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Changes in Air Temperature and Precipitation over the Syrian Coastal Region (Lattakia Governorate) from 1970 to 2016

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Abstract

This study aims to analyze the changes in the annual and seasonal averages of air temperature and precipitation over Lattakia Governorate during the period 1970-2016. Annual and seasonal trends for temperature and precipitation were calculated by using the non-parametric Mann-Kendall test. The mean differences between the two periods 1970-2000 and 2001-2016, were assessed at the annual and seasonal scales by using the non-parametric Mann-Whitney U test. Furthermore, the occurrence of extreme high/low values were analyzed at the annual scale by using the normal distribution curve.

The study found that the annual temperature averages significantly (p<0.05) increased by 0.22 ˚C/decade and 0.17 ˚C/decade, respectively at Lattakia and Hiffeh stations during the period 1970-2016. Summer exhibited strong and significant (at level 0.01) increasing trends by 0.39 ˚C/decade at Lattakia, and by 0.34 ˚C/decade at Hiffeh. Total spring precipitation significantly decreased by -6.5 mm/decade at Lattakia and by -12.1 mm/decade at Hiffeh. Probability of the occurrence of the value 20.2 ˚C or more as an extreme value increased by 40.8% at Lattakia station during the period 2001-2016.

Keywords: Syria; Mann-Kendall test; Temperature; Precipitation

Resumen

Cambios en la temperatura del aire y las precipitaciones en la región costera de Siria (gobernación de Lattakia) de 1970 a 2016

Este estudio tiene como objetivo analizar los cambios en los promedios anuales y estacionales de la temperatura del aire y las precipitaciones en la gobernación de Lattakia durante 1970-2016. Las tendencias anuales y estacionales para la temperatura y la precipitación se calcularon utilizando la prueba no paramétrica de Mann-Kendall. Las diferencias de medias entre los dos períodos (1970-2000) / (2001-2016) se evaluaron en los niveles anuales y estacionales mediante el uso de la prueba no paramétrica de Mann-Whitney U. Además, la aparición de valores extremadamente altos / bajos se analizó a nivel anual mediante el uso de la curva de distribución normal.

El estudio encontró que los promedios anuales de temperatura aumentaron significativamente (p <0.05) en 0.22 ˚C / década y 0.17 ˚C \ década, en las estaciones de Lattakia y Hiffeh, respectivamente, durante 1970-2016. El verano reveló tendencias fuertes y significativas al alza (a nivel

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0.01) en sus promedios de temperatura en 0.39 ˚C / década en Lattakia, y en 0.34 ˚C / década en Hiffeh. El promedio de precipitaciones de primavera disminuyó significativamente en -6.5 mm / década en Lattakia y en -12.1 mm / década en Hiffeh. La probabilidad de la aparición del valor de 20.2 ˚C o más como valor extremo aumentó en la estación de Lattakia durante 2001-2016 en un 40.8%.

Palabras clave: Siria; Prueba Mann-Kendall; Temperatura; Precipitación

Résumé

Évolution de la température de l'air et des précipitations dans la région côtière syrienne (gouvernorat de Lattaquié) de 1970 à 2016

L'objectif de cette étude est d'analyser les changements dans les moyennes annuelles et saisonnières de la température de l'air et des précipitations sur la région du gouvernorat de Lattaquié entre 1970 et 2016. Les tendances annuelles et saisonnières de la température ont été calculées à l'aide du test non-paramétrique de Mann-Kendall. Les différences moyennes entre les périodes 1970-2000 et 2001-2016 ont été évaluées par année et saison en utilisant le test non-paramétrique de Mann-Whitney U. En ce qui concerne l'occurence de valeurs extrêmement élevées/ basses, celle-ci a été analysée sur une base annuelle en utilisant la courbe de distribution normale.

L'étude a révélé que les températures moyennes annuelles ($p<0,05$) ont augmenté significativement de 0,22 ˚C / décennie et de 0,17 ˚C / décennie, dans les cas respectifs des stations de Lattakia et de Haffah durant la période 1970-2016. L'été a laissé voir une tendance marquée à la hausse (au niveau de 0,01) de ses moyennes de température : 0,39 ˚C / décennie à Lattaquié et 0,34 ˚C / décennie à Hiffeh. La moyenne des précipitations printanières a diminué de manière significative, soit de -6,5 mm / décennie à Lattakia et de -12,1 mm / décennie à Hiffeh. La probabilité d'apparition de la valeur de 20,2 ˚C ou plus comme valeur extrême a augmenté de 40,8% pour la station de Lattaquié pendant la période 2001-2016.

