SINAI Journal of Applied Sciences 13 (1) 2024 073-094

Available online at www.sinjas.journals.ekb.eg

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SINAI Journal of Applied Sciences

Print ISSN 2314-6079
Online ISSN 2682-3527

ARU-EGYPT SJAS TrustScience | ItCreates

IMPACT OF CLIMATIC CHANGES ON THE SURFACE WATER RESOURCES: A CASE STUDY OF EGYPT

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ARTICLE INFO

Article history:
Received: 02/02/2024
Revised: 20/02/2024
Accepted: 30/02/2024

Keywords:
Climatic changes,
Rainfall,
reference evapotranspiration,
Water resources,
Egypt.

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ABSTRACT

Egypt is a country in northeastern Africa that spans latitudes 22° and 32° and longitudes 24° to 37°. Its total area is over 1002000 Km^2. Our goal in this research is to investigate how climate change affects the country's surface water supplies. To accomplish this goal, we will assess the temperature and precipitation distribution across Egypt's many regions, look into the consequences of current climatic changes on resources for surface water, and forecast the effects of future climatic changes on resources for surface water. Data related to monthly climate variables were gathered for Egypt region from 32 meteorological stations, covering the period from 1991 to 2020. The variables were wind speed, air humidity, sunshine duration, irradiance, precipitation, and minimum and maximum air temperature. The Egypt Atmospheric and CLIMWAT databases served as the data's primary sources. Graphs are created to visualize changes over time in weather stations. Data were presented using Boxplot. The aridity index was calculated to classify the different climates and assess the available water resources in Egypt. For geographical areas with similar weather conditions. The aridity scale was calculated as a means of describing the water shortage in each area. As for the reference statistic for average annual evaporation (ETo) (5.032 mm/day), the annual average rainfall in Egypt (19.6 mm), The results showed that water evaporation is approximately 94 times greater than rainfall. The annual percentage of rainfall is significantly less than the annual percentage of water loss *via* evaporation.

INTRODUCTION

As stated in Egypt's Initial National Communication (INC) to the UNFCCC (**EEAA, 1999**), the UNDP Global HDR 2006 (**UNDP, 2006**), and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (**IPCC, 2007**), Egypt is extremely vulnerable to the effects of climate change. Egypt ranks 28th out of 215 countries and regions in terms of emissions, with its contribution to global GHG emissions being approximately 0.60% (**Global Carbon Atlas, 2016**). Egypt ranks 91st out of 181 nations in the ND-Gain Index for climate sensitivity. Egypt ranks 73rd in terms of readiness and 87th in terms of vulnerability. Climate forecasts indicate that Egypt's development gains and poverty reduction initiatives may be jeopardized by changes in existing and future climatic circumstances, which constitute a severe environmental risk.

Egypt has a dry, hot, and desert climate overall, with a moderate winter that brings rain to the coastal regions and a scorching, dry summer, according to Egypt's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC). The number

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https://doi.org/10.21608/SINJAS.2024.273677.1254
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of hazy, misty, turbid, frequent sandstorm, and hot days have all increased between 1961 and 2000, according to data gathered by the Egyptian Meteorological Authority and local universities. These trends point to a general trend toward an increase in the temperature of air (**EEAA, 2010**). The nation boasts very favorable wind patterns, with prime locations around the Mediterranean and Red Sea coasts offering tremendous potential for wind energy production. Since the management of water resources depends on all these variables, climatic changes have a negative impact on water resources in many parts of the world.

Egypt's rapidly expanding population and scarce water supplies present serious concerns. In the 1960s, per capita water use was 2200 m^3/year; by 2050, however, that figure is expected to drop to just 324 m^3/ year (**MWRI, 2005**). As a result, it is anticipated that climatic changes will have far worse effects on the environment, society, and economy nationwide. Egypt does not currently have enough water to meet its needs for home use, industry, agriculture, and other uses when commitments to transboundary water accords are present. Furthermore, the development plans in the countries that make up the upper Nile Basin pose a threat to Egypt's portion of the Nile. It is important to note that climatic changes might present possibilities as well as difficulties for the nations in the Nile River Basin (NRB) to work together to lessen climatic changes negative effects.

Thus, the main goal of this research study was to assess how Egypt's surface water supplies will be affected by climate change. The following aim was pursued in order to achieve this goal: (i) Analyzing Egypt's temperature and precipitation patterns throughout time and space; (ii) estimating the effects of certain climatic change on Egypt's surface water supplies. (iii) Researching how Egypt's surface water resources may be impacted by climate change in the future.

MATERIALS AND METHODS

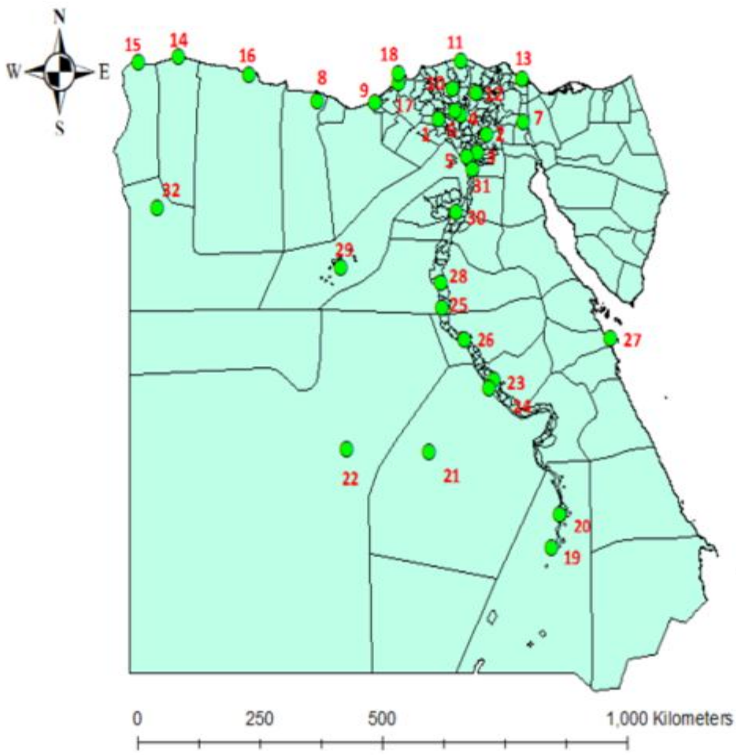
Study Area

Egypt is the main subject of this study. Egypt is a country in northeastern Africa, with the Red Sea and Mediterranean Seas on its eastern and northern coasts, respectively. Egypt lies in the latitude range of 24° to 37° and the longitude range of 22° to 32°. Egypt shares land borders with Libya to the west, Sudan to the south, and Palestine to the northeast. About one million km^2 make up its whole area. There are three distinct climatic types in Egypt. A Mediterranean climate prevails on the northern shore, a desert climate is found inland, and a milder desert climate is found on the Red Sea coast. According to Fig. 1. The Nile River provides more than 95% of Egypt's freshwater resources. Egypt is regarded as a downstream nation, and the water of the Nile originates from beyond its borders. Egypt receives 55.5 Billion cubic metres of the river's water annually.

Data on monthly climate variables were gathered for this study between 1991 and 2020 from 32 meteorological stations in Egypt. The air temperature (°C) minimum and maximum, air humidity (%), wind speed (km/day), sunlight period (hour), radiation (MJ/m²/day), and rainfall (mm) were among the factors. The CLIMWAT 2.0 databases were the source of the data. Fig. 1 displays the longitudes, latitudes, and elevations of the meteorological stations.

Temporal Changes in Temperatures, And Precipitation

Graphs were created using Microsoft Excel 356 to visualize the changes over time in data from meteorological stations, specifically maximum and minimum temperatures, and precipitation. The XLSTST program version 2016 was used to present the annual averages of various climatic data obtained from meteorological stations in the Philippines, including maximum and



No	Station name	Latitude	Longitude
1	TAHRIR	30.65	30.70
2	BILBEIS	30.40	31.58
3	CAIRO	30.13	31.40
4	GEMMEIZA	30.71	31.11
5	GIZA	30.05	31.21
6	TANTA	30.78	31.00
7	ISMAILIA	30.60	32.25
8	DABAA	30.93	28.46
9	BORG-EL-ARAB	30.90	29.53
10	SAKHA	31.11	30.95
11	BALTIM	31.55	31.10
12	MANSOURA	31.05	31.38
13	PORT-SAID-EL-GAMIL	31.28	32.23
14	SIDI-BARRANI	31.61	25.90
15	SALLOUM	31.53	25.18
16	MERSA-MATRUH	31.33	27.21
17	ALEXANDRIA-NOUZHA	31.20	29.95
18	ALEXANDRIA	31.36	29.95
19	ASSWAN	23.96	32.78
20	KOM-OMBO	24.48	32.93
21	KHARGA	25.45	30.53
22	DAKHLA	25.48	29.00
23	SOHAG	26.56	31.70
24	SHANDAWEEL	26.43	31.63
25	MALLAWI	27.70	30.75
26	ASYUT	27.20	31.16
27	HURGUADA	27.23	33.85
28	MINYA	28.08	30.73
29	BAHARIA	28.33	28.90
30	BENI-SUEF	29.20	31.01
31	HELWAN	29.86	31.33
32	SIWA	29.25	25.51

Fig. 1. Locations map of different weather stations (green dots) in Egypt

minimum temperatures, precipitation, humidity, number of hours of sunshine, and wind speed. The data was displayed using Boxplot.

