

Article

Variation in Seasonal Precipitation over Gaza (Palestine) and Its Sensitivity to Teleconnection Patterns

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Abstract: The seasonal precipitation (SP) trend and its sensitivity to teleconnection patterns over the East Mediterranean (EM) region remain inconsistent. Based on rainfall records during 1974–2016 at seven meteorological stations in the Gaza region, this study aims to (1) analyze the observed SP trend over the Gaza region, and (2) examine the SP sensitivity to climate indices. Pearson and Spearman correlations between climate indices and SP in the current and following years were calculated, and the seasonal period (particular month) with the highest correlation was identified. Results show that the climate indices, with greater impact on SP over the Gaza region in the autumn and spring, were in the order; El Niño-Southern Oscillation (ENSO) > East Atlantic/Western Russia (EAWR) > North Atlantic Oscillation (NAO) > Arctic Oscillation (AO). The indices' impact was minimal in the winter precipitation. ENSO types' correlations (Southern Oscillation Index-SOI and Niño 3.4) were moderate and significant at $\alpha = 0.05$. Rainfall at most stations positively correlates with AO and EAWR in spring and autumn. During the study period, warm phases of ENSO (i.e., El Niño) intensified autumn precipitation. Simultaneously with warm phases of EAWR or AO, more influence on autumn precipitation is exerted. Cold phases of ENSO (i.e., La Niña) have an adverse impact compared to El Niño. EAWR co-variation was evident only with the ENSO. Regarding AO, a non-meaningful action was noticed during the neutral phases of ENSO and EAWR. The findings of this study help understand and predict the seasonal trend of precipitation over the Gaza region. This is essential to set up climate change mitigation and adaptation strategies in the EM region.

Keywords: climate change; seasonal precipitation; NAO; ENSO; AO; EAWR; East Mediterranean



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1. Introduction

Understanding precipitation changes is fundamental to mitigate its risk and various adaptation measures, especially in developing countries. The latter have high population densities, limited water resources, and poor infrastructures, making them vulnerable to precipitation changes. Extremes in precipitation affect social and economic development and may result in lives losses [1]. It also affects crop yield and regional economic systems negatively [2]. Their current implications are alarming for scientists and decision-makers. The Eastern Mediterranean (EM) is a “hotspot” region, strongly projected to future warming and drying. It is exceptionally vulnerable to anomalies in precipitation extremes [3]. Barlow, et al. [4] and Kaniewski, et al. [2] forecasted severe floods during the rainy season and longevity in the drought season in the EM region. The present economic and political challenges exacerbate this issue.

There is still a discrepancy in the change in seasonal precipitation (SP) over the EM region [4]. Kelley, et al. [5] observed a decreasing trend in rainfall over the Mediterranean after 1950. Shohami, et al. [6] found a non-significant decreasing trend in precipitation over the region during 1964–2003. The change varied between 1 and 20 mm decade^{−1}. Similarly, Alpert, et al. [7] noticed a dominant decreasing trend in the A2 scenario over the EM after 1960. Another study from Steinberger and Gazit-Yaari [8] showed a non-significant decreasing trend, 6 mm decade^{−1}, in rainfall during 1960–1990 over the EM. In

contrary to the previous, other studies documented a growing trend in rainfall over the EM region. Kafle and Bruins [9] found a non-significant positive trend, $6\text{--}21\text{ mm decade}^{-1}$, during 1970–2002 in 12 meteorological stations in the same region. Ziv, et al. [10] noticed a negligible trend in the Gaza region vicinity. Ajjur and Riffi [11] examined the trends in 11 extreme precipitation indices in the Gaza region. Most indices increased after the 1980s. Total precipitation, for example, has risen over two periods 1985–2004 and 2009–2016. The source of variations in the extreme precipitation metrics in [11] is still unknown. These variations seem to be organized in coherent temporal patterns that suggest two options. First, the trend is the consequence of some very wet outlier years that occurred towards the end of the study period and could be attributed to extreme events, which are obvious from max 1- and 5-day precipitation values. Second, the trend is related to other aspects of teleconnection patterns.

There is no agreement on how teleconnection patterns such as the North Atlantic Oscillation (NAO), El Niño-Southern Oscillation (ENSO), Arctic Oscillation (AO), and the East Atlantic/Western Russia (EAWR) contribute in SP over EM region. The relationship between these climate indices and the EM rainfall over the course of seasons is not clear. For example, studies linked the precipitation over EM with the NAO [5,12], the ENSO [4,13], and the EAWR [14]. Cullen, et al. [12] demonstrated that the NAO affects winter rains in the Middle East region. Eshel and Farrell [15] considered that the NAO modules precipitation over the EM region. Kelley, et al. [5] suggested that the Mediterranean winter precipitation decreased due to a positive trend in NAO during 1960–2000. Krichak, et al. [16] observed a reduction of precipitation over the EM when the NAO and the EAWR are both positive. Conversely, Krichak, et al. [17] linked wet (dry) winters in the EM region with positive (negative) EAWR. Black [14] found no correlated variation between NAO and EAWR indices. The correlation between the NAO and the EAWR during winter was 0.12 (non-significant). She showed enhancement of winter precipitation during European circulation regimes. Furthermore, Ben-Gai, et al. [18] and Ziv, et al. [19] found a poor relationship between the NAO/ENSO and precipitation. Donat, et al. [13] found that the NAO and ENSO are less influencing precipitation extremes in the Arab region.

There are some uncertainties associated with SP's projection over the EM region. Using regional climate simulations, Önoğlu and Semazzi [20] reported a significant decreasing trend in winter precipitation (December, January, February) for some Middle East countries. By the end-21st century, the reduction in the A2 scenario will reach 23.7% in Israel and 29% in Jordan, Lebanon, and Syria. Peleg, et al. [21] obtained similar results using four models in the 5th Coupled Model Intercomparison Project Phase (CMIP5). Peleg and co-workers forecasted a 10–22% decreasing trend in precipitation in the north of Israel by the mid-21st century. Similarly, 23 models participating in the CMIP5 agreed that total precipitation would decrease by 20–35% in the EM region [22]. This is consistent with the prediction of Krichak, et al. [23], suggesting a decline in winter rainfall (up to 20%) in the EM region by the end-21st century. According to Evans [24], a significant drop in rainfall rate ($1\text{--}3\text{ mm year}^{-1}$) until the turn of the 22nd century should be expected. Similarly, Terink, et al. [25] suggested a declining trend in rainfall in the Gaza region until the mid-21st century. Contrastingly, Alpert, et al. [7] forecasted an increasing trend in precipitation over the south and central Israel. The trend in A2 and B2 scenarios indicated extreme events as well as drier and wetter conditions in the upcoming years. Using a regional model, Hochman, et al. [26] have predicted an increasing trend in winter and spring precipitation ($\sim 40\%$ under the Representative Concentration Pathway RCP4.5 scenario) in southern Israel. Together, these studies suggest no agreement regarding the trend of SP in the EM region or its sensitivity to teleconnection patterns. Another motivation for current research is that SP over the Gaza region is a local subject of attention. Since 2008, changes in precipitation have resulted in severe floods and droughts. Flash floods caused fatalities, injuries, and substantial losses in homes and infrastructures.

