Assessment of Meteorological Drought in North-Western Egypt using Rainfall Deciles, Standardized Precipitation Index and Reconnaissance Drought Index

Attia M. El-Tantawi[1*], Anming Bao[2], Ying Liu[2] and Gamil Gamal[1]

1. Faculty of African Postgraduate Studies, Cairo University, EGYPT

2. State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, CHINA

*a_eltantawi@yahoo.com

Abstract

The aim of the study is to assess the meteorological drought in North-Western Egypt using three drought indices: Rainfall Deciles (RD), Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI). These indices of drought were investigated at three meteorological stations Barrani, Matrouh and Dabaa. The results showed that the drought and the wet years were almost equal, but the study area faced extreme drought underlining a growing magnitude of climate change in more recent years. The drought years were intense 11%, severe 10%, moderate 9% and mild 10% over the study period. The mild drought years were 63%, 73%, 68%, the moderate were 17%, 18%, 18%, the severe years were 12%, 6%, 0% and 8%, 3%, 14% were extreme drought at Barrani, Matrouh and Dabaa respectively. SPI and RDI standardized values were correlated at 99% showing approximately similar results at all stations and the affected years by the drought were mostly after 1980.

The severe drought years were from 1990-2000 at Barrani, from 1981 to 1987 at Dabaa and from 2008 to 2016 at Matrouh. The future trend of SPI over 2021-2050 was analyzed using ensemble mean of monthly rainfall simulated by different CORDEX regional climate models. Barrani and Matrouh experienced negative trends of SPI under RCP4.5 and RCP8.5 while Dabaa experienced positive trend of SPI12 under RCP8.5. The importance of future projection of drought intensity is to support stakeholders and decision makers to reduce the negative implications on vital sectors such as agriculture.

Keywords: Meteorological Drought, Rainfall Deciles, Reconnaissance Drought Index, Standardized Precipitation Index, CORDEX models, Egypt.

Introduction

Drought is the major natural hazard in semi-arid and sub-moist lands, it affects most of human activities in both developing and developed countries. Thornthwaite[26] described drought as a situation in which the quantity of water required for evapotranspiration surpasses the quantity accessible in the soil. When precipitation is more than water need, the climate is moist, while when the deficiency is large in comparison with the need, the climate is dry. American Meteorological Society defined drought as continued and irregular moisture insufficiency.[20] Drought is a temporary imbalance in water availability related to precipitation lower than the averages water demands and it occurs in most climatic regions with various frequencies, severity and duration.[19]

The seriousness of the drought is expressed by four classes: mild, moderate, severe and extreme.[20] If rainfall is fewer than 75% of the long-standing average, the mild drought can occur, while severe drought occurs if the amount of rainfall is less than 25% of the average. Drought is an inevitable part of normal climate change and should be considered as a recurring, albeit unpredictable, environmental feature which must be included in the forthcoming development.[27] The impacts of drought can be observed across diverse fields as meteorological drought (deficit of rainfall), hydrological drought (decrease of ordinary stream flows or groundwater levels) and agricultural drought which occurs when the moisture level in soils is insufficient to maintain average crop yields.[11,23]

Many indices of drought were developed and used by meteorologists and climatologists around the world,[31] such as Palmer drought severity index[20], rainfall deciles created by Gibbs and Maher,[10] surface water supply index, rainfall anomalies, Foley drought index, effective precipitation, standardized precipitation index developed by McKee et al,[17] Palmer's Z-index and precipitation percent normal.[28]

Numerous articles about drought in many regions worldwide using different methods were reviewed. In India, Shah et al[22,23] used SPI and Rainfall Deciles to assess drought in Khedbrahma and estimated the Reconnaissance Drought Index for Bhavnagar area. In Mauritania, Yacoub and Tayfuri[33] evaluated and assessed the meteorological drought by different methods. Adnan et al analyzed drought over Pakistan through the period (1951-2010) while in Egypt, El Afandi et al[6] estimated the drought index over the North coastline of Egypt using SPI and Precipitation Deviation Percentage (PDP). Mossad et al[19] handled the seasonal drought dynamics in El-Beheira Governorate.

***Author for Correspondence**

Dai[5] studied the characteristics and long-term trends of Palmer drought severity index globally during 1900-2008; he found that the global percentage of dry areas has increased about 1.74% (of global land area) per period from 1950 to 2008. Zarch et al[34] investigated drought in Iran using Reconnaissance Drought Index. In Slovenia, Ceglar et al[3] analyzed the meteorological drought using standardized precipitation index (SPI) and Palmer drought severity index (PDSI). Hence, this study aims to assess and analyze meteorological drought intensity in north-western Egypt (Matrouh Governorate) using different drought indices: Rainfall Deciles (RD), Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) based on rainfall and temperature data.

Study area

Matrouh Governorate occupies North Western Egypt bordered by Libya in the west, the Mediterranean Sea in the north, Alexandria Governorate in the east and the western desert in the south. The total area of Matrouh is 166,563 km^2 and mostly is desert. Only 1% of its area is inhabited in the coastal strip along the Mediterranean where the rainfall occurs from October to April. In the south of the coastal areas, there is the Qattara depressions -133 m below the sea level and Siwa Oasis (Figure 1). Climate is arid (BWh) in the south and semi-arid (BSh) in the coastal parts.[9] In general, it is hot-dry in summer and moderate-low rain in winter. Temperature varies widely southward inland desert areas, especially in summer season.

Mean annual temperature is 20 °C ranging between 19.1 °C at Barrani in the north and 22.2 °C at Siwa in the south and from 14 °C in winter as an average minimum to 30 °C in summer as an average maximum. Rainfall starts from autumn (Sep.-Nov.) which receives about 20% and ends in spring (Mar.-May) which receives about 15% of the total annual rainfall. Most of rainfall 60-70% occurs in winter season (Dec.-Feb.), but the rainfall in autumn is very important to start a successful growing season of crops.

The annual total rainfall ranges from 135 mm at Matrouh to 106 mm at El-Sallom in the coastal area caused by the depressions coming from the west on the Mediterranean Sea while it decreases gradually southward to reach 8 mm only in Siwa Oasis. The wettest month differs annually between January and December. Due to the wet and dry months after Walter and Leith (R=2t) where R is annual rainfall in mm and t is the temperature in °C, all the months except January and December are dry months as evapotranspiration is higher than rainfall (Figure 2).

Data and Methods

Continuing precipitation and temperature dataset for three meteorological stations (Table 1) over the period of the study were acquired as follows: Matrouh and Dabaa stations for long-time period from 1950 to 2016 and from 1956 to 2010 respectively from Climatic Research Unit, University of East Anglia, CRU TS v3.25 / v4.01,[12] which is widely used in climate research (http://www.cru.uea.ac.uk/about-cru). Climate data of Barrani station from 1950 to 2006 were obtained from the Egyptian Meteorological Authority quality controlled and homogenized datasets by El-Kenawy et al.[7]