Aridity indices

Aridity indices are measures of the dryness of a region or climate. They are used to assess the availability of water resources and the potential for drought, as well as to classify different types of climates (**Thornthwaite, 1948; FAO, 1998**). Aridity indices take into account factors such as temperature, precipitation, and evaporation, and are typically expressed as a ratio of precipitation to potential evaporation (**Van der Schrier *et al.*, 2013; Vicente-Serrano *et al.*, 2010**).

Aridity index (AI)

The Aridity Index (AI), sometimes referred to as the De Martonne aridity index (**De Martonne, 1926**), is one often used aridity measure. It is computed as the ratio of the average annual temperature to the average yearly precipitation. The ratio of mean annual precipitation to mean annual temperature is used to create the De Martonne aridity index, usually referred to as the Aridity Index (AI), which is a frequently used aridity indicator (**Thornthwaite and Mather, 1955**). The AI is computed using the following formula:

$$AI = \frac{P}{T + 10}$$

Where P is the mean annual precipitation in millimeters, and T is the mean annual temperature in degrees Celsius. Different types of climates are classified based on their aridity using the AI, where arid or semi-arid conditions are indicated by values below 20, semi-humid conditions by values between 20 and 40, and humid conditions by values above 40. Therefore, the application of the De Martonne aridity index is beneficial in classifying various climates and evaluating available water resources in a region. It has a wide range of applications, including agriculture, hydrology, and climate modeling.

Emberger's bioclimatic coefficient (Q2)

Emberger's coefficient (Q2) is a measure of aridity that is often used in the field of biogeography and ecology. It was developed by French botanist Jean-Pierre Emberger in the mid-20th century as a way of characterizing the water deficit in each area. The Q2 index's formula is **Vessella and Schirone (2022)**:

$$Q2 = \frac{2000 \times P}{M^2 - m^2}$$

The variables P, M, and m represent the mean annual rainfall (in millimeters), mean maximal temperatures (in Kelvin degrees) of the warmest and coldest months, respectively, and mean minimal temperatures (in Kelvin degrees). K = °C + 273.15, is the formula to convert Celsius to Kelvin. Different types of climates are classified based on their aridity using the Q2, where barren conditions are indicated by values below 10, arid conditions by values between 10 and 45, semi-arid conditions by values between 45 and 70, subhumid conditions by values between 70 and 110, humid conditions by values between 110 and 150 and humid conditions by values above 150 (**Thornthwaite, 1948**).

Reference evapotranspiration (ETo)

Is the amount of water that would be evaporated and transpired by plants if there was an unlimited supply of water (ETo) is a measure of the water demand of the atmosphere, and is influenced by factors such as temperature, humidity, wind speed, and solar radiation (**Allen *et al.*, 1998**). (ETo) is an important variable in hydrological modeling and water resource management, as it provides an estimate of the amount of water that is required to meet the demand of vegetation and the atmosphere (**Maidment, 1993**). (ETo) is used in conjunction with actual evapotranspiration (AET) to estimate water use by vegetation and to assess the water balance of a particular region or ecosystem. The FAO Penman-Monteith equation, which estimates the quantity of water that would be lost from the reference crop under ideal circumstances by taking into account a number of meteorological data like temperature, humidity, wind speed, and solar radiation, is the basis for calculating ETo. According to **Allen *et al.* (1998) and Jensen *et al.* (1990)**, the Penman-Monteith equation can be stated as follows in order to compute ETo using Cropwat:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T + 273.16}\right)u2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u2)}$$

Where: ETo is the reference evapotranspiration measured in millimeters per day; delta is the saturation vapor pressure curve's slope (kPa/°C); R_n is the net radiation at the Earth's surface (MJ/m^2/ day); G is the soil heat flux density (MJ/m^2/ day); gamma is the psychrometric constant (kPa/°C); T is the average daily air temperature measured at 2 meters (°C); u2 is the wind speed at 2 meters (m/Sec); es is the saturation vapor pressure (kPa); and ea is the actual vapor pressure (kPa).

Correlation matrix

The correlation coefficients between several variables are shown in a table called a correlation matrix. The correlation coefficient, which has values between -1 and 1, indicates the direction and intensity of the linear link between two variables. When two variables have a positive correlation coefficient, it suggests a positive linear relationship, which means that when one variable rises, the other variable also tends to rise. A negative correlation coefficient suggests a negative linear relationship, whereby an increase in one measure is typically accompanied by a drop in the other. The absence of a linear relationship between the variables is shown by a correlation coefficient of zero (**Tabachnick and Fidell, 2007; Hair *et al.*, 2010)**. Using R programming language, a correlation matrix was created to investigate the relationships between various variables in a dataset, including maximum and minimum temperatures, precipitation, humidity, number of hours of sunshine, net radiation at the Earth's surface, aridity indices, and

ETo. The correlation matrix provides a useful tool for identifying any significant correlations between the variables and exploring the patterns of their relationships.

Climate Zones Delineation Using Cluster Analysis

Climate zones are geographical areas with similar climatic conditions, based on factors such as temperature, precipitation, and vegetation (**Köppen, 1936**). Climate zones can be defined at various scales, from regional to global, and they are often used in climate research, environmental monitoring, and urban planning (**Trewartha, 1961**). Climate zones have important implications for human activities and natural systems, as they impact factors such as agriculture, water availability, and biodiversity (**IPCC, 2014**). Understanding the characteristics and boundaries of climate zones is essential for developing effective policies and management strategies to address climate change and its impacts (**FAO, 2016**).

Cluster analysis is a statistical technique that involves grouping data points or objects according to their similarities, into clusters. or dissimilarity (**Everitt *et al.*, 2011**). The goal of cluster analysis is to find significant structures or patterns in the data, such as natural groupings or clusters of related observations (**Jain *et al.*, 1999**). Similar meteorological stations were grouped into a cluster using cluster analysis on the data collected from the stations to delineate climate zones then the climate zones were mapping using ArcMap.

RESULTS AND DISCUSSION

Temporal Changes of Annual Meteorological Elements in Egypt

Boxplot of annual meteorological elements averages in Egypt

Results in Table 1 and Fig. 2. show Boxplot of annual meteorological elements averages, aridity index (AI) and Emberger coefficient (Q2) in Egypt during the past 30 years (1991-2020) including maximum and minimum temperatures, precipitation, humidity, number of hours of sunshine, and wind speed. The data was displayed using Boxplot.

This trend of results is the same as that of **Fouad (2021)**. The yearly temperature increased by 0.87°C throughout this time, clearly showing a positive trend. Seasonally, the summer had the largest warming trends (an increase of 1.35), while the winter had the lowest warming trends (an increase of 0.46). Egypt's temperatures are clearly trending upward.

And trend of results is the same as that of **Gado (2020) and Elmenoufy *et al.* (2017) and Gado *et al.* (2022)**. There are regions of the nation that experience severe winds, particularly near the shore. The average yearly wind speed along the Red Sea coast is between 8.0 and 10.0 m/s, and along the Mediterranean coast it is between 6.0 and 6.5 m/s. In Upper Egypt is nearly zero mm, the yearly rainfall is almost nonexistent, while it varies from 200 mm in the northern coast.

On the other hand, **Sobh *et al.*(2022)** maintain a grip on the sun radiation, wind speed, relative humidity, and maximum and lowest temperatures The greatest of all empirical equations and AI models. Daily estimates of reference evapotranspiration for arid Egypt (ETo) allowed for the detection of a notable rise in the agriculture-dependent Nile Delta, ranging from 0.12 to 0.16 mm/node. And **Sahour *et al.* (2020)** cleared up the increase in in the aridity index in Egypt ranged from 20 to 96%.