Consequently, the United Nations Development Program gave the highest level of priority to flood contingency plans and measures, but few actions were taken. For

instance, floods caused one fatality and three injuries in January 2013 [1], four deaths, and nine injuries on 6–10 January 2015 [27]. Additionally, floods destroyed more than 217 and 650 homes in 2010 and 2013, respectively [1]. The Gaza region losses due to floods progressively increased over time. About 2000 homes were flooded on 8–9 December 2019 [28]. UNRWA-OCHA [29] stated that every fourth person in the Gaza region lives in flood-prone areas. Regrettably, floodwater is not utilized either, in agriculture, although it makes abundant freshwater available. Seasonal drought is frequent in the region [11]. There is a need to recharge the aquifer in the Gaza region, which is the primary source of water. The longevity of the drought season, along with the high groundwater abstraction, have severely over-exploited the aquifer [30]. As such, climate change consequences (mainly rainfall changes) become disastrous, and the ecological environment of the Gaza region is more fragile [31].

This study clears the discrepancy in the Gaza SP by (1) analyzing the observed trend of SP in the Gaza region between 1974 and 2016, and (2) examining its sensitivity to the principal modes of climate variability, particularly the NAO, ENSO, AO, and EAWR. The findings of this study help understand and predict the seasonal trend of precipitation over the EM region. This is essential to set up mitigation and adaptation plans to avert the negative impacts of flooding and droughts.

1.1. Study Area

The Gaza region is a coastal land ($31^{\circ}13'–31^{\circ}35'$ N, $34^{\circ}13'–34^{\circ}34'$ E), which has an area of 365 km^2 (Figure 1). The total population is 2.1 million inhabitants, with an average density of 5750 individuals per km^2 . The surface elevation varies between 93 m above mean sea level (amsl) in the southeastern areas to msl (0 m) in the western part. The mean annual temperature in the Gaza region is 25°C [32]. According to Köppen-Geiger climate classification, the Gaza region is classified mainly into semi-arid (BSH class) in the middle and southern parts, and temperate with dry summer (Csa class) in the northern region. The small southern part lies under hot-desert (BWh) climate type [33]. Generally, the northern parts receive more rain than the south. During the study period, the annual average rainfall value was 404 mm in the northern region, where it was 230 mm in the southern region. The four seasons are defined in the Gaza region as Spring (March, April, and May-MAM); Summer (June, July, and August-JJA); Autumn (September, October, and November-SON); and Winter (December, and January and February into the following year-DJF).

1.2. Water Scarcity

The dramatic situation of water resources in Gaza makes it vital to understand the reasons behind this situation. Previous literature considered Gaza water scarcity with engineering methods [11,34]; however, attention should be drawn to a discursive analysis that helps understand the causes of the water scarcity problem and how to solve it [35–37]. The current dominant discourse of water scarcity in Gaza includes two narratives: insufficient water resources and lack of fund. The insufficiency narrative emphasizes that Gaza is a small region with a very high population density and minimal water resources (see study area description-Section 1.1). This narrative also includes the negative impact of climate change on water resources [11]. The second narrative (lack of fund) indicates that the water scarcity problems did not receive adequate fund. The non-governmental organizations (NGOs), the primary source of funds for water resources projects, did not implement major projects solving the water scarcity problem like large desalination plants and managed aquifer recharge systems. Further research is needed to investigate these two narratives and explore the discursive construction of Gaza water scarcity. This becomes essential to ensure that all Gazans have access to water, as stated by the sixth indicator in the UN Sustainable Development Goals (SDGs). It is assumed that water crisis discourses such as water security and water, energy, and food security (WEF) nexus are linked to the SDG6 (Sustainable Development Goal 6). Implementing the SDG6 indicator could have unplanned practical consequences for fragile environments such as Gaza [38].

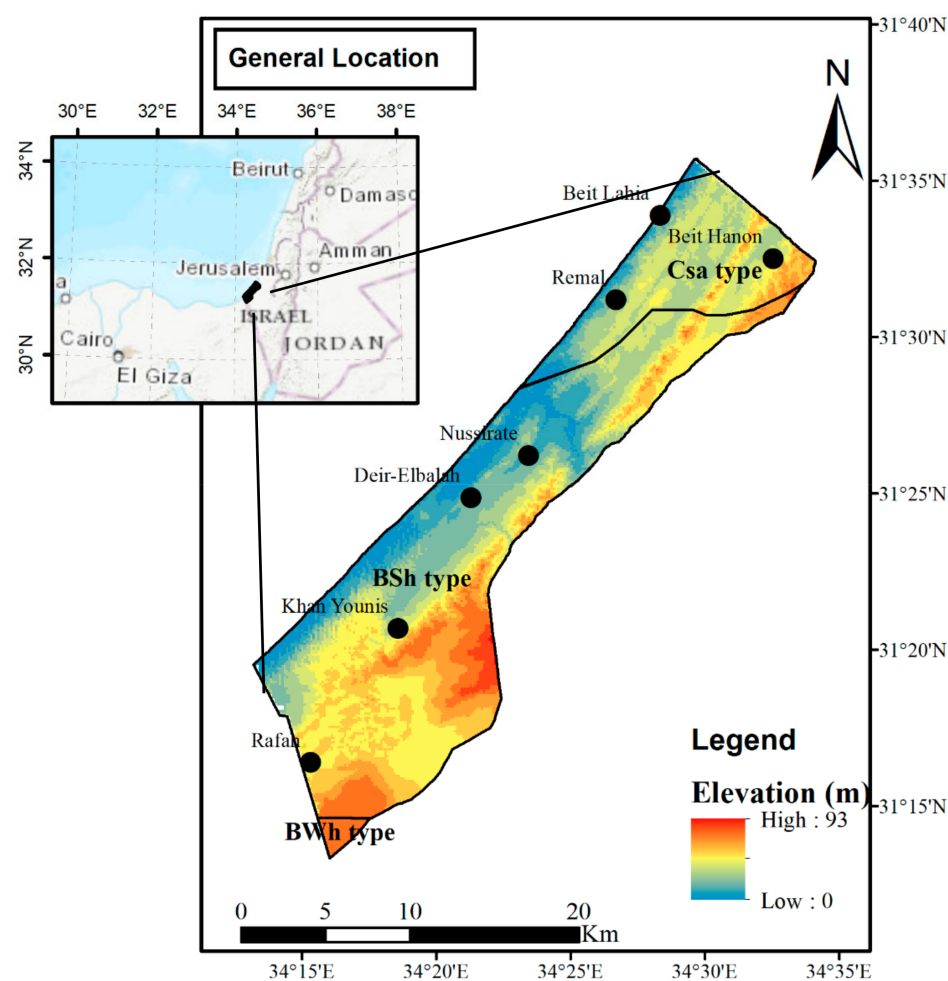


Figure 1. Location map of Gaza, climate classes according to Köppen-Geiger climate classification and meteorological stations.

