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Performance Assessment of Satellite Rainfall Estimates Products to Describe Recent Variability and Trends of Rainfall along the Egyptian Mediterranean Coast

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ABSTRACT

Understanding long-term changes in precipitation characteristics is the best way to study the vulnerability of a region to climate change. While, observed rain data obtained from meteorological stations are the most accurate data, their poor spatiotemporal distribution is an obstacle to long-term rain studies. Satellite rainfall data products are a suitable alternative to use, but sometimes this data is inaccurate and does not represent reality. Hence, the performance of satellite data for the study area must be evaluated before relying on it to study the rainfall characteristics of the area. Science the Egyptian Mediterranean coast (EMC) is considered one of the highly vulnerable regions to climate change impacts, this study aims to evaluate the performance of three satellite rainfall data products in comparison with the ground stations observed data along the EMC during the period 2007-2021. In addition, to analyzing the observed data to investigate the recent daily, monthly, and annual changes in precipitation to spotlight the intensity and frequency of extreme events. Evaluating the performance of satellite rainfall data products showed that none of them are suitable for providing a complete picture of rainfall patterns in the study area. This performance limitation may be due to the measurement time discrepancy between ground-based and satellite rainfall products. On the other hand, the results of analyzing observed rain data showed a considerable increase in annual rainfall across the EMC with a positive trend of (22.33mm/year), also a positive trend of rainy days' number of (3.47 days/year), another notable result was that EMC has an annual average rainy day of 27 days, among those rainy days, only 2.3 days are characterized by heavy and extreme rain.

INTRODUCTION

Egypt is especially vulnerable to the effects of climate change due to its high population density and inability to deal with extreme weather events, such as flash floods, which result from intense rainfall lasting from a few hours to a few days and may cause damage. Studying the spatial and temporal changes in rainfall extremes in Egypt is crucial for the assessment of the potential impacts of climate change and then for developing adaptation and mitigation measures **(Hamed *et al*., 2021)**.

Egypt's climate is often characterized by hot, dry summers and mild, rainy winters. Precipitation in Egypt is relatively scarce and irregular; the amount of rainfall varies widely by region, with some areas receiving almost no rain at all while others receive occasional heavy downpours. Precipitation in Egypt is highly seasonal; the rainy season extends only from September to April, with the heaviest rainfall typically occurring in December and January. However, even during the rainy season, precipitation levels are generally quite low **(El Kenawy *et al*., 2010)**. In detail, **El Kenawy *et al*. (2010)** showed that rain is uncommon in Egypt, except along the Mediterranean coast.

When studying a region's hydrology and climate, rainfall is the most important factor. The climatology of rainfall in a region affects the design of hydraulic infrastructure, the requirements and timing of irrigation, the suitability of land for the cultivation of various types of crops, and the vulnerability of the area to dangers like floods and droughts **(Shahid *et al*., 2017)**. It also describes a region's ecology, social structure, economic outlook, and environment, which are all seen as crucial for socioeconomic development **(Sharafati *et al*., 2020)**.

Unfortunately, few studies were conducted to study the characteristics of rainfall data in the Middle East and the North African region. At the same time, it has recently become clear that some regions of Egypt have seen extremely heavy rainfall, some of which has prompted severe flash floods, these spatial and temporal changes in rainfall in Egypt could be due to anthropogenic climate change or multi-decadal timescale natural variability **(Gado *et al*., 2019)**.

The natural occurrence of precipitation is complicated and characterized by high temporal and spatial variability. To conduct research or make predictions about climate change, very accurate temporal-spatial and long-term precipitation data are required to give considerable support for identifying regions with major changes in rainfall patterns **(Zhao *et al*., 2017)**. Although the most accurate and trustworthy method for measuring rainfall is thought to be relying on observations from metrological stations as a key source of data, ground-based rain gauge networks are frequently unevenly dispersed in a given area due to meteorological, economic, and other limited circumstances **(Twardosz *et al*., 2011)**. However, developments in the science of remote sensing have made it possible to calculate rainfall from satellite observations, and they are now a significant source of rainfall data **(Ayehu *et al*., 2018)**. In general, satellite-based precipitation products provide several benefits over ground-based observation, including sample data collection, extensive coverage, suitable temporal and geographic resolutions, long-term and continuous recording, and reduced effects from climate and terrain variability. As a result, satellite-based technology has advanced significantly in recent years **(Zhao *et al*., 2017)**.

Insufficient climatic data that is both long-term and spatially comprehensive is the primary hindrance to conducting a complete analysis of rainfall trends using data collected from meteorological stations located across the entire study region. Location-specific or climatic models with a coarser spatial resolution are the climatic data that are most frequently used for those studies. However, very few studies have used satellite-estimated rainfall data to identify rainfall trends. Rainfall estimates based on satellite or hybrid (satellite plus ground data) data provide a useful and complementary alternative to ground data in the absence of long-term field-measured rainfall data. On the other hand, high-resolution raster rainfall data generated using either satellite estimates or models are suitable for numerous analysis, including those of rainfall trends and drought monitoring. Since, they capture the spatial variability of a given geographical area. The benefit of satellite-based rainfall estimates is that they use a diverse set of algorithms to cover the entire spatial extent of a certain area **(Alahacoon *et al*., 2022)**.

There are numerous sources of satellite-derived rainfall estimates, including 1) thermal infrared radiation from geostationary satellites, this method estimates rainfall from cloud-top brightness temperatures through an indirect relationship which may be subjected to substantial uncertainty **(Paredes Trejo *et al*., 2016)**. 2) passive microwave channels from Low-Earth-orbiting satellites, this method would provide more accurate rainfall estimations since it is based on direct observations of atmospheric liquid water content and rainfall intensity by penetrating clouds **(Kummerow *et al*., 2001)**.

Satellites cannot measure rainfall independently and must be used in association with one or more surrogate variables. Hence, techniques for estimating rainfall using satellites have limitations and inherent uncertainties. As a result, the uncertainties could come from algorithmic errors, temporal sampling methods, or even the satellite sensors themselves **(Gebremichael *et al*., 2014)**. Regarding rainfall products produced from satellites, the question of accuracy has drawn a lot of attention. When these are used for numerous purposes, like studying rainfall patterns and variability, they may have an impact on the precision of satellite-derived rainfall products and result in substantial inaccuracies. In this regard, rigorous validation is necessary to confirm the product's performance in a variety of physiographic settings and use it for specified applications **(Ayehu *et al*., 2018)**.

Multiple satellite rainfall products have recently been examined for performance over many different regions of the world, and the findings of these studies revealed that the quality of these products varies by region, season, and elevation **(Li *et al*., 2018)**.

Some earlier relevant studies are available, where **Norrant & Douguédroit (2006)** stated that during the second half of the twentieth century in the Mediterranean region, there were non-significant trends dominated for daily, monthly, seasonal, and annual precipitation at 63 stations distributed across the Mediterranean region. Another study conducted in 40 locations around the Mediterranean region found that the patterns of annual rainfall and rainy days in the examined area showed significant negative trends between 1901 and 2009 **(Philandras *et al*., 2011)**.

MATERIALS AND METHODS

1.0 Data and methods of analysis

This study aims to investigate the recent changes in precipitation along the Egyptian Mediterranean Coast (EMC). Daily, monthly, and annual precipitation were studied among six stations (Sallum Plateau - Mersa Matruh - Dabaa - Alexandria - Port Said - El Arish) using the daily observed data from 2007 to 2021, as seen in Fig. (1). In the same context, three different precipitation databases were used: 1) Copernicus Climate Data Store (ERA5), 2) NASA Global Land Data Assimilation System (GLDAS-2.1), and 3) Tropical Applications of Meteorology Using Satellite Data and Ground-Based Observations (TAMSAT). The accuracy of those different databases for the studied along (EMC) is examined by comparing these data with the independent observation.

The first step is to correlate local observations with the three different gridded independent datasets (ERA5, GLDAS, and TAMSAT). The second step is to decide which database will be used to describe the present precipitation system.