Correlation Matrix for Egypt

Fig. 3. Shown Correlation matrix between studied meteorological elements, and the reference evapotranspiration (ETo) in millimeters per day in Egypt , which the correlation between (ETo) with radiation is 0.78 which indicates that they're strongly positively correlated, and the correlation

Table 1. Annual meteorological elements averages distributions in Egypt from (1991-2020)

Parameter	Minimum	Maximum	Median	Mean	Variance	Standard deviation
Air minimum temperature (°C)	2.5	26.3	15.1	14.9	31.4	5.6
Air maximum temperature (°C)	16.6	41.0	28.2	28.1	38.1	6.2
Air humidity (%)	7	98	61	57.9	296.5	17.2
Wind speed (km/day)	17	576	251	266.2	14892.7	122.1
Sunshine period (hr)	4.5	11.9	9.1	8.9	2.5	1.6
Radiation (MJ/m²/day)	9.7	27.9	21	19.8	27.3	5.2
Reference evapotranspiration (ETo). (mm/day)	1.4	12.5	4.9	5.032	5.1	2.3
Rainfall (mm)	0	61	0	4.34	84.6	9.2
Eff. rainfall (mm)	0	55	0	4.2	75.1	8.7
Aridity Index (AI)	0	2.3	0	0.2	0.14	0.4
Emberger coefficient (Q2)	0	615.4	0	29.8	5765.6	75.9

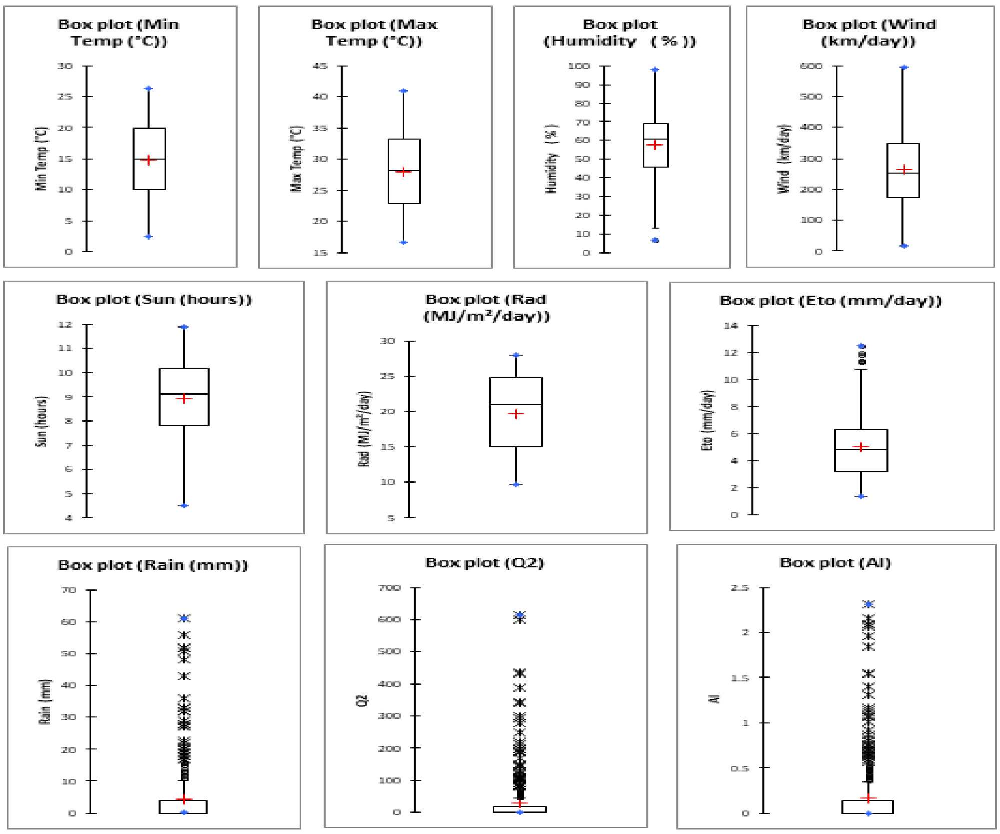


Fig.2. Boxplot of annual meteorological elements averages, aridity index (AI) and Emberger coefficient (Q^2) in Egypt from (1991-2020)

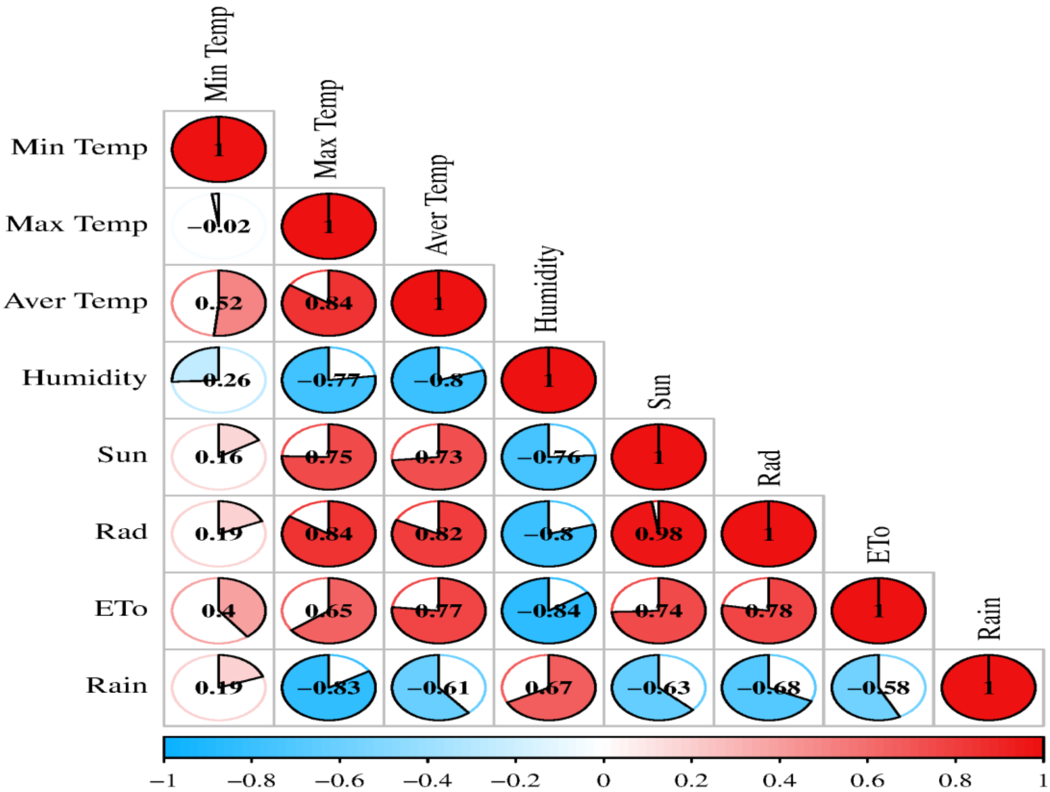


Fig. 3. Correlation matrix between studied meteorological elements, and ETo. in Egypt from (1991-2020)

between (ETo) with sunshine period is 0.74 which indicates that they're positively correlated, the correlation between (ETo) with maximum and aver and minimum air temperatures is 0.65, 0.77 and 0.4, respectively which indicates that they're positively correlated, the correlation between (ETo) with air humidity and rainfall is - 0.84 and - 0.58, respectively which indicates that they're weakly negatively correlated.

These results are consistent with many previous results Studies for Correlation of Egypt The values for ETo, sunshine duration, relative humidity, and wind speed were 0.72, 0.76, and 0.27, in that order. When 30-year meteorological data from 1985-2014 **(Noreldin *et al.*, 2016)** was used, the coefficient of correlation between ETo and temperature (maximum, minimum, mean, and dew point) was 0.91, 0.01, 0.86, and 0.60, respectively. Additionally, they reported that the values of the Coefficient of Correlation for wind speed, ETo, and solar radiation were 0.23 and 0.52, respectively. In contrast, there was a 0.60 coefficient of correlation between the dew point temperature and ETo. Using weather data over ten years (**Ouda and Noreldin, 2017; Ouda and Taha, 2019**). In the Valley and Delta of the Nile to compute ETo. Furthermore, they stated that the values of the coefficient of correlation between ETo and the mean temperature were 0.79 and 0.21, respectively, with the dew point temperature. Additionally, there was a 0.58 coefficient of correlation between ETo and solar radiation. The difference in wind speed and ETo was 0.37. While the results of these investigations were insightful, Egypt had never before performed temporal and spatial variability analysis on meteorological elements and ETo data.

