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Estimation of Drought Index over the Northern Coast of Egypt

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ABSTRACT

The precipitation deficit from normal has significant impacts on water resources all over the globe. This deficiency of precipitation will lead to drought over different areas for specific time. Therefore, assessing the severity of drought period and magnitude will considered as one of the very important tool for sustainable agriculture. The main objective of this research is to investigate the performance of Precipitation Deviation Percentage (PDP) and Standardized Precipitation Index (SPI), to monitor and assessing the meteorological drought. As well as, to estimate the drought index over the northern coast of Egypt, to assist stakeholders and decision-makers. Calculations of PDP and SPI (at short or long time scales 3 and 6 or 12 months respectively) as drought indices have based on the CRU TS3.23 monthly average precipitation data, through the period from 1951 to 2014 over nine stations at the northern coast of Egypt.

Results of both PDP and SPI during the selected period revealed that, small or large amounts of rainfall were not associated with very low or high SPI values, but the PDP was very sensitive to any decrease or increase in rainfall. Despite, the PDP and SPI can perform as good indicators for meteorological drought monitor and assessment over the north coast of Egypt. Further analysis of PDP and SPI values have revealed drought occurrence started nearly 2005 and reached to extremely dry in 2010. As well as, both PDP and SPI trends have decreased as lower than zero with time. Hence, the northern coast of Egypt has exposed to drought during the last five years of the studying period.

Based on these results, it has recommended using both PDP and SPI operationally as warning system to monitor different drought conditions across the north coat of Egypt. This system will support in minimizing the negative impacts of drought on different sectors, mainly agriculture sustainability.

Keywords: Precipitation Deviation Percentage (PDP), Standardized Precipitation Index (SPI), Climate Research Unit (CRU), Drought and north coast of Egypt.

I. INTRODUCTION

Drought represents a costly natural hazard that influences different sectors of society (Dutra et al., 2014). It has regarded as a creeping phenomenon, that is slower and less dramatic than other natural disasters, but its effects are long lasting and widespread (Mavi and Tupper, 2004). Generally, the definitions of drought state that it is an environmental disaster associated with a deficit of water resources due to the breakdown of the rainfall regime (Asadi and Vahdat, 2013; Łabędzki and Bąk, 2014). Drought generally results from a combination of natural factors that enhanced by anthropogenic influences. The primary cause of any drought is a deficiency in precipitation, in space, time and intensity in relation to the existing water storage, demand, and use (Karavitis et al., 2011).

Agricultural drought occurrence has affected by the various characteristics of meteorological and hydrological drought (Łabędzki and Bąk, 2014). It is meaning that the meteorological drought is the main drought, which has characteristics that effect on hydrological and agricultural droughts occurrence, because all of them are associated with a deficit of water resources due to the breakdown of the rainfall. The negative effect of meteorological droughts is complex and can observed in various branches of the national economy (Łabędzki and Bąk, 2014). It is particularly visible in agriculture, hydrology and all sectors that are dependent on the water availability. As well as, the amount, seasonality and form of precipitation differ widely across different regions and countries according to their vulnerability depending on their locations (Dutra et al., 2014). Consequently, droughts are mainly regional in its extent and each region has its specific climatic characteristics (World Meteorological Organization, 2012). Therefore, studying and assessing the meteorological drought has regarded as one of the most important point and vital task over any region and location in the world.

Meteorological drought is the earliest and the most explicit climate event in the process of occurrence and sequence of drought conditions (Kumar et al., 2009). Rainfall is the primary causes and driver of meteorological drought. There are different numerous indicators based on rainfall used for drought monitoring (Smakhtin and Hughes, 2007). Deviation of rainfall from normal i.e. long-term mean is the most commonly used indicator for drought monitoring, i.e. Meteorological drought (Kumar et al., 2009).
The drought can begin to occur if the total season's rainfall is less than 75% of the long-term mean. While, severe drought occurs when the season's rainfall is less than 25% of normal (www.imd.gov.in). The deviation criteria for declaring drought vary from region to another. The simplicity way and widely adopted indicator for assessing drought occurrence and intensity is the deviation of rainfall from the long-term mean. Rainfall deviations cannot applied uniformly to different areas having different amounts of mean rainfall, since high and low rainfall areas can have the same rainfall deviation for two different amounts of actual rainfall. Therefore, rainfall deviations across space and time need to deal with utmost care (Kumar et al., 2009).