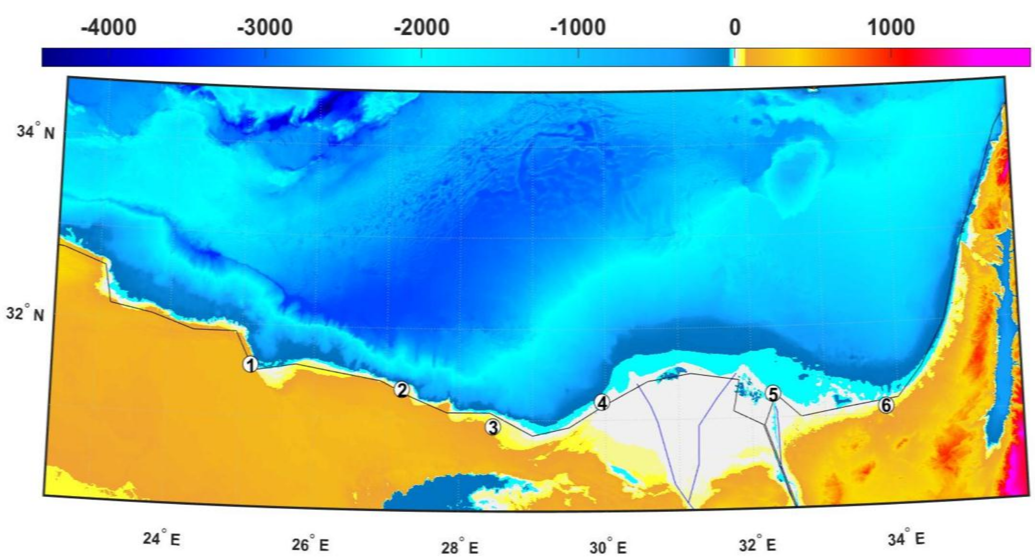

Fig. 1. Bathymetric chart of the study area with the six considered weather observation stations: 1) Sallum Plateau, 2) Mersa Matruh, 3) Dabaa, 4) Alexandria/Nouzha, 5) Port Said, and 6) El Arish.

2.0 Data used

2.1 (ERA5) Satellite data from 2007 to 2021

The rainfall hourly data from 2007-2021 continuously were obtained freely from the European Eyes on Earth (Copernicus) website (https://cds.climate. copernicus. eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form).

ERA5 is the fifth and latest version of the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric, oceanic, and land-surface reanalysis product. This version replaced its popular predecessor, ERA-Interim reanalysis, with a finer spatial grid of 0.25˚ x 0.25˚ and temporal hourly resolution to improve spatial and temporal resolution.

2.1.1 NASA Global Land Data Assimilation System (GLDAS-2.1) satellite data from 2007 to 2021

The rainfall sub-daily (3-hourly) data from 2007-2021 continuously were downloaded freely from (https://disc.gsfc.nasa.gov/datasets/GLDAS_NOAH025_3H_2.1/summary).

The NASA Global Land Data Assimilation System (GLDAS) uses sophisticated land surface modeling and data assimilation techniques to ingest satellite and ground-based observational data sources and produce optimal fields of land surface states and fluxes **(Rodell *et al*., 2004)**.

NASA GLDAS-2 has three components: GLDAS-2.0, GLDAS-2.1, and GLDAS-2.2. GLDAS-2.1 is forced using model- and observation-based data from 2000 to the present. The temporal resolutions for the GLDAS-2 products are 3-hourly and daily, with a spatial resolution of 0.25° x 0.25° archived in NetCDF-4 format.

On January 1, 2000, the GLDAS-2.1 model simulation got underway using the parameters from the GLDAS-2.0 simulation. The Global Data Assimilation System (GDAS) and National Oceanic and Atmospheric Administration (NOAA) atmospheric analysis fields were used to force this simulation **(Derber *et al*., 1991)**, the daily analysis precipitation fields from the Global Precipitation Climatology Project (GPCP) V1.3 **(Huffman *et al*., 2001; Adler *et al*., 2003)**, and the radiation fields of the AGRicultural METeorological modeling system (AGRMET) of the Air Force Weather Agency.

2.1.2 Tropical Applications of Meteorology Using Satellite Data and Ground-Based Observations (TAMSAT) Data from 2007 to 2021

The daily rainfall data from 2007-2021 was continuously obtained freely from the University of Reading website (https://www.tamsat.org.uk/data).

Numerous studies have emphasized the superiority of the rainfall products developed by the TAMSAT team at the University of Reading in the UK for use in research in Africa, as well as the accuracy, spatial resolution, and wider use of TAMSAT data for trend analysis. The high-resolution Meteosat thermal infrared (TIR) observations and data from rainfall stations constitute the foundation of the gridded TAMSAT rainfall products. Furthermore, as TAMSAT rainfall products cover the entirety of Africa from 1983 to the present and have a spatial resolution of 4 km, they offer an invaluable foundation for a more fruitful investigation of a long-term rainfall trends. The Meteosat data and integrated ground data were used to construct the TAMSAT data using an exploratory calibration method. The use of infrared data rather than synthetic aperture radar (SAR) data for TAMSAT rainfall estimations may have improved the accuracy and applicability of the data **(Alahacoon *et al*., 2022)**.

2.1.3 Observed data.

The daily rainfall data from 2007-2021 was continuously obtained from the automated weather stations (AWS) located at the international airports among six stations shown in Table (1), with their related meteorological stations that have been registered in the World Meteorological Organization (WMO). The data was freely downloaded from the website (https://en.tutiempo.net/climate/egypt.html).

Table 1. Elevations and positions of automated weather stations. (The period of recorded data for all stations is 15 years from 2007 to 2021). The identification numbers (IN) 1 to 6 are also included in association with Figure 1.

Station Names	IN	Elevation Above Sea Level (m)	Geographic Position		International Station Number
			Latitude	Longitude	
Sallum Plateau	1	180	31.56°	25.13°	62305
Mersa Matruh	2	25	31.33°	27.21°	62306
Dabaa	3	17	30.93°	28.46°	62309
Alexandria/Nouzha	4	-2	31.20°	29.95°	62318
Port Said	5	6	31.26°	32.29°	62333
El Arish	6	31	31.08°	33.83°	62337

2.2 Method of analysis

2.2.1 Validation of rainfall satellite datasets

The ERA5 dataset was accumulated to daily values from the hourly downloaded rainfall time series. Also, the GLDAS dataset accumulated to daily values from the 3 hourly downloaded rainfall time series. Then, the monthly and annual timescales for all four rainfall datasets (observed, ERA5, GLDAS, and TAMSAT) were aggregated from the obtained daily rainfall data.

The statistical evaluation method generally uses one of the following approaches: 1) pixel-to-pixel pairwise approach, which compares the spatially interpolated observed-based and satellite-based data, and 2) point-to-pixel pairwise approach, which compares generated satellite rainfall estimates for each observation location **(Kabite Wedajo *et al*., 2021)**. This study followed the second approach. This is because the distribution of the six rainfall stations used in this study is too uneven for them to adequately reflect the spatial variability of rainfall in the EMC, as required by the first approach.

To assess the efficiency and overall performance of the investigated satellite rainfall products on a daily, monthly, and annual basis, over the six stations studied, various statistical indices are used. 1) Pearson correlation coefficient (r), is used to evaluate how well the estimates from satellite products correspond to the observed rainfall values, where a value of 1 is the perfect score, 2) Root mean square error (RMSE), measures the absolute mean difference between two datasets to identify the average magnitude of the estimate errors, a value of 0 is the perfect score, 3) Nash-Sutcliffe efficiency (NSE), demonstrates how well the estimate from satellite products predicted the observed rainfall time series, a value of 1 is the perfect score, and 4) Bias, measures the magnitude of the average satellite rainfall compares to the ground rainfall observation, a value of 1 is the perfect score, above 1 indicates satellite overestimation, and below 1 indicates satellite underestimation. Table (2) lists mathematical descriptions of the applied statistical indices.

Table 2. Mathematical descriptions of the applied statistical indices.

<table>
<tr><th>Indices</th><th>Formula</th><th>Parameters</th><th>Indices Range</th></tr>
<tr><td>r</td><td>$\frac{\sum(O-\bar{O})(S-\bar{S})}{\sqrt{\sum(O-\bar{O})^2}\sqrt{(S-\bar{S})^2}}$</td><td rowspan="4">**O** is the observed rainfall.
S is satellite rainfall estimates.
$\bar{O}$ is the observed rainfall average.
$\bar{S}$ is satellite rainfall estimates average.
n is the number of data pairs.</td><td>**-1 to 1**
With a value of -1 meaning a total negative linear correlation, 0 is no correlation, and + 1 meaning a total positive correlation</td></tr>
<tr><td>RMSE</td><td>$\sqrt{\frac{\sum(O-S)^2}{n}}$</td><td>**0 to ∞**
They are negatively oriented scores: Lower values are better</td></tr>
<tr><td>NSE</td><td>$1-\frac{\sum(S-O)^2}{\sum(O-\bar{O})^2}$</td><td>**- ∞ to 1**
A value of one indicates a perfect fit, while a value of zero indicates that a mean value would have produced the same level of accuracy</td></tr>
<tr><td>Bias</td><td>$\frac{\sum S}{\sum O}$</td><td>**0 to ∞**
When the number of observed occurrences of the event is small, the denominator becomes small and the bias correspondingly large and unstable.</td></tr>
</table>

In general, r > 0.7 validates satellite rainfall estimates as a trustworthy resource for measuring precipitation **(Condom *et al*., 2011)**. The RMSE is reliable when the RMSE of the estimated rainfall was <50% of the measured rainfall amount. Conversely, when the RMSE was equal to or greater than 50% of the magnitude of the reference rainfall, the estimate was considered unreliable for the region considered **(Franchito *et al*., 2009)**.