2. Data and Methods

2.1. Data

There are 12 rain gauge stations recording daily precipitation since 1974 in the Gaza region. Precipitation data at these stations were processed through an appropriate methodology to ensure its homogeneity and quality. An R package software, *RHtests_dlyPrp* [39], was used to test the homogeneity. Additionally, a two-step quality control test was applied as follows: (a) rainfall records have to be comprehensive, and observations collected over more than a day should be less than 5% of rainy days. (b) Following Zhou, et al. [40] approach in Yangtze River extreme precipitation analysis in China, (b) outliers', which surpass five-folds the study period's standard deviation, should be less than 5% of all records. Among the 12 rain gauge stations, only seven stations passed the homogeneity and quality tests. As reported by the Palestinian Ministry of Agriculture, the selected seven stations had no systematic changes in their location or measurement methods during the study period. Only data at the elected stations were further manipulated as follows: (a) accumulated records were distributed similarly between days, and (b) outliers were substituted by the maximum value during the study period. Figure 1 shows the selected stations used in the study. These stations lay in two climate classes (Csa and BSh). The altitude at these stations ranges between 7 and 71 m amsl. The latitude and longitude coordinates and Thiessen weight are shown in Table 1.

Table 1. Meteorological stations in Gaza and climate classes according to Köppen-Geiger climate classification.

Station Name	Latitude_N	Longitude_E	Altitude_m	Climate Class	Thiessen Weight (–)
Beit-Hanon	31°32'30"	34°32'24"	62	Csa (dry temperate)	0.097
Beit-Lahia	31°33'51"	34°28'10"	7		0.057
Remal	31°31'09"	34°26'33"	30		0.156
Nuseirat	31°26'08"	34°23'19"	23	BSHa (semi-arid)	0.128
Deir-Elbalah	31°24'47"	34°21'11"	32		0.105
Khan-Yunes	31°20'35"	34°18'30"	43		0.275
Rafah	31°16'16"	34°15'16"	71		0.181

2.2. Methods

Several statistical and analysis parameters, including the mean (μ), maximum (max), and minimum (min), were computed to understand the characteristics of SP in the Gaza region. Further, the linear least square method and Mann Kendall test were used to detect and evaluate the variation in SP during 1974–2016. The Linear least square method shows the trend of SP, and the Mann Kendall method assesses the direction and significance of this trend. Mann Kendall is a non-parametric statistical method, which does not require a specific distribution of parameters [41]. When Mann Kendall Z value is positive, then the trend is increasing, and vice versa. Significant values of Z must exceed 1.96 (1.645) at 5% (10%) significant level. There might be autocorrelation in small time series (sample size < 50), which increases the probability that the Mann Kendall test will yield a significant trend [42]. Therefore, we applied a prewhitening test to remove any potential effect of serial correlation in SP prior to the Mann Kendall test. No autocorrelation was found in the SP trend at any station. These methods, linear least square, prewhitening, and Mann Kendall, are widely used to analyze rainfall data within time series [6,10,42–46].

Climate indices

This research examined the relationships between several global teleconnection patterns (NAO, ENSO, AO, and EAWR) and the SP over the Gaza region. NAO is a major weather pattern in the North Atlantic Ocean that affects winter precipitation in the northern hemisphere [47]. The NAO index is obtained by the difference in the normalized pressure between Azores (Portugal) and Reykjavik/Stykkisholmur (Iceland) [47]. ENSO is a coupled ocean-atmosphere pattern in the tropical Pacific Ocean, which is considered as the most dominant phenomenon affecting much of the tropics, subtropics, and beyond. There are two extreme opposite phases of the ENSO cycle, which are the warm phase (El Niño) and the cold phase (La Niña). We used two indices to characterize the ENSO types: the Southern Oscillation Index (SOI) [48], and the Niño 3.4 [49]. The SOI is measured by the difference in standardized pressure between Tahiti (central South Pacific Ocean) and Darwin (Australia) [48]. El Niño phase generally corresponds to the negative values of SOI, whereas the positive values indicate the La Niña phase. Niño 3.4 is a prominent index, defined by the average equatorial Sea Surface Temperature (SST) across the central equatorial Pacific (5° S–5° N, 170° W–120° W) [49]. The AO is a weather leading principle phenomenon at the Arctic poles north of 20 degrees latitude [50]. EAWR is a prominent teleconnection pattern that affects Eurasia throughout the year. EAWR index is determined by the pressure difference over the East Atlantic and the North Caspian Sea [51]. Details on the climate indices are available in our data source, the National Oceanographic and Atmospheric Administration (NOAA). The NAO, SOI, Niño 3.4, and AO data are available at https://www.psl.noaa.gov/gcos_wgsp/Timeseries (accessed on 25 May 2020), while the EAWR data are available at <https://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml> (accessed on 25 May 2020).

During 1974–2016, the monthly values of NAO index ranged between −4.7 (December 1996) and 5.26 (February 1997), SOI index ranged between −3.46 (February 1983) and

3.02 (April 2011), Niño 3.4 index ranged between -2.18 (November 1988) and 2.57 (November 2015), AO index ranged between -4.26 (February 2010) and 3.5 (January 1993), and EAWR ranged between -3.30 (August 2016) and 2.72 (February 1998). To classify them, we considered three main classes of each index, as shown in Table 2. Several studies [52,53] adopted similar classifications.

Table 2. The classification of NAO, SOI, Niño 3.4, AO, and EAWR indices.

Indices Range	NAO	SOI	Niño 3.4	AO	EAWR
$I \leq -2$ $-2 < I \leq -1$	Cold	Very active El Niño Active El Niño	Warm	Cold	Cold
$-1 < I \leq 1$	Neutral	Neutral	Neutral	Neutral	Neutral
$1 < I \leq 2$ $I \geq 2$	Warm	Active La Niña very active La Niña	Cold	Warm	Warm

I is the value of each climate index

The Pearson linear correlation and Spearman correlation coefficients between monthly NAO, SOI, Niño 3.4, AO, and EAWR indices, and the SP values over the Gaza region were computed. Pearson correlation tests the linear relationship between variables, whereas Spearman correlation shows the monotonic relationship between two ranked variables. Spearman correlation is a non-parametric test. Both correlation methods are widely used to detect regional rainfall teleconnection with climate indices [10,43,45,52,54,55].