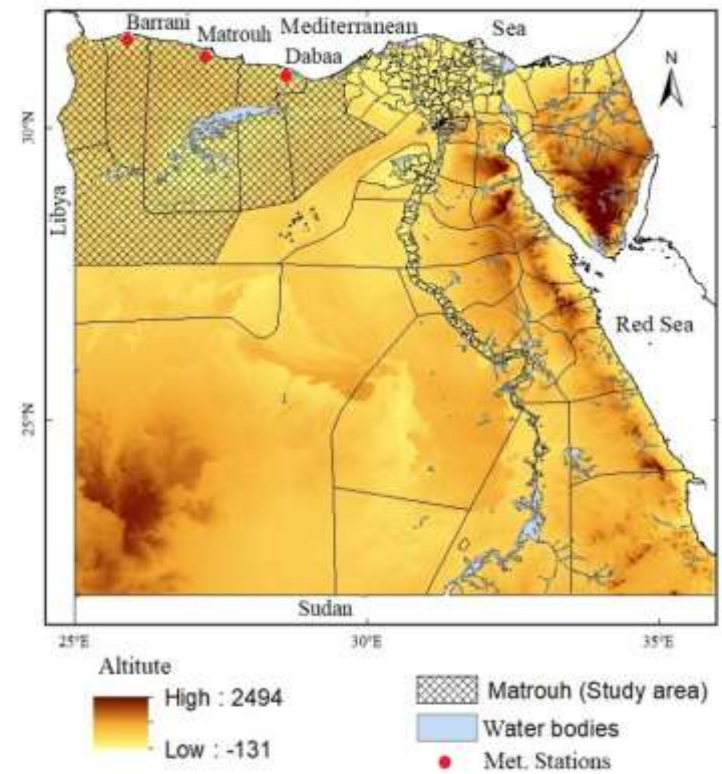

Figure 1: Location of Matrouh Governorate and the stations on DEM map

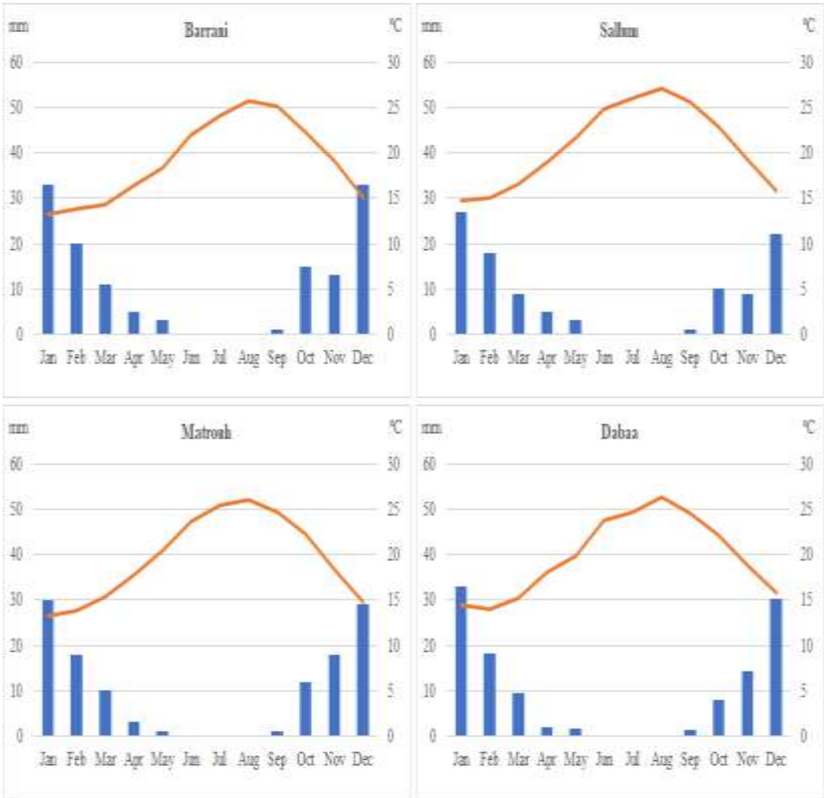

Figure 2: Climatic chart, wet and dry months at some stations in Matrouh governorate

Table 1
Meteorological stations under study with their location, elevation, average annual rainfall and temperature

Station	Lat.	Long.	Alt. m	Temp	Rainfall	Period
Matrouh	31.33	27.21	26	19.6	135	1950-2016
Barrani	31.37	25.55	25	19.1	134	1950-2006
Dabaa	30.56	28.28	17	19.8	125	1956-2010

Climate data was tested by the Standard Normal Homogeneity Test (SNHT) and the missing values were estimated from nearby stations using linear regression in accordance with El-Kenawy et al.[7] To assess the meteorological drought intensity, we used data series of monthly rainfall and temperature of length 66 years (1950 – 2016) at Matrouh, 55 years at Dabaa and 56 years at Barrani for the calculation of three drought indices: RD for annual total rainfall to classify the dry and wet years; SPI for four different time scales (3, 6, 9 and 12 months – SPI3, SPI6, SPI9 and SPI12) and RDI for the annual total rainfall and for the growing season (October – March). These different indices were calculated using DrinC software.[29] DrinC calculates the SPI including other drought indices.[1,2,24,25]

Rainfall Deciles[10] are easy to be used and the impacts of temperature and other variables are not considered during the assessment of drought. The historical data is divided into ten equal deciles and the drought can be classified based on the decile order: the lowest decile 1 means intense drought, 2 means severe drought, 3 means moderate drought and 4 means mild drought, from 5 to 6 is normal and more than 6 the deciles are classified as wet years.

As for SPI[17] based on precipitation only. SPI is basically the discrepancy of rainfall from the mean for a specific time divided by the standard deviation where the mean and standard deviation are established from previous data. SPI can be computed as follow:

$$SPI = (P-P^*) / \sigma p$$

where P is precipitation values, p* is mean of the time series and σp is the standard deviation.

SPI can be calculated for smaller period SPIs, for example, 1-, 2- or 3-month SPIs, it can give quick alert of drought and improve assess drought severity and it allows for comparisons between different locations in different climates but it is based only on precipitation.[31] Drought intensities can be defined from the SPI values: from 0 to -0.99 is a mild drought, from -1.0 to -1.49 is moderate drought, from -1.5 to -1.99 is a severe drought and ≥ -2 is an extreme drought.[17]

Reconnaissance Drought Index (RDI) created by Tsakiris and colleagues[30] contains a simplified water balance equation considering precipitation and potential evapotranspiration.[32] For the assessment of drought severity, apart from rainfall, the presence of evapotranspiration provides a further accurate estimation of water shortage.[30] Drought severity can be categorized based on standard values of RDI in mild, moderate, severe and extreme, with corresponding boundary values of (-0.5 to -1.0), (-1.0 to -1.5), (-1.5 to -2.0) and (< -2.0), respectively.

Thornthwaite method was applied to get PET which is needed to calculate RDI as eT=1.6(10T/I)a where eT is unadjusted PET in centimeters for a 30-day month; T is mean monthly air temperature in degrees centigrade; I is heat index and a is cubic function of I.[4] Thornthwaite heat index (I) is calculated as I=(T/5) 1.514. According to Tsakiris and Vangelis[30], the initial value (α0) of RDI is calculated for the i-th year in a time basis of j (months) as follows:

$$\alpha_0 = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} ET_{ij}}$$

$$RDI_n^{(i)} = \frac{\alpha_0^{(i)}}{\overline{\alpha_0}} - 1$$

$$RDI_{st}(k) = \frac{y_k - \overline{y}_k}{\hat{\sigma}_k}$$

where Pj and PETj are the precipitation and potential evapotranspiration of the j-th month of the hydrological year. Normalized values are calculated from the division of the initial value of each year with the mean of the time series then minus one. For RDI standardized values are computed as the initial value for each year minus the mean of all values and then divided by the standard deviation of the time series.

Results and Discussion

Rainfall is badly distributed over time and space in the target region and happens irregularly. In addition, high inter-annual and intra-annual variability of rainfall leads to drought. Although a prolonged spell of drought can come to a sudden end through a long spell of especially heavy rainfall as in case of depression or cyclone,[23] the drought assessment is important as it causes wide-spread failure of food producing systems.[14] Monthly temperature and rainfall dataset were analyzed at three stations Barrani, Matrouh and Dabaa in Matrouh Governorate over the last 6 decades to assess the meteorological drought and to investigate its intensity.