2.2.2 Observed rainfall data analysis.

By relying upon the daily, total monthly, and total annual observed rainfall values for the analysis of rainfall patterns, descriptive statistics (mean: The average rainfall amount, median: The middle value of rainfall amounts, Variance, and standard deviation: Measures of rainfall variability, and Skewness and kurtosis: Measures of the shape of the rainfall distribution) were calculated to provide a general sense of the distribution of rainfall over the time period and location, then Investigate trends and seasonal patterns in the data.

According to **World Meteorological Organization (2021)**, observed rainfall data were categorized into two types: drizzle, and rain with a specific classification into the four intensity categories, namely slight, moderate, heavy, and extreme according to the rates of precipitation fall as shown in Table (3).

Table 3. Criteria for rainfall intensity.		
Rainfall type	Rate range (I refer to rain amount mm h^{-1})	Intensity
Drizzle	I < 0.1	Slight
	0.1 ≤ I < 0.5	Moderate
	I ≥ 0.5	Heavy
Rain	I < 2.5	Slight
	2.5 ≤ I < 10.0	Moderate
	10.0 ≤ I < 50.0	Heavy
	I ≥ 50.0	Extreme

RESULTS AND DISCUSSION

3. Evaluate the performance of three gridded reanalysis rainfall satellite datasets.

The performances of satellite rainfall estimates were evaluated using four statistical indices (r, RMSE, NSE, and Bias). Tables (4, 5, & 6) lists the results of statistical evaluation indices that were calculated for the evaluated satellite rainfall datasets compared with rainfall observed data on a daily, monthly, and annual basis for all studied locations. High values of r and NSE; small values of RMSE; and Bias values of 1 (or near to 1) indicate good performance of the satellite rainfall products.

3.1 Evaluation of Daily Satellite Rainfall Estimates

All three satellite estimates among the six studied stations have a weak correlation with observed data, except ERA5 at Alexandria, and Dabaa, which show a moderate correlation where the value of r equals 0.51, and 0.4 respectively. In addition, NSE values were unsatisfactory across six studied stations for all three satellite estimates, where all values are less than 0. Furthermore, RMSE shows a poor fit to the data, where ERA5 shows higher values than both GLDAS and TAMSAT. On the other hand, Bias values were satisfactory for GLDAS at three locations, where Bias values equal 1.20, 1.04, and 0.87 at Mersa Matruh, Dabaa, and Alexandria respectively. Moreover, Bias values were satisfactory for TAMSAT at three locations, where Bias values equal 1.15, 0.84, and 0.83 at Sallum Plateau, Mersa Matruh, and Dabaa respectively. The most notable finding of this analysis was that the performance of the daily timescale is poor and can be ignored as shown in Fig. (2). This finding may be due to the measurement time discrepancy between ground-based and satellite rainfall products.

Table 4. Statistical analysis and correlation between the daily-observed data together with (ERA5, GLDAS, and TAMSAT) during the period from 2007 to 2021.

Station	Dataset	r	RMSE	NSE	Bias
Sallum Plateau	ERA5	0.16	5.2	-4.39	5.00
	GLDAS	0.10	3.05	-0.85	2.40
	TAMSAT	0.08	2.78	-0.54	1.15
Mersa Matruh	ERA5	0.25	4.02	-0.51	1.79
	GLDAS	0.10	3.82	-0.36	1.20
	TAMSAT	0.004	3.89	-0.41	0.84
Dabaa	ERA5	0.40	3.29	-1.88	2.19

	GLDAS	0.15	2.47	-0.63	1.04
	TAMSAT	0.11	2.41	-0.54	0.83
Alexandria	ERA5	0.51	6.99	-4.39	3.29
	GLDAS	0.15	3.67	-0.48	0.87
	TAMSAT	0.02	3.85	-0.64	0.55
Port Said	ERA5	0.31	4.31	-11.48	7.05
	GLDAS	0.16	1.81	-1.19	2.56
	TAMSAT	0.03	1.64	-0.81	1.73
El Arish	ERA5	0.32	7.41	-14.04	8.03
	GLDAS	0.09	2.96	-1.39	1.89
	TAMSAT	0.03	3.27	-1.92	2.26

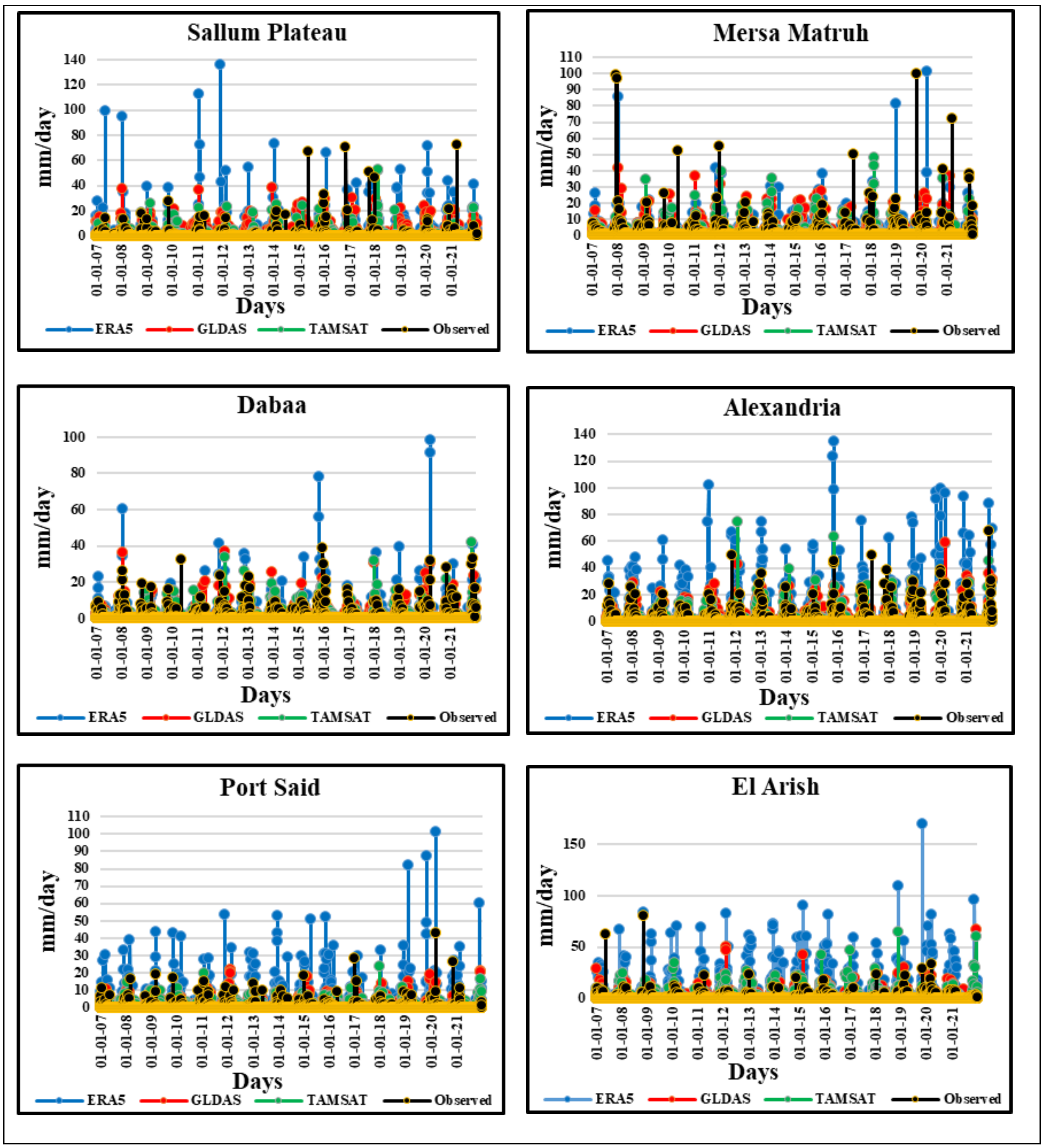

Fig. 2. Daily time series for considered satellite rainfall estimates compared to observed data during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

3.1.1 Evaluation of Monthly Satellite Rainfall Estimates

Monthly statistical evaluation results for each satellite rainfall estimate at six studied locations were presented in scatter points charts, Fig. (3). The results of statistical evaluation indices (r, RMSE, NSE, and Bias) were calculated to evaluate satellite rainfall estimates performance compared with monthly rainfall observed data at six studied locations are listed in Table (5).