Spatial Distribution Maps for Egypt

Results in Table 2 and Figs. 4 and 5 are shown IGS Spatial distribution maps are graphical representations that display the distribution of a particular variable across a geographic area. The variable can be any measurable quantity, such as temperature, rainfall, population density, or land use. Spatial distribution maps can be created using various techniques, involving statistical techniques, remote sensing, and geographic information systems (GIS). Were gathered in Egypt between 1991 and 2020. Minimum and Maximum air temperatures (°C), air Humidity (%), Wind speed (km/day), amount of Sunshine (hour), Radiation (MJ/m²/day), and rainfall (mm) were among the factors. The reference evapotranspiration in millimeters per day (ETo) and the Aridity Index (AI) are used. Each map displays the distribution's areas as well as the percentage.

Results showed that, more than 24.6% of Egypt area lies between the average annual air temperature distribution from (21.99-23.08)°C includes an area 246880.64894 km^2, more than 23.1% of Egypt area lies between the average annual air temperature from (20.74-21.98)°C includes an area 231549.540275 km^2, more than 20.7% of Egypt area lies between the average annual air temperature from (24.42-25.9)°C includes an area 207094.465547 km^2, more than 19.5% of Egypt area lies between the average annual air temperature from (23.09-24.41)°C includes an area 195142. 603571 km^2 and more than 12.1% of Egypt area lies between the average annual air temperature (18.7-20.37)°C includes an area 121332.74 km^2.

Also, the average annual of air humidity distribution, more than 41.14% of Egypt area lies between air humidity from (35.7-46.66)% includes an area 412250.3 km^2, more than 31.72% of Egypt area lies between air humidity from (46.67-56.09)% includes an area 317809.3 km^2, more than 16.51% of Egypt area lies between air humidity from (56.1-67.06)% includes an area 165458.5 km^2 and more than 10.63% of Egypt area lies between air humidity from (67.07-87.97)% includes an area 106464.1 km^2.

Also, the average annual of wind speed distribution, more than 48.6% of Egypt area lies between wind speed from (269.05-298.11) km/day includes an area 487020.6 km^2, more than 27% of Egypt area lies between wind speed from (223.37-269.04) km/day includes an area 270713.2 km^2, more than 16.23% of Egypt area lies between wind speed from (298.12-336.87) km/day includes an area 162595.12 km^2, more than 4.2 % of Egypt area lies between wind speed from (111.24-223.36) km/day includes an area 41884.9 km^2 and more than 3.97% of Egypt area lies between wind speed from (336.88 - 464.22) km/day includes an area 39786.2 km^2.

Also, the average annual of daily duration of maximum possible sunshine hours distribution, more than 48.63% of Egypt area lies between sunshine hours from (9.49-9.67) hr includes an area 487269.6 km^2, more than 23.75% of Egypt area lies between sunshine hours from (9.19-9.48) hr includes an area 238005.7 km^2, more than 13.1% of Egypt area lies between sunshine hours from (8.78-9.18) hr includes an area 131096.99 km^2, more than 12.61% of Egypt area lies between sunshine hours from (8.31-8.77) hr includes an area 126383.83 km^2 and more than 1.91% of Egypt area lies between sunshine hours from (7.48-8.3) hr includes an area 19243.92 km^2.

Also, the average annual of the solar radiation reaching soil surface distribution, more than 12.2% of Egypt area lies between solar radiation from (17.6-19.29) MJ/m²/day includes an area 122364.301182 km^2, more than 11.97% of Egypt area lies between solar radiation from (19.3-20) MJ/m²/day includes an area 119963.257482 km^2, more than 14.23% of Egypt area lies between solar radiation from (20.01-20.61) MJ/m²/day includes an area 142693.137847 km^2,

Table 2. Spatial distribution maps of climatic elements for Egypt from (1991-2020)

Parameter	Range	Area (km^2)	Range	Area (km^2)	Range	Area (km^2)	Range	Area (km^2)	Range	Area (km^2)
Air temperature (°C)	18.7-20.37	121332.74	20.74-21.98	231549.54	21.99 -23.08	246880.65	23.09-24.41	195142.6	24.42-25.9	207094.47
Air humidity (%)	22.94 -35.69	17.8	35.7-46.66	412250.3	46.67-56.09	317809.3	56.1-67.06	165458.5	67.07-87.97	106464.1
Wind speed (km/day)	111.24 -223.36	41884.87	223.37-269.04	270713.23	269.05-298.11	487020.59	298.12-336.87	162595.12	336.88-464.22	39786.18
Sunshine (Hr)	7.48 -8.3	19243.92	8.31-8.77	126383.83	8.78-9.18	131096.99	9.19-9.48	238005.68	9.49-9.67	487269.59
Solar radiation (MJ/m²/day)	17.6 -19.29	122364.30	19.3-20	119963.26	20.01-20.61	142693.14	20.62-21.11	277649.58	21.12-21.48	339329.72
rainfall (mm)	0.00124-1.052	619113.56	1.053-3.068	184827.01	3.069-5.45	91417.52	5.451-7.97	56077.71	7.971-11.68	50564.20
ETo (mm/day)	3.16 -4.89	152386.24	4.9-5.86	329921.19	5.87-6.84	292304.84	6.85-7.92	127611.03	7.93-8.89	99776.70
AI	0.000115-0.0394	50742.06	0.0395-0.117	56522.35	0.118-0.21	91061.81	0.211-0.311	182461.54	0.312-0.458	621212.25
Q2	0.1725 -7.684	65984.24	7.685-21.04	73311.87	21.05-34.67	89994.67	34.68-49.69	177641.66	49.7-71.11	595067.56

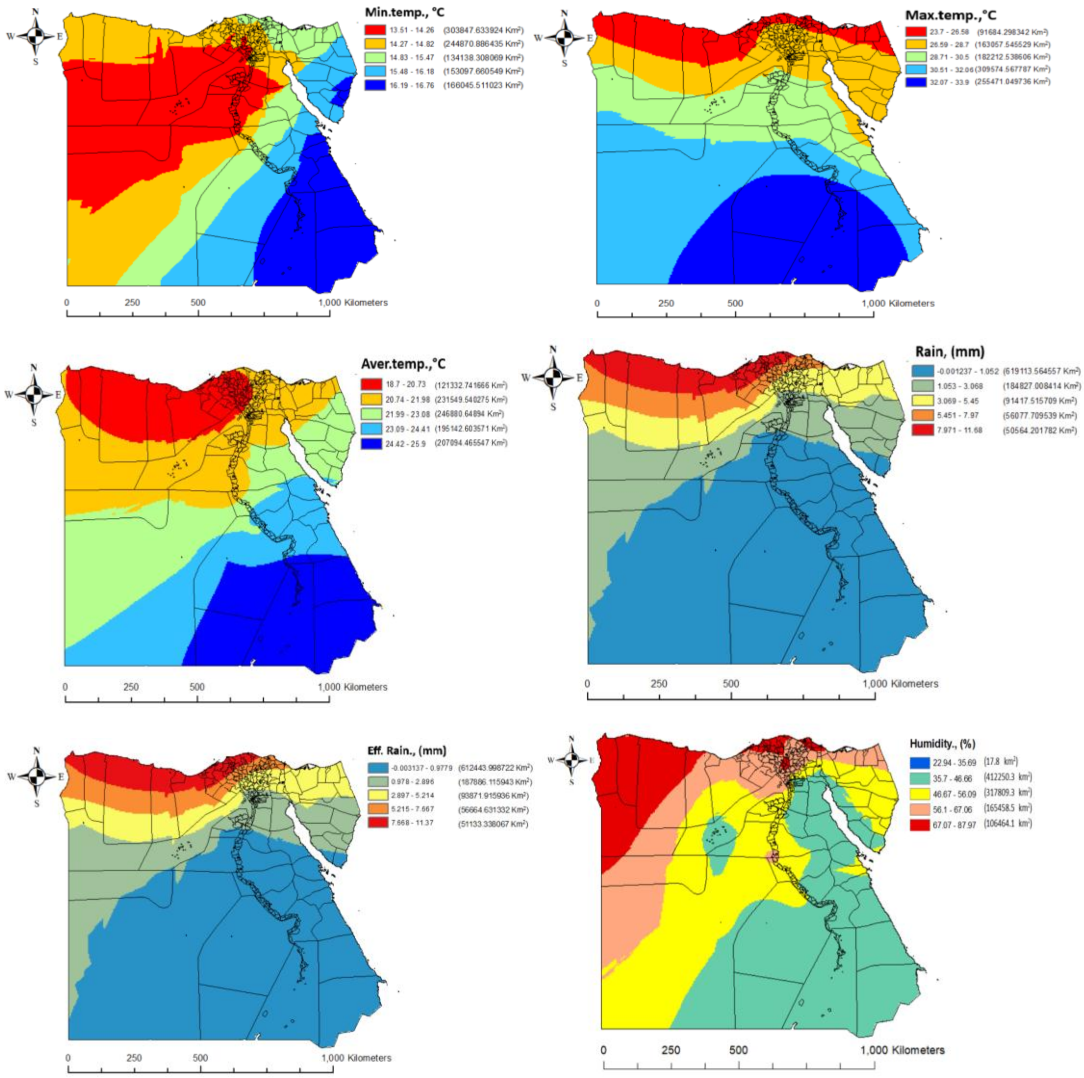


Fig. 4. Spatial distribution map of annual [minimum temperature of the air (°C), maximum temperature of the air (°C), average temperature of the air (°C), rainfall (mm), effective rainfall (mm), air humidity (%)] in Egypt from (1991-2020)