Depending on the demand on water resources, the regional or large-scale droughts can lead to water scarcity (Van Loon and Van Lanen, 2013). Near-real time drought monitoring can be used as an important tool to water resources management, and could be further complemented by drought forecasting (Pozzi et al., 2013). The accuracy of operational drought monitoring on a global scale crucially depends on the availability of rainfall estimation, and therefore on the spatial coverage and temporal frequency of in situ observations (Dutra et al., 2014).

The precipitation data are widely used to determine the meteorological drought indicators. Such indicators can be used for drought analysis, without the need for the physical properties of the site (Wanders et al., 2010). A challenge for all indicators based on precipitation is the high variety in temporal and spatial distribution of precipitation (Steinemann et al., 2005). To deal with this problem, often-monthly values or moving average values are taken.

There are many indicators and methods that have been developed and are used in assessment and determine the intensity of meteorological drought on the global and continental scale (e.g. Ziese et al., 2011). As well as, on the regional and local scales, there are also several studies evaluating different drought indexes (e.g. Hao and AghaKouchak, 2013; Sepulcre-Canto et al., 2012; Shukla et al., 2011; Tadesse et al., 2004). Among them, the standardized precipitation index SPI has received special attention in recent years since its introduction by McKee et al. (1993, 1995). It was used and applied to the assessment and analyse droughts in some regions over the world. Examples of these regions are, in Portugal (Paulo et al., 2002; Alfonso, 2005; Paulo and Pereira, 2006), in Crete (Tsakiris and Vangelis, 2004), and for the whole of Europe (Lloyd-Hughes and Saunders, 2002). SPI is widely recommended by the World Meteorological Organization (WMO) and it is very simple and objective measure of meteorological drought (Vermes et al., 2000; U.S. National Drought Mitigation Center (http://drought.unl.edu)). In addition to the SPI, there are some studies (e.g. Łabędzki and Bąk, 2014) have used other meteorological drought indices like Relative Precipitation Index (RPI), to classes of dry periods according to (Kaczorowska, 1962; Tomaszewska, 1994), and Effective Drought Index (EDI) that is a measure of precipitation needed for a return to normal conditions (Tokarczyk and Szalińska 2013). Recently, a numerous drought-monitoring indices that serve different aspects and sectors at various locations over the globe especially for meteorological drought.

This study has estimated two meteorological drought indices (SPI and PDP), to monitor and observe drought conditions over different locations at the north coast of Egypt.

The goal of the present study was to analyse the response of seasonal PDP and SPI values to drought situation and vice versa. Moreover, comparison of SPI with rainfall deviation from normal PDP during winter, spring and autumn seasons over the selected stations at the north coast of Egypt.

The main objective was to investigate whether the PDP or SPI can perform as better indicators for meteorological drought monitor and assessment.

II. STUDY AREA AND METHODOLOGY

A. The Study Area

Drought has represented as a common natural disaster in many countries. As well as, the previous studies showed that large to local scales are exposing to drought with different severities. To monitor and estimate the meteorological drought over Egypt, nine stations at different locations in the north coast have selected as shown in table (1) and figure (1).

TABLE I
SELECTED STATIONS IN THE NORTHERN COAST OF EGYPT

Station Name	Latitude (°N)	Longitude (°E)	Elevation (m)
Sidi-Barrani	31.61	25.93	24.00
Marsa-Matrouh	31.33	27.32	30.00
El-Alamein	30.82	28.96	07.00
Burj-Elarab	30.90	29.58	56.00
Alex-Nozha	31.21	29.97	07.00
Rosetta	31.40	30.43	15.00
Damanhour	31.03	30.51	07.00
Damietta	31.41	31.87	16.00
Port-Said	31.24	32.32	06.00

Egypt is located in both northern part of Africa and southwest of Asia and has shorelines on the Mediterranean Sea at northern border and the Red Sea at East border as shown in figure (1).
Egypt has a weather that is ranging between arid to semiarid conditions. There are four seasons in Egypt, summer, winter, autumn and spring. Most of rainfall events occurrence in Egypt received in the winter season (Soliman, 2007).