Mots-clés: Syrie; Test de Mann-Kendall; Température; Précipitation

1. Introduction

Climate change has been an issue of special interest globally duo to the fact that it poses serious environmental, economic and social implications. The Mediterranean region is generally more vulnerable to climate change, especially with the existing water resources shortage, weakness of existing infrastructure, low adaptive capacity, frequent drought periods, all of these factors are escalated by the political conflicts and the rapid population growth (Al-Qinna et al., 2011; Lelieveld et al., 2012; Terink et al., 2013). According to the studies of Intergovernmental Panel on Climate Change (IPCC), the rate of warming in southern and eastern Mediterranean over this century will be larger than global average warming, and the annual precipitation is very likely to decrease (IPCC, 2007; IPCC, 2013). Furthermore, southern and eastern Mediterranean regions suffer from severe water shortages of up to 100 m^3/person/year, and some of them reach up to 500 m^3/person/year (Simone, 2011).

The Arab region, although it forms 10.2% of the total area of land, it receives only 2% of the world's average annual precipitation and contains less than 1% of the world's fresh water reserve (Dabour, 2006). Syria is one of the countries which are especially vulnerable to climate change

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due to the dependence of more than 62% of its agricultural lands (equivalent to about 14,258 Km²) on rainfall as the main source of irrigation (Cafiero, 2009). In addition, rainfall represents 68.5% of all available water resources, and the agricultural water requirements are expected to increase by 6% in 2020 (ACSAD, 2011).

Representative examples are the drought episode that hit Syria between 1995 and 2005, causing a severe water deficit averaging of 651 million m³ (Erian et al., 2011), and the drought event during (2007-2010) impacted severely and negatively the social, economic and health of more than a million people in Aleppo, Raqqa, Al-Hasakah and DeirEzzor, where 75% of all wheat production come from (Kelleya et al., 2015; Salah et al., 2018). This lead to a decline in agricultural productivity and a large population migration in the worst drought waves experienced by the eastern regions (Kaniewskia et al., 2012 El-Ashry et al., 2010). Since early 2009 the migration flow increased dramatically where 65,000 families have already abandoned their villages. From this total, 35,000 are from Al-Hasakh and 30,000 from DeirEzzor, Raqqa and Aleppo (UN, 2010). Moreover, the current political situations in Syria can lead to a more critical water scarcity in the nearest future (Mathbouta et al., 2018).

General tendencies of temperature increase and precipitation decrease have been recorded over the last decades across vast areas of the Middle East and North Africa (e.g. Hassanean, 2001, 2004; Zhang et al., 2005; Hassanean and Abdel basset, 2006; Rehman, 2010; AlSarmi and Washington, 2011). The Mediterranean experienced a downward precipitation trend through the second half of the twentieth century (Xoplaki et al., 2004), and this trend is expected to continue, with a decrease of up to 20% in total annual rainfall by the year 2050 (Black, 2009).

This study aims to analyze the temporal changes in the annual and seasonal averages of temperature and precipitation over Lattakia Governorate during the period (1970-2016). We also compared changes in air temperature and rainfall between two sub-periods: 1970-2000 and 2001-2016. We finally assessed the probability densities of occurrence extreme high/low values in the annual averages of temperature and the annual total of precipitation.

