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Monthly and annual variations in the rainfall pattern along the Southern Levantine Coastline

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Abstract

Monthly and annual rainfall variations along the southern Levantine Basin were studied using a 12-year time data series (2009-2020) from six locations: Marsa Matrouh, Alexandria, Rosetta, Damietta, Port Said, and Arish, from west to east, respectively. The general statistics were calculated in addition to the coefficients of variations, the seasonal variation index, the precipitation index, and the cross-correlations. The highest mean monthly rainfall occurred in January (Marasa Matrouh and Rosetta), in November (Alexandria, Damietta and Port Said) and in March (Arish). The lowest mean monthly rainfall for all locations was in September. The highest annual amount of rainfall was 441.1 mm in 2020 in Rosetta, while the minimum was 22.56 mm in 2010 in Marsa Matrouh. The southern border of the Levantine received 8193.61 mm of rainfall over the period 2009-2020, with a precipitation rate of 2.28 mm/rainy day. Alexandria had the highest rate (3.33 mm/rainy day), while Arish had the lowest rate (1.78 mm/rainy day). On the other hand, Port Said had the highest number of rainy days (701 days), while Arish had the lowest number (566 days). Five locations exhibited seasonal rainfall in 3 months or less with high concentration except Marsa Matrouh where long dry seasons persisted. The indices of seasonal variations and precipitation concentration showed that rainfall is highly seasonal and highly concentrated in five locations receiving rainfall in three months but Marsa Matrouh, which has markedly seasonal rainfall regime with a long dry season. The cross-correlations suggested two distinct rainfall zones along the southern Levantine Basin: zone 1 extends from Marsa Matrouh to Port Said and zone 2 comprises only Arish. The rainfall variability along the southern Levantine coastline is substantially higher on a monthly or seasonal basis than on a yearly basis, and its spatial distribution is heavily influenced by local factors such as topography and location.

Keywords: Egypt; Southern Levantine; Rainfall; Seasonal index; Precipitation concentration index; Coefficient of variation.

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1. Introduction

Understanding the seasonal behaviour of rainfall is crucial for a wide range of water-related activities, such as water resource management, agricultural planning, flood frequency analysis, flood threat mapping, hydrological simulation processes, water resource assessments, impacts of climate change, and other environmental audits (Michaelides *et al.*, 2009). Many studies have been performed worldwide on the temporal and spatial characteristics of rainfall, e.g. in China (Zhang *et al.*, 2015; Huang *et al.*, 2018; Lu *et al.*, 2019); in Greece (Livada and Asimakopoulos, 2005); in Hawai (Chu *et al*. 2010); in Italy (Cannarozzo *et al.*, 2006; Caloiero *et al.*, 2019); in Malawi (Kumbuyo *et al.*, 2014); in Nigeria (Mercy, 2015; Chinago, 2020) and many other locations all over the globe. A pattern of rising rainfall from the equator to tropical along eastern Africa from 1901 to 2005 and a decreasing trend in Africa south of 20°S was recorded by the Intergovernmental Panel on Climate Change (IPCC), which means that the rainfall amounts and intensities in the wet season may have increasing trends (Morishima and Akasaka, 2010).

Egypt is one of the countries that are truly exposed to the potential impacts of climate change. Climate change will influence every development segment in Egypt but principally will impact on water supplies, coastal and agronomic resources, tourism sector, and public health. Climate change is also expected to intensify water shortages in Egypt's arid to the semiarid environment and result in increasing heat waves severity and frequency, in addition to changing the rainfall behaviour over the country (El-Raey, 2010). The Egyptian Mediterranean coast is the southern border of the Levantine Basin extending for about 1170 km from Sallum (west) to Rafah (east). It comprises four different sections based on the physiographical characteristics (Figure 1). Section 1 occupies the most northwest Egyptian Mediterranean region, from Sallum to Alamein, and is classified by being the highest elevation above the mean sea level (MSL) along the whole Egyptian Mediterranean coast. Section 2 is the middle northern Egyptian Mediterranean area extending from Alamein to Alexandria, comprising Alexandria Western Harbour, the principal Egyptian harbour on the Mediterranean. The Egyptian Nile Delta region represents the third section, from Rosetta to Port Said, where the highest population density exists and the main region of Egypt agriculture activities takes place. Lastly, section 4 occupies the most north-eastern Egyptian Mediterranean