The rainfall in the southern parts of Egypt is less than the northern parts, and some areas even receive no rainfall for years. Sometimes sporadic rainfall occurs and leads to flash floods occurrence.

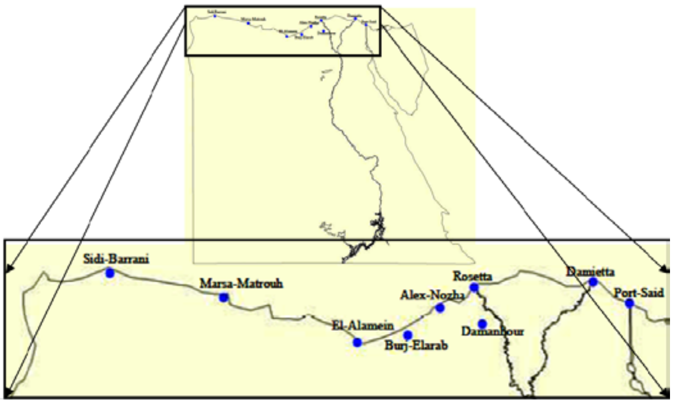

Figure 1: Locations of selected stations at the northern coast of Egypt

On a very thin strip of the northern coast of Egypt, (shoreline on the Mediterranean Sea) the rainfall can be as high as 410 mm, with most of the rainfall between October and March (Soliman, 2006). Most of the annual average precipitation falls as rain mainly during winter (December, January and February) (Hafez and Hasanean, 2000). The influence of the northern coast of Egypt during wintertime precipitation focused on the present of the anticyclonic blocking systems over Europe (El-Fandy, 1946; Hafez, 1995 and 1999). In general, climatic fluctuations that occur on the north Atlantic influence weather and climate over the Mediterranean (Rogers, 1997). Generally, in Egypt winter season, the rainfall occurrence is coincide with Mediterranean low pressures, but when these low pressure systems are not associated with upper air cold troughs, they cross the north coast of Egypt quickly with very little precipitation. While, in the transit seasons (spring and autumn), rain is usually associated with small desert low-pressure systems (Sudan monsoon low) with cold upper troughs (El-Fandy, 1946). Whereas, the summer season (June to August) in Egypt has characterized by warm, dry and rainless climate, and clear skies.

Consequently, this study will be focus on the northern coast of Egypt, because it receives the largest amount of rainfall.

B. Data used

The accuracy of operational drought monitoring on a global scale crucially depends on the availability of rainfall estimation, and therefore on the spatial coverage and temporal frequency of in situ observations (Dutra et al., 2014). The University of East Anglia, Climate Research Unit (CRU) TS3.23 has released monthly average precipitation data.

These are gridded data, month-by-month variations in climate over the period 1901-2014, on high-resolution (0.5x0.5 degree) grids. It based on monthly observational data, which calculated from daily or sub-daily data by national meteorological services and other external agents (University of East Anglia Climatic Research Unit et al., 2015). The CRU is widely recognised as one of the world's leading institutions concerned with the study of natural and anthropogenic climate change (http://www. cru.uea.ac.uk/about-cru).The precipitation data from the CRU has used to derive gridded drought indices such as the SPI in some researches (e.g. Guenang and Kamga, 2014).

This data from January 1951 to December 2014 has been collected and used, to assess the variability and behaviour of precipitation and consequently monitor and estimate drought indices at the selected stations over the study area. The Grid Analysis and Display System (GRADS), grid to station interpolation function, has used to interpolate the global CRU TS3.23 data for the selected stations.

C. Meteorological drought indices

The Precipitation Deviation Percentage (PDP) and Standardised Precipitation Index (SPI) are two different indices. It have used for meteorological drought monitoring and assessment at the north coast of Egypt. The PDP and SPI calculations based on long period CRU monthly precipitation data from January 1951 to December 2014 (64 years).