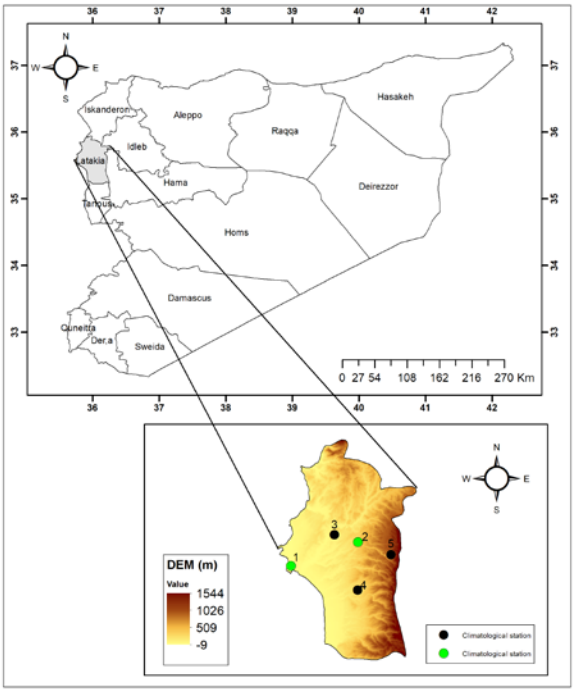
2. Methodology

2.1. Study Area and Data

Lattakia Governorate is situated in the northwestern parts of Syria, between 35.6°N and 36°E. Its area is 2297 Km², and its total population is approximately one million (Syrian Central Bureau of Statistics, 2014). It is bordered by the Iskenderun region from the north and by the Idlib and Hama governorates from the east, and by Tartus governorates from the south and the Mediterranean Sea from the west (Fig. 1).

The study area has a varied topography where it gradually decreases from east to west. Elevation of the eastern and southeastern parts (along the border with Hama governorate) range from 800 to 1544 m. The northeastern parts (along the border with Idlib governorate) and the interior parts of the eastern and southern regions have elevation range (250-800) m, whereas the western and northwestern areas (Syrian coastal areas) are characterized by their low elevations (-9-235) m (Fig. 1). Eastern mountains chain forms a barrier separating between the coastal and inland regions. Besides it affects the climate of the region by limiting the influence of continental (maritime) influences coming from the east (west).

Figure 1. Study area overview and spatial distribution of observed stations. Names of stations as mentioned in Table 1.



A climatic database of monthly air temperature and precipitation for five stations was used for purpose of this study. Not all of these stations were used in the analysis of trends, where they have undergone a data quality control (QC). Such dataset was obtained from the Syrian Meteorological Department (Table 1).

Table 1: Meteorological stations that were used in the study.

No.	Stations	Longitude E	Latitude N	Elevation (m)
1	Lattakia	35.52	35.78	7
2	Hiffeh	35.61	36.05	335
3	Al-Bahlouliyah	35.63	35.95	180
4	Al-Qardahah	35.45	36.05	300
5	Slanfah	35.57	36.18	1173

2.2. Data quality control (QC)

The main aims of (QC) are to identify any systematic errors, missing data and outliers (Alexander et al., 2006; El Kenawy et al., 2013). Time series were filtered based on the temporal continuity (at least 40 years) and coverage for the recent years (at least until 2016). The stations with shorter records or with low data quality (Al-Bahlouliyah, Al-Qardahah and Slanfah) were not used for the trends analysis but they were still useful in completing missing data in longer time series and outliers at nearby stations (distance <25Km, with correlation r > 0.80).

In the first stage, all monthly time series for Lattakia and Hiffeh stations were plotted and scanned to detecting for any systematic errors such as (T < -20, P <0). In the second stage, monthly time series were checked missing data and outliers. In this context, any missing data in one monthly

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value were filled in by average value of neighboring months (temporal interpolation), while missing data in two or more consecutive monthly values were filled in based on the neighboring stations (linear spatial interpolation) with (distance < 25 Km, correlation r > 0.8) (Xu., 2016; Alvera-Azcárate et al., 2007). In the whole data set, the total missing values were 148 values (6.5%) (Table 2).

Table 2: The percentage of missing data and outliers detected in the observed stations.

Stations	(%) of missing data		(%) of outliers	
	Temperature	Precipitation	Temperature	Precipitation
Lattakia	0	0.17	0	0.53
Hiffeh	12.5	11.7	0.88	1.2
Total	12.5	13.6	0.88	1.7

Outlier values are defined as unique observations that deviate significantly from the majority of observations (Posio et al., 2008; Hawkins, 1980). Such observations will negatively affect the compatibility and homogeneity of the data and though the result in statistical analyze errors, leading to erroneous and inaccurate results (Osbome et al., 2004). In this study, the thresholds of outliers were defined within the range of ±3 standard deviations for monthly temperature averages (Hunt., 2007; Harmel et al., 2002), and ±5 standard deviations for the monthly precipitation total (Peterson et al., 1998). The total outliers detected in the whole data set were 15 values (Table 2). All outliers were manually edited by replacing them with the long-term monthly averages of their time series.