As the global indices may affect SP in the current (0-year) and following (1-year ahead) year [54], then Pearson and Spearman correlation coefficients (r) between SP and monthly climate indices in the current and following years were calculated. The correlation was classified as weak if the absolute r value is between (0.10 and 0.29), moderate (0.30–0.50), and strong (> 0.50). Values between -0.10 and 0.10 indicated no correlation. Further, the Student's t -test was performed at a significance level ($\alpha = 5\%$). We considered a $|p - \text{value}| > 0.05$ as the null hypothesis, which means that there is no correlation ($r = 0$) between climate indices and the SP. On the other hand, the alternative hypothesis is satisfied, and a correlation exists ($r \neq 0$) between climate indices and SP, when $|p - \text{value}| \leq 0.05$. We further identified the month, which has the highest correlation with SP. This month is assumed to have the greatest effect on SP. The time series of each climate index in this month were categorized into different groups, as shown in Table 2. Finally, we computed the anomalies in the seasons in each year to see the overall impact of climate indices on SP. Understanding how SP changes with the classification of global patterns can help forecast future change.

3. Results

3.1. Spatial and Temporal Analysis of SP

Figure 2 shows the average trend of autumn, spring, winter, and annual precipitation in the Gaza region between 1974 and 2016, whereas Table 3 presents a statistical analysis of these trends. Despite the small area of the Gaza region, SP varied temporally and spatially. This is due to the coastal transitioning between the temperate, semi-arid, and arid climates.

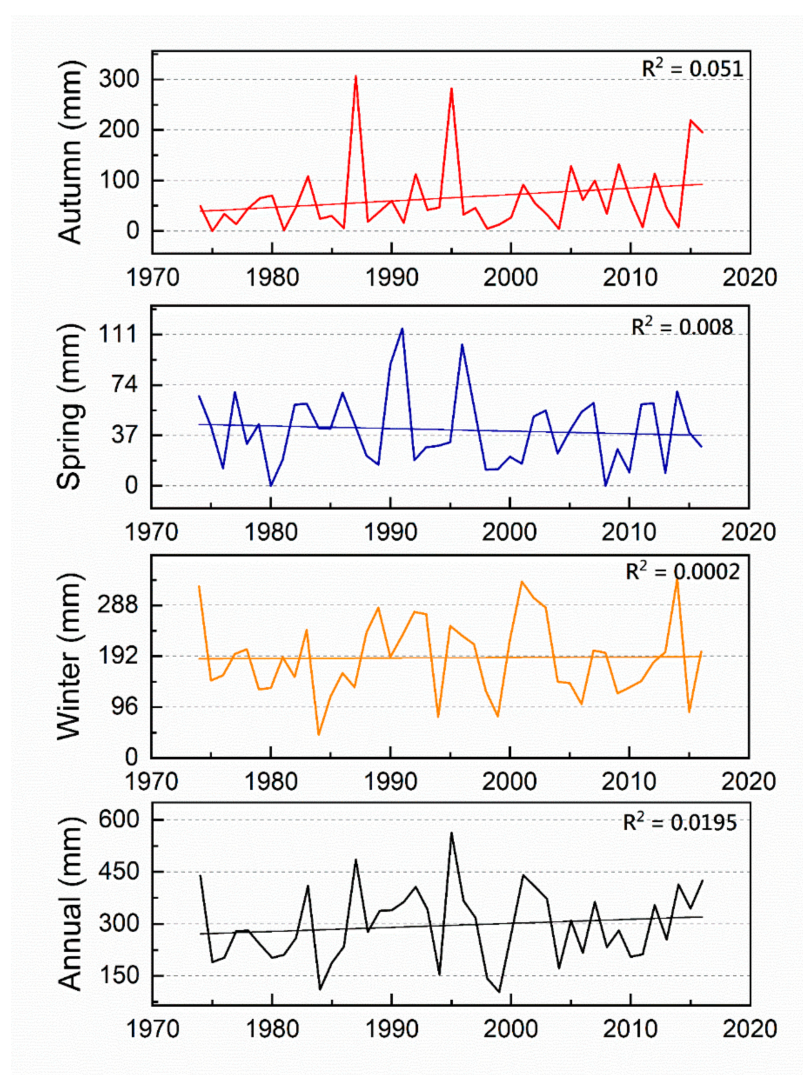


Figure 2. The average seasonal and annual rainfall trends in Gaza between 1974 and 2016. The straight line represents the linear trend.

Table 3. The average long-term (1974–2016) seasonal and annual precipitation trends in Gaza based on linear regression and Mann Kendall test.

Season	Mean (μ)	Max	Min	Average Trenda (Linear Slope)	MK Testa (Z)	Percentage of Stations with Positive Trend	Percentage of Stations with Negative Trend
Winter	188.9	337.1	43.8	0.08	0.02	43%	57%
Spring	41.1	115.5	0	−0.19	−0.55	14%	86%
Summer	-	-	-	-	-	-	-
Autumn	65.9	306.5	0	1.27	1.63	100% (28%)	-
Annual	295.8	563	103.4	1.17	1.15	100	-

Percentage in parentheses indicates stations with significant trends at $\alpha = 0.05$.

Several years have experienced no considerable rainfall in the autumn and spring. For example, in all stations, no rain fell in autumn (1975) and spring (1980 and 2008). On average, no rain (≤ 8 mm) fell in autumn in seven years (1975, 1981, 1986, 1998, 2004, 2011, and 2014). As shown in Table 3, the mean precipitation in autumn was 65.9 mm, while the maximum precipitation was 306.5 mm in 1987. The autumn precipitation at all stations showed an increasing trend, which was significant at $\alpha = 0.05$ in Remal and Nuseirat stations. Autumn precipitation increased for the study period (43 years), at the rate of $1.27 \text{ mm year}^{-1}$ (close to being significant at $\alpha = 0.10$). Spring rains were negligible

(less than 13 mm) in 1976, 1980, 1998, 2008, 2010, and 2013. It is noticeable that half of these were within the last decade of the study period. The mean precipitation in the spring was 41.1 mm. The maximum precipitation was 115.5 mm in 1991. The trend of spring precipitation decreased non-significantly in all stations (except Remal) at a rate of $-0.19 \text{ mm year}^{-1}$. In the winter, precipitation varied, on average, between 43.8 mm in 1984 and 337.1 mm in 2014, with a mean value of 188.9 mm. The precipitation increased in Remal, Khan-Yunes, and Rafah stations, whereas it decreased in other stations. Although insignificant, there was a general increase in precipitation at the rate of $0.08 \text{ mm year}^{-1}$. The winter and autumn significantly contributed to the annual precipitation with up to 64% and 22%, respectively. Only about 13% was recorded in the spring. There was no precipitation in the summer. Annual rainfall reached its maximum (minimum) value of 563 (103.4) mm in 1995 (1999).