1) Precipitation Deviation Percentage (PDP)

The PDP is the ratio between the deviation of precipitation from the average for the given period $(P - \bar{P})$ and the long-term average for the same period $(\bar{P})$ as a percentage value.

$$PDP = \frac{P - \bar{P}}{\bar{P}}$$

Where P and $\bar{P}$ are the precipitation and long-term average precipitation respectively.

2) The Standardized Precipitation Index (SPI)

Despite, there are numerous indices for meteorological drought assessment in different studies at different locations; the Standardized Precipitation Index (SPI) represents the most important and mostly recommended indicator by WMO for meteorological drought assessment. SPI represents a standardized deviation of precipitation, in a particular period, from the median long-term value for the same period (McKee et al., 1993, 1995). Alternatively, expresses the rainfall as standardized departure from rainfall probability distribution function, since it is widely used in recent years as a potential drought indicator for assessment of drought intensity in many countries (Kumar et al., 2009). Although, SPI is convenient and relatively simple to use as a meteorological drought indictor, it requires long-term data for precipitation to determine the probability distribution function. As well as, SPI can be used at different locations with different time scales, short-term time scale (3, 6 and 9 months) or long-term time scale (12, 24 and 48 months) (Asadi and Vahdat, 2013). Where, different time scales reflect the drought impact on the different water resources availability. In addition, the SPI has a fixed expected value and standard deviation, which is a precondition for comparing its values between different regions or locations.

Mckee et al., (1993) define criteria for a drought event for any of the time scales; drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.00 or less and the event ends when the SPI becomes positive. Where, the drought begins when the SPI first falls below zero and ends with the positive value. In addition to, the positive values of SPI indicating that the precipitation is greater than the long-term average precipitation, and the negative values indicating that the precipitation is less than the long-term average precipitation (Edwards and McKee, 1997). McKee et al (1993) suggested the SPI ranges corresponding to different severity levels of drought as shown in table (2).

TABLE II
DROUGHT CATEGORIES CLASSIFICATIONS FROM SPI
(SOURCE: MCKEE ET AL., 1993)

SPI	Drought category and Classification
2.00 or more	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0 to 0.99	Mildly wet
0 to −0.99	Mild drought
−1.00 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
−2.00 or less	Extreme drought

During this study the SPI was calculated at two different time scales; short-term (3 and 6 months) and long-term (12 months) periods. These calculations have performed using the SPI_SL_6.exe program that has downloaded, from the National Drought Mitigation Center site (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx).

To run this program, you must have at least 30 consecutive years without missing monthly data, and more than 60 years is recommended (U.S. National Drought Mitigation Center (http://drought.unl.edu)).

III. RESULTS AND DISCUSSION

The rainfall amounts that occur every season and year over the north coast of Egypt are larger than any other region along the country. The selected stations in this study can be relatively representing the north coast of Egypt. The long-term seasonal and annual rainfall averages for the selected period from 1951 to 2014 at the selected stations shown in table (3). One may notice that, the highest amount of rainfall has received during the winter season, while this amount has decreased during autumn and spring respectively. In the same time, the rainfall values over all stations mostly have reached zero during summer. Therefore, this study is focussing on winter, autumn and spring seasons only.

TABLE III
SEASONALLY AND ANNUALLY LONG-TERM RAINFALL AVERAGES FROM 1951 TO 2014 AT THE SELECTED STATIONS

Station	Winter	Spring	Summer	Autumn	Annual
Salloum	36.02	11.15	00.79	14.87	20.68
Sidi-Barrani	40.24	10.00	00.59	15.23	21.82
Marsa-Matrouh	27.53	05.59	00.71	10.89	14.67
El-Alamein	27.11	04.29	00.18	07.65	13.02
Burj-Elarab	27.88	04.56	00.22	07.55	13.33
Alex-Nozha	49.83	10.47	00.10	12.15	24.15
Rosetta	36.43	05.78	00.00	13.23	18.48
Damanhour	47.72	09.73	00.09	11.69	23.05
Damietta	21.55	07.15	00.00	09.14	12.61
Port-Said	59.48	14.24	00.00	19.51	31.08

The results revealed that, the large amount of annually average rainfall has received at Port Said, Alex-Nozha, Damanhour, Sidi-Barrani and Salloum stations respectively. This is due to the effect of excess of rainfall during the winter over these stations.