Rainfall Deciles (RD): Rainfall Deciles (RD) depends on the rainfall parameter only to assess the meteorological drought. In the study area, RD has been calculated at the stations: Barrani in the west, Matrouh in the middle and Dabaa in the east. Figure 3 displays the RD, the classification of drought at the stations and the percentage of each drought class for the study period. It can be observed that the drought and the wet years were mostly equal over the study period and the normal years were 19-20% against 39-40% for both the wet and drought years respectively.

The drought was classified at Barrani station in the west to 10% for the intense drought, 9% for the severe drought, 11% for the moderate drought and 9% for the mild drought. As for the wet years, they were 11%, 12%, 7% and 11% for the intense, severe, moderate and mild wet respectively. The intense drought affected Barrani in the years 1952-54, 1962-64, 1980-82, 1990-93 and from 1995 to 1997, the rainfall was very much below normal. The severe drought prevailed in individual years 1967-68, 1970-71, 1976-77 and from 2003-2005. Intense and severe wet years were more before 1990.

For Matrouh station, the degree of drought was intense 11%, severe 9%, moderate 11% and mild 9%, the drought prevailed from 1950-84 and from 2008 to 2016 while the wet years prevailed from 1985-98. In the east of the governorate at Dabaa station, RD indicated that the drought scattered over the study period, intense and severe drought were 21% from the period of the study and the affected years were in 1980-82, 1983-87 and 2008-2010 (Table 2).

Standardized Precipitation Index (SPI): The simplicity and flexibility of SPI are the reasons for its wide application. It was intended to measure the rainfall shortfall for various timescales.[17] Different scales of SPI are useful to investigate the different type of droughts, for example, 1- or 3-month SPI for meteorological drought, from 1-month to 6-month SPI for agricultural drought and from 6-month up to 24-month SPI or more for hydrological drought investigations and applications.[31] Figure 4 shows the evolution of the annual scale at 12-month, SPI3, SPI6 and SPI9-months scales. Drought frequency decreases inversely and period rises linearly with a time scale.[17]

SPI on three-month time scale showed a negative trend for autumn rainfall (Sep.-Nov.) which is the highly essential factor for people to start farming in the study region, especially November rainfall which has an essential effect on agriculture because it represents a limiting factor to the crop yields of barley and wheat.[18]

It was also apparent from the trend analyses of the SPI3 months' time scale at all stations (Figure 4) that the trends of the values were negative and moving towards more drought, 0.14 mm/decade, 0.10 mm/decade and 0.02 mm/decade at Barrani, Matrouh and Dabaa respectively and this is in accordance with different studies overall the world and corresponding with the current climate change.

Houghton et al[13] in IPCC third assessment report of climate change mentioned that the frequency and intensity of droughts have been increased in recent decades in some regions such as parts of middle Asia and Africa north of Sahara. In many regions, these changes are dominated by inter-annual and inter-decadal climate variabilities. The trends of drought in the study area were not significant based on trend/noise ratio because of the high inter-annual variability of rainfall.

According to Mckee et al[17], drought happens once the SPI first falls below zero and ends with the positive value of SPI following a value of -1.0 or less. Drought intensity of the study area was investigated based on the values of the SPI categories from 0 to more than -2 showing that the most affected years by drought were mild between 0 and -.99 while severe and extreme droughts were for few years at all stations (Table 3).

Table 2
Rainfall deciles in Matrouh Governorate (affected years)

Stations	Range of rainfall deciles and Condition (much below normal 1-2)	Range of rainfall deciles and condition (below normal 3-4)
Barrani	1952-54, 1958-59, 1962-64, 1980-81, 1990-93, 1995-96, 1998-99	1950-51, 1967-70, 1970-71, 1973-74, 1976-77, 1981-82, 1996-97, 2000-01, 2003-05
Matrouh	1952-55, 1959-63, 1967-68, 1970-71, 1976-77, 1978-79, 1983-84, 2008-10	1950-51, 1966-67, 1972-73, 1975-76, 1980-82, 1990-91, 1993-94, 2004-05, 2010-11, 2013-16
Dabaa	1958-59, 1969-70, 1972-73, 1980-81, 1983-87, 2008-10	1960–63, 1967–68, 1976–77, 1981–82, 1984–85, 1990–91, 1993–94, 2000–01, 2006–07

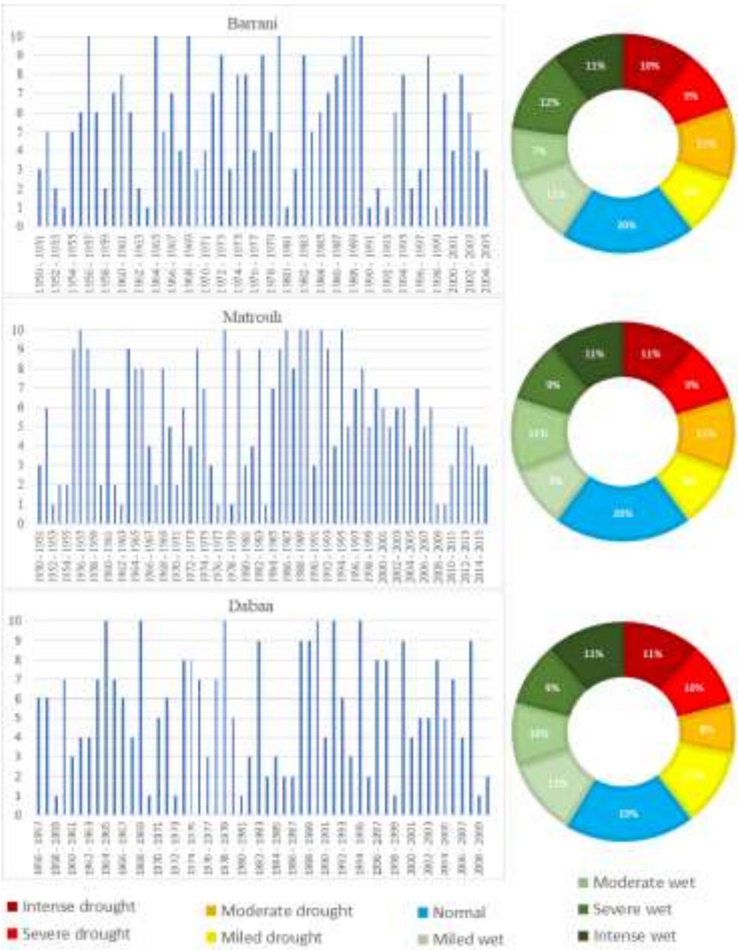

Figure 3: Rainfall Deciles and frequency of drought at the stations under study

Table 3
Drought intensity in the study area based on SPI

Station	Barrani	Matrouh	Dabaa
Study period	54	66	54
Affected years	24	34	22
Extreme	2	1	3
Severe	3	2	0
Moderate	4	6	4
Mild	15	25	15

Because of rainfall seasonality in North Western Egypt, the frequency of drought was almost similar between the scales, the annual scale was totally correlated with SPI9-months which receive the rainfall. The difference was very clear between SPI3-months scale (October-December) and the annual scale and the correlation was 0.72, 0.77 and 0.61 at Barrani, Matrouh and Dabaa respectively. While the correlation between the annual SPI and SPI6-months scales was high at 0.95 at Barrani and 0.98 at Matrouh, it was moderate 0.61 at Dabaa (Table 4).