In the third stage, monthly time series were tested for homogeneity. A homogeneous climate time series is defined as one where variations are caused only by variation in the weather and climate (Conrad et al., 1950). In this study, two homogeneity tests were selected and applied at 5% significance level, namely SNHT for a single break (Alexandersson, 1986) and Pettitt tests (Pettitt, 1979). The results indicated that all monthly precipitation total at Lattakia and Hiffeh stations were homogeneous according to the two tests. The significant change points found in the same months (May, June, July, August and September) and in the same dates (1994/1997/1998) for Lattakia and Al-Hiffeh stations. For these reasons, the change points detected in the monthly averages of temperature were considered as results of climatic factors. Furthermore, many studies indicated the relationship between heating during El-Niño year 1997/1998 and the change points in this year (Athar, 2014; AlSarmi et al., 2011).

2.3. Trend detection in the annual and seasonal averages

The annual and seasonal time series were derived from monthly time series for each station. Trends for each station at the annual and seasonal scales were calculated by the Mann-Kendall non-parametric test (MK-test) (Mann, 1945; Kendall, 1975) and Sen's slope estimator (Sen, 1968). Mann-Kendall test is less sensitive to the non-normality of a distribution and less affected by outliers in the series (Zhang et al., 2000). The statistical significance of the trends was assessed at the 0.1, 0.05, 0.01 and 0.001 levels.

In addition, the significance of the means shifting in the annual and seasonal averages between the two periods (1970-2000) and (2001-2016) were analyzed using the Mann-Whitney U non-parametric test for two independent samples (Mann and Whitney, 1947). This test does not assume any data distribution or that the differences between the two samples are normally distributed.

The normal distribution curve was applied at the annual scale for temperature averages and precipitation total during (1970-2000) and (2001-2017). This method was used for analyzing the probability density of occurrence extreme high/low values based on the change of areas under the normal distribution curve, between the first (1970-2000) and the second (2001-2017) periods. Prior to applying the normal distribution, the annual averages of temperature and the annual total of precipitation were tested for the normality. In this context, the Jarque-Bera and Lilliefors tests (Jarque and Bera, 1987; Lilliefors, 1967) were applied at 0.05 significance level. The results showed that the annual averages of temperature and the annual total of precipitation were followed the normal distribution.

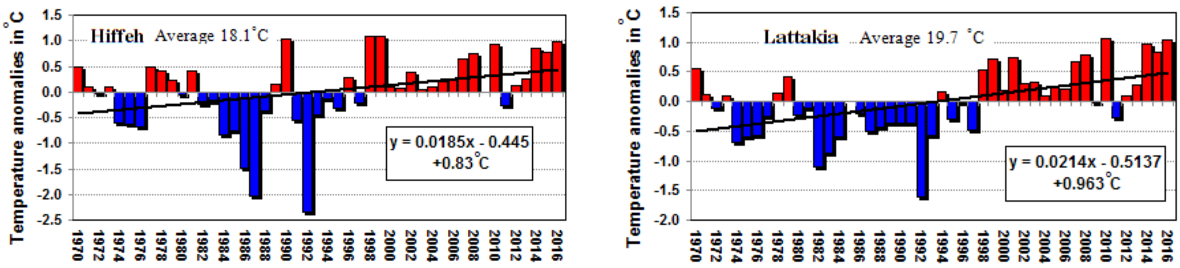
Finally, RStudio V. 3.4.3 was used for all calculations that related to trends, means shifting, outliers, homogeneity and normality. ArcMap V. 10.4.1 was used to design maps.

3. Results

3.1. Changes in temperature.

The long-term annual averages of temperature during (1970-2016) are 19.7 ˚C and 18.1 ˚C at Lattakia and Hiffeh stations, respectively (Fig. 2). The coolest annual averages were in 1992 for Lattakia and Hiffeh stations by 16.4 ˚C and 18.1 ˚C, respectively. The warmest annual average was in 2010 by 20.8 ˚C for Lattakia station, whereas it was in 1998 and 1999 by 19.2 ˚C for Hiffeh station. Trenberth et al. (2007) found that the year 1998 was the warmest year in their study of global land areas, and Kharel Kafle et al. (2007) also found that the years 1992 and 1998 were the coolest and warmest years, respectively in their study of temperature trends in Israel during (1970-2002). Furthermore, the annual averages of temperature have not generally retreated from their long-term average since 1996 at Lattakia Station and since 1998 at Hiffeh station (Fig. 2).