Referring to strong correlation r values were higher than 0.7 for ERA5, and GLDAS at Alexandria, and Dabaa, where the value of r equals 0.87, and 0.8 for ERA5 at Alexandria, and Dabaa respectively, and the value of r equals 0.8, and 0.77 for GLDAS at Alexandria, and Dabaa respectively, otherwise r values for TAMSAT at all stations < 0.3, which means weak correlation.

GLDAS shows the most acceptable results at Mersa Matruh, Dabaa, and Alexandria, where at Mersa Matruh r, RMSE, NSE, and Bias were 0.56, 19.82, 0.27, and 1.2 respectively, while at Dabaa they were 0.77, 11.24, 0.58, and 1.04 respectively. Finally, at Alexandria, they were 0.8, 19.61, 0.6, and 0.87 respectively. Whereas, at Sallum Plateau, Port Said, and El Arish results are not acceptable. TAMSAT results show weak correlation at all stations, underestimate at Mersa Matruh, Dabaa, and Alexandria, and overestimate at Sallum Plateau, Port Said, and El Arish. ERA5 results show a weak correlation at all stations except Dabaa and Alexandria and also show overestimated values at all stations. NSE values were unsatisfactory for both TAMSAT and ERA5 across six studied stations, where all values were less than 0.

Table 5. Statistical analysis and correlation between the monthly-observed data together with (ERA5, GLDAS, and TAMSAT) during the period from 2007 to 2021.

Station	Dataset	r	RMSE	NSE	Bias
Sallum Plateau	ERA5	0.48	46.1	-10.28	5.00
	GLDAS	0.45	18.19	-0.76	2.40
	TAMSAT	0.09	21.14	-1.37	1.15
Mersa Matruh	ERA5	0.50	28.26	-0.47	1.79
	GLDAS	0.56	19.82	0.27	1.20
	TAMSAT	0.11	28.86	-0.54	0.84
Dabaa	ERA5	0.80	24.43	-0.97	2.19
	GLDAS	0.77	11.24	0.58	1.04
	TAMSAT	0.28	18.43	-0.12	0.83
Alexandria	ERA5	0.87	72.17	-4.46	3.29
	GLDAS	0.80	19.61	0.60	0.87
	TAMSAT	0.15	35.66	-0.33	0.55
Port Said	ERA5	0.64	46.43	-30.08	7.05
	GLDAS	0.57	13.2	-1.51	2.56
	TAMSAT	0.22	11.85	-1.02	1.73
El Arish	ERA5	0.62	84.74	-36.18	8.03
	GLDAS	0.50	16.67	-0.44	1.89
	TAMSAT	0.23	24.62	-2.14	2.26

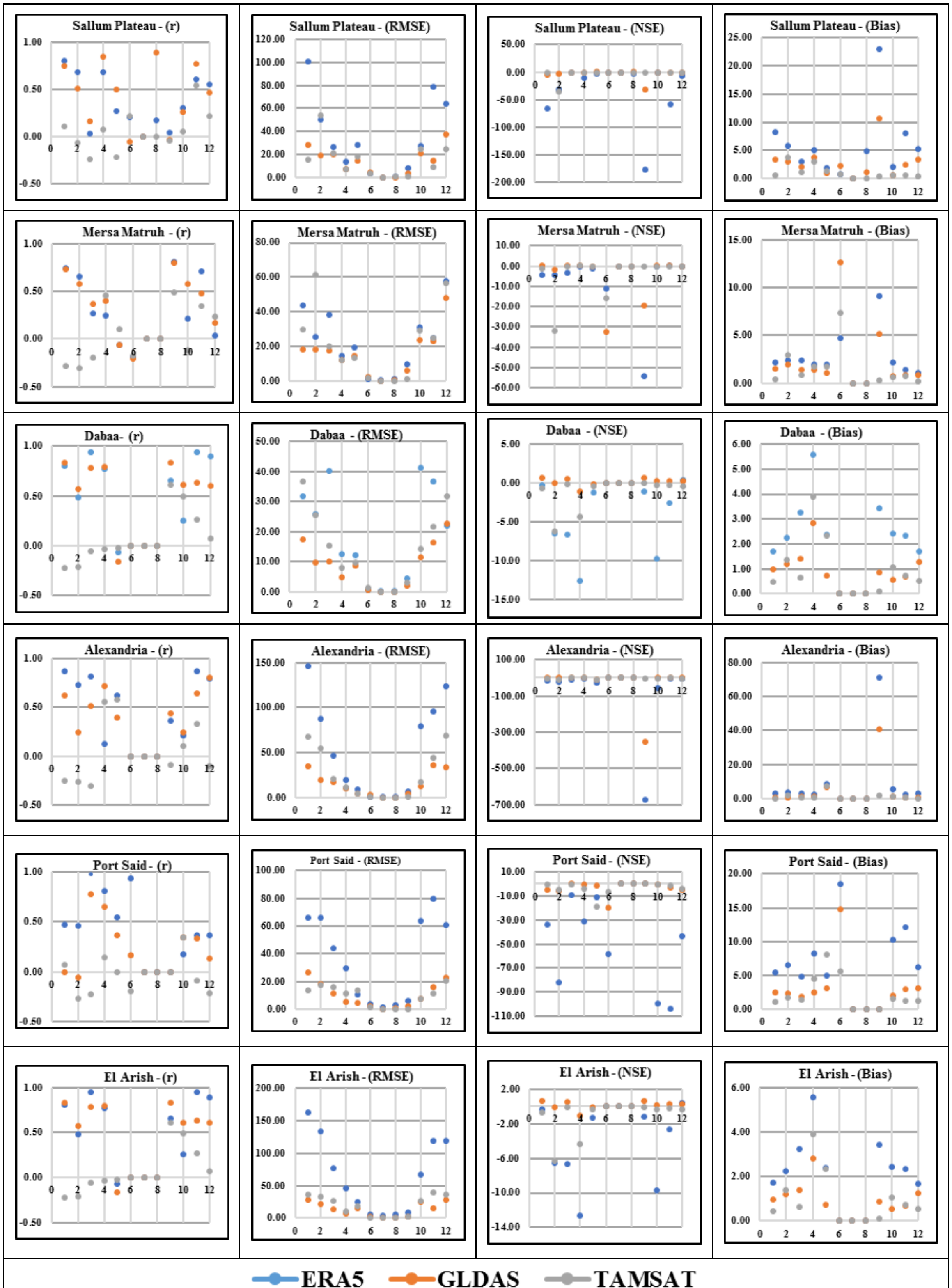

Fig. 3. Monthly statistical evaluation results for considered satellite rainfall estimates during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

3.1.2 Evaluation of Annual Satellite Rainfall Estimates

Fig. (4) shows the annual rainfall amounts for satellite rainfall estimations for the investigated locations. The outcomes of statistical evaluation indices created to assess the performance of satellite rainfall estimates in comparison with rainfall observed data on an annual basis are provided in Table (6).

ERA5 results show weak correlation at all stations except Dabaa and Alexandria. Where r values are 0.8, and 0.74 respectively. Moreover, all other statistical evaluation indices results were unsatisfactory across six studied stations, where RMSE values are very high, NSE values are less than 0, and Bias values shows overestimate.

TAMSAT results show a very weak correlation at all stations, where the maximum r values are 0.28 at Alexandria, NSE results were unsatisfactory across six studied stations with values less than 0, Bias values show an overestimate at Sallum Plateau, Port Said, and El Arish, but underestimated at Mersa Matruh, Dabaa, and Alexandria, only RMSE results are accepted at Sallum Plateau and Port Said with values of 81.89, and 59.39 respectively.

GLDAS shows the most acceptable results at Dabaa, and Alexandria, where at Dabaa r, RMSE, NSE, and Bias were 0.67, 40.66, 0.43, and 1.04 respectively. However, at Alexandria they were 0.71, 66.93, 0.4, and 0.87 respectively. While, at Sallum Plateau, Mersa Matruh, Port Said, and El Arish results are not acceptable.

Table 6. Statistical analysis and correlation between the annual-observed data together with (ERA5, GLDAS, and TAMSAT) during the period from 2007 to 2021.