Less frequency of the drought on longer time scale was observed. The correlation between annual and SPI9 was 1 as the annual total amount of rainfall occurs during autumn, winter and spring, while summer is completely arid in the study area. Drought incident occurs when the SPI is always negative and achieves an intensity of -1.0 or less. The event ends when the SPI becomes positive.[3,31]

Figure 4 revealed that the 1991-2000 was the worst decade of rainfall at Barrani in the west, years 1990-91 and 1992-93 experienced extreme drought, 1999-2000 was severe drought, while 1995-96 and 1998-99 were affected by moderate drought. At Dabaa in the east: 1990-91 and 1995-96 experienced extreme drought. For Matrouh station most of the affected years were after 2000. It can also be noticed from figure 4 and table 4 that the annual SPI scale is like SPI9-months scale as there was no rainfall during the summer season from June to August.

We can conclude that 63%, 73%, 68% of the study period were mild, 17%, 18%, 18% were moderate, 12%, 6%, 0% were severe and 8%, 3%, 14% were extreme drought at Barrani, Matrouh and Dabaa respectively. The high drought stress in the target area may be a part of the drying of the large Mediterranean Basin which is associated to the strengthening of the anticyclonic circulation and poleward move of the Atlantic cyclone paths.[15]

Reconnaissance Drought Index (RDI): Reconnaissance Drought Index differs from RD and SPI, as it is calculated based on both rainfall and temperature data. The use of potential evapotranspiration based on temperature gives a better representation of the full water balance of the region than SPI provides and RDI will give a better indication of the drought severity.[32] Large historical datasets are required in order to compute RDI for studying drought which involves complex inter-relationship between temperature and rainfall.

Table 4
Correlation between SPI3, SPI6, SPI9 and SPI12 for the study area

Barrani	SPI3	SPI6	SPI9	SPI12
SPI3	1.00	0.72	0.72	0.72
SPI6		1.00	0.95	0.95
SPI9			1.00	1.00
SPI12				1.00
Matrouh	SPI3	SPI6	SPI9	SPI12
SPI3	1.00	0.78	0.77	0.77
SPI6		1.00	1.00	0.98
SPI9			1.00	0.99
SPI12				1.00
Dabaa	SPI3	SPI6	SPI9	SPI12
SPI3	1.00	0.62	0.62	0.61
SPI6		1.00	0.91	0.61
SPI9			1.00	0.91
SPI12				1.00

Potential evapotranspiration is needed to calculate RDI, we used Thornthwaite method to get seasonal and annual PET at stations under study resulting high values comparing to the amount of rainfall and the maximum PET was noticed in summer season (JJA) ranged from 28 to 148 mm, 27 to 151 mm and 27 to155 mm in February and in August at Barrani, Matrouh and Dabaa respectively (Figure 5).

The difference between PET and total rainfall was shown in the table 5 explaining the deficit of water and how much can drought affect this marginal land especially with recent temperature change as the water balance controlled by rainfall and potential evapotranspiration.

A reduction of rainfall amount and increasing temperature due to recent climate change affect the severity of drought in the study area, the trends of the initial values were negative at all stations (Figure 6), the study area experienced drought in recent decades. The trends were not linear because of high variability of rainfall which is necessary to define a wet year and dry year.[16] The severity of drought was categorized based on standardizing values of RDI-6 and 12-months scales according to Tsakiris and Vangelis[30] as mild, moderate, severe and extreme with corresponding boundary values of (-0.5 to -1.0), (-1.0 to -1.5), (-1.5 to -2.0) and (< -2.0) respectively (Table 6).

The standardized RDI values were similar in nature to SPI values and can be compared to it directly explained by the similar climate characteristics. The correlation between standardized RDI and SPI on time scale 6-months (growing season) at the stations under study showing high correlation 0.99 between them at all stations is shown in figure 7.

Finally, it can be concluded that the indices of drought reflected a high similarity between the RDI and SPI on all scales. Both indices indicated that after 1950 Barrani experienced worst drought conditions in the 1990s, the decade 1980s was the worst at Dabaa, while at Matrouh the drought was very clear after 2000. RD method results were almost the same with both SPI and RDI methods but having different index values.

Projection of Drought 2050: The future trend of the Standardized Precipitation Index (SPI) was calculated using simulated monthly rainfall data for the stations under study, all simulations have 50 km (0.44°) resolution over the CORDEX-Africa domain for the future period (2021-2050) with two different representative concentration pathways RCP4.5 and RCP8.5. The regional climate models CORDEX and their driven GCM models were presented in table 7 and 8 respectively and can be downloaded using the Earth System Grid Federation (ESGF) nodes such as http://esgf-node.dkrz.de/

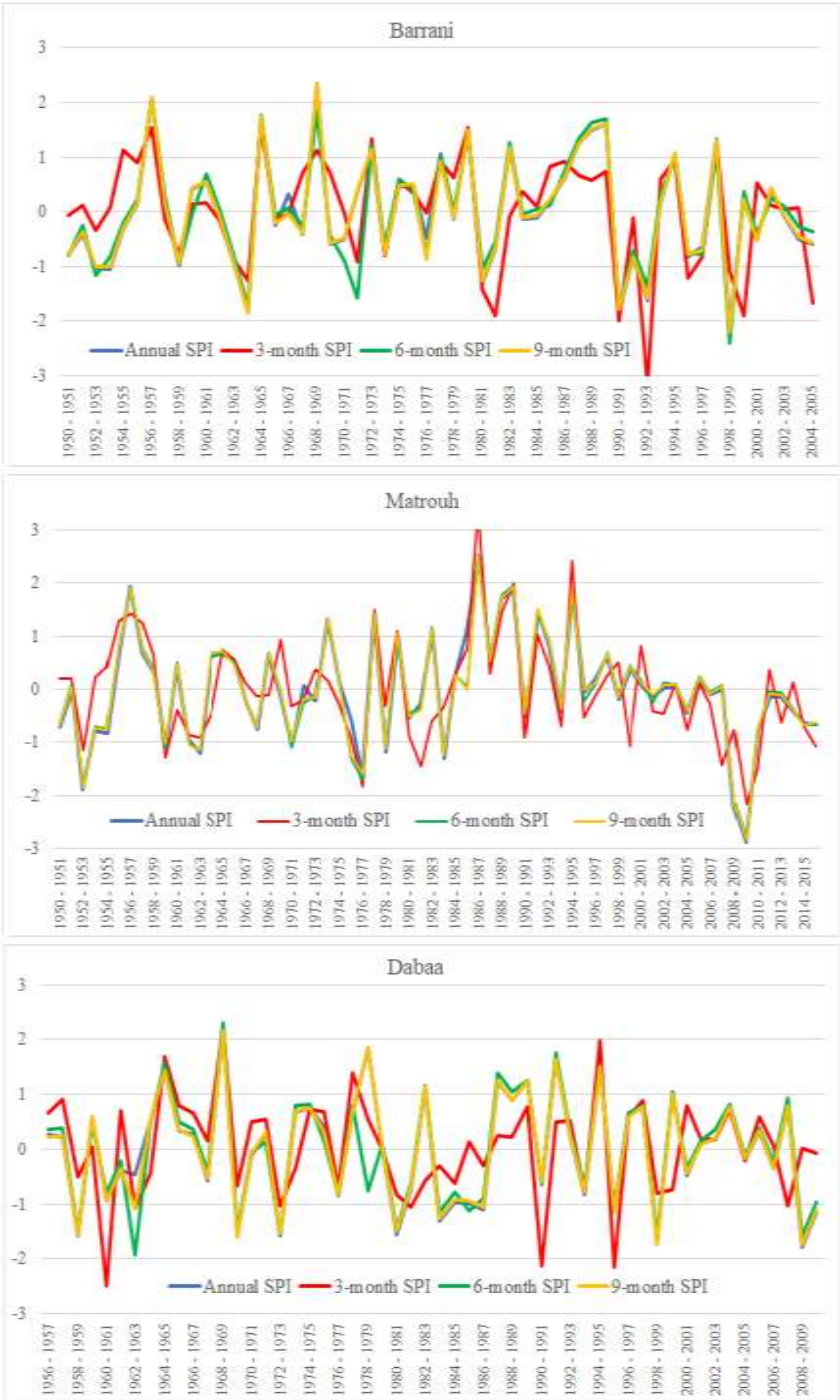

Figure 4: Drought classification based on Standardized Precipitation Index (SPI)