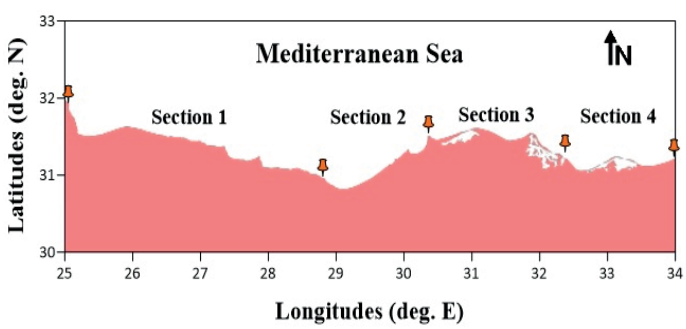

Figure 1. The four sections of the Egyptian Mediterranean Coast (Source: drawn in Surfer16 software)

region, extending from Port Said to Rafah comprising Egypt's main industrial and commercial activity zone, including the Suez Canal, in addition to the well-known Arish City in Northern Sinai Governorate.

In Egypt, rainfall is very scarce, with mean annual rainfall ranging from 0 mm/year (desert areas) to 200 mm/year (northern coastal regions). The rain comes in the form of scattered rains only during the winter season (Abdel-Shafy and Aly, 2002). The rainfall along the Egyptian Mediterranean coast, southern bound of the Levantine Basin, decreases eastward from about 200 mm/year at Alexandria to about 75 mm/year at Port Said (Abdel-Shafy *et al*., 2010). In the last decade, a variety of heavy rainfall events have occurred in various regions of Egypt, leading to significant flash floods in some cases. For example, in 2010, Alexandria endured its worst extreme winter when the coastline was hit by a severe storm and heavy rainfalls associated with a drop in the recorded air temperature from 22.2°C to 8.8°C from 11 to 15 December 2010 (Tonbol *et al*., 2018). Luckily, the storm caused only partial damage to some coastal structures and moderate lowland flooding within the City (Said *et al*., 2012). In two successive years, 2015 and 2016, flash floods occurred in many regions of the northern coast of Egypt including the Delta region and caused dozens of deaths and hundreds of demolished residences (Gado *et al*., 2019). Despite its importance, the study of changes in rainfall behaviour in Egypt has not received adequate concern. Only a few researches can be listed in this field, e.g. A great variation of rainfall statistical characteristics throughout Egypt was concluded by Gado (2017) using historical daily rainfall records at 30 stations. He used a rainfall series varying from 14 to 81 years, with an average of 30 years. El-Hagrsy *et al*. (2018) examined the possible changes in rainfall pattern based on a detailed statistical analysis using historical daily rainfall records at 31 stations in Egypt. They concluded negative trends for most of the examined locations; indicating a decrease in the amount of precipitation in these regions. They also recommended locating more meteorological stations so as to determine any impact of climate change on the rainfall pattern in Egypt. Gado *et al*. (2019) studied the spatial and temporal rainfall patterns in Egypt using parametric (Pearson) and non-parametric (Mann–Kendall and Spearman) tests on both annual and seasonal precipitation indices; to establish the rainfall temporal trends. Nashwan *et al*. (2019) investigated spatial trend patterns for annual and seasonal rainfall over Egypt using daily data of the period 1948–2010. They concluded a significant increase in annual rainfall in the central and southeast parts of Upper Egypt and northeast of the Nile Delta

This paper presents an analysis of the seasonal variations in the rainfall pattern over the southern Levantine Basin, based on monthly rainfall records at six locations along the Egyptian Mediterranean Coast.