Station	Dataset	r	RMSE	NSE	Bias
Sallum Plateau	ERA5	0.45	309.32	-29.71	5.00
	GLDAS	0.67	107.2	-2.69	2.40
	TAMSAT	-0.19	81.89	-1.15	1.15
Mersa Matruh	ERA5	-0.01	153.94	-6.50	1.79
	GLDAS	-0.03	76.6	-0.86	1.20
	TAMSAT	-0.27	90.66	-1.60	0.84
Dabaa	ERA5	0.80	163.78	-8.30	2.19
	GLDAS	0.67	40.66	0.43	1.04
	TAMSAT	0.19	64.32	-0.43	0.83
Alexandria	ERA5	0.74	513.1	-34.30	3.29
	GLDAS	0.71	66.93	0.40	0.87
	TAMSAT	0.28	133.92	-1.37	0.55
Port Said	ERA5	0.36	348.34	-216.45	7.05
	GLDAS	0.26	92.77	-14.42	2.56
	TAMSAT	-0.62	59.39	-5.32	1.73
El Arish	ERA5	0.43	640.18	-123.24	8.03
	GLDAS	0.27	98.54	-1.94	1.89
	TAMSAT	-0.51	153.17	-6.11	2.26

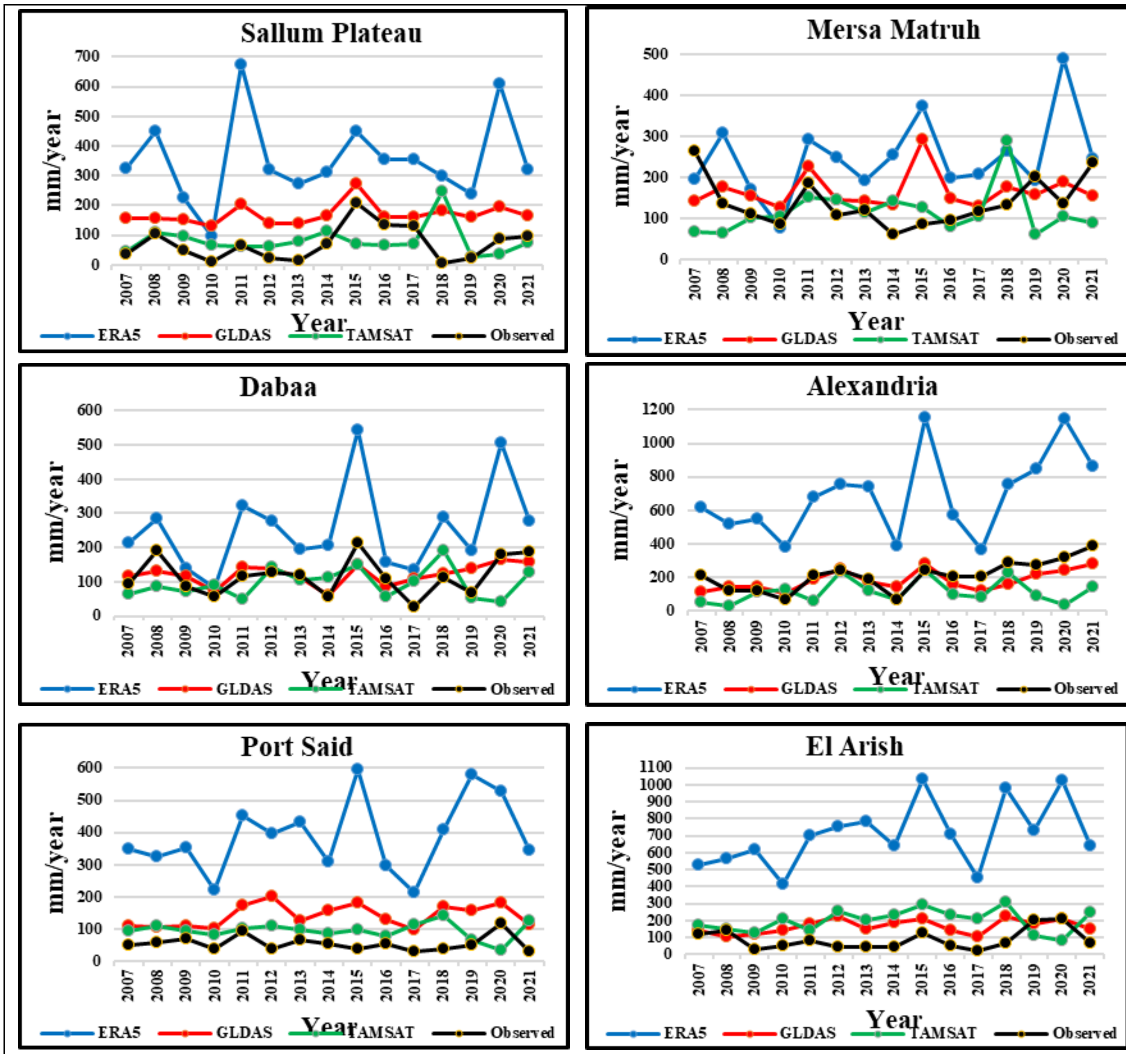

Fig. (4). Annual time series for considered satellite rainfall estimates compared to observed data during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

3.2 Observed rainfall data analysis.

Table (7) shows the descriptive statistics for daily, monthly, and total annually observed data during the period from 2007 to 2021. Where, the maximum mean values were at Alexandria with a value of 0.57mm daily, 17.47mm monthly, and 209.6mm annually. The minimum mean values were at Port Said with a value of 0.15mm daily, 4.57mm monthly, and 54.84mm annually. While, the highest maximum daily and monthly amounts were at Mersa Matruh with a value of 100.08mm and 202.7mm respectively. The highest maximum annual amount was at Alexandria with a value of 384.83mm. On the other hand, the lowest maximum daily amount was at Dabaa with a value of 39.12mm, and the lowest maximum monthly and annual amounts was at Port Said with a value of 55.63mm, and 118.35mm respectively.

Table 7. Descriptive statistics for daily, total monthly, and total annual observed data during the period from 2007 to 2021.

	Station	Mean (Max.)	Median	Sample Variance	STD	Ske.	Kur.
Daily	Sallum Plateau	0.19 (72.14)	0	5.01	2.24	22.59	616.02
	Mersa Matruh	0.38 (100.08)	0	10.74	3.28	20.62	533.28
	Dabaa	0.32 (39.12)	0	3.75	1.94	10.29	135.16
	Alexandria	0.57 (68.07)	0	3.01	9.07	9.62	127.21
	Port Said	0.15 (42.93)	0	1.49	1.22	17.14	421.66
	El Arish	0.24 (80.01)	0	3.66	1.91	23.62	798.81
Monthly	Sallum Plateau	5.88 (85.09)	0	189.4	13.76	3.55	13.82
	Mersa Matruh	11.53 (202.7)	1.15	544.64	23.34	4.23	26.5
	Dabaa	9.7 (102.35)	0.76	305.12	17.47	2.7	8.41
	Alexandria	17.47 (145.31)	1.02	959.59	30.98	2.25	4.79
	Port Said	4.57 (55.63)	0.25	69.75	8.35	2.84	10.25
	El Arish	7.32 (92.2)	0.76	194.25	13.94	3.09	11.67
Annual	Sallum Plateau	70.61 (209.55)	64.77	3337.8	57.78	0.97	0.76
	Mersa Matruh	138.41 (263.13)	120.39	3386.56	58.19	0.98	0.18
	Dabaa	116.42 (215.11)	111.23	3090.05	55.59	0.33	-0.77
	Alexandria	209.60 (384.83)	211.80	7990.85	89.39	0.03	-0.22
	Port Said	54.84 (118.35)	51.33	597.89	24.45	1.50	2.30
	El Arish	87.88 (211.28)	67	3534.40	59.45	1.09	0.14

The intensity of rainfall during the period from 2007 to 2021 for all six locations is given in Table (8). Where, all six stations had no slight drizzle during the study period, heavy drizzle and moderate rain were the most frequent rainfall intensity among all stations where the percentage from the total number of rainy days ranged from (22-39%) and (23-41%) respectively, except El Arish which has moderate drizzle and heavy drizzle more than moderate rain. The most notable finding of this analysis was that extreme rainfall is rare in the study period, where there were no extreme events at Dabaa, and Port Said at all. While, Sallum Plateau, Mersa Matruh, Alexandria, and El Arish extreme events were 4, 7, 3, and 2 times respectively, which represents a percentage of (1-2%) from the total number of rainy days. There is no evidence proofing that extreme rainy days have a climatic change signature.

Table 8 The frequency and intensity of rainfall during the period from 2007 to 2021.

