2025-2080

Table 7 Bivariate Local Moran's I (Bivariate LISA) for Relative Humidity and Mosquito

R.H and MOS 2006-2024	**Moran's I**	**Bivariate LISA**	**P-Value**
Al Jabal al Akhdar	0.637	0.770	0.027
Sirt	-0.597	0.216	0.024
Mizdah	-0.483	0.802	0.037
Region All	0.144	-	-
R.H and MOS 2025-2080	Moran's I	Bivariate LISA	P-Value
Al Jabal al Akhdar	0.665	0.790	0.012
Sirt	-0.507	0.278	0.031
Mizdah	-0.435	0.736	0.049
Region All	0.161	-	-

The difference is apparent, evident, precise in the second period (2025-2080) due to climate change, we see the amounts of Precipitation concentrated in the west. The place affiliated to the west is all except for the Bani Walid and Misratah areas. It has a significance level of P = 0.05, and Al-Jifarah with a significance level of P 0.001, and Yafran and Al-Marqab with a significance level of P = 0.01. At temperature and mosquito numbers during the period 2006-2024, the places affiliated in Tajura, Al-Marqab, Sirt and Al-Jabal Al-Akhdar regions have a significance level of P = 0.05, while due to the increase in temperatures according to climate scenarios in the period 2025-2080, the places affiliated in Tajura, Al-Marqab and Al-Jabal Al-Akhdar only have a significance level of P = 0.05.