The seasonal precipitation deviation from seasonal long-term average of the selected period has calculated using the PDP equation. Where, the negative values of the PDP are reflecting that, rainfall occurrence during this season is less than the normal one. In addition, the occurrence of the meteorological drought increases with decreasing PDP below zero. As well as, the lowest PDP value cannot decrease than -1.00, which reflect that there is no rainfall occurrence during this season and has a zero value of rainfall. On the other hand, the values of PDP that are larger than zero cannot be defined. In other words, if the PDP values reached to one, two and so on, it means the occurrence of rainfall during this season is twice or thrice the amount of normal rainfall and so on respectively. As well as, the SPI will be classified as shown in table (2) based on McKee et al., (1993).

Therefore, the analysis of the meteorological drought during this study was depending on these two drought indices (PDP and SPI) and their behaviour in drought monitoring.

The PDP and SPI Drought indices curves and charts were produced by estimating the annual average values from their seasonal (winter, spring and autumn) values.
It observed that, the behaviour's of PDP and SPI (with different time scales 3, 6 and 12) refers that the selected stations have received small values of rainfall than normal, as shown in figures (2) and (3) respectively. It also noticed that, during the first five years at the beginning of the studying period, the PDP and SPI values mostly are less than zero and tend to be dry. These drier five years have followed by five years of wet and it has reached to be extremely wet at most of the stations. After these ten years, both the PDP and SPI mostly oscillating between mild wet and mild dry at most stations until the moderately dry period between 1980 and 1985. It have followed by the mild wet period until nearly year 2000 and the oscillating period until 2009 between mild wet and mild dry. But, 2010 at most stations of the study can be regarded as the severely or extremely dry year, because the value of SPI reached to be less than -2.00 and the value of PDP reached to be nearly -1.00. This extremely dry year caused deviate of the trends for PDP and SPI at all stations toward drought. During the period from 2011 until 2014, the PDP and SPI values are mostly below zero and reached to be mild dry and rarely become mild wet. One may noticed at most stations, the results from PDP and SPI indices are often similar and have the same behaviour.