2. Data and Methods of analysis

Monthly rainfall records for the period 2009-2020 from 6 rainfall stations along the southern border of the Levantine Basin were used in this study. The stations are Marsa Matrouh, Alexandria, Rosetta, Damietta, Port Said and Arish, from west to east, respectively (Figure 2.). The rainfall monthly data were obtained from the automated weather stations located at the international airports at three stations with

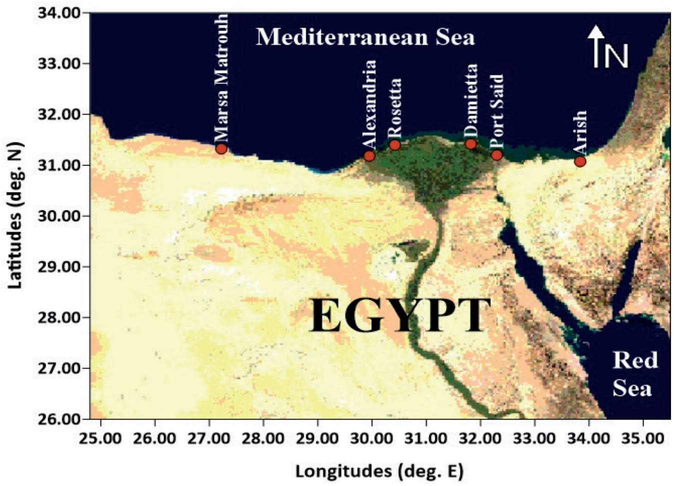

Figure 2. The southern Levantine Basin and the six locations of investigation

their related meteorological stations that have been registered in the World Meteorological Organization: Marsa Matrouh (62306), Alexandria (62318), and Arish (62337), while the data of Rosetta, Damietta, and Port Said were downloaded from the website www.worldweatheronline.com, on monthly basis too.

Mean monthly and mean annual rainfall values were calculated. However, the mean precipitation value does not express the natural temporal variability of rainfall. Therefore, the coefficient of variation (CV) expressed as a percentage (%) was calculated in the present work. The higher the CV (%), the more temporal rainfall variability of a location is.

To assess the behavior of rainfall seasonality along the southern border of the Levantine Basin, the Seasonal Index (SI) derived by Walsh and Lawler (1981) was used in this study. This index is given as

$$SI = \frac{1}{R}\sum_{n=1}^{12}\left|X_n - \frac{R}{12}\right| \qquad (1)$$

where, R is the annual rainfall (mm/year) and X_n is the rainfall of month n (mm/month)

Table 1 shows the different class limits of SI and the corresponding rainfall regimes (Kumbuyo *et al*., 2014; Patil, 2015).

The seasonality of rainfall pattern was estimated by using the Precipitation Concentration Index

Table 1. SI Classification

SI	Rainfall regime
< 0.19	Equal rainfall spread throughout the year
0.20-0.39	Equal rainfall throughout the year but with a definite wetter season
0.40-0.59	Seasonal rainfall regime with a short dry season
0.60-0.79	Seasonal rainfall regime
0.80-0.99	Markedly seasonal rainfall regime with a long dry season
1.00-1.19	Most rain occurs in 3 months or less
> 1.20	Extreme seasonality with almost all rain in 1 to 2 months