Figure 2. Deviations of the annual temperature averages from their long-term averages.



The results shown in table 3 indicated that the significant increasing trends in the annual and seasonal temperature averages during entire period (1970-2016) at Lattakia station are higher than those at Hiffeh station. The annual averages showed significant increase trends by 0.22 ˚C/decade (at 0.01 significance level) at Lattakia, and by 0.17 ˚C/decade (at 0.05 significance level) at Hiffeh. Rehman (2010) found significant increasing trends at the annual scale of temperature averages over Dhahran. Saudi Arabia during (1970–2006). Furthermore, summer exhibited strong and significant (at 0.01 level) increasing trends by 0.39 ˚C/decade at Lattakia, and by 0.34 ˚C/

decade at Hiffeh. Hasanean et al. (2006) found that the significant and positive trends (warming) in summer temperature occurred over most 19 stations in their study of variability of summer temperature over Egypt. In addition, summer mean temperatures increased at most stations of Turkey (Turkes, et al., 2002).

Apart from summer, Hiffeh station exhibited very weak and non-significant increasing trends for the remaining seasons. On the other hand, Lattakia station also exhibited significant increasing trends for spring and autumn by 0.19 and 0.15 ˚C/decade, respectively. Kenawy et al. (2009) also found significant increasing trends in the annual, summer and spring temperature averages in the most coastal stations in Libya.

In addition, the annual means of the second period (2001-2016) significantly increased by 0.7 ˚C compared with the first period (1970-2000) (at 0.001 level) at Lattakia station and by 0.6 ˚C (at 0.01 level) at Hiffeh station. At the seasonal scale, the summer, spring and autumn means witnessed significant increase at 0.001, 0.001 and 0.05 significance levels, respectively at Lattakia station by 0.8 ˚C, 1.1 ˚C and 0.4 ˚C. For Hiffeh station, spring and summer means witnessed significant increase at 0.05 and 0.001 significance levels, respectively by 0.7 ˚C, and 1.1 ˚C (Table 3).

Table 3: Trends for annual and seasonal temperature averages during (1970-2016), and Mann-Whitney U significance of the difference means for the two periods (1970-2000)/(2001-2016). (***) if trend at α = 0.001 level of significance. (**) if trend at α = 0.01 level of significance. (*) if trend at α = 0.05 level of significance. (+) if trend at α = 0.1 level of significance.

Station	Season	Trend 2016-1970 (°C/decade)	Average 1970-2000	Average 2001-2016	Difference
Lattakia	Year	0.22**	19.5	20.2	0.7***
	Winter	0.13	12.7	13.1	0.4
	Spring	0.19*	17.6	18.4	0.8***
	Summer	0.39**	25.6	26.7	1.1***
	Autumn	0.15*	21.9	22.3	0.4*
Hiffeh	Year	0.17*	17.9	18.5	0.6**
	Winter	0.01	10	10.2	0.2
	Spring	0.09	16.6	17.3	0.7*
	Summer	0.34**	24.6	25.7	1.1***
	Autumn	0.10	20.3	20.6	0.3

Figure 3 shows the normal distribution for the annual averages of temperature during the two periods (1970-2000)/(2001-2017). The increase in the annual averages of temperature during (2001-2016) is accompanied by changes in the probabilities of their occurrence. In this study, the analysis focused on the high/low extreme values, which are equal or less than 5% of the annual averages.

The probability of occurrence of the value 20.2 ˚C (as an extreme value) increased in Lattakia station from 6.7% during (1970-2000) to 45.7% during (2001-2016), by an increase of about 40.8%. It became a non-extreme value in the period (2001-2016). Furthermore, the probability of occurrence annual temperature values, which less than 18 ˚C decreased from 55.9% to 11.9% (Figure. 5).