Figure 3 depicts how SP varied spatially in the seven stations. There is a general reduction in SP from the northern stations to the southern ones. The highest value of the winter shower was 530 mm at Beit-Hanon station in 2003. The values at other stations were close, to some extent. However, winter precipitation at southern stations (Khan-Yunes and Rafah) were much lower. The maximum winter precipitation at Khan-Yunes was 305 mm in 2001, and at Rafah was 283 mm in 2014. Apart from northern stations, spring rainfall did not exceed 125 mm. In 1991, the maximum spring precipitation fell to 179 mm and 157 mm at Beit-Hanon and Beit-Lahia stations, respectively. At no specific period, the spring precipitation was high at all stations. The highest records hit the Gaza region in 2011 at Remal station, 1996 at Nuseirat and Deir-Elbalah stations, 1991 at Khan-Yunes station, and in 1990 at Rafah station. In autumn, the max precipitation was 409.5 mm at Deir-Elbalah station in 1987. Low values of autumn rainfall were found at Khan-Yunes (293.6 mm in 1987) and Rafah (252.5 mm in 1995). It can be concluded that there is a spatial difference in the distribution of SP over Gaza. To investigate the coherence in SP variability in space, we calculated the correlations among winter, spring, and summer precipitation at all stations. Figure A1 in the Appendix A shows that there is a strong correlation between all SP at stations in the northern and middle parts. Whereas correlations between SP at stations in the southern region (Rafah and Khan-Yunes) and other stations were only strong in autumn.

3.2. Correlation Between Climate Indices and SP

All Pearson linear and Spearman correlation analysis showed that the results are somewhat close. However, several correlations were detected only by one method and not the other. To explore all data patterns and include all possible relationships, we considered the highest value (positive or negative) between both correlations.

Figure 4 displays the correlation values between SP and the NAO, SOI, Niño 3.4, AO, EAWR in the current and following years. It also presents the month where each climate index has the highest impact on SP at each station (labels). A range of correlations were observed with climate indices and the three seasons; NAO correlations ranged between -0.324 (with winter) and 0.47 (with autumn), SOI correlations ranged between -0.574 (with spring) and 0.38 (with autumn), Niño 3.4 correlations ranged between -0.30 (with winter) and 0.53 (with autumn), AO correlations ranged between -0.35 (with spring) and 0.49 (with autumn), and EAWR correlations ranged between -0.35 (with winter) and 0.41 (with autumn). All correlations exceeding 0.30 were significant at $\alpha = 0.05$. The weakest impact of climate indices was on the winter precipitation in general. The most important climate indices, in order of higher impact on SP in the Gaza region, were SOI, Niño 3.4, EAWR, NAO, and AO. The effect of such indices was for the spring and autumn precipitation. Their correlations were weak with winter precipitation.

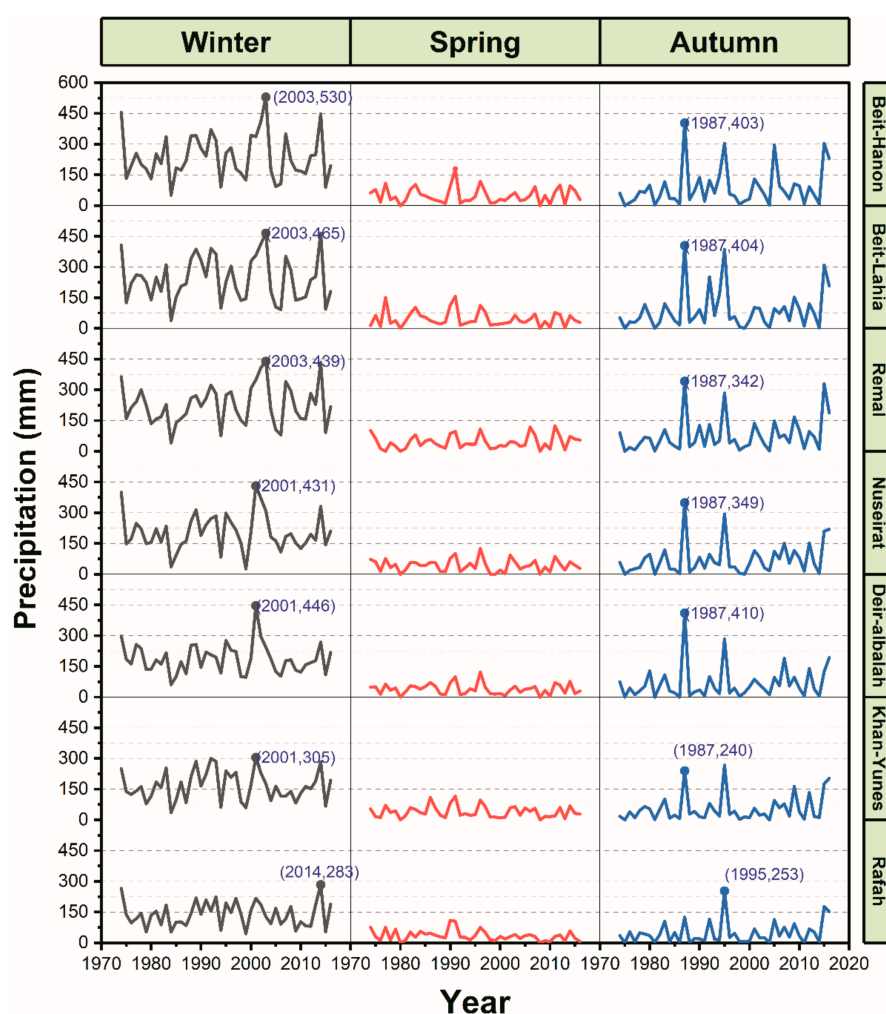


Figure 3. Seasonal precipitation at seven meteorological stations in Gaza during 1974–2016.

According to the NAO, moderate correlations, 0.31 and 0.36, were found in the current winter at two stations only (i.e., Khan-Yunes and Rafah) in August. Other stations showed weak negative correlations. Similarly, correlations for the following year were also weak. In spring, the correlation was mostly positive and weak (0.11–0.35) in both years. This relationship turns to negative (between -0.28 and -0.10) in autumn at all stations, except Rafah correlation was positive. However, comparison with the following year showed that, at 86% of the stations, there was a significant positive correlation between autumn precipitation and NAO (the correlation was between 0.31 and 0.47), raising the possibility of a good relationship with NAO (only in autumn). We can conclude that NAO is less (high) affecting winter and spring (autumn) precipitation over the Gaza region.

No significant correlation was found for the SOI in winter. Correlations were weak and non-meaningful in the current and following years. This implies a negligible impact of SOI on winter precipitation. In spring and autumn, the relationship was evident and significant. Spring precipitation has a moderate negative correlation with SOI in November at all stations (except Remal, the relation was weak). Similar strong correlations were observed when comparing autumn precipitation and SOI in April and May (for the current year) and August (next year). Apart from the Remal station, the present year correlation varied between -0.57 and -0.30 and -0.42 and -0.30 in spring and autumn, respectively. SOI correlation with SP was the most significant among other indices, in general.