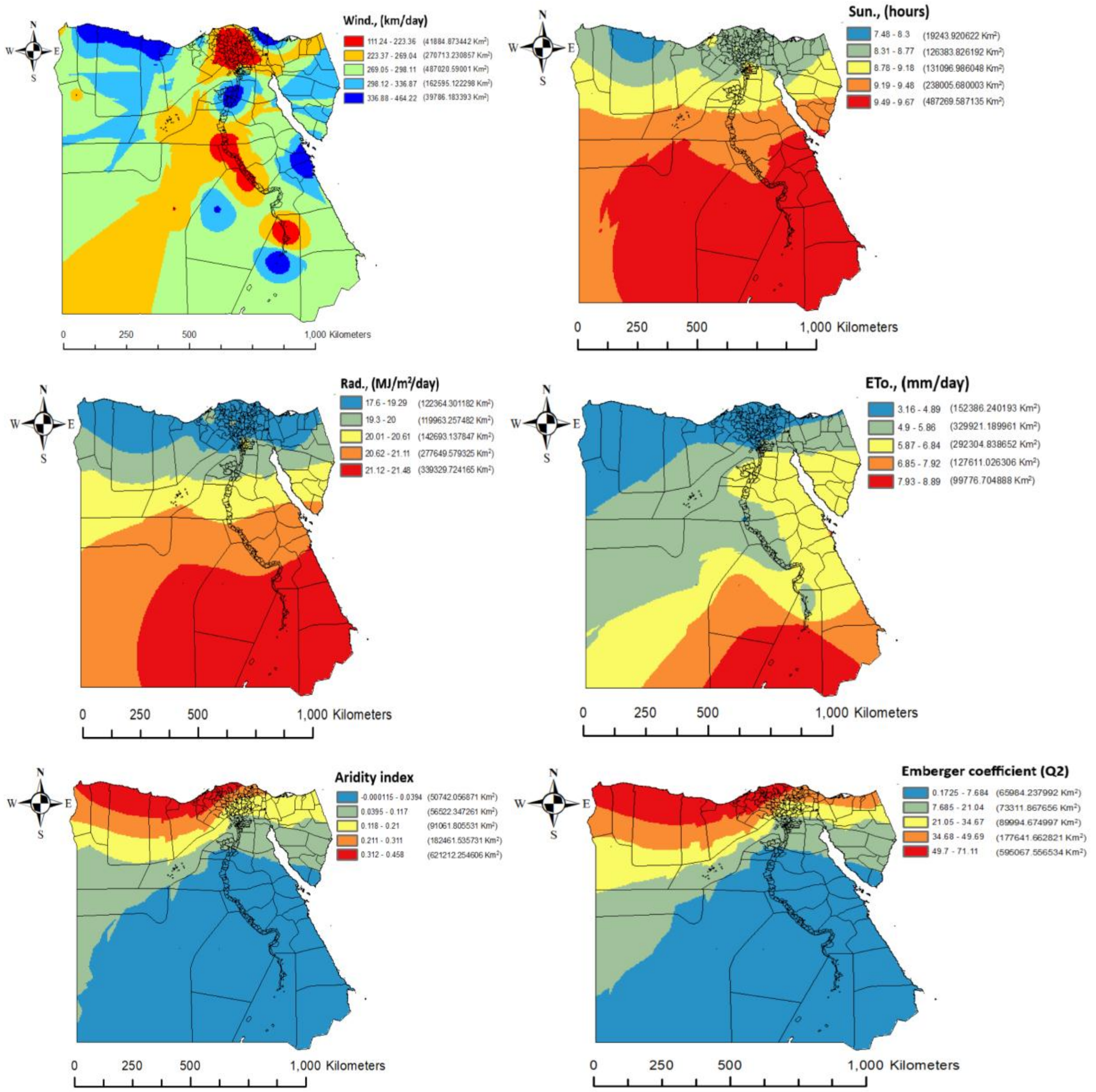


Fig. 5. Spatial distribution map of [The Wind speed (km/day), The Sunshine period (hr), The Radiation (MJ/m²/day), The Aridity Index (AI) and (ETo) the reference evapotranspiration in millimeters per day. Emberger's coefficient (Q2)] in Egypt from (1991-2020)

more than 27.7% of Egypt area lies between solar radiation from (20.62-21.11) MJ/m²/ day includes an area 277649.579325 km^2 and more than 33.9% of Egypt area lies between solar radiation from (21.12-21.48) MJ/m²/ day includes an area 339329.724165 km^2.

Also, the average annual of rainfall distribution, more than 61.79% of Egypt area lies between rainfall from (-0.001237 -1.052) mm includes an area 619113.6 km^2, more than 18.45% of Egypt area lies between rainfall from (1.053-3.068) mm includes an area 184827.01 km^2, more than 9.12% of Egypt area lies between rainfall from (3.069 - 5.45) mm includes an area 91417.52 km^2, more than 5.6% of Egypt area lies between rainfall from (5.451-7.97) mm includes an area 56077.71 km^2 and more than 5.05% of Egypt area lies between rainfall from (7.971-11.68) mm includes an area 50564.201782 km^2.

Also, the average annual of the reference evapotranspiration (ETo) distribution, more than 15.21% of Egypt area lies between (ETo) from (3.16-4.89) mm/day includes an area 152386.24 km^2, more than 32.93% of Egypt area lies between (ETo) from (4.9-5.86) mm/day includes an area 329921.19 km^2, more than 29.17% of Egypt area lies between (ETo) from (5.87-6.84) mm/day includes an area 292304.84 km^2, more than 21.74% of Egypt area lies between (ETo) from (6.85-7.92) mm/day includes an area 127611.03 km^2 and more than 9.96% of Egypt area lies between (ETo) from (7.93-8.89) mm/day includes an area 99776.7 km^2.

Also, the average annual of aridity index (AI) distribution, more than 5.06% of Egypt area lies between (AI) from (-0.000115 - 0.0394) includes an area 50742.06 km^2, more than 5.64% of Egypt area lies between (AI) from (0.0395-0.117) includes an area 56522.35 km^2, more than 9.09% of Egypt area lies between (AI) from (0.118-0.21) includes an area 91061.8 km^2, more than 18.21% of Egypt area lies between (AI) from (0.211-0.311) includes an area 182461.54 km^2 and more than 62% of Egypt area lies between (AI) from (0.312-0.458) includes an area 621212.25 km^2.

And the average annual of Emberger's coefficient (Q2) distribution, more than 6.59% of Egypt area lies between (Q2) from (0.1725-7.684) includes an area 65984.24 km^2, more than 7.32% of Egypt area lies between (Q2) from (7.685-21.04) includes an area 73311.87 km^2, more than 8.98% of Egypt area lies between (Q2) from (21.05-34.67) includes an area 89994.67 km^2, more than 17.73% of Egypt area lies between (Q2) from (34.68-49.69) includes an area 177641.66 km^2 and more than 59.39% of Egypt area lies between (Q2) from (49.7-71.11) includes an area 595067.56 km^2.

These results are consistent with many previous results Studies for ETo (**Farag *et al.*, 2014; IPCC, 2007; Diodato *et al.*, 2010; Irmak *et al.*, 2012; Nour El-Din, 2013**). The Nile Delta regions are represented by the average air temperature in the following regions: North Delta, Central Delta, West Delta, East Delta, and South Delta. Greatest average. According to the data, the average temperature ranged from 13.2 to 27.1°C. The mean air temperature readings in Middle and Upper Egypt followed the same prior trends. Under the current circumstances, Upper Egypt has the highest average air temperature. And Interpolation section ETo Egypt This trend of results is the same as that of **Farag *et al.* (2014), Capdevila *et al.* (2011) and Nour El-Din (2013)**: ranged between 3.0 to 10.0 mm/day in five delta zones; the North Delta reported the lowest ETo value, while the Upper Egypt region recorded the highest ETo values (8.1–10 mm). and (**El-Menoufy *et al.*, 2017**). With 8.0 to 10.0 m/s on average yearly wind speed along the Red Sea coast and roughly 6.0 to 6.5 m/s in the Mediterranean shore.