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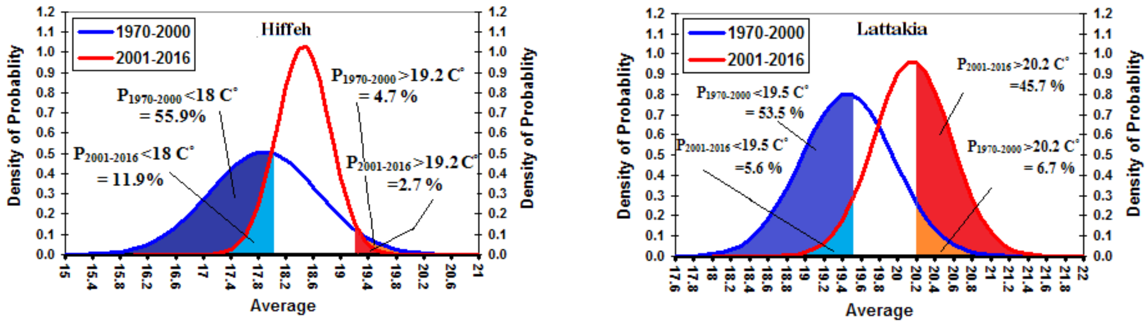
In Hiffeh, the probability of increase for annual temperature averages to more than 19.2 ˚C decreased by of 2%, and the probability of decrease for them to less than 18 ˚C decreased from 53.3% to 5.6%.

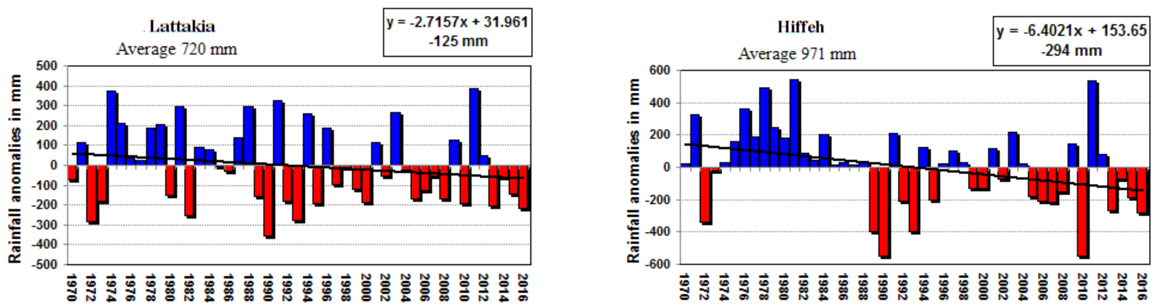
Figure 3. Changes in the probability density of the annual averages of temperature during (2001-2016) compared to (1970-2000). Red color indicates the percentage of increase/decrease in the probability of the extreme values during (1970-2000) that became as normal values during (2001-2016).



3.2. Changes in precipitation.

The long-term annual total of precipitation is 720 mm and 971 mm for Lattakia and Hiffeh stations, respectively. The lowest annual total of precipitation was in 1990 by 362.6 mm at Lattakia, and in 2010 by 422.5 mm at Hiffeh. The highest annual total of precipitation was in 2011 by 1104.4 mm and 1506.6 mm for Lattakia and Hiffeh stations, respectively (Fig 4). It is noticed that the negative deviations from the long-term averages extensively occurred since 1990 onward at the two stations, where during (1970-1990) the most annual precipitation total was above the long-term averages, especially at Hiffeh station (Fig. 4).

Figure 4. Deviations of the annual total of precipitation from their long-term averages.



The results shown in table 4 indicated that the decreasing trends during the period (1970-2016) in the annual and seasonal precipitation at Hiffeh station are higher than those at Lattakia station. Furthermore, the significant ($\alpha \leq 0.05$) changes in the precipitation are less than those in temperature. For temperature, Lattakia station exhibited strong significant changes, whereas Hiffeh station exhibited strong significant changes for precipitation.

At the annual scale, Lattakia and Hiffeh stations showed significant decreasing trends by -26.3 mm/decade (at 0.1 level) and -52.5 mm/decade (at 0.05 level), respectively. Seasonally, the significant decreasing trends were only found in spring by -6.5 mm/decade (at 0.01 level) for Lattakia station, and by -12.1 mm/decade (at 0.01 level) for Hiffeh station. In winter, stations showed weak and non-significant decreasing trends by -0.8 and -1.4 mm/decade, respectively. The study of Freiwan et al. (2008) over Jordan revealed significant decreasing trends at 0.05 significance level in the annual total of precipitation at Shoubaq station by -22 mm/decade. It also found significant decreasing trends only in spring averages of precipitation at Shoubaq, Wadi Duleil and QAIA stations by -22.5, -23.9 and -20.7 mm/decade, respectively. In addition, annual precipitation total showed decreasing trends at all stations in the Northern Jordanian Badia region during (1984-2010) (Abu Sada et al., 2015). Moreover, the decreasing trends at annual and spring precipitation were found in Iran at 30 stations in the annual total precipitation and at all observed stations (140 stations) in the spring averages during (1975-2014) (Javari, 2017).