Station	No. of rainy days	Slight drizzle 0 - 0.1 mm/day	Moderate drizzle 0.1 - 0.5 mm/day	Heavy drizzle 0.5 - 1.5 mm/day	Slight rain 1.5 - 2.5 mm/day	Moderate rain 2.5 - 10 mm/day	Heavy rain 10 - 50 mm/day	Extreme rain > 50 mm/day
Sallum Plateau	221	0	33 (15%)	74 (33%)	25 (11%)	63 (29%)	22 (10%)	4 (2%)
Mersa Matruh	431	0	44 (10%)	143 (33%)	60 (14%)	149 (35%)	28 (6%)	7 (2%)
Dabaa	426	0	49 (12%)	138 (32%)	58 (14%)	142 (33%)	39 (9%)	0 (0%)
Alexandria	535	0	24 (4%)	120 (22%)	93 (17%)	219 (41%)	76 (14%)	3 (1%)
Port Said	305	0	53 (17%)	120 (39%)	46 (15%)	72 (24%)	14 (5%)	0 (0%)
El Arish	510	0	163 (32%)	144 (28%)	67 (13%)	117 (23%)	17 (3%)	2 (1%)

3.2.1 Monthly rainfall pattern

The statistics of the total monthly rainfall for all six locations over the 15 years of investigation are given in Table (9). January had the highest total monthly rainfall amount for three stations with the amount of 434.15, 857.66, and 197.1mm at Dabaa, Alexandria, and Port Said, respectively. October had the highest total monthly rainfall amount of 204.19mm at Sallum Plateau. Also, February had the highest total monthly rainfall amount of 247.12mm at El Arish. Finally, at Mersa Matruh, the highest total monthly rainfall amount occurred in December (592.11mm). The lowest total monthly rainfall amount was in June with the amount of 2.04, 2.03, and 0.21mm at Mersa Matruh, Port Said, and El Arish, respectively. Also, September had the lowest total monthly rainfall amount of 18.55, and 1.02mm at Dabaa, and Alexandria, respectively. Finally, at Sallum Plateau, the lowest total monthly rainfall amount occurred in August (2.03mm). The main noteworthy result of this analysis was that rainfall is primarily concentrated between October and March, with variable little amounts occurring in

April, May, June, August, and September, and total absence in July for all stations as shown in Fig. (5).

Table 9. Total monthly rainfall amount (mm) during 2007 - 2021.

	Month	Sallum Plateau	Mersa Matruh	Dabaa	Alexandria	Port Said	El Arish
Total monthly rainfall amount (mm) during 2007 - 2021	January	169.94	382.23	434.15	857.66	197.1	238.55
	February	122.56	224.31	235.65	402.85	163.2	247.12
	March	100.32	174.25	147.33	213.61	122.2	211.17
	April	33.79	75.2	29.96	78.48	38.09	45.17
	May	93.74	69.34	40.39	10.17	25.91	87.41
	June	17.81	2.04	0	0	2.03	0.21
	July	0	0	0	0	0	0
	August	2.03	0	0	0	0	0.21
	September	4.25	10.41	18.55	1.02	0	6.3
	October	204.19	169.67	157.38	138.92	56.38	164.71
	November	122.44	376.65	308.82	622.81	86.32	144.6
	December	188.12	592.11	374.1	820.47	131.3	172.86

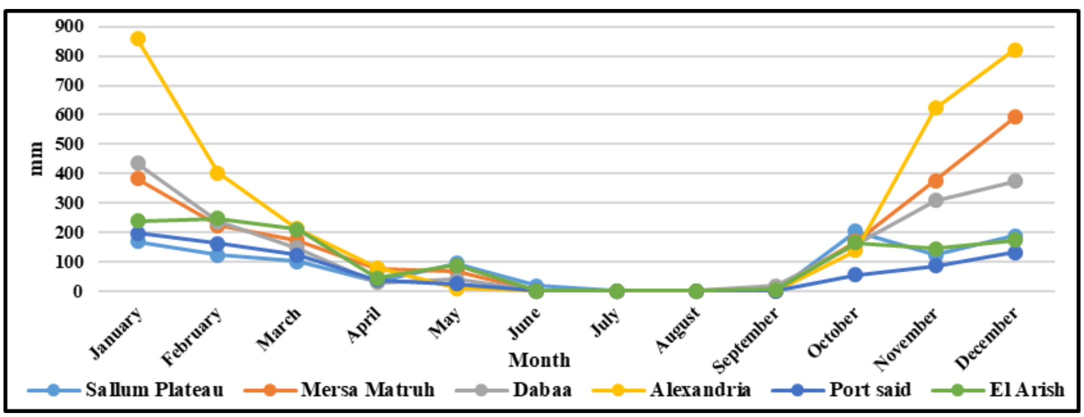

Fig. 5. Total monthly rainfall amount (mm) during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

Table (10) shows the rainy days for all six locations over the 15 years of investigation. January had the highest number of rainy days for five stations with a number of 48, 103, 95, 152, and 71 days at Sallum Plateau, Mersa Matruh, Dabaa, Alexandria, and Port Said, respectively. Also, December had the highest number of rainy days 92 days at El Arish. The lowest number of rainy days was in June for three stations with a number of 2, 1, and 1 days at Mersa Matruh, Port Said, and El Arish, respectively. While the lowest number of rainy days was in September for two stations with a number of 5 and 1 days at Dabaa, and Alexandria, respectively. Sallum Plateau shows the lowest number of rainy days in August with a number of 1 day as shown in Fig. (6).

Table 10. Number of monthly rainy days during 2007 - 2021.

	Month	Sallum Plateau	Mersa Matruh	Dabaa	Alexandria	Port Said	El Arish
No. of monthly rainy days during 2007 - 2021	January	48	103	95	152	71	79
	February	42	76	71	90	65	90
	March	21	42	41	41	36	64
	April	12	23	17	16	19	35
	May	14	8	8	4	7	17
	June	3	2	0	0	1	1
	July	0	0	0	0	0	0
	August	1	0	0	0	0	1
	September	6	6	5	1	0	8
	October	17	24	28	36	21	44
	November	24	57	67	80	34	79
	December	33	90	94	115	51	92

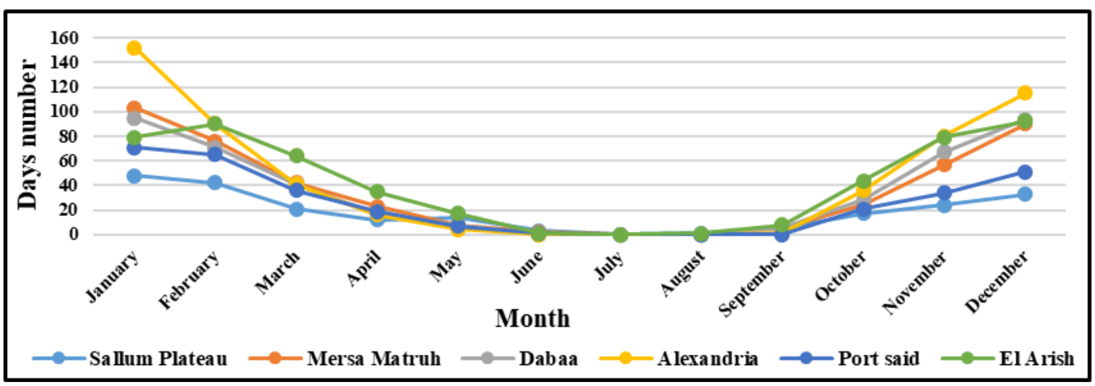

Fig. 6. Number of monthly rainy days during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

3.2.2 Annual rainfall pattern

The statistics of the total annual rainfall for all six locations over the 15 years of investigation are given in Table (11). The highest annual amount of rainfall over the study period was 384.83mm in 2021 in Alexandria, while the minimum was 5.32mm in 2018 in Sallum Plateau. Investigations also revealed that there is a great deal of variability in the rainfall from year to year, where the year 2010 shows the lowest total amount of rainfall with a value of 306.6mm over all six locations, while the year 2020 shows the highest total amount of rainfall with a value of 1051mm over all six locations. The other notable finding of this analysis was that Port Said had the lowest total rain amount during the study period with a value of 822.54mm, while Alexandria had the highest total rain amount during the study period with a value of 3145.99mm.

Four of the studied stations, Alexandria, El Arish, Sallum Plateau, and Dabaa rainfall showed a positive trend most markedly (14.21, 3.11, 2.86, and 1.75mm/year) respectively. While, Mersa Matruh and Port Said rainfall showed a non-significant trend (0.68, and -0.27mm/year) respectively. Overall, the EMC received a sum of 10169mm during the study period with a positive trend of rainfall amount of (22.33mm/year) as shown in Fig. (7).

Table 11. Total annual rainfall amount (mm) during 2007 - 2021.