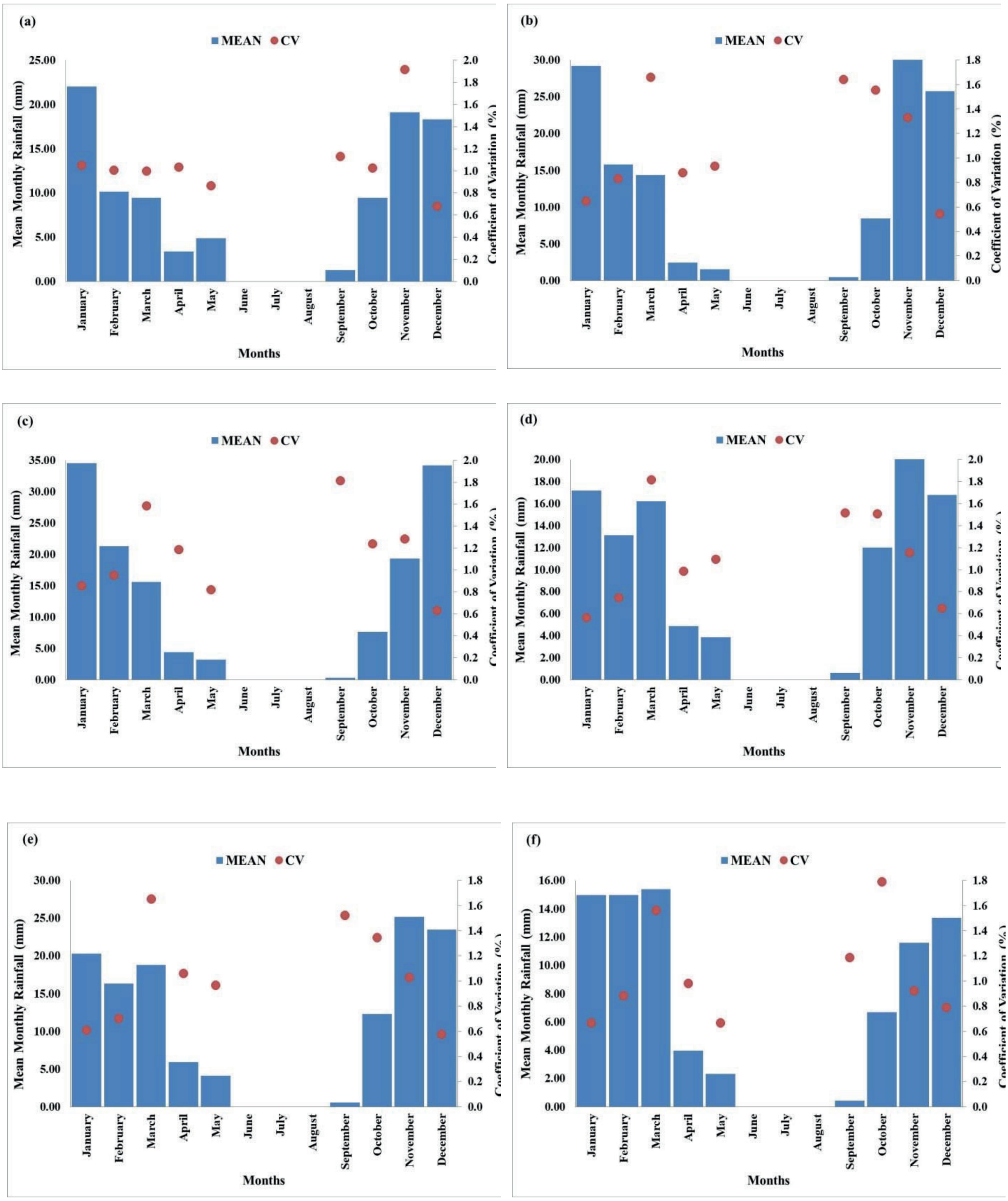

Figure 3. Mean monthly rainfall and the associated coefficients of variations at (a) Marsa Matrouh, (b) Alexandria, (c) Rosetta, (d) Damietta, (e) Port Said, and (f) Arish over the study period (2009-2020)

(PCI) as expressed by Oliver (1980):

$$PCI = \frac{(\sum_{i=1}^{12} P_i^2)}{(\sum_{i=1}^{12} P_i)^2} \times 100 \quad (2)$$

The PCI was derived and defined by Oliver (1980) as uniform (PCI = 8.3–10), moderately seasonal (PCI = 10–15), seasonal (PCI = 15–20), highly seasonal (PCI = 20–50) and irregular (PCI = 50–100).

3. Results

3.1. Monthly Rainfall Pattern

Figure 3 depicts the mean monthly rainfall and CV for all stations calculated over the 12 years of investigation for the six locations. January had the highest mean monthly rainfall for two stations with mean values of 22.05 and 34.55 mm and CV of 1.1% and 0.9%, at Marsa Matrouh and Rosetta, respectively. Also, November had the highest mean monthly rainfall for three stations with mean values of 30.04, 20.92 and 25.20 mm and CV of 1.3%, 1.2% and 1.0%, at Alexandria, Damietta and Port Said, respectively. Lastly, at Arish, the highest mean monthly rainfall occurred in March (15.38 mm) with a CV of 1.6%. The lowest mean monthly rainfall for all stations was in September with a mean value of 2.2 mm and CV of 2.8%. The most noteworthy result of this analysis was that rainfall is primarily concentrated with considerable measures between October and March, and with little amounts occurring in April, May, and September for all stations.

3.2. Annual Rainfall Pattern

The statistics of the total annual rainfall for all the six locations are given in Table 2. The highest annual amount of rainfall over the study period was 441.1 mm in 2020 in Rosetta, while the minimum was 22.56 mm in 2010 in Marsa Matrouh. The southern border of the Levantine Basin received 8193.61 mm of rainfall over the period 2009-2020, with a precipitation rate of 2.28 mm/rainy day. Alexandria had the highest rate (3.33 mm/rainy day), while Arish had the lowest rate (1.78 mm/rainy day). On the other hand, Port Said had the highest number of rainy days over the study period (701 days), while Arish had the lowest number (566 days).