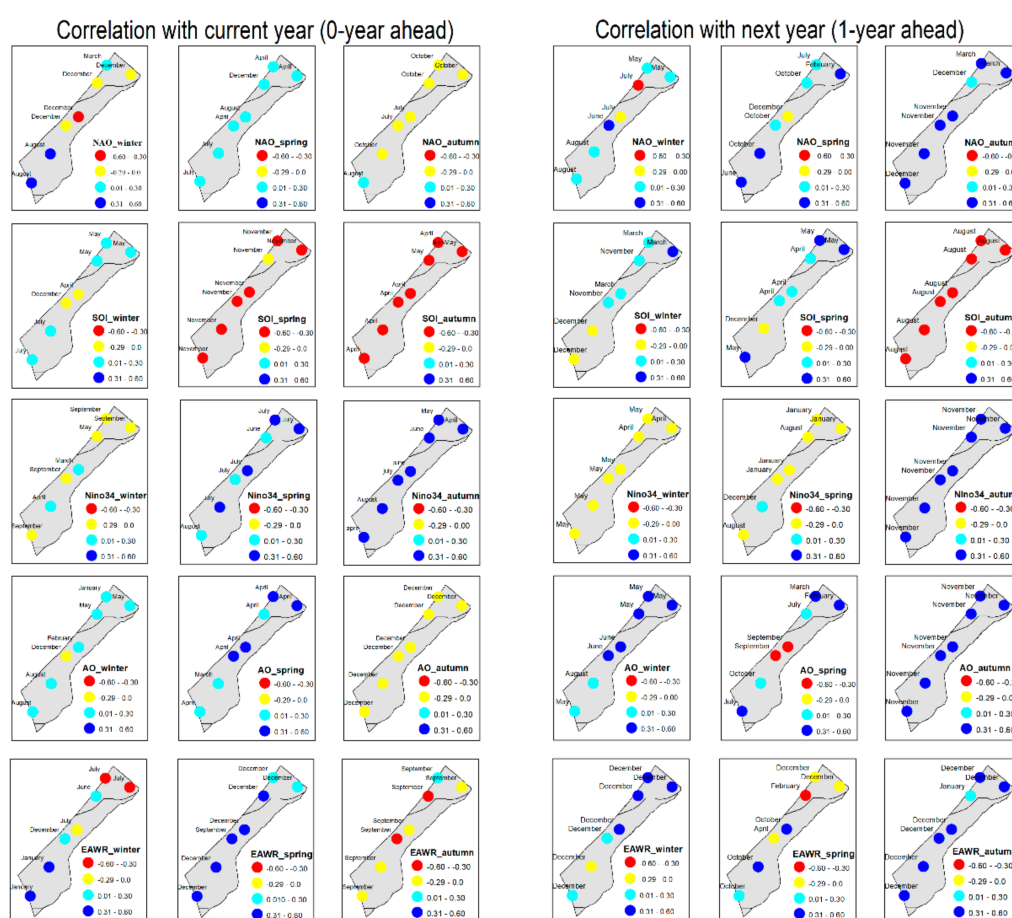


Figure 4. The correlation between the seasonal precipitation over Gaza and the NAO, SOI, Niño 3.4, AO, and EAWR. The left (right) panel shows the correlation with the current (next) year. Labels at the meteorological stations indicate the month, which has the highest correlation with SP.

Similar to SOI, Niño 3.4 correlation was very weak and non-meaningful in the winter. It varied between -0.25 and 0.17 in the current and following years. In contrast, a strong relationship seems to be with spring and autumn precipitation. All stations showed relatively-strong positive correlations (0.40 – 0.53) between autumn precipitation and Niño 3.4. Similar results were observed between spring precipitation and Niño 3.4 in July at 57% of the stations. Other stations showed weak relationships. The correlation with the Niño 3.4 was more evident than the SOI in autumn; however, the SOI correlation is clearer in spring.

The analysis showed no substantial impact of AO on spring precipitation over the Gaza region. Only a positive moderate correlation was between spring precipitation and AO in April at four stations (Beit-Hanon, Beit-Lahia, Nuseirat, and Deir-albalah). Other stations showed weak positive trends. Winter correlation was more evident in the following year. The AO demonstrates a significant positive relationship in all stations except the southern part. In autumn, the correlations were negative at all stations. However, these correlations were weak (value ≤ -0.29) in the current year. It turns to positive and rises to 0.49 in autumn in the following year. This indicates that the positive phase of AO may increase autumn precipitation in the Gaza region.

Results showed no meaningful relationship between winter precipitation and EAWR. The correlation in the current (following) year varied between -0.35 (0.39) at the northern part and 0.4 (-0.27) at the southern part. The impact of EAWR on spring precipitation was more substantial than AO. In spring, all stations showed positive correlations, which were significant at five stations (70% of the stations) in the current year. The relationship with other parts was weak (≤ 0.30). The month of the EAWR with the highest correlation

was December. In autumn, the relationship was mainly weak and negative (moderate and positive) in the current (next) year.

To investigate the overall impact of climate indices on SP in Gaza, the three indices with the highest impact on SP (i.e., SOI, EAWR, and AO) were selected and categorized according to Table 2. We considered SOI to measure ENSO events' intensity, as its impact was more evident in general. Table 4 shows how these categories had varied during the study period. It also presents the anomalies (increase or decrease) in each season. The anomalies were computed as the total variations in precipitation in each season from its long-term (1974–2016) average value. The average precipitation in seasons is presented in Table 3. Results showed that each climate index, or ensemble of two/three climate indices, has its unique impact on spring and autumn precipitation. Anomalies in winter precipitation were not relevant to climate indices categories. Possible conclusions are:

1. The active and very active El Niño phases can intensify autumn precipitation significantly in the Gaza region. Its impact on winter and spring precipitation was not telling. Autumn precipitation increased by 64% in 1983, and 95% in 2005. Additionally, during the active and very active El Niño phases, the warm periods of the EAWR/AO exert more influence on the Gaza region, and the change becomes much more substantial. For instance, during warm EAWR, autumn precipitation increased by 365% in 1987. During warm AO, autumn precipitation increased by 328% in 1995. Autumn precipitation had tripled in 2016 (very active El Niño and warm EAWR and AO).
2. On the other hand, the Gaza region encountered a substantial decrease in autumn precipitation during the active and very active La Niña phases. Spring precipitation might also decrease. For instance, autumn precipitation decreased by 25% in 1974, 100% in 1975, and 55% in 1985. The decrease was typically similar during the cold phases of the EAWR/AO. In 1989 (very active La Niña and cold EAWR), spring (autumn) precipitation decreased by 62% (41%). Similarly, the decline in spring (autumn) precipitation was 48% (59%) in 2000. Both AO and EAWR were in cold phases in 1999, which caused a drop of 70% (81%) in spring (autumn) precipitation.
3. During the neutral phases of EAWR and SOI, AO has a negligible impact on spring and autumn precipitation in the Gaza region. The cold phases of AO decreased autumn precipitation by 97% in 1981, 91% in 1986, and 50% in 2003. Nevertheless, cold AO intensified autumn precipitation by 39% in 2001. In spring, cold AO caused a decline of 53% (61%) in 1981 (2001). However, a dominant rise was noticed in 1986 (66%) and 2003 (34%). Similarly, the warm phases of AO increased autumn precipitation by 73% in 2012; however, it decreased autumn precipitation by 89% in 2014. Its impact was also minimal in 1979.
4. A quite a few changes, especially during the last two decades, still uninterpretable. For example, active La Niña increased spring (autumn) precipitation by 32% (101%) in 2006 (2009). Also, very active La Niña and cold EAWR lead to notable growth in spring precipitation (45%) in 2011. Still, previous inferences (1–3) are highly projected.