	Year	Sallum Plateau	Mersa Matruh	Dabaa	Alexandria	Port Said	El Arish	Total
Total rainfall amount (mm)	2007	34.56	263.13	94.74	215.9	51.33	121.17	780.8
	2008	105.41	137.16	189.74	117.13	59.44	142.72	751.6
	2009	49.52	109.5	86.81	118.13	68.84	33.52	466.3
	2010	8.63	87.12	57.68	67.08	37.08	49.03	306.6
	2011	64.77	185.72	115.06	213.83	93.74	80.41	753.5
	2012	22.86	106.67	128.8	245.62	37.86	44.68	586.5
	2013	15.4	120.39	120.41	186.19	64.01	47.74	554.1
	2014	70.31	60.96	57.65	70.34	52.34	48.25	359.9
	2015	209.55	86.37	215.11	240.83	37.05	127.76	916.7
	2016	134.37	93.98	108.44	205.23	55.61	51.56	649.2
	2017	131.06	116.85	27.18	203.46	31.24	22.6	532.4
	2018	5.32	134.11	111.23	289.14	36.06	70.23	646.1
	2019	22.72	201.94	65.8	271.77	50.3	200.36	812.9
	2020	87.68	135.86	181.07	316.51	118.4	211.28	1051
	2021	97.03	236.45	186.61	384.83	29.29	67	1001
	2007 - 2021	1059.19	2076.21	1746.33	3145.99	822.54	1318.31	10169

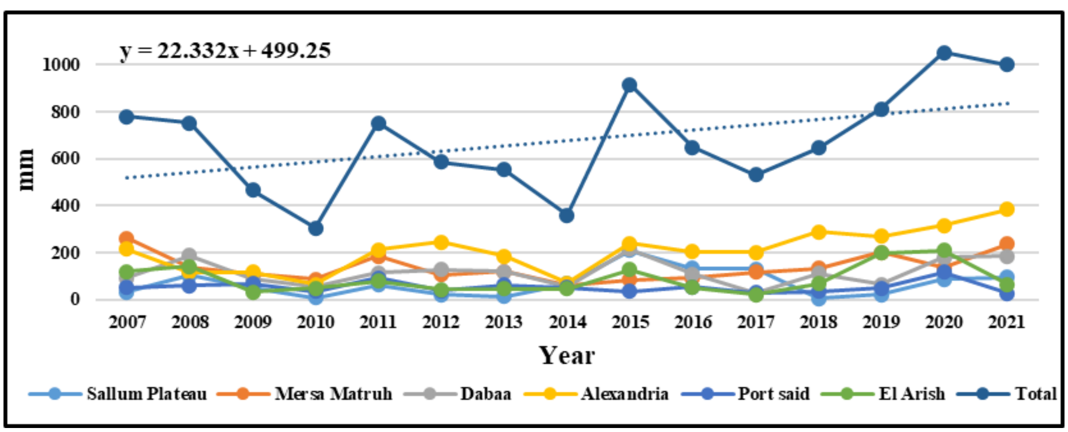

Fig. 7. Total annual rainfall amount (mm) during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

On the other hand, as given in Table (12). Alexandria had the highest number of rainy days over the study period (535 days), while Sallum Plateau had the lowest number (221 days). Total rainy days during the study period show a positive trend of rainy days of (3.478 days per year) as shown in Fig. (8).

Table 12. Number of annual rainy days during 2007 - 2021.

	Year	Sallum Plateau	Mersa Matruh	Dabaa	Alexandria	Port Said	El Arish	Total
No. of rainy days	2007	15	32	32	36	23	23	161
	2008	31	35	41	37	26	22	192
	2009	15	26	28	35	21	13	138
	2010	7	15	14	14	15	16	81
	2011	15	45	41	47	25	44	217
	2012	5	37	38	48	21	22	171
	2013	13	22	27	21	15	10	108
	2014	9	23	25	21	15	16	109
	2015	27	33	39	39	28	31	197
	2016	16	17	20	32	17	27	129
	2017	15	23	11	29	12	9	99
	2018	5	23	23	44	19	45	159
	2019	16	27	20	42	22	81	208
	2020	24	38	42	50	30	89	273
	2021	8	35	25	40	16	62	186
	2007 - 2021	221	431	426	535	305	510	2428

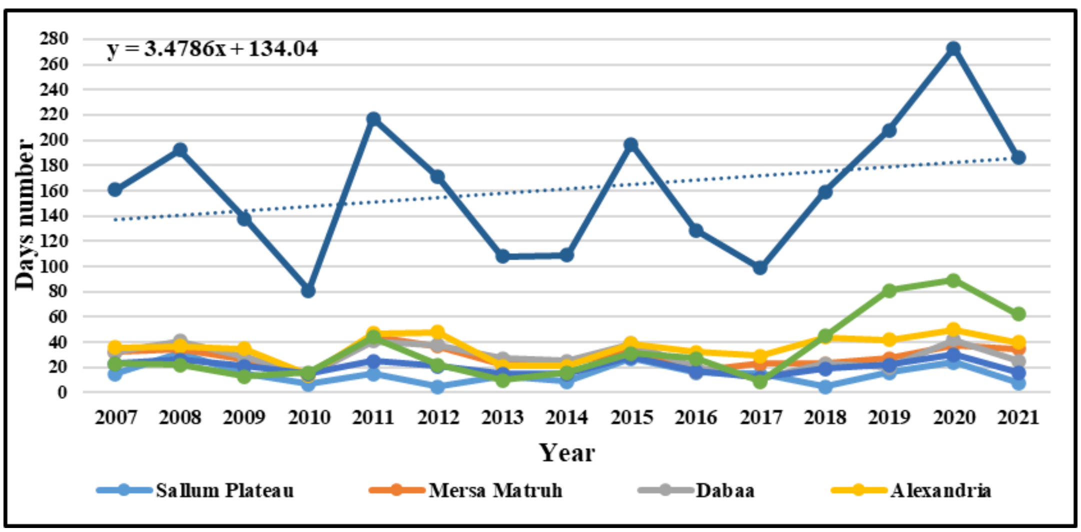

Fig. 8. Number of annual rainy days during (2007-2021) over Sallum Plateau, Mersa Matruh, Dabaa, Alexandria/Nouzha, Port Said, and El Arish.

Table (13) shows the average rain rate for all six locations over the 15 years of investigation. Alexandria had the highest rain rate with an average of (5.88 mm/rainy day), while El Arish had the lowest rain rate average of (2.58mm/rainy day).

Table 13. Annual rain rate during 2007 - 2021.

	Year	Sallum Plateau	Mersa Matruh	Dabaa	Alexandria	Port Said	El Arish
Rate (mm/rainy day)	2007	2.30	8.22	2.96	6.00	2.23	5.27
	2008	3.40	3.92	4.63	3.17	2.29	6.49
	2009	3.30	4.21	3.10	3.38	3.28	2.58
	2010	1.23	5.81	4.12	4.79	2.47	3.06
	2011	4.32	4.13	2.81	4.55	3.75	1.83
	2012	4.57	2.88	3.39	5.12	1.80	2.03
	2013	1.18	5.47	4.46	8.87	4.27	4.77
	2014	7.81	2.65	2.31	3.35	3.49	3.02
	2015	7.76	2.62	5.52	6.18	1.32	4.12
	2016	8.40	5.53	5.42	6.41	3.27	1.91
	2017	8.74	5.08	2.47	7.02	2.60	2.51
	2018	1.06	5.83	4.84	6.57	1.90	1.56
	2019	1.42	7.48	3.29	6.47	2.29	2.47
	2020	3.65	3.58	4.31	6.33	3.95	2.37
	2021	12.13	6.76	7.46	9.62	1.83	1.08
	2007 - 2021	4.79	4.82	4.1	5.88	2.70	2.58

CONCLUSION

The Egyptian Mediterranean Coast (EMC) is a unique region that experiences a variety of climatic conditions. In the last 15 years, there have been significant changes in the precipitation patterns in this region.

To evaluate the performance of (ERA5, GLDAS, and TAMSAT) satellite rainfall estimates, ground-based observation measurements were used as a reference, and a point-to-pixel-based comparison was carried out at daily, monthly, and annual temporal timescales using various statistical indices.

Daily statistical evaluation results show that all three satellite rainfall products have poor performance, this finding corresponds with the results of earlier research **(Zhao *et al*., 2017; Ayehu *et al*., 2018; Li *et al*., 2018; Kabite Wedajo *et al*., 2021)**.

Monthly statistical evaluation results show that all three satellite rainfall products have discouraging rainfall estimations at Sallum Plateau, Port Said, and El Arish. While, at Mersa Matruh, Dabaa, and Alexandria, GLDAS shows the most acceptable results. Furthermore, ERA5 shows a strong correlation at Alexandria and Dabaa but with overestimated values.

Annual statistical evaluation results show that all three satellite rainfall products have an unsatisfactory rainfall estimation at all six studied stations, except ERA5 at Dabaa and Alexandria, which shows a strong correlation.

Generally, evaluating the performance of (ERA5, GLDAS, and TAMSAT) satellite rainfall estimates over EMC during the study period clearly revealed that none of them are suitable for providing a complete picture of rainfall patterns, which may be due to the Satellite estimates are mainly dependent on detecting the presence of water vapor in the atmosphere, which can be affected by several factors, such as clouds, smoke, and dust. Additionally, the region's topography and climatic conditions affect the rainfall estimation algorithm accuracy. Therefore, satellite rainfall estimate products should be locally evaluated before they are used.