Rosetta lying at the northwestern side of the Nile Delta had the highest mean annual rainfall of 140.51 mm and a CV of 0.79%. Arish, the eastern extremity of the present area of investigation, received the lowest mean annual rainfall of 83.68 mm with a CV of 0.70%. Moreover, two locations had a mean annual rainfall above 125 mm, one location had a mean annual rainfall greater than 100 mm, and one location had a mean annual rainfall of less than 100 mm: Alexandria (127.84 mm), Port Said (126.99 mm), Damietta (105.60 mm) and Marsa Matrouh (98.04 mm). Port Said and Marsa Matrouh had the lowest and highest CV of 0.67% and 0.84%, respectively. Over the 12-year period of investigation, the different locations in the present study examined increasing patterns in their rainfall trends with different rates of 11.6 mm/yr, 10.1 mm/yr, 18.7 mm/yr, 12.9 mm/yr, 12.6 mm/yr and 10.0 mm/yr at Marsa Matrouh, Alexandria, Rosetta, Damietta, Port Said and Arish from west to east, respectively. The total amount of rainfall in the last two years: 2019 and 2020 greatly impacted on the trend of variations; being much higher than any recorded amount in the precedent years from 2009 to 2018 over the six locations. The year 2015 was also a year of high rainfall amounts when the total annual amounts exceeded 90 mm over the six locations of interest.

Table 2. Statistics of the total annual rainfall

	Marsa Matrouh	Alexandria	Rosetta	Damietta	Port Said	Arish
2009	81.85	118.13	90.87	48.76	51.83	29.59
2010	22.56	67.08	65.54	47.36	43.06	32.79
2011	103.1	221.8	116.28	92.28	173.63	80.74
2012	71.63	81.58	106.87	78.45	117.26	70.86
2013	65.62	77.07	92.54	74.53	107.85	85.05
2014	59.85	47.11	52.33	79.04	108.96	62.02
2015	119.86	128.95	147.86	146.14	139.76	90.64
2016	52.09	65	99.18	62.92	62.18	44.06
2017	44.82	45.23	63.71	40.03	46.51	31.18
2018	60.91	66.55	103.69	88.58	99.28	65.44
2019	144.8	245	306.2	202.8	221.4	194.7
2020	349.43	370.6	441.1	306.3	352.2	217.1
Total rainfall (mm)	1176.52	1534.10	1687.17	1267.19	1523.92	1004.7
No. of rainy days	604	461	655	599	701	566
Rate (mm/rainy day)	1.95	3.33	2.58	2.16	2.17	1.78
Mean (mm)	98.04	127.84	140.51	105.60	126.99	83.68
Standard Deviation	82.35	96.19	110.57	74.72	85.10	58.45
CV %	0.84	0.75	0.79	0.71	0.67	0.70

Table 3. Seasonal index (SI) and Precipitation Concentration Index (PCI) at the six locations of investigation

Location	Marsa Matrouh	Alexandria	Rosetta	Damietta	Port Said	Arish
SI	0.95	1.10	1.07	1.01	1.00	1.04
PCI	21.8	25.5	23.7	21.9	19.7	22.6

3.3. Seasonality and Precipitation Concentration Indices

The results of the seasonality analysis show that Marsa Matrouh with an annual SI of 0.95 was the only location with rainfall classified as markedly seasonal rainfall regime with long dry season (Table 3). The other five locations had SI in the range 1.00-1.19, which means that most rain occurs in 3 months or less. Furthermore, the PCI values ranged from 19.7 to 25.5. Only Port Said, with a PCI value of 19.7, had seasonal rainfall concentration. Marsa Matrouh, Alexandria, Rosetta, Damietta, and Arish, on the other hand, are of highly seasonal rainfall concentration, with

Table 4. Cross-correlation of rainy months among the six locations of interest

	Marsa Matrouh	*Alexandria*	*Rosetta*	*Damietta*	*Port Said*	*Arish*
Marsa Matrouh	1.00					
Alexandria	0.95	1.00				
Rosetta	0.78	0.77	1.00			
Damietta	0.73	0.86	0.62	1.00		
Port Said	0.75	0.89	0.61	0.93	1.00	
Arish	0.23	0.39	0.31	0.30	0.41	1.00

PCI values greater than 20. The results for SI and PCI both indicate that rainfall time series at the six locations under consideration have pronounced seasonality.