Table 4. The classification of climate indices and total changes in seasonal precipitation between 1974 and 2016.

Year	SOI	EAWR	AO	Variation from the Long-Term (1974–2016) Average		
				Winter	Spring	Autumn
1974	active La Niña	Neutral	Neutral	+71%	+60%	−25%
1975	active La Niña	Neutral	Neutral	−23%	+6%	−100%
1976	Neutral	Neutral	Neutral	−16%	−69%	−49%
1977	active El Niño	Neutral	Neutral	+4%	+67%	−79%

Table 4. Cont.

Year	SOI	EAWR	AO	Variation from the Long-Term (1974–2016) Average		
				Winter	Spring	Autumn
1978	Neutral	Neutral	Neutral	+9%	−25%	−32%
1979	Neutral	Neutral	Warm	−31%	+10%	−1%
1980	active El Niño	Neutral	Neutral	−30%	-	+6%
1981	Neutral	Neutral	Cool	-	−53%	−97%
1982	Neutral	Neutral	Neutral	−19%	+45%	−28%
1983	active El Niño	Neutral	Neutral	+28%	+47%	+64%
1984	Neutral	Neutral	Neutral	−77%	+3%	−63%
1985	active La Niña	Neutral	Neutral	−39%	+2%	−55%
1986	Neutral	Neutral	Cool	−15%	+66%	−91%
1987	Very active El Niño	Warm	Neutral	−29%	+11%	+365%
1988	Neutral	Neutral	Neutral	+25%	−46%	−72%
1989	very active La Niña	Cool	Neutral	+50%	−62%	−41%
1990	Neutral	Neutral	Neutral	+1%	+117%	−9%
1991	active El Niño	Neutral	Neutral	+22%	+181%	−75%
1992	Very active El Niño	Warm	Neutral	+46%	−54%	+71%
1993	Very active El Niño	Warm	Neutral	+44%	−31%	−37%
1994	Very active El Niño	Warm	Neutral	−59%	−29%	−29%
1995	active El Niño	Neutral	Warm	+32%	−22%	+328%
1996	Neutral	Neutral	Neutral	+22%	+152%	−50%
1997	active El Niño	Neutral	Neutral	+13%	+41%	−30%
1998	Very active El Niño	Warm	Neutral	−33%	−71%	−93%
1999	very active La Niña	Cool	Cool	−58%	−70%	−81%
2000	active La Niña	Cool	Neutral	+18%	−48%	−59%
2001	Neutral	Neutral	Cool	+76%	−61%	+39%
2002	Neutral	Neutral	Neutral	+60%	+24%	−17%
2003	Neutral	Neutral	Cool	+50%	+34%	−50%
2004	active El Niño	warm	Neutral	−24%	−42%	−94%
2005	active El Niño	Neutral	Neutral	−25%	−2%	+95%
2006	active La Niña	Neutral	Neutral	−46%	+32%	−7%
2007	Neutral	Neutral	Neutral	+7%	+48%	+52%
2008	Neutral	Neutral	Neutral	+5%	-	−47%
2009	active La Niña	Neutral	Neutral	−35%	−35%	+101%
2010	active La Niña	Cool	Neutral	−30%	−84%	−6%
2011	very active La Niña	Cool	Neutral	−23%	+45%	−89%
2012	Neutral	Neutral	Warm	−5%	+47%	+73%
2013	Neutral	Neutral	Neutral	+6%	−77%	−31%
2014	Neutral	Neutral	Warm	+79%	+68%	−89%
2015	Neutral	Neutral	Neutral	−54%	−5%	+232%
2016	Very active El Niño	Warm	Warm	+6%	−29%	+196%

4. Summary and Discussion

This study analyzed rainfall records at seven meteorological stations over the Gaza region to examine the observed trend of SP during 1974–2016 and to investigate its sensitivity to the principal modes of climate variability, particularly the NAO, SOI, Niño 3.4, AO, and EAWR. The results may serve as good indicators for the trend of SP over the EM region.

During 1974–2016, 64% of all precipitation fell in winter, 22% fell in autumn, and 13% fell in spring. Mann Kendall's analysis showed that annual precipitation had increased at all stations, which does not agree (until now) with climate projections in adjacent areas [23,24]. Only Remal station recorded a significant trend at $\alpha = 0.10$ ($Z = 1.88$). Based on Pearson linear and Spearman non-parametric correlations, the SOI, Niño 3.4, EAWR, NAO, and AO have the most significant impact on spring and autumn precipitation, respectively. All correlations varied between -0.574 and 0.52 . The weakest result of the climate indices was in winter, which supports previous literature [56,57], suggesting that winter precipitation is caused by the Red sea trough and mid-latitude cyclones. The

study shows that NAO has a negligible impact on SP compared to the ENSO and EAWR, which agrees with previous works in the EM region [10,19]. However, other studies such as [14,58] stated that positive NAO enhances precipitation in the region. The correlation between NAO and autumn precipitation (in the next year) fills this gap. All stations (except Remal) have significant positive correlations with autumn precipitation (Figure 4). There is no specific month where NAO has the highest impact on autumn precipitation. However, correlations of other indices are clear within particular months. For instance, spring precipitation was correlated to the SOI in November, Niño 3.4 in July, AO in April, and to the EAWR in December. Autumn precipitation was best correlated to the Niño 3.4 and AO in November (next year) and to the EAWR in December (next year).

The presented analysis shows a significant negative relationship between SOI and autumn (spring) precipitation at all (86% of the) stations. It also shows a significant positive correlation between Niño 3.4 and autumn precipitation at all stations. This demonstrates a meaningful relationship between spring and autumn precipitation and ENSO, which is consistent with previous research [13,59]. However, there is a discrepancy with [18,19], who concluded a low correlation with ENSO. This refers partially to the differences in the study period and the spotted index. For example, Price, et al. [59] found a high correlation between 1975 and 1995, while Ziv, et al. [19] found a low correlation between 1950 and 2002. Price, et al. [59] studied the Niño 3 index; however, Ziv, et al. [19] studied southern oscillation. This research examined the correlation between SOI and Niño 3.4 between 1974 and 2016. One should find the appropriate index, which best represents the ENSO in his/her region. The correlation with different indices may lead to different results. Although previous research in the Mediterranean region [13,60] showed that SST indices are less relevant to present the ENSO, our findings prove that SST indices such as Niño 3.4 can also expose the ENSO impact in the EM region. The Niño 3.4 produced slightly stronger correlations than the SOI do in autumn. This indicates the multifaced, complicated and dynamic nature of the ENSO phenomenon and, hence, the necessity to include several different indices when studying its impact on rainfall.