These findings align with a large number of earlier sun radiation study findings (**Trabea *et al.*, 2000**). June has the highest levels of solar radiation, while December sees the lowest levels. Global solar radiation on the horizontal surface is measured at 22.76 MJ/m^2/day in Aswan, 22.11 MJ/m^2/ day in Kharga, 19 MJ/m^2/day in Cairo, 18.93 MJ/day in Matro, and 19.75 MJ/m^2/ day in Al-Arish on an annual average basis. However, Aswan and Kharga (in southern Egypt) have greater global solar radiation levels than Cairo (in central Egypt), Matrouh, and Arish (in northern Egypt). This is because, in contrast to other areas, the weather in Aswan and Kharga is dry and pure. In comparison to the center and north, the south has more sunshine hours each day on average. Whereas the yearly mean values in Cairo are 9.43 hours, in Al-Matro and Al-Arish they are 9.32 hours, and in Sin Aswan and Kharga they are 10.79 and 10.41 hours, respectively. Maximum temperature February has lower values while July has higher monthly mean daily maximum temperatures. The mean annual maximum temperatures at

Aswan, Al-Kharga, Cairo, Matrou, and El-Arish are 33.44, 32.56, 27.23, 24.06, and 24.6°C, respectively, as one moves northward from the south. This is because the solar declination in the south of Egypt is less than that in the middle and northern regions, and the sun is normal in Aswan and Al-Kharga. Percentage of relative humidity. The moisture content is higher in Matrou and El-Arish because of their proximity to the Mediterranean Sea; nevertheless, it is lower in the south. The yearly average is 40.66% and 27.46% in Kharga and Aswan, 68.38% and 69.54% in Matrou and Arish, and 57.95% in Cairo. Pressure of water vapor (hpa) August saw the highest monthly mean daily values of vapor pressure in Matrou, Arish, and Cairo; October saw the highest values in Aswan; and July saw the highest values in Al-Kharga. In February, however, they had the lowest values among all the chosen stations. Al-Matrou, El-Arish, Cairo, Al-Kharga, and Aswan had yearly mean values of 16.22, 16.08, 14.98, 12.28, and 8.98, respectively.

These results are consistent with many previous results Studies for aridity index (**Ismael, 2016**). Egyptian Delta region, Precipitation variations demonstrated that the amount of precipitation received by this location varies with the season. There were periods of moderate drought in the Egyptian Delta, including the years 2002, 2010, and 2012, when precipitation fell to 25% less than average. And Dakhla Oasis: the indicator was the occurrence of a severe drought. It is situated in the southwest in an extremely arid region and has received the least amount of rain. And the Sinai region, which is in northwest Egypt and has a semi-arid climate, is a part of the Mediterranean region. The occurrence of a severe to extremely severe drought in some years was the drought index. Furthermore, the Fayoum Governorate is situated southwest of Cairo in a semi-arid area. There was a severe drought and less irregular precipitation in the Assiut and Aswan Governorates, which are in southern Egypt's semi-arid region and receive the least amount of rainfall. A severe drought served as the drought indication.

Climate Zones Delineation Using Cluster Analysis in Egypt

Figure 6 depicts Egypt's climatic zones together with the seasonal variations in mean temperature and precipitation for the most recent climatology, which runs from 1991 to 2020. The Köppen-Geiger climate classification system, which splits the climate into five major climatic groups and then subdivides them based on seasonal precipitation and temperature trends, is the source of classifications for climatic zones. (A) stands for tropical, (B) for dry, (C) for temperate, (D) for continental, and (E) for polar. A seasonal precipitation subgroup (second letter) is assigned to all climates, with the exception of those in group (E). The climate classification by dragging the mouse pointer over the legend. Following the situations is a narrative synopsis of Egypt's environment.

Fig. 7. Shows dendrogram of clustered stations for 32 stations' the figure shows the division of Egypt into four climatic regions as shown in Fig. 48. Digital map of climatic zones (CZ) in Egypt based on meteorological elements, aridity index (AI), Emberger coefficient (Q) and ETo, the 1st climatic zone (CZ 1) includes an area 173568.78 km^2, percentage 17.3% of the total area of Egypt. The 2nd climatic zone (CZ 2) includes an area 365581.14 km^2, percentage 36.5%. The 3rd climatic -zone (CZ 3) includes an area 284087.93 km^2 percentage 28.4% and the 4th climatic zone (CZ 4) includes an area 178762.15 km^2 percentage 17.8%.

These results are consistent with many previous results Studies for climatic regions of Egypt, (**Egyptian Environmental Affairs Agency, 2019; Gado *et al.*, 2022; Hereher, 2016**): According to its geomorphology, Egypt is divided into four regions: the eastern desert (22%), the Sinai Peninsula (6%), the Nile river and delta (4%), which are the most densely populated areas of the

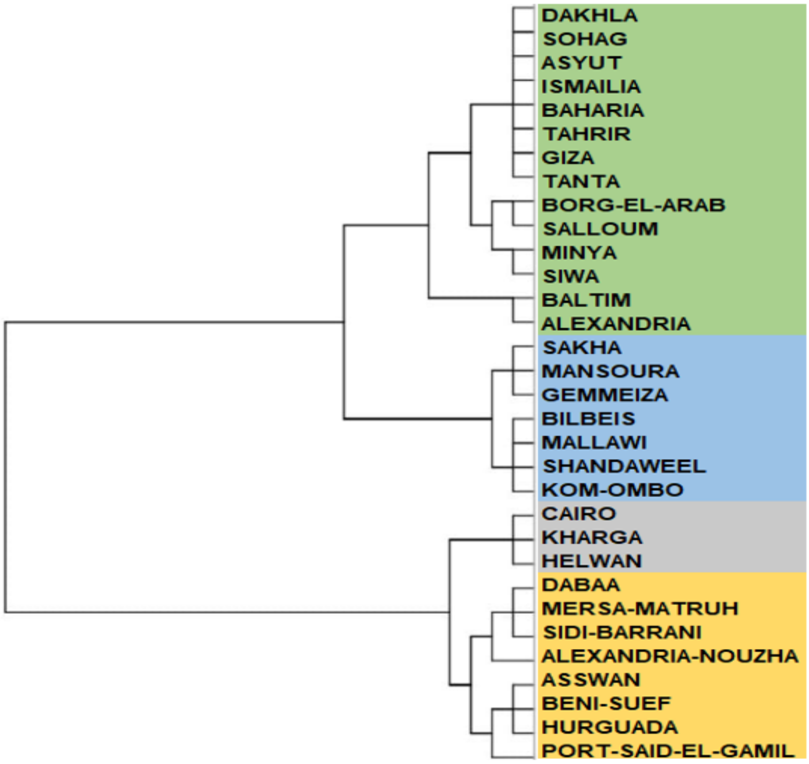
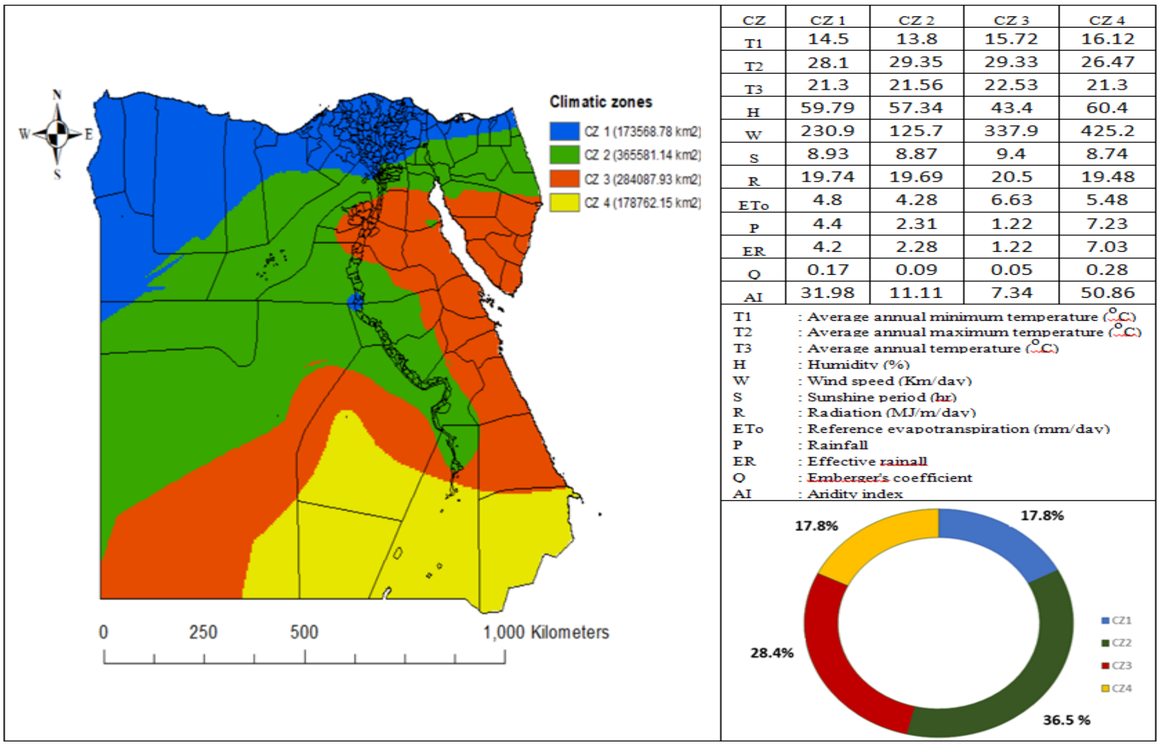