Figure 5: Potential Evapotranspiration in Matrouh governorate

Table 5
PET and total rainfall scales of 3-, 6-, 9- and 12-months

PET	PET3	PET6	PET9	PET12	Rain3	Rain6	Rain9	Rain12
Barrani	194	348	530	937	61	125	133	134
Matrouh	183	282	561	983	68	129	132	135
Dabaa	184	285	563	986	57	118	123	125

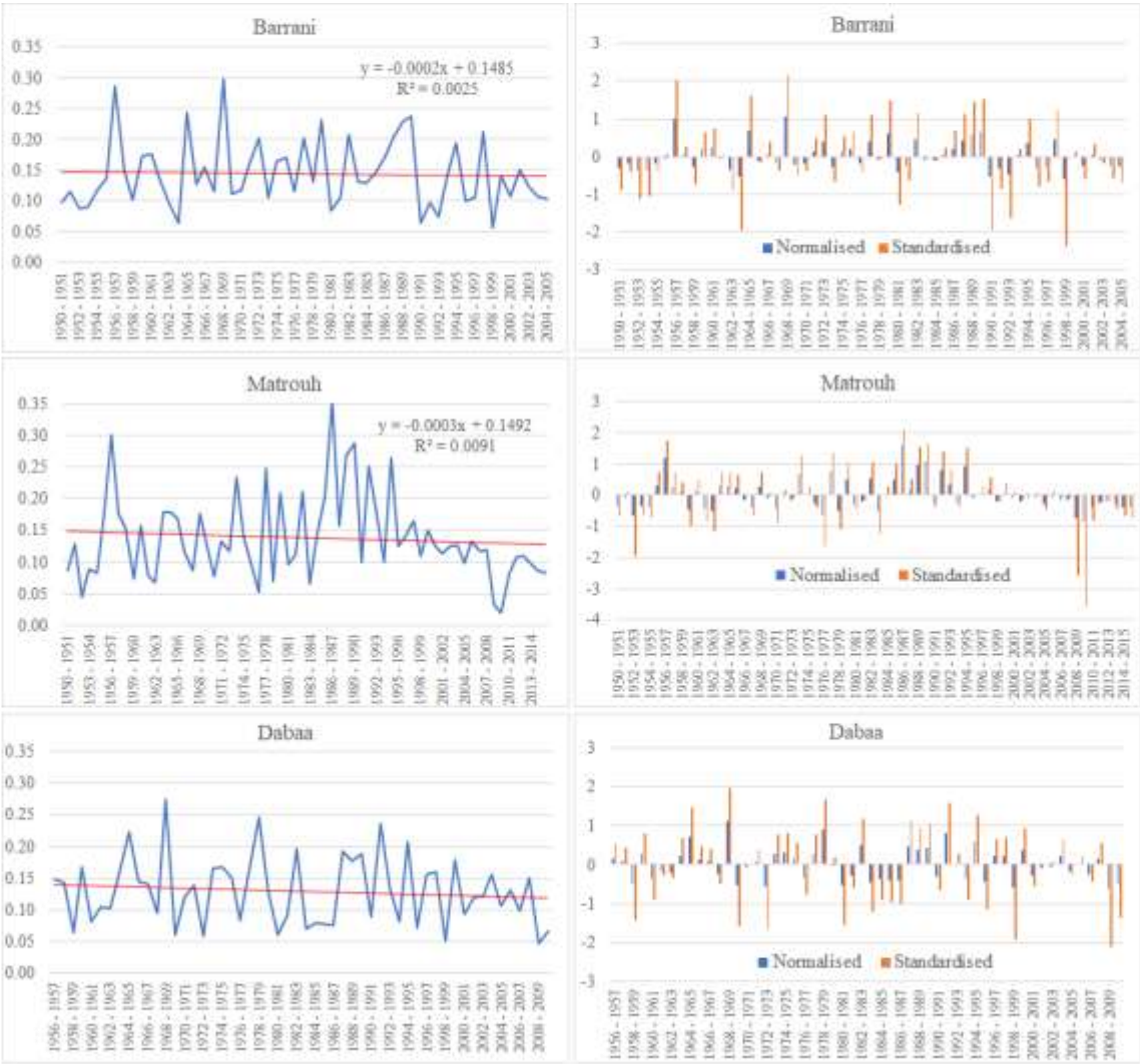

Figure 6: Trends of Initial values and Drought category based on Reconnaissance Drought Index (RDI), Normalized and Standardized values