For the EAWR, 70% (86%) of the Gaza stations showed significant positive correlations with spring (autumn) precipitation in the current (following) year. During the study period, warm phases of EAWR increased autumn precipitation up to 365%, whereas cold phases decreased spring and autumn rainfall up to 62%. All warm (cold) phases of EAWR were in El Niño (La Niña) years. On the contrary, warm phases of EAWR were distributed in positive and negative NAO (not shown), which agrees with Black [14], who reported a 57% chance of EAWR positivity when NAO is positive. In other words, the warm EAWR and ENSO were more likely than warm EAWR and warm NAO, demonstrating that warm EAWR works together with El Niño to increase precipitation in the Gaza region. In contrast, cold EAWR works together with La Niña to decrease precipitation in the Gaza region. EAWR co-variation is apparent with the ENSO, not with the NAO.

The present inconsistency of SP sensitivity to global teleconnection patterns in the Mediterranean region is attributed mostly to the study's scale, time period, data limitation and data source. In this study, 43 years might not be sufficient to tell the whole story in the Gaza region. Observing different and more extended time periods can lead to more definite conclusions. In many cases, time-dependent teleconnection climate indices are non-stationary [4,14,60]. Prominent teleconnection patterns such as the NAO, EAWR may also indirectly affect other circulations within a long-time scale. Black [14] confirmed that positive NAO could affect European circulation regimes, which increase winter precipitation over Israel. In addition, previous works acquired data from different sources. Black [14], Xoplaki, et al. [60] used rainfall observations at meteorological stations, whereas Ziv, et al. [19], Saeed and Almazroui [58] used reanalysis data. Others used both sources [16,17]. Given the lack of meteorological stations over the region, uncertainty is highly expected in reanalysis data compared with rain gauge data. Zittis [61] concluded a wide variation, over the Mediterranean region, between monthly precipitation parameters when obtained from different observational datasets (rain gauge and satellite information).

A simple look at Ziv, et al. [19] study supports this idea firmly. The authors extracted ten extremely driest/wettest seasons during 1950–2002 from the archive of the cooperating reanalysis project between the National Center for Environmental Prediction and the National Center for Atmospheric Research Reanalysis (NCEP/NCAR). Among these seasons, five dry and six wet years are after 1974 (the onset of our study period). Comparison with records at the Gaza stations showed a big difference. However, during 1974–2002, two out of the five driest winters (i.e., 1996 and 1991) are wetter than 66% of all winters in the Gaza region. Similarly, one out of the six wettest winters (i.e., 1980) is drier than 76% of all winters in the Gaza. This implies that reanalysis data might not be the optimum source to investigate the trend of SP in the EM region, characterized by spatial complexity.

This study highlights the importance of forecasting future changes in SP. Downscaling from Global Circulation Models (GCMs) is a key concern because of the coarse spatial resolution. This resolution hinders the GCMs' ability to identify local weather conditions in small areas such as Gaza. Improvements are apparent in the GCMs. However, most of them still having large horizontal resolutions. Due to the present uncertainty in the EM region (see introduction part) and the pressing need for forecasting SP in Gaza, further research is highly recommended, and there is a potential for using stochastic rainfall generators to investigate the trend of SP under climate change at the finest hydrological scales [62,63]. The study also sheds light on assessing the impact of SP changes on a regional scale. It is recognized that the correlation measures the dependence (co-variability) of given variables, which does not indicate that there is a causal link between variables. The associated uncertainty should be considered, and better correlations of SP can be obtained with regional circulation indices [64]. The occurrence of periodicity in SP over the region should also be a subject of attention [65]. Still, being a developing area with minimal water resources, the proposed changes in SP over the Gaza region will mostly have principal consequences on the hydrological budget. Examples from adjacent countries such as Lebanon demonstrate the occurrence of these consequences [66]. Possible areas of effect in Gaza are irrigation demand, groundwater resources, the economy, and social development.

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Appendix A

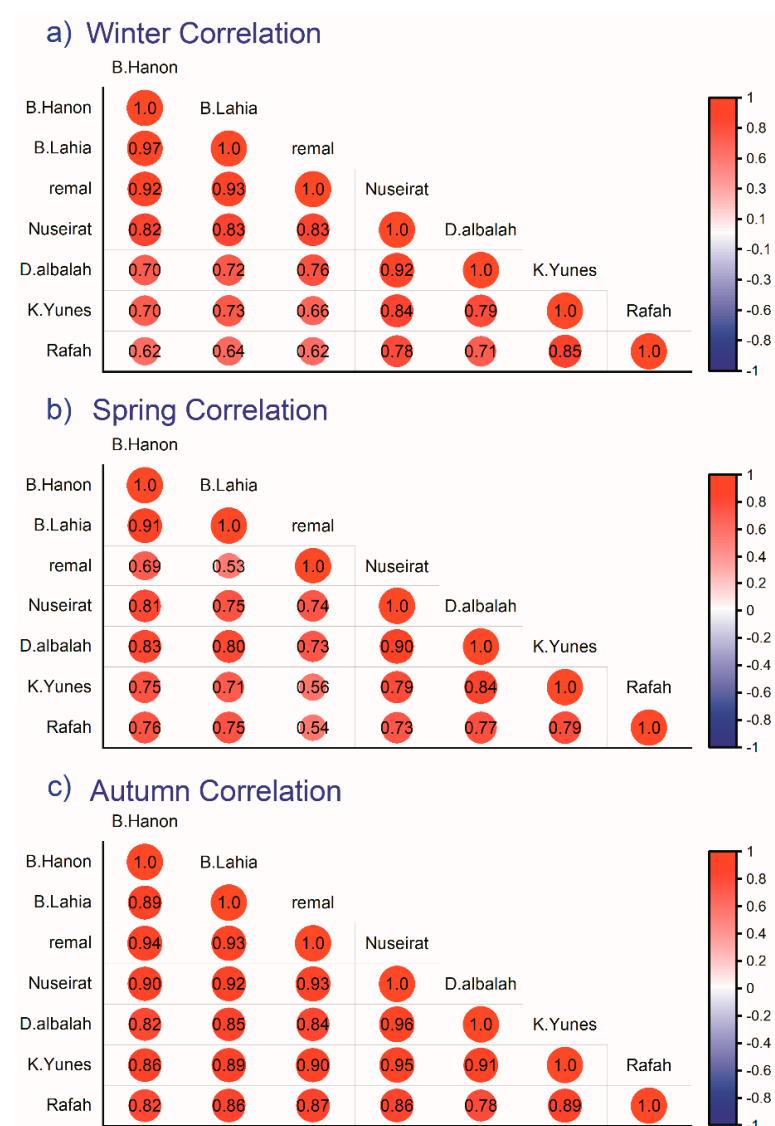


Figure A1. The correlation of seasonal precipitation between Gaza stations.

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