3.4. Cross-correlation between locations

The cross-correlations among the six locations of interest were calculated for the period from October to March; being the months of high means during the wet period over the southern Levantine basin. The result is given in Table 4. Arish has its own rainfall characteristic among the examined locations with a weak correlation coefficient of less than 0.45. The other five locations are highly correlated to each other with coefficients greater than 0.60.

Discussion

Changes in rainfall patterns can potentially impact on habitats and biodiversity, agronomy, water supplies and the flow of rivers. Different global climate models suggest that annual average rainfall amounts may increase, but the turnaround time for heavy rainfall events may in the meanwhile decrease (Lionello *et al.*, 2002). This shift in the rainfall patterns may result in increased flooding during the rainy season, above all in low-lying coastal areas (Sánchez-Arcilla *et al.*, 2011).

The present study aimed at investigating the seasonal variations in the rainfall patterns along the southern border of the Levantine basin: The Egyptian Mediterranean Coast. The study is based on monthly data at six locations from January 2009 to December 2020, i.e. 12 years, with 0% missing data. These locations are distributed over the Egyptian Mediterranean Coast comprising the important cities of Marsa Matrouh, Alexandria, Rosetta, Damietta, Port Said, and Arish, from west to east, respectively. The investigation is built-up on the statistical analysis of both mean monthly and mean annual rainfall amounts. The coefficients of variations of the two means were calculated in addition to the seasonality and precipitation indices. Results revealed that the southern Levantine Basin examined a rainfall rate of 2.28 mm/rainy day over the 12 years. The highest calculated mean annual rainfall amount was 140.51 mm in Rosetta, while the lowest was 83.68 mm in Arish. Over the 12-year period of investigation, the different locations in the present study examined increasing patterns in their rainfall trends with different rates of 11.6 mm/yr, 10.1 mm/yr, 18.7 mm/yr, 12.9 mm/yr, 12.6 mm/yr and 10.0 mm/yr at Marsa Matrouh, Alexandria, Rosetta, Damietta, Port Said and Arish from west to east, respectively. The total amount of rainfall in the last two years: 2019 and 2020 greatly impacted on the trend of variations; being too much higher than any recorded amount in the precedent years from 2009 to 2018 over the six locations.

The coefficient of variation of year-to-year rainfall reflected a general westward increase in the coefficient. The area along the southern Levantine can be divided into two groups: Group I from Rosetta to Damietta with CV ≥ 0.75, and Group II from Damietta to Arish with 0.65 < CV < 0.75. It is essential to mention that rainfall variability along the area of interest is significantly higher on monthly or seasonal basin than on yearly. This is in agreement with the conclusion of Schulze (2007) in Africa, Kumbuyo *et al*. (2014) in Malawi and Arvind *et al*. (2017) in India.

Conclusion

To conclude, the analysis of the pattern of fluctuation of the monthly and annual rainfall over the period 2009-2020 along the Egyptian Mediterranean Coast revealed the following points:

- There was a low spatial variability of both monthly and annual rainfall, with coefficients of variations not to exceed 2.8% and 0.84% on a monthly and annual basis, respectively.
- Rainfall was supreme from November to March with peaks occurring at different months at different locations: January (Marsa Matrouh and Rosetta), November (Alexandria, Damietta and Port Said), and March (Arish). September was the month of the lowest mean monthly rainfall for all locations.
- The rainfall pattern along the southern Levantine coastline suggests that local factors as topography and location may have a dominant role in the spatial distribution of rainfall.
- Based on seasonal indices, five locations exhibit seasonal rainfall in 3 months or less except Marsa Matrouh where long dry seasons are expected. Also, Only Port Said has been classified as being of seasonal rainfall pattern, while the other five locations are of the highly seasonal pattern.
- Given the importance of rainfall to the diverse anthropogenic activities along the Egyptian Mediterranean coast, these variations need to be applied to the planning of water resources management.

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