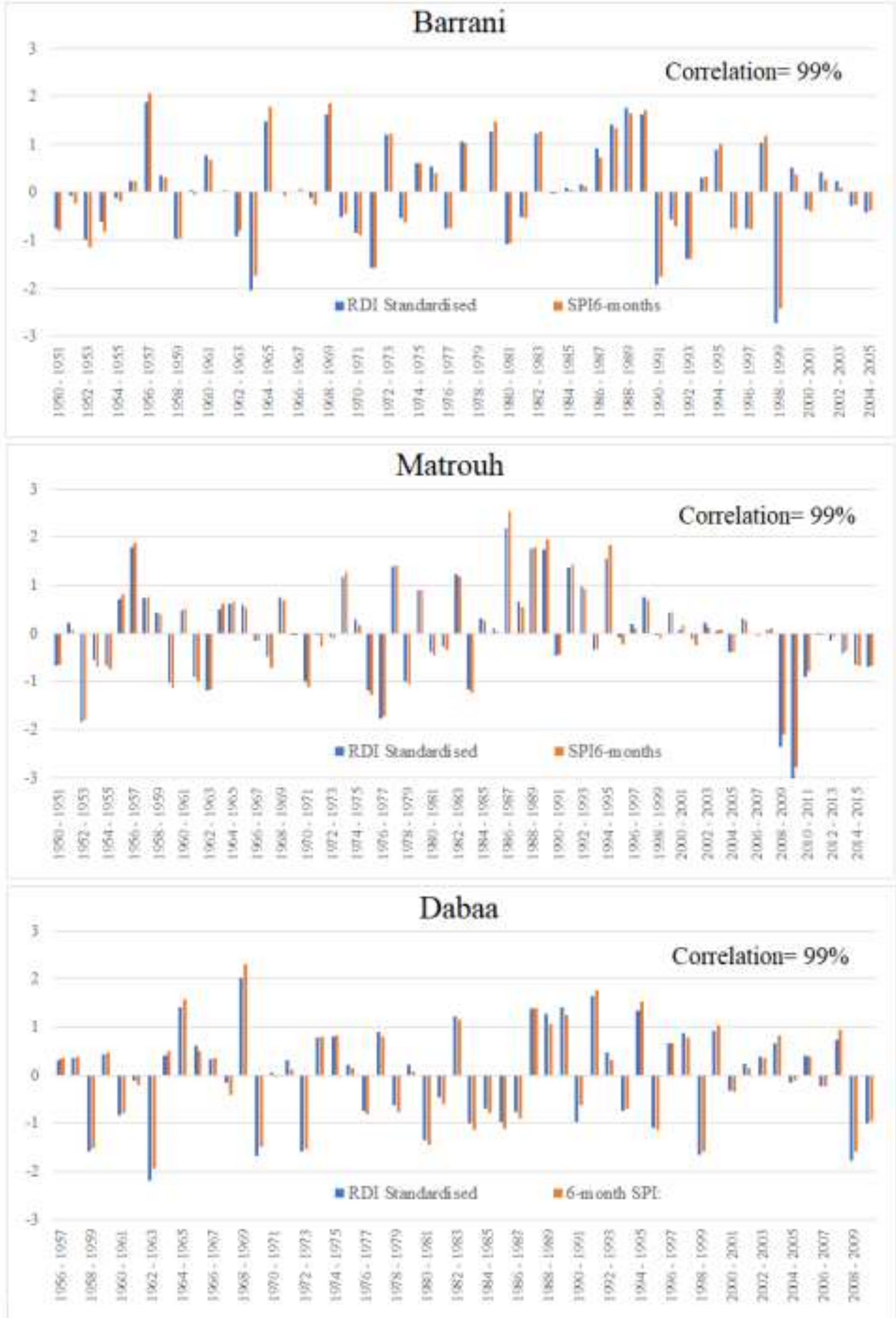

Figure 7: SPI and RDI for the rainfall season (October-March)

Table 6
Drought severity in the research area based on RDI-6 and 12-months scales

Station	Barrani Ann.	Barrani (Oct.-Mar)	Matrouh Ann.	Matrouh (Oct.-Mar)	Dabaa ann.	Dabaa (Oct.-Mar)
Study period	55	55	66	66	54	54
Affected years	21	19	17	18	19	18
Extreme	1	2	2	2	1	1
Severe	3	2	2	2	4	5
Moderate	3	2	3	5	5	4
Mild	12	12	10	9	9	8

RCP4.5 characterizes scenarios including annual GHG emissions topping in nearby 2040 and diminishing through the later 21st period, while RCP8.5 is a scenario demonstrating yearly GHG emissions remaining to rise throughout the 21st century, subsequent in 4.5 and 8.5 $W m^{-2}$ of forcing by the end of the 21^{st} century, respectively (van Vuuren et al., 2011).

Standardized precipitation index depends mainly on precipitation, so the possible changes on rainfall were assessed for the near future period (2021-2050) over Egypt as a whole. Comparing with the average of rainfall in the period of 1981–2010 under the RCP4.5 and RCP8.5 scenarios, rainfall of the target area in the north western Egypt will decrease over the period 2021-2050 (Figure 8) where this reduction will influence the strength and length of the drought.

Table 7
List of CORDEX regional climate models

RCM	Institution
CCLM	Climate Limited-area Modelling Community (CLMcom)
HIRHAM	Danish Meteorological Institute
RACMO	Royal Netherlands Meteorological Institute
RCA4	Swedish Meteorological and Hydrological Institute, Rossby Centre
REMO	Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology

Table 8
List of driven General Circulation Models (GCM)

Institution full name	Driven GCM
Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique	CNRM-CM5
Canadian Centre for Climate Modelling and Analysis	CanESM2
Commonwealth Scientific and Industrial Research Organization	CSIRO-MK3-6-0
Irish Centre for High-End Computing, European Consortium	ICHEC-EC-EARTH
National Oceanic and Atmospheric Administration	GFDL-ESM2M
Institut Pierre Simon Laplace	IPSL-CM5A-MR
Atmospheric and Ocean Research Institute (AORI)	MIROC5
Max Planck Institute for Meteorology (MPI)	MPI-ESM-LR
EarthClim	NORESM1-M

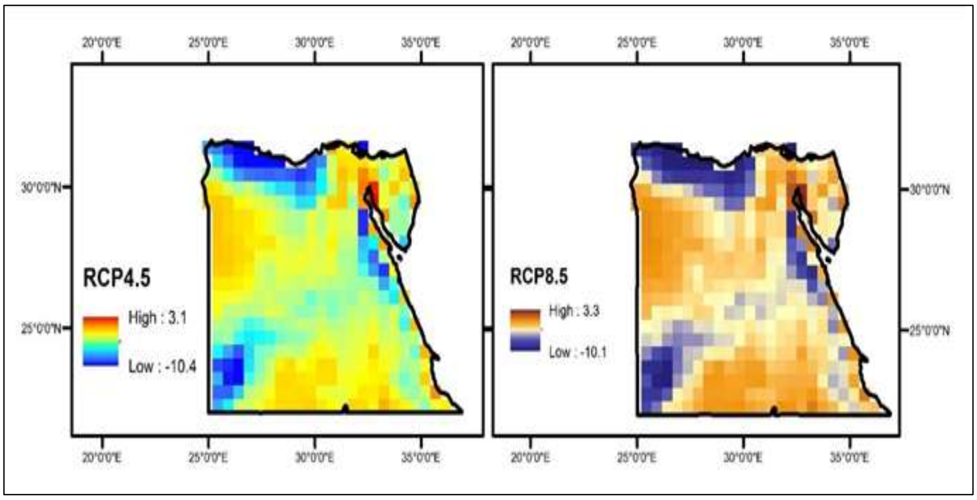

Figure 8: The historical rainfall (1981-2010) comparing with (2021-2050)

The temporal variation of the SPI different timescales (SPI3, SPI6, SPI9 and SPI12) at stations Barrani, Matrouh and Dabaa over (2021-2050) under RCP4.5 and RCP8.5 scenarios was illustrated in figure 9. The future SPI was calculated using the simulated monthly rainfall of the ensemble of RCMs-GCMs models. The distributions showed decreasing trends at the three stations over the study period under RCP4.5 and RCP8.5 scenarios and also, a slightly increasing trend in Dabaa station under RCP8.5 scenario. The peak values in Barrani station decreased from 0.72 to nearly −1.41, also decreasing from 1.25 (year 2045) to -3.33 (year 2047) indicating that the majority of the station might experience a transfer of wet to dry (extreme drought conditions) during the projection period. The linear trends of SPI12 were -0.024/year and -0.026/year for RCP4.5 and RCP8.5 respectively.

Similar SPI characteristics at Matrouh and Dabaa were observed, although the concentrated distribution positions and ranges varied. For Matrouh station, the linear trend of SPI12 was -0.002/year and -0.034/year for RCP4.5 and RCP8.5 respectively. In general, Matrouh station would be expected to experience more severe drought conditions: one extreme year under RCP4.5 and two severe drought years under RCP8.5. Matrouh has the large number of mild drought years about 14 compared with other stations while it has 7 years of moderate drought events. At Dabaa station, the linear trend of SPI12 was -0.002/year and 0.009/year for RCP4.5 and RCP8.5 respectively. Almost all drought cases were characterized mild (13 years for RCP4.5 and 11 years for RCP8.5).

The number of affected years and drought severity are represented at table 9. Matrouh station has the highest record of the affected years by 19 years corresponding to RCP8.5 (the worst scenario) while Dabaa station recorded 18 years under RCP4.5 scenario (the good one). Based on results of the future projection of SPI, Matrouh station will have one extreme year and 2 severe dry years. Dabaa station recorded that more than 50 % of the future period will influence the drought disaster. As shown in table 9, the exacerbation of drought under the sharper-emissions scenario means the requirement of reproduction management of CO_2 emissions.