Fig. 6. Dendrogram of clustered stations by the Ward's method using Euclidean distance method. in Egypt from (1991-2020)



CZ	CZ 1	CZ 2	CZ 3	CZ 4
T1	14.5	13.8	15.72	16.12
T2	28.1	29.35	29.33	26.47
T3	21.3	21.56	22.53	21.3
H	59.79	57.34	43.4	60.4
W	230.9	125.7	337.9	425.2
S	8.93	8.87	9.4	8.74
R	19.74	19.69	20.5	19.48
ETo	4.8	4.28	6.63	5.48
P	4.4	2.31	1.22	7.23
ER	4.2	2.28	1.22	7.03
Q	0.17	0.09	0.05	0.28
AI	31.98	11.11	7.34	50.86

T1 : Average annual minimum temperature (°C)
T2 : Average annual maximum temperature (°C)
T3 : Average annual temperature (°C)
H : Humidity (%)
W : Wind speed (Km/day)
S : Sunshine period (hr)
R : Radiation (MJ/m/day)
ETo : Reference evapotranspiration (mm/day)
P : Rainfall
ER : Effective rainall
Q : Emberger's coefficient
AI : Aridity index

Fig. 7. Digital map of climatic zones based on meteorological elements, aridity index (AI), Emberger coefficient (Q) and ETo in Egypt from (1991-2020)

nation, and the western desert (68%). Since the Nile River supplies about 96% of Egypt's freshwater resources, it is the nation's primary supply of freshwater. Summer (June 21–22 September), Autumn (September 23–20 December), Winter (December 21–20 March), and Spring (March 21–20 June) are the four seasons of Egypt.

Also According to a survey of the literature, Egypt has four distinct climatic zones. This section contains a description of those classifications. Egypt was divided into three climatic zones according to the Köppen–Geiger method (**Geiger, 1954; Köppen, 1936**): dry semiarid with low latitude and altitude, dry arid with low latitude and altitude, and dry arid with mid-latitude and high altitude (**Peel *et al.*, 2007**). Additionally, (**Hamed *et al.*, 2021**) attempted to seven unique climatic zones were created *via* the merging of comparable climate zones.

Second, a small number of other research have attempted to categorize Egypt's climate. Egypt's climate was classified into six main regions by **Ibrahim *et al.* (1994)**, the Mediterranean, Nile Delta, Middle Egypt, Upper Egypt, Red Sea, and Sinai Mountains. High rainfall, thin strips along the Mediterranean and Red Sea are designated as the Mediterranean and Red Sea, respectively, while height determines the definition of Sinai Mountains. The remaining zones are identified by latitude-based temperature variation. Each zone is given a thorough explanation in **Nashwan *et al.* (2019a)**.

Eight climate zones were identified by another study (**HBRC, 2006; Sayed *et al.*, 2013**), North Coast, East Coast, Delta and Cairo, Northern Upper Egypt, Southern Upper Egypt, Southern Egypt, Altiplano, and Desert. The previous climatic zonation system has been upgraded with this classification. The Egyptian Code of Practice for Enhancing Energy Use in Buildings included a proposal for its engineering applications. The mean temperature, precipitation, humidity, wind speed, solar radiation, height, and topography all have a role in the classification.

It classified the remainder of the country as "Desert," focusing mainly on Egypt's coastal regions, the Nile Delta, and the Valley. The fact that the eastern and western deserts' north and south have different climates was overlooked in this classification. Furthermore, the east and west of the Nile valley were separated by climate without any valid reason.

The final section displays the agroclimatic categorization suggested **by Ouda and Norledin (2017)**, which is based on potential evapotranspiration data from 10 (2005–2014) and 20 (1995–2014) years, respectively. Reference evapotranspiration (ETo) for several study periods in various governorates served as the basis for both classes. Daily solar radiation, wind speed, dew point temperature, Tmax, Tmin, and Tmean, all obtained from meteorological stations, were used to calculate ETo. The primary shortcomings of these two classifications are as follows: (A) they focus only on the fertile land in the Nile Delta and Valley, using sparse meteorological records to represent a large area; (B) they use administrative boundaries as the boundaries of each climate zone; and (C) their limited land coverage. This significantly limited their utility, particularly with regard to upcoming development and rehabilitation of desert terrain. In order to reduce inaccuracy when calculating the geographical feature of climate variability, a number of studies have stressed the significance of selecting a representative sample of gauge records for a given area or catchment. (**Morrissey *et al.*, 1995; Sharp *et al.*, 1961; Zawadzki, 1973; Barbalho *et al.*, 2014; Hwang and Ham, 2013; Lee *et al.*, 2013**).

The Impacts of Climate Change on Water Resources in Egypt

The results showed that Egypt's climate is generally dry and hot. In coastal regions, the winter minimum temperature is 14°C (From the beginning of November until the end of April), and the summer high is 30°C (From the beginning of May until the end of October). In the interior desert regions, the temperature can vary significantly from 7°C at night to 43°C during the day, especially in the summer. The desert experiences milder temperature fluctuations in the winter, with nighttime lows of 0°C and daytime highs of 18°C. Egypt has relatively little annual rainfall and is a fairly arid nation. Most rain occurs near the coast, and the most falls on Alexandria, where there is an annual rainfall rate of roughly 200 (mm). Cairo receives slightly more than 10 mm of rain annually, with the amount decreasing further south. Little rain falls in the areas south of Cairo.

As for the reference statistic for average annual evaporation (ETo) (5.032 mm/day), The annual average of the Aridity Index (AI) statistic is 0.168 and According to World Bank data, the annual average rainfall in Egypt (19.6 mm), The change in water resources in Egypt showed that water evaporation is approximately 94 times greater than rainfall. The annual water loss rate due to evaporation is much higher than the yearly rate of rainfall in Egypt, and with increasing temperatures, evaporation will increase and water loss will become greater, Significant variations in hydrological events have been reflected in the effects of climate change on water balance, which has resulted in increased evaporation losses and decreased stream flow.

The results showed that the temporal distribution and the Spatial distribution maps for Egypt, Climatic changes has had a major impact on the water balance and has profound implications on hydrological systems, especially in forested watersheds. Climatic changes is expected to alter the hydrological processes in the studied watersheds. It is anticipated that more frequent occurrences of more extreme hydrological events, such as intense rainfall, variable stream flow volumes, and higher evaporation losses, will occur. The ecosystem in and around the watersheds, livelihoods, biodiversity in Egypt, and the viability of agricultural production could all suffer significantly as a result of this. Projected effects on water supplies ought to be a vital source of knowledge for mitigating the effects of climatic changes.

Egypt's only source of water is the Nile River because the bulk of the nation is made up of a vast desert region that is mainly uninhabited. This extensive range of water use raises concerns and vulnerabilities about trends in climate change that could affect the Nile's natural flow. These trends include decreased rainfall in the upper Nile Basins, decreased rainfall in the east Mediterranean coastal zone, and the impact of sea level rise on the quality of groundwater in coastal aquifers, As of **Egyptian Environmental Affairs Agency (2016)** and **Ani (2023)**, Over 95% of Egypt's yearly water needs are met by the Nile River, which is the country's only significant water source. The estimated yearly rainfall ranges from 0 (mm) in the desert to 200 (mm) in the northern delta region, with a mean of 18 (mm). Outside the River Nile valley, non-renewable subterranean fossil water supplies can be found, particularly in the isolated oases. Therefore, the management of the River Nile and agricultural development are intimately related, and both would be impacted by climatic changes. The annual flow of the Nile is expected to fluctuate between a 30% increase and a 70% decline, according to models. These two extremes might have major effects, such as heightened risks of flooding or droughts that would reduce food production, increase the amount of job losses, and cause conflicts over water.