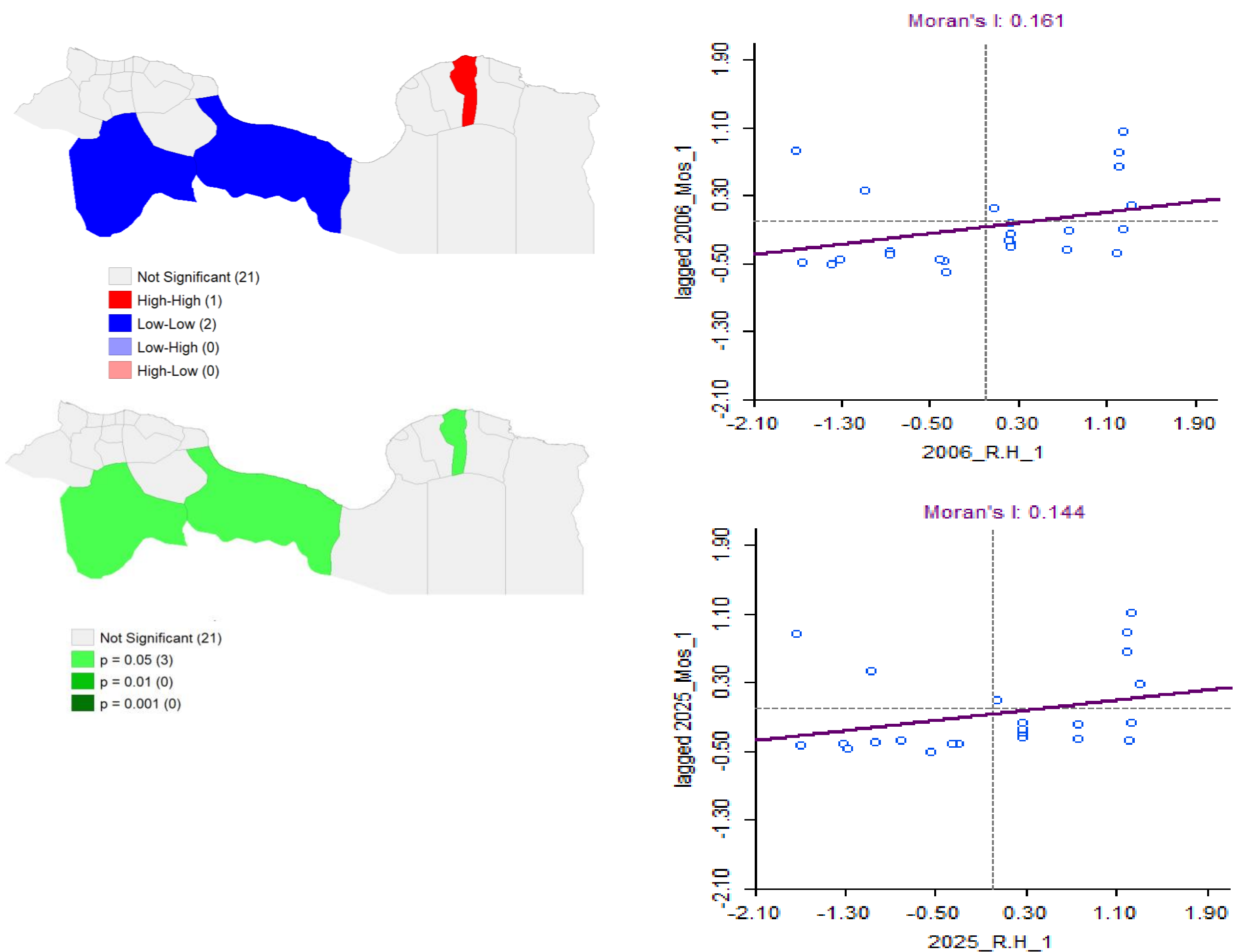

Figure 6 Bivariate Local Moran's I (Bivariate LISA) values for Relative Humidity and Mosquito for period 2006-2024 and 2025-2080.

As for the effect of climate factors with each other on the number of mosquitoes, the places affiliated (Nalut, Yafran, Sabratah, Al-Jifarah, Tajura, Tripoli, Az-Zawiyah, Tarhunah, Al-Marqab) have a significant level of P = 0.05, except for Yafran P = 0.01. In the second period, the places affiliated are the same with an increase in Ajdabiya and a significance level of P = 0.05, except for Al-Marqab P = 0.01 each of the three climatic factors plays a role in mosquito reproduction according to the region's environment.