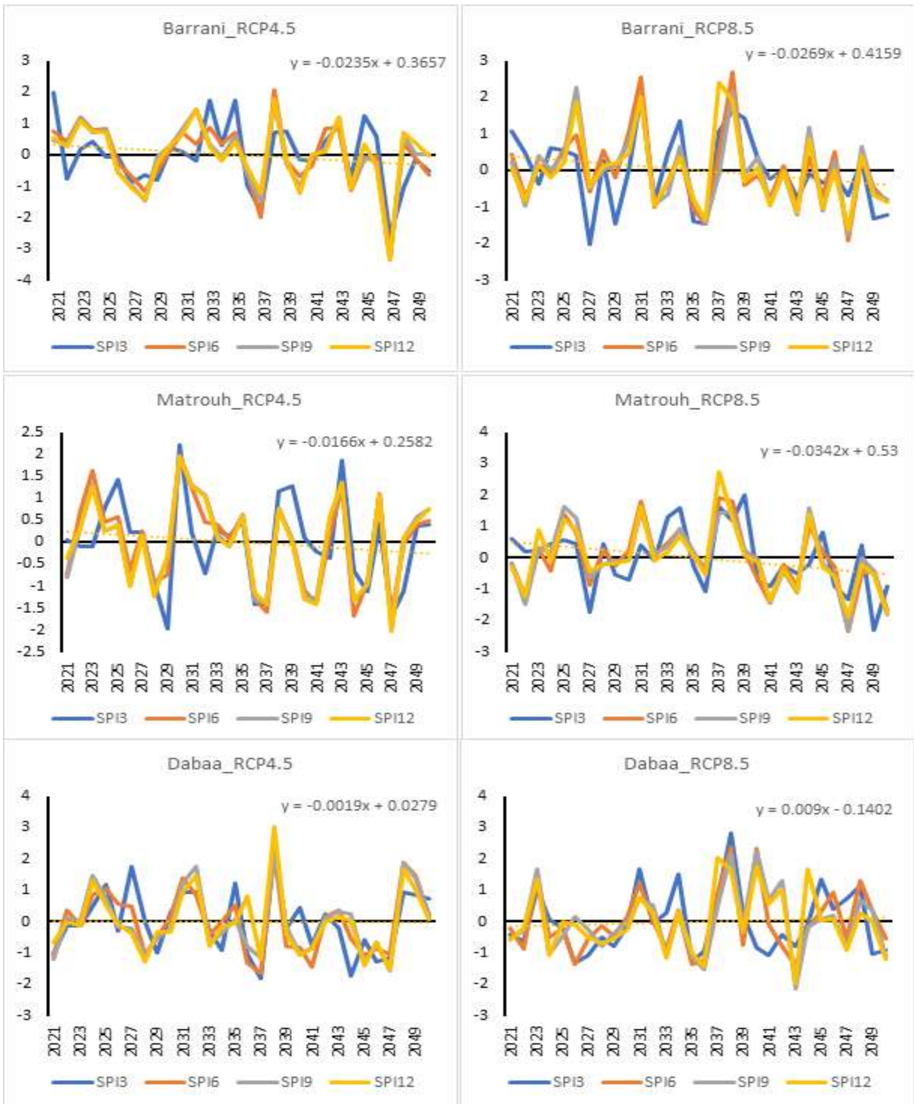

Figure 9: The temporal variation of the SPI different timescales under RCP4.5 and RCP8.5 scenarios

Table 9
Drought severity on the target stations based on SPI 12

Station	Barrani		Matrouh		Dabaa	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.6	RCP8.5
Study period	30	30	30	30	30	30
Affected years	11	15	13	19	18	16
Extreme	1	-	1	-	-	-
Severe	-	1	-	2	1	1
Moderate	5	3	7	3	4	4
Mild	5	11	5	14	13	11

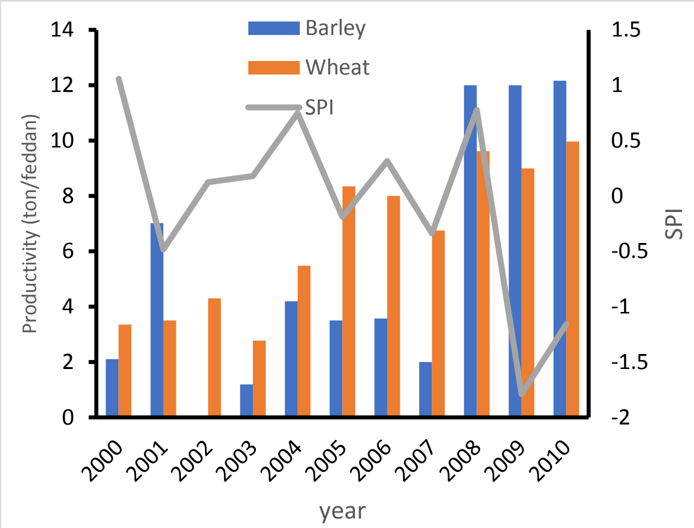

Figure 10: The productivity of Wheat and Barley (ton/feddan) against SPI index

Potential impacts of drought over the region: Although the amount of rainfall in Matrouh Governorate is small not more than 150 mm/year, its deficiency or drought has clear effects on livelihood. Drought affects the social, environmental and economic standard of living.[23] Drought leads to water scarcity, reduction of yields and livestock. It causes habitat loss, fragmentation and the establishment of exotic varieties and accelerates desertification process. For example, the yields of principal crops cultivated in the area of study are wheat, barley, citrus fruits, dates and olives determined by the characteristic of rain throughout the growing season from October to May every year. As shown in figure 10, the inter-annual variability of the productivity of two main crops barley and wheat is related to SPI values. A high productivity (ton/feddan) for barley and wheat as in year 2008 is related to the positive value of SPI.

So, it may be necessary for some areas to switch from one crop to another and to change weed control strategies.[21] The various drought factors produced specific chemical properties in fragile soils causing soil erosion. Drought can also affect water supplies and can still cause to increased food prices. Concerning the vegetation, drought causes a decrease in the vegetation ability to resist some pests and diseases.[8] The temporal and spatial drought indicate that an urgent and appropriate contingency planning is needed in the context of drought management strategies.[19]

Conclusion

Drought is an environmental threat originating from the lack of rainfall. It is not possible to avoid drought but we can manage the problem and minimize its negative effects. One of the management tools of the drought is to assess its intensity to understand the problem and to put an action plan to mitigate it. As drought is a slow disaster, the observing and early warning methods are crucial to minimize its effects. Rainfall and temperature data have been utilized to derive three drought indices, RD, SPI and RDI at three stations in Matrouh Governorate, north-western Egypt to assess the meteorological drought over the last six decades. Referred data was gathered from CRU and EME and SPI and RDI were calculated on different time scales which enable us to better master the drought and to determine the onset and end of drought more accurately.

It has been observed that different temporal and spatial shapes of drought were noticed. Both indices SPI and RDI indicated that after 1950 Barrani, Dabaa experienced worst drought situations in the 1990s and in 1980s respectively while at Matrouh the drought was very clear after 2000. The results of this work are up to date after El Afandi et al, to evaluate the drought over Egypt especially the Northwestern Coast. The drought became a dominant problem in the last decade. The future SPI was calculated using the simulated monthly rainfall of the ensemble of RCMs-GCMs models. The distributions showed decreasing trends at the three stations over the study period below RCP4.5 and RCP8.5 scenarios and also, a slightly increasing trend in Dabaa station under RCP8.5 scenario. The study area experienced drought in recent decades under recent climate change.