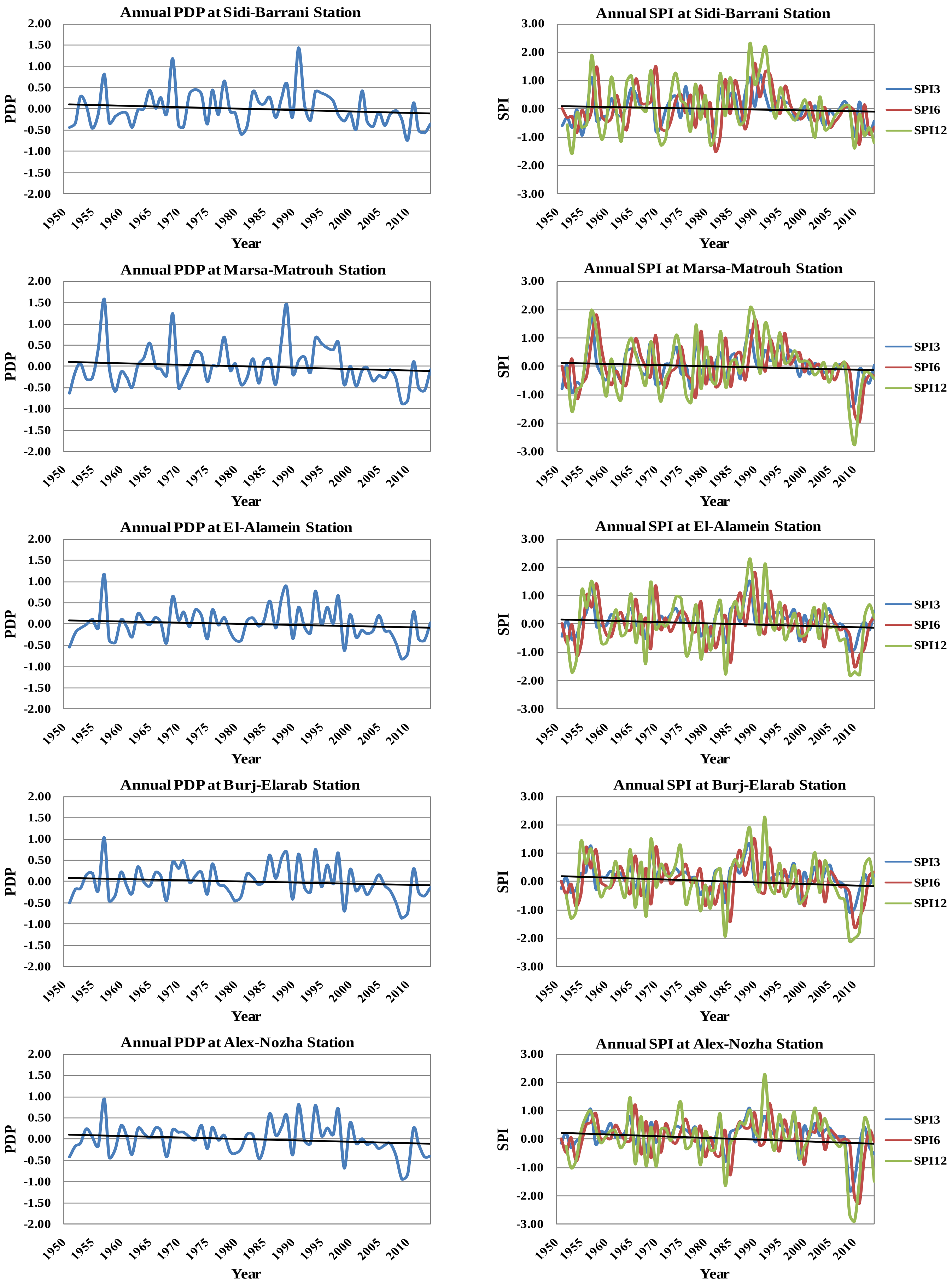

Figure 2: The PDP and SPI distributions and trends over Sidi-Barrani, Marsa-Matrouh, El-Alamein, Burj-Elarab and Alex-Nozha stations during the period from 1951 to 2014.