Rainfall variability and trends across EMC have been studied using observed data. The analysis of the daily, monthly, and annual rainfall from 2007 to 2021 shows that Alexandria has the highest rainfall mean values, the highest annual amount of rainfall over the study period was at Alexandria in 2021, the highest number of rainy days and the highest rain rate average also was at Alexandria, while the highest maximum daily and monthly amounts were at Mersa Matruh. On the other hand, Port Said has the lowest rainfall mean values and the lowest maximum monthly and annual amounts.

Investigations also revealed that the rainfall is mainly concentrated between October and March, with variable little amounts occurring in April, May, and September and almost absent in June, July, and August, with the highest number of rainy days in December and January. Interestingly, EMC has an annual average rainy day of 27 days, most markedly over Alexandria (35.6 days) and El Arish (34 days). Among those rainy days, only 2.3 days are characterized by heavy and extreme rain.

The most frequent rainfall intensities across the EMC during the study period were heavy drizzle and moderate rain, while there was no slight drizzle and extreme rainfall was rare. We can say that there is a great deal of variability in the rainfall from year to year, the annual rainfall trend analysis of this study clearly shows a significant increase in annual rainfall across the EMC with a positive trend of (22.332mm/year) and a positive trend of rainy days' number of (3.478 days/year), this finding corresponds with the results of earlier research **(El-Geziry, 2021).**

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REFERENCES

- **Adler, R. F.; Huffman, G. J.; Chang, A.; Ferraro, R.; Xie, P.-P.; Janowiak, J.; Rudolf, B.; Schneider, U.; Curtis, S.; Bolvin, D.; Gruber, A.; Susskind, J.; Arkin, P. And Nelkin, E. (2003)**. *The Version-2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present)*. http://precip.gsfc.nasa.gov
- **Alahacoon, N.; Edirisinghe, M.; Simwanda, M.; Perera, E. N. C.; Nyirenda, V. R. and Ranagalage, M. (2022)**. Rainfall variability and trends over the african continent

using tamsat data (1983-2020): Towards climate change resilience and adaptation. *Remote Sensing*, *14*(1). https://doi.org/10.3390/rs14010096

- **Ayehu, G. T.; Tadesse, T.; Awoke, B. G.; Dinku, T. and Gessesse, B. (2018)**. Validation of new satellite rainfall products over the Upper Blue Nile Basin, Ethiopia. Atmos. Meas. Tech, 11. https://doi.org/10.5194/amt-2017-294
- **Condom, T.; Rau, P. and Espinoza, J. C. (2011)**. Correction of TRMM 3B43 monthly precipitation data over the mountainous areas of Peru during the period 1998-2007. Hydrological Processes, 25(12): 1924-1933. https://doi.org/10.1002/hyp.7949
- **El-Geziry, T. M. (2021).** Monthly and annual variations in the rainfall pattern along the Southern Levantine Coastline. *Research in Marine Sciences*, 6(2): 915-925.
- **El Kenawy, A.; López-Moreno, J.; M.Vicente-Serrano, S. and Morsi, F. (2010)**. Climatological modeling of monthly air temperature and precipitation in Egypt through GIS techniques. *Climate Research*, 42(2): 161-176. https://doi.org/10.3354/cr00871
- **Franchito, S. H.; Rao, V. B.; Vasques, A. C.; Santo, C. M. E. and Conforte, J. C. (2009)**. Validation of TRMM precipitation radar monthly rainfall estimates over Brazil. Journal of Geophysical Research Atmospheres, 114(2). https://doi.org/10.1029/2007JD009580
- **Gado, T. A.; El-Hagrsy, R. M. and Rashwan, I. M. H. (2019)**. Spatial and temporal rainfall changes in Egypt. *Environmental Science and Pollution Research*, *26*(27): 28228-28242. https://doi.org/10.1007/s11356-019-06039-4
- **Gebremichael, M.; Bitew, M. M.; Hirpa, F. A. and Tesfay, G. N. (2014)**. Accuracy of satellite rainfall estimates in the Blue Nile Basin: Lowland plain versus highland mountain. *Water Resources Research*, *50*(11): 8775-8790. https://doi.org/10.1002/2013WR014500
- **Hamed, M. M.; Nashwan, M. S. and Shahid, S. (2021)**. Performance evaluation of reanalysis precipitation products in Egypt using fuzzy entropy time series similarity analysis. *International Journal of Climatology*, *41*(11): 5431-5446. https://doi.org/10.1002/joc.7286
- **Kabite Wedajo, G.; Kebede Muleta, M. and Gessesse Awoke, B. (2021)**. Performance evaluation of multiple satellite rainfall products for Dhidhessa River Basin (DRB), Ethiopia. Atmospheric Measurement Techniques, 14(3): 2299-2316. https://doi.org/10.5194/amt-14-2299-2021
- **Kummerow, C.; Hong, Y.; Olson, W. S.; Yang, S.; Adler, R. F.; McCollum, J.; Ferraro, R.; Petty, G.; Shin, D. B. and Wilheit, T. T. (2001)**. The evolution of the Goddard profiling algorithm (GPROF) for rainfall estimation from passive microwave sensors. *Journal of Applied Meteorology*, *40*(11): 1801-1820. https://doi.org/10.1175/1520-0450(2001)040<1801:TEOTGP>2.0.CO;2
- **Li, D.; Christakos, G.; Ding, X. and Wu, J. (2018)**. Adequacy of TRMM satellite rainfall data in driving the SWAT modeling of Tiaoxi catchment (Taihu lake basin, China). Journal of Hydrology, 556: 1139-1152. https://doi.org/10.1016/J.JHYDROL.2017.01.006

- **Norrant, C. and Douguédroit, A. (2006)**. Monthly and daily precipitation trends in the Mediterranean (1950-2000). *Theoretical and Applied Climatology*, *83*(1-4): 89-106. https://doi.org/10.1007/s00704-005-0163-y
- **Paredes Trejo, F. J.; Barbosa, H. A.; Peñaloza-Murillo, M. A.; Alejandra Moreno, M. and Farías, A. (2016)**. Intercomparison of improved satellite rainfall estimation with CHIRPS gridded product and rain gauge data over Venezuela. *Atmosfera*, *29*(4): 323-342. https://doi.org/10.20937/ATM.2016.29.04.04
- **Philandras, C. M.; Nastos, P. T.; Kapsomenakis, J.; Douvis, K. C.; Tselioudis, G. and Zerefos, C. S. (2011)**. Long term precipitation trends and variability within the Mediterranean region. *Natural Hazards and Earth System Sciences*, *11*(12): 3235-3250. https://doi.org/10.5194/nhess-11-3235-2011
- **Rodell, M.; Houser, P. R.; Jambor, U.; Gottschalck, J.; Mitchell, K.; Meng, C. J.; Arsenault, K.; Cosgrove, B.; Radakovich, J.; Bosilovich, M.; Entin, J. K.; Walker, J. P.; Lohmann, D. and Toll, D. (2004)**. The Global Land Data Assimilation System. *Bulletin of the American Meteorological Society*, *85*(3): 381-394. https://doi.org/10.1175/BAMS-85-3-381
- **Shahid, S.; Pour, S. H.; Wang, X.; Shourav, S. A.; Minhans, A. and Ismail, T. bin. (2017)**. Impacts and adaptation to climate change in Malaysian real estate. *International Journal of Climate Change Strategies and Management*, *9*(1): 87-103. https://doi.org/10.1108/IJCCSM-01-2016-0001
- **Sharafati, A.; Khazaei, M. R.; Nashwan, M. S.; Al-Ansari, N.; Yaseen, Z. M. and Shahid, S. (2020)**. Assessing the uncertainty associated with flood features due to variability of rainfall and hydrological parameters. *Advances in Civil Engineering*, *2020*. https://doi.org/10.1155/2020/7948902
- **Twardosz, R.; Niedźwiedź, T. and Łupikasza, E. (2011)**. The influence of atmospheric circulation on the type of precipitation (Kraków, southern Poland). *Theoretical and Applied Climatology*, *104*(1-2): 233-250. https://doi.org/10.1007/s00704-010-0340-5
- **World Meteorological Organization (WMO). (2021)**. Guide to Instruments and Methods of Observation Volume I-Measurement of Meteorological Variables.
- **Zhao, Y.; Xie, Q.; Lu, Y. and Hu, B. (2017)**. Hydrologic Evaluation of TRMM Multisatellite Precipitation Analysis for Nanliu River Basin in Humid Southwestern China. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-02704-1