Acknowledgement

This work is supported by CAS President's International Fellowship Initiative (PIFI) for Visiting Fellows (Grant No. 2017VCA0012). The authors are grateful to CORDEX, Africa for providing future model data used in this study.

References

1. Abdelmalek M.B. and Nouiri I., Study of trends and mapping of drought events in Tunisia and their impacts on agricultural production, Science of The Total Environment, 139311 **(2020)**

2. Al-Hedny S.M. and Muhaimeed A.S., Drought Monitoring for Northern Part of Iraq Using Temporal NDVI and Rainfall Indices, In Environmental Remote Sensing and GIS in Iraq, Springer, Cham, 301-331 **(2020)**

3. Ceglar Andrej, Zalika Črepinsek and Lučka Kajfez-Bogataj, Analysis of meteorological drought in Slovenia with two drought indices, BALWOIS 2008 – Ohrid, Republic of Macedonia – 27, 31 May 2008 **(2008)**

4. Cruff R.W. and Thompson T.H., A comparison of methods of estimating potential evapotranspiration from climatological data in arid and sub-humid environments, Geological survey water supply paper 1H9-M and the California department water resources, USGPO, Washington **(1967)**

5. Dai A., Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008, *J. Geophys. Res*., doi:10.1029/2010JD015541, **116**, D12115 **(2011)**

6. El Afandi G., Morsy M. and Kamel A., Estimation of Drought Index over the Northern Coast of Egypt, *International Journal of Scientific Research in Science, Engineering and Technology*, **2(6),** 335-344 **(2016)**

7. El Kenawy A., López-Moreno J.I., Vicente-Serrano S.M. and Morsi F., Climatological modeling of monthly air temperature and precipitation in Egypt through GIS techniques, **Climate Research**, **42(2),** 161-176 **(2010)**

8. El-Tantawi A.M., Climate change in Libya and desertification of Jifara Plain, PhD thesis, Johannes Gutenberg University-Mainz, Germany **(2005)**

9. EMA: Egyptian Meteorological Authority, Annual meteorological report, Marine and weather forecast over Mediterranean, Cairo, Egypt **(2013)**

10. Gibbs W.J. and Maher J.V., Rainfall Deciles as Drought Indicators, Bureau of Meteorology Bulletin, Melbourne, doi:10.1016/S0022-1694(00)00340-1 **(1967)**

11. Gupta A.K., Tyagi P. and Sehgal V.K., Drought disaster challenges and mitigation in India: strategic appraisal, *Current Science*, **100(25),** 1795-1806 **(2011)**

12. Harris I., Jones P.D., Osborn T.J. and Lister D.H., Updated high-resolution grids of monthly climatic observations –the CRU TS3.10, Dataset, *International Journal of Climatology*, doi: 10.1002/joc.3711, **34(3)**, 623-642 **(2014)**

13. Houghton J.T., Ding Y., Griggs D.J., Noguer M., Linden P.J., Dat X., Maskell K. and Johnson C.A., Climate Change: The Scientific Basis, Working Group I, Third Assessment Report, Intergovernmental Panel on Climate Change, UNEP and WMO **(2001)**

14. Kassas M., Drought and desertification, Land use policy 4, issue 4, Elsevier Science Ltd., Amsterdam, London, 389-400 **(1987)**

15. Lionello P. and Giorgi F., Winter precipitation and cyclones in the Mediterranean region: future climate scenarios in a regional simulation, *Advances in Geosciences*, **12(12),** 153-158 **(2007)**

16. Lockwood J., World climatology 'an environmental approach', Edward Arnold, London **(1974)**

17. Mckee T.B., Doesken N.J. and Kleist J., The relationship of drought frequency and duration to time scales, Preprints, 8th Conference on Applied Climatology, January 17–22, Anaheim, California, 179–184 **(1993)**

18. Mgely M., A forecasting model for monthly precipitation and temperature and analysis of the characteristics of droughts in central California, unpublished Ph.D., Department of Geography, Indiana University **(1984)**

19. Mossad A., Mehawed H.S. and El-Araby A., Seasonal drought dynamics in El-Beheira Governorate, Egypt, *American Journal of Environmental Sciences*, **10(2),** 140-147 **(2014)**

20. Palmer W.C., Meteorological drought. Research Paper No. 45, U.S. Weather Bureau, [NOAA Library and Information Services Division, Washington, D.C. 20852] **(1965)**

21. Pittock A.B., The greenhouse effect and future climatic change, In Gregory S., eds.,1988: Recent Climatic Change (A Regional Approach), Belhaven Press: London, 306–315 **(1988)**

22. Shah I.L., Suryanarayana T.M.V. and Parekh F.P., Use of SPI and Rainfall Deciles for Drought Assessment, *International Journal for Scientific Research and Development*, **5(2),** 2321-0613 **(2017)**

23. Shah R., Manekar V.L., Christian R.A. and Mistry N.J., Estimation of Reconnaissance Drought Index (RDI) for Bhavnagar District, Gujarat, India World Academy of Science, Engineering and Technology, *International Journal of Environmental and Ecological Engineering*, **7(7)**, 2013 **(2013)**

24. Real-Rangel R.A., Pedrozo-Acuña A., Breña-Naranjo J.A., and Alcocer-Yamanaka V.H., A drought monitoring framework for data-scarce regions, *Journal of Hydroinformatics*, **22(1),** 170-185 **(2020)**

25. Surendran U., Anagha B., Raja P., Kumar V., Rajan K. and Jayakumar M., Analysis of Drought from Humid, Semi-Arid and Arid Regions of India Using DrinC Model with Different Drought Indices, *Water Resources Management,* **33(4),** 1521-1540 **(2019)**

26. Thornthwaite C.W., An approach toward a rational classification of climate, *Geographical Review*, **38(1),** 55-94 **(1947)**

27. Thurow T. and Taylor C., Viewpoint: The role of drought in range management, *Journal of Range Management,* **52(5),** 413-419 **(1999)**

28. Tian L., Yuan Sh. and Quiring S.M., Evaluation of six indices for monitoring agricultural drought in the south-central United States, *Agricultural and Forest Meteorology*, **249**, 107-119 **(2018)**

29. Tigkas D., Vangelis H. and Tsakiris G., DrinC: a software for drought analysis based on drought indices, *Earth Sci Inform*., doi:10.1007/s12145-014-0178-y **(2014)**

30. Tsakiris G. and Vangelis H., Establishing a drought index incorporating evapotranspiration, *European Water*, **9/10**, 3-11 **(2005)**

31. World Meteorological Organization, Standardized Precipitation Index User Guide, (WMO-No. 1090), World Meteorological Organization, Geneva, Switzerland **(2012)**

32. World Meteorological Organization (WMO) and Global Water Partnership (GWP), Handbook of Drought Indicators and Indices Svoboda M. and Fuchs B.A., Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2, Geneva **(2016)**

33. Yacoub E. and Tayfuri G., Evaluation and Assessment of Meteorological Drought by Different Methods in Trarza Region, Mauritania, *Water Resource Manage*, DOI 10.1007/s11269-016-1510-8, **31**, 825–845 **(2017)**

34. Zarch M.A.A., Malekinezhad H., Mobin M.H., Dastorani M.T. and Kousari M.R., Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran, *Water Resource Manage,* DOI 10.1007/s11269-011-9867-1, **25**, 3485–3504 **(2011)**.

(Received 02nd July 2020, accepted 05th September 2020)