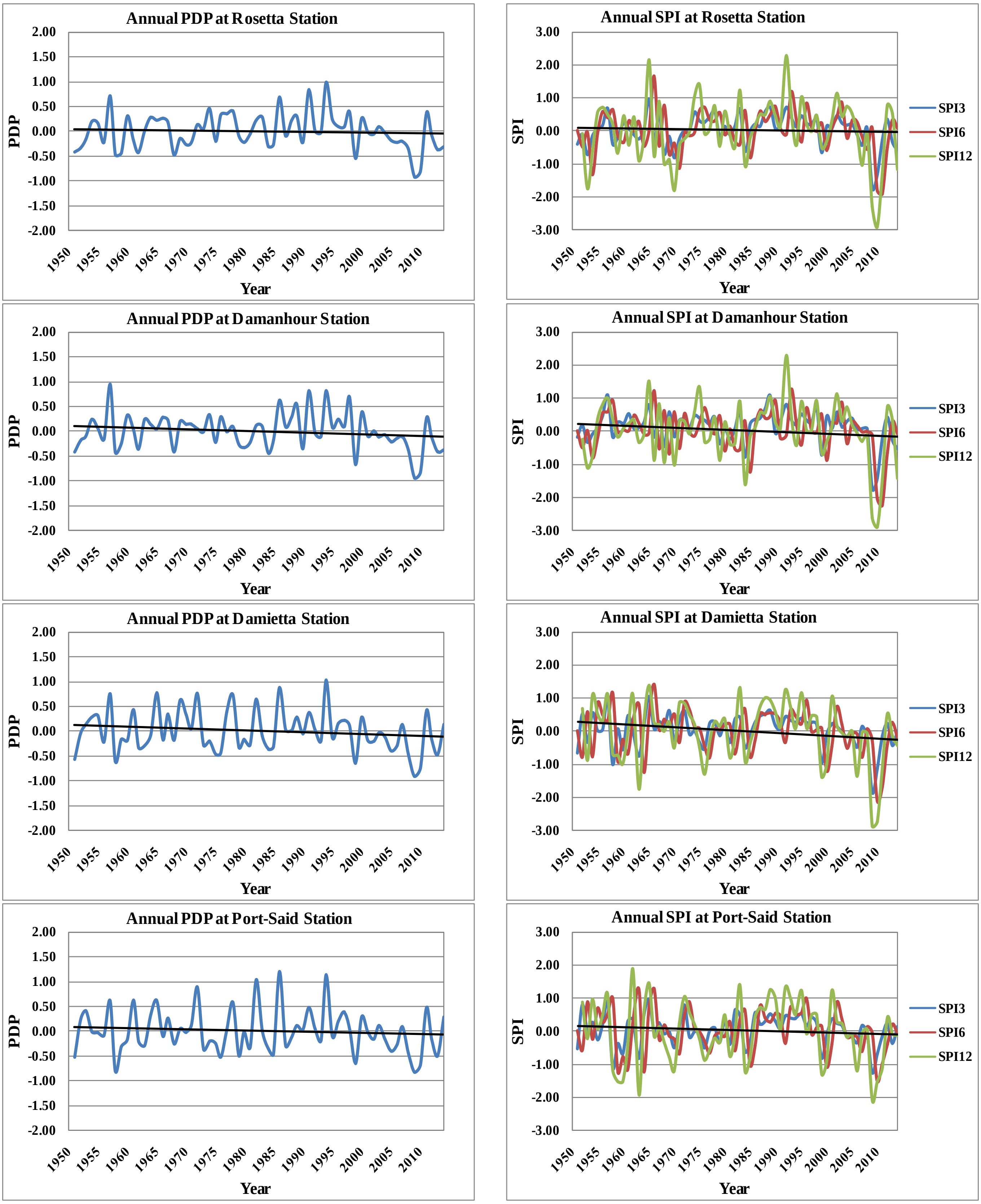

Figure 3: The PDP and SPI distributions and trends over Rosetta, Damanhour, Damietta and Port-Said stations during the period from 1951 to 2014.

It is also evident from figures (2) and (3) that, there was a relation between PDP and SPI values. Where, the very low PDP values that reached to near zero were associated with an extremely dry of -2.00 of SPI at most stations. On the other hand, the positive values of PDP found to be coincides with the positive values of SPI. Generally, there is a positive relation between PDP and SPI at different stages and categorise of drought, but the extent of the negative or positive PDP and the corresponding SPI values does not indicate the same degree of dryness or wetness. Nevertheless, the results form PDP are sensitively more, because its dependency on the local conditions.

IV. CONCLUSION

In this study, PDP and SPI have calculated for the period of 64 years (1951 to 2014) of monthly average precipitation data from CRU TS3.23 over nine stations selected at the northern coast of Egypt. Since, the SPI values of the selected period were analyzed with PDP values. It is indicated that, the SPI is less sensitive to low rainfall events and this is coincide with conclusion from Kumar et al., (2009). Where, very small or very large amounts of rainfall have not corresponding to very low or very high of SPI values, but the PDP is very sensitive to the lower or higher rainfall values. Despite, the PDP and SPI can perform as better indicators for meteorological drought monitor and assessment over the north coat of Egypt.

Overall results, PDP and SPI values and behaviours have indicated to drought occurrences, which begin nearly from 2005 and reaches to its maximum values in 2010. As well as the PDP and SPI, trends tended to decrease lower than zero with time over the northern coast of Egypt.

Furthermore, the supplied information using PDP and SPI could be used as drought warning system. This will support decision maker aimed to mitigate or minimizing the negative impacts of meteorological drought.

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