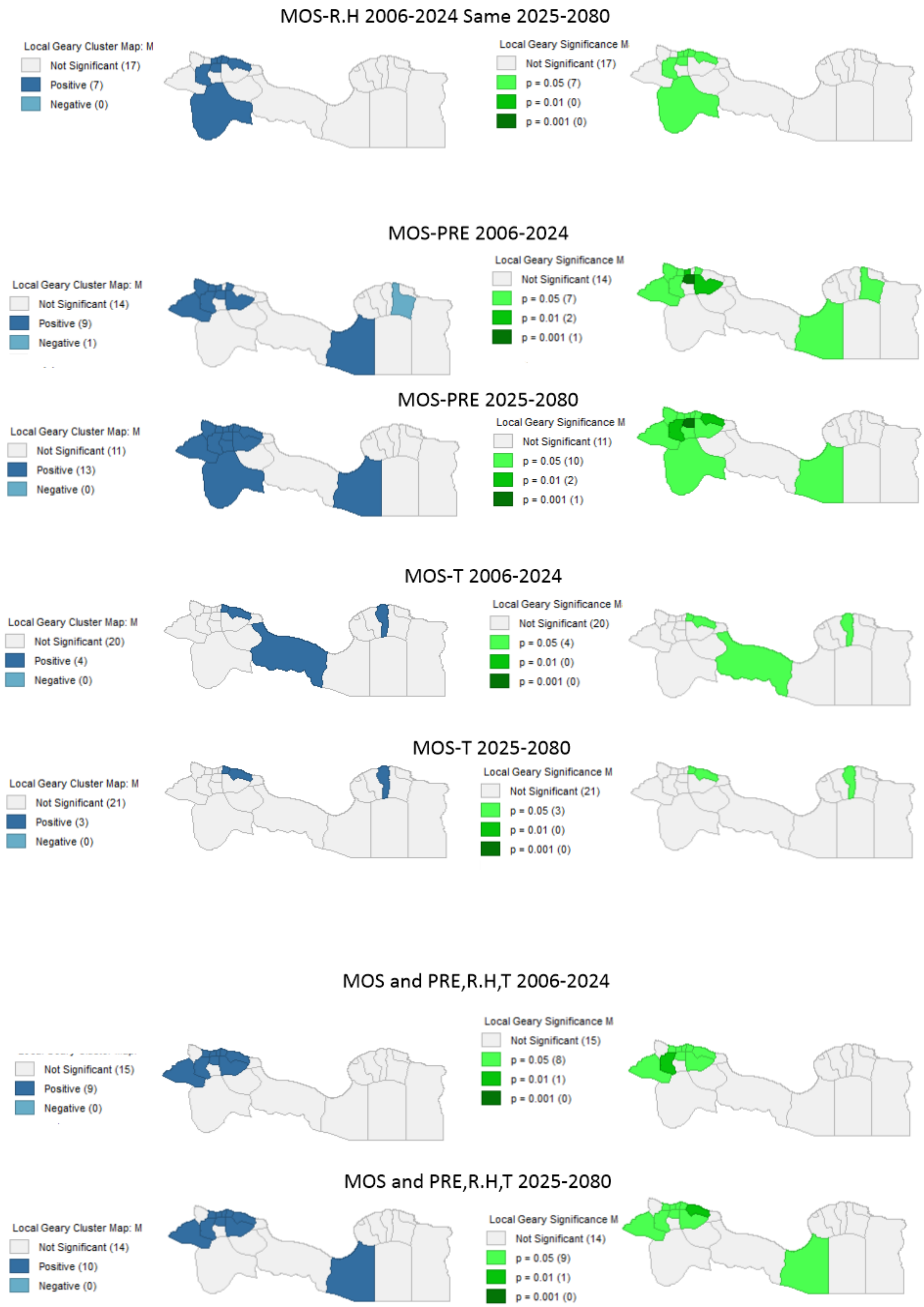

Figure 7 Multivariate Local Geary Cluster and Significance Map

4. CONCLUSION

Climate is a focus of our daily and future lives and its impact on the lives of humans, animals, and plants, so climate scenarios have highlighted the *Aedes Albopictus* mosquito and the diseases it carries. Here in this study, we learned about the increase and decrease of mosquitoes due to climate factors by analyzing data for the period 2006-2024, and the inverse relationship between mosquitoes and air temperature was intense, substantial, while there was a direct and substantial relationship between relative humidity and Precipitation, and the highest concentration of mosquitoes was in the Green Mountain region, where the environment is suitable for reproduction. The regression coefficient shows that all variables have a significant effect on the mosquito rate, and in general, temperature is the factor that has the most significant impact on the mosquito rate, meaning that high temperatures reduce the reproduction and spread of mosquitoes and the mosquito rate decreases during the period 2025-2080.

The focus was precisely on spatial analysis by using Local Moran's I spatial analysis of the two variables. It was shown that the increase represented by hot spots in the Al-Jabal Al-Akhdar region and cold spots in the Sirt and Mizdah regions for both relative humidity and Precipitation with mosquito quantities, while it has a low effect for the temperature variable, at the significance level of $P < 0.05$. From the local Geary group, identify the places dependent and independent of climate variables and the extent of their impact on mosquito numbers and determine the significance level for the regions. The change in the effect of relative humidity on mosquito numbers over the same effect in the same areas, while we observe that Precipitation covers the entire western region during the period 2025-2080 more than during the period 2006-2024, and temperature rises during the period 2025-2080 more than during the period 2006-2024.

Author Contributions

All authors contributed to the study's conception and design. All authors are equal in material preparation, data collection, and analysis. All authors have read and agreed to the published version of the manuscript.

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Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

Publicly available datasets were analyzed in this study. This data can be found here: Climate Data Store. https://www.cds.climate.copernicus.eu. World Data Center for Climate. https://www.wdc-climate.

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