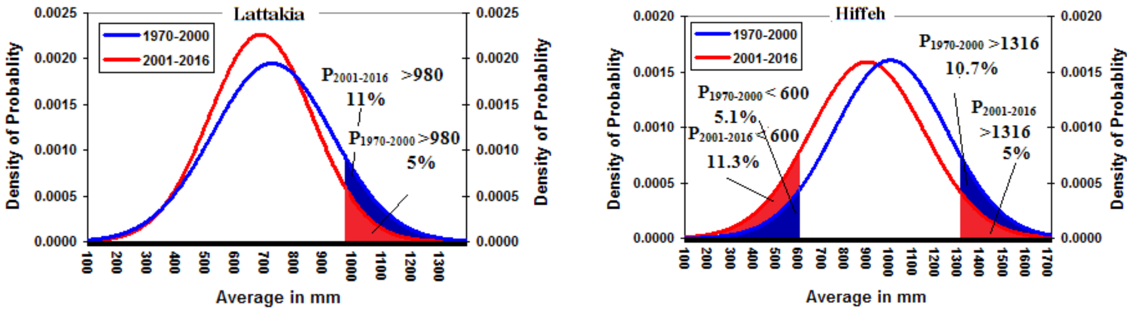
In addition, the annual and seasonal means of precipitating for the period (2001-2016) decreased at Lattakia and Hiffeh stations compared with those for the period (1970-2000), except winter mean at Lattakia station which non-significantly increased by 15 mm. Furthermore, the significant decreased means of the period (2001-2016) were only found in spring at 0.05 significance level by -38 mm for Lattakia station and by -94 mm for Hiffeh station (Table 4).

Table 4: Trends for annual and seasonal precipitation total during (1970-2016), and Mann-Whitney U significance of the difference means for the two periods (1970-2000)/(2001-2016). (***) if trend at α = 0.001 level of significance. (**) if trend at α = 0.01 level of significance. (*) if trend at α = 0.05 level of significance. (+) if trend at α = 0.1 level of significance.

Station	Season	Trend 2016-1970 (mm/decade)	Average 1970-2000	Average 2001-2016	Difference
Lattakia	Year	-26.3+	729	690	-39
	Winter	-0.8	393	408	15
	Spring	-06.5**	160	122	-38*
	Autumn	0.2	167	159	-7
Hiffeh	Year	-52.5*	1006	904	102-
	Winter	-01.4	503	487	16-
	Spring	-12.1**	271	177	94-*
	Autumn	0.1	206	195	10-

The probability of occurrence of the precipitation extreme value (more than 980 mm) decreased from 11% to 5% at Lattakia station, whereas that (more than 1316 mm) decreased by 5.7% (from 10.7% to 5%) at Hiffeh station (Fig. 5).

Figure 5. Changes in the probability density of the annual total of precipitation during (2001-2016) compared to (1970-2000). Red color indicates the percentage of increase/decrease in the probability of the extreme values during (1970-2000) that became as normal values during (2001-2016).



4. Conclusion

The changes in temperature and precipitation at observed stations in this study are consistent with those observed in the Mediterranean region; e.g. Turkey (Turkes, et al., 2002), Egypt (Hasanean et al., 2006); Israel (Kharel Kafle et al., 200), Jordan (Freiwan et al. 2008; Abu Sada et al., 2015), Libya (Kenawy et al., 2009), Saudi Arabia (Rehman, 2010), Iran (Javari, 2017). The results revealed significant tendencies towered warming during (1970-2016) in the annual, summer, spring and autumn temperature averages at Lattakia station, as well as Hiffeh station witnessed significant warming in its annual and summer averages. For precipitation, the study revealed significant decreasing trends in the annual total precipitation and spring precipitation at Lattakia and Hiffeh stations. Furthermore, spring precipitation means of the period (2001-2016) showed significant decrease compared to the period (1970-2001) at Lattakia and Hiffeh stations. The probability of occurrence of extreme values increased at Lattakia station from 6.7% during (1970-2000) to 45.7% during (2001-2016).

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