Future Forecasts for Egypt's Water Resources

Urbanization and population growth exacerbate water resource challenges, Egypt is a historically water-stressed country that is facing increasing contemporary pressures, particularly after building the Nahda Dam in Ethiopia. Reviewing historical management approaches in Egypt as well as current conditions is very important to plan future water resource management strategies. Decreasing rainfall and rising temperature change runoff regimes and thus change water availability. In the rainy season, evaporationis low, rainfall is high, so the total amount of water is expected to increase. On the other hand, in the dry season, the possibility of evaporation in the basin is high, the amount of rainfall is small, so the total amount of water is small. Overall, the declining trend of water resources in Egypt suggests that water resourcesare inadequate to support the water development in the Nile basin country's. Therefore, strategies for managing the water resources of the Nile basin country's are needed to prevent future impacts of climate change on water availability. In order to develop water resource management strategies, predicted climate change scenarios and simulated impacts of climate change need to be incorporated into Nile basin country's adaptation decision analysis. Such strategies can provide optimal benefits in terms of maintaining the availability of water resources, mitigating and adapting to adverse climatic conditions, and thus maintaining or ensuring the development of water resources. Therefore, all efforts must be made to preserve every water droplet. As the agriculture sector consumes the largest amount of water resources, this sector must apply all agricultural practices that will rationalize water and raise the efficiency of irrigation at the field level; this will maximize the utilization, maintenance, and sustainability of every drop of water.

The expected effects of climate change on Nile River flows are still highly uncertain. While some studies suggest that rising temperatures and increased evaporation rates could reduce water availability by up to 70%, other studies suggest that increased rainfall in the Ethiopian highlands and Blue Nile Basin could increase flows by 15% to 25%. Since the headwaters of the Nile River are located outside of Egypt, the nation is extremely susceptible to shocks and changing weather conditions both inside and outside of its borders. Furthermore, most people reside near the Nile River, which increases their vulnerability to floods. The urban poor are especially vulnerable and exposed to these catastrophes. especially from the farming industry, which uses over 80% of the freshwater that is now accessible. The North African region, which is expected to house about a billion people by the middle of the century, will see an increase in population in addition to rising temperatures. (**USAID, 2018**). The Upper Blue Nile River Basin is expected to become warmer and wettier in the 2050s, which is one of the additional predicted climate consequences on the Nile. However, it seems unlikely that Egypt and Sudan's access to water will be materially impacted by the prospect of proposed future dam construction. (**Environmental Affairs Agency of Egypt, 2016**). Changes in evaporation and rainfall have an effect on groundwater recharge rates as well as surface water infiltration rates. Low water storage capacity makes the nation more dependent on erratic patterns of rainfall. Variations in evaporation and rainfall have a direct impact on variations in groundwater recharge and surface water infiltration. This could further reduce the dependability of unimproved surface water and groundwater sources during extended dry seasons or droughts. Falling water levels around wells or boreholes, especially in high-demand locations, and increased strain on pumping mechanisms that could result in failures if maintenance is neglected.

Furthermore, even in the presence of rising rainfall, temperature rises may lead to greater deficits in soil moisture.

Lastly the **World Bank (2007)** states that most Middle Eastern nations are unable to meet their present water needs. The combination of declining precipitation and possible increases in evaporation is causing severe drought in many Middle Eastern countries. Given that the Middle East region is among the water-poorest in the world, effective short- and long-term water management is crucial to supplying the region's expanding population with the water they need.

Conclusions

Egypt was divided into four weather regions based on data collected from meteorological stations across the regions of Egypt. The first, the second, the third and the fourth climate zones covered 17.8%, 36.5%, 28.4%, and 17.8 of the total area of Egypt, respectively. Each zone had different values for various climate indicators. In the first climatic zone, The mean yearly minimum temperature was 14.5°C, The mean yearly maximum temperature was 28.1°C, The mean yearly temperature was 21.3°C, the humidity was 59.79%, the wind speed was 230.9 Km/day, the sunshine period was 8.93 hours, the radiation was 19.74 MJ/m/ day, the reference evapotranspiration was 4.8 mm/day, the rainfall was 4.4 mm, the effective rainfall was 4.2 mm, the Q value was 0.17, and the aridity index was 31.98. The second climatic zone had different values, with an The mean yearly minimum temperature of 13.8°C, an The mean yearly maximum temperature of 29.35°C, an The mean yearly temperature of 21.56°C, a humidity of 57.34%, a wind speed of 125.7 Km/day, a sunshine period of 8.87 hours, a radiation of 19.69 MJ/m/day, a reference evapotranspiration of 4.28 mm/day, a rainfall of 2.32 mm, an effective rainfall of 2.28 mm, a Q value of 0.09, and an aridity index of 11.11. The third climatic zone had its own set of values, including an The mean yearly minimum temperature of 15.72°C, an The mean yearly maximum temperature of 29.33°C, an The mean yearly temperature of 22.53°C, a humidity of 43.4%, a wind speed of 337.9 Km/day, a sunshine period of 9.4 hours, a radiation of 20.5 MJ/m/day, a reference evapotranspiration of 6.63 mm/day, a rainfall of 1.22 mm, an effective rainfall of 1.22 mm, a Q value of 0.05, and an aridity index of 7.34. Lastly, the fourth climatic zone had an The mean yearly minimum temperature of 16.12°C, an The mean yearly maximum temperature of 26.47 °C, an The mean yearly temperature of 21.3°C, a humidity of 60.4%, a wind speed of 425.2 Km/day, a sunshine period of 8.74 hours, a radiation of 19.48 MJ/m/day, a reference evapotranspiration of 5.48 mm/day, a rainfall of 7.23 mm, an effective rainfall of 7.03 mm, a Q value of 0.28, and an aridity index of 50.86.

As for the reference statistic for average annual evaporation (ETo) (5.032 mm/day), The annual average of the Aridity Index (AI) statistic is 0.168 and According to World Bank data, the annual average rainfall in Egypt (19.6 mm), The change in water resources in Egypt showed that water evaporation is approximately 94 times greater than rainfall. The rate at which water is lost annually due to evaporation is much higher than the yearly rate of rainfall in Egypt, and with increasing temperatures, evaporation will increase and water loss will become greater.

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الملخص العربي

تأثير التغيرات المناخية على الموارد المائية السطحية: دراسة حالة مصر

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محور هذه الدراسة هو مصر، تقع مصر في شمال شرق أفريقيا، بين خطي عرض 22 درجة و32 درجة وخطي طول 24 درجة 37 درجة، وتبلغ مساحتها الإجمالية حوالي 1002000 كيلومتر مربع. نهدف في هذه الدراسة إلى تحليل تأثير تغير المناخ على موارد المياه السطحية في مصر. ولتحقيق هذا الهدف، قمنا بتقييم توزيع درجات الحرارة وهطول الأمطار في مناطق مختلفة من مصر، وتم دراسة التأثيرات الحالية لتغير المناخ على موارد المياه السطحية، والتنبؤ بالآثار المستقبلية لتغير المناخ على موارد المياه السطحية. تم جمع البيانات المتعلقة بالمتغيرات المناخية الشهرية لمصر من 32 محطة أرصاد جوية، للفترة من 1991 إلى 2020. وشملت المتغيرات درجة حرارة الهواء (الحد الأدنى والحد الأقصى)، وسرعة الرياح، ورطوبة الهواء، وفترة سطوع الشمس، والإشعاع، وهطول الأمطار. وكانت مصادر هذه البيانات هي محطات الارصاد وكذلك قواعد بيانات CLIMWAT. تم إنشاء الرسوم البيانية لتصور التغييرات مع مرور الوقت في محطات الطقس. تم تقديم البيانات باستخدام Boxplot. تم حساب مؤشر الجفاف لتصنيف المناخات المختلفة وتقييم الموارد المائية المتاحة في مصر. للمناطق الجغرافية ذات الظروف الجوية المماثلة. تم حساب مقياس الجفاف كوسيلة لوصف نقص المياه في كل منطقة. أما بالنسبة للإحصائية المرجعية لمتوسط التبخر السنوي (ETo) (5.032) (ملم/يوم)، فإن المتوسط السنوي لإحصائية مؤشر الجفاف (AI) هو 0,168 ووفقًا لبيانات البنك الدولي، فإن متوسط هطول الأمطار السنوي في مصر (19.6 ملم). وأظهر التغير في الموارد المائية في مصر أن تبخر المياه يزيد بنحو 94 مرة عن سقوط الأمطار. المعدل السنوي لفقد المياه بسبب التبخر أكبر بكثير من المعدل السنوي لهطول الأمطار في مصر، ومع ارتفاع درجات الحرارة سيزيد التبخر ويصبح فقدان المياه أكبر.

الكلمات الإسترشادية: التغيرات المناخية، هطول الأمطار، التبخر المرجعي، موارد المياه، مصر.

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