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LONG TERM SPATIO-TEMPORAL ANALYSIS OF ANNUAL, SEASONAL, AND EXTREME PRECIPITATION TREND OVER MENA REGION

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Climate change is a serious issue resulting in global variation in the precipitation pattern. One of the major problems hindering research in examining the change and variation in precipitation trend in Middle East and North Africa (MENA) is a lack of high-quality, long-term data. Therefore, in the current study, the spatial and temporal annual, seasonal, and extreme precipitation trend were analyzed over 118 years (1901-2018) using high resolution Climate Research Unit data (CRU TS 4.03) over the entire region. Durbin Watson was used to test the autocorrelation in the annual and seasonal series, the modified Mann-Kendall (MMK) and Sen's slope estimator tests were used to detect trend for the autocorrelated time series data. The monthly CRU data was then converted to daily using MODAWEC model in order to test the trend in extreme precipitation and for evaluating the change in four indices (R5D, R20, RR1, and SDII). The results showed decreasing trend affecting most of the countries in the region especially in annual and winter series with Yamen, Palestine and Lebanon got the highest significant negative trend. There were no signal toward negative or positive trend in extreme precipitation series. Arabian Peninsula (Kuwait, Qatar, Yamen, and Bahrain) showed positive trend in extreme indices (R5D, R20, SDII) while the western side exhibited negative trend. North Africa had stationary condition except for Egypt where negative trend detected.

Key Words: *CRU TS 4.03, annual, Seasonal precipitation, Serial correlation Modified Man-Kendall, Sen's Slop, MODAWEC model, extreme precipitation, extreme indices*

1. INTRODUCTION

Precipitation is one of the most important climate variables which receive high attention as it has many applications in hydrology and water resources management. According to the report of the Intergovernmental Panel on Climate Change1), it is highly probable that the observed global warming has led to a local or regional change in precipitation patterns. therefore, the study of precipitation patterns and trend analysis on various spatial and temporal scales has been of great significance over the past century because of the scientific community's attention given to global climate change.

Middle East and North Africa (MENA) received less attention and limited studies regarding climate change and precipitation trend analysis2), observed tendency towards drier condition since 1960 except for the western parts of the Arab region. Another regional study focused on changes in climate extremes over the Middle East region, the area was found to be characterized by a strong interannual variability without any significant trend[3]. For Maghreb countries (Morocco, Algeria, and Tunisia) heavy precipitation showed neither positive nor negative trend in general but there were significant negative trend affecting Algeria and Morocco at a regional scale[4]. Similar observation of the precipitation trend for local analysis focusing on the Arabian Peninsula they found decreasing trends for Oman, Saudi Arabia and United Arab Emirates respectively[5,6,7].

The main objectives of this study are (1) To analyze the impact of climate change in the annual, seasonal and extreme precipitation trend over MENA region. (2) To reach a better understanding regarding extreme events phenomena which become noticeably more frequent in some areas of the region especially in the last decade. The implication of such analysis would be of great importance for such region especially when most of its countries suffer from water scarcity and extreme precipitation events.

Using CRU TS 4.03 (Climatic Research Unit Time) dataset, the precipitation trend analysis for annual and seasonal series were analyzed by the most widely used tool non-parametric Mann-Kendall test[8,9] and Sen's slope estimator[10]. The serial correlation has been analyzed for the precipitation series using Durbin Watson test and found to be autocorrelated. Therefore, the modified Man-Kendall (MMK) test[11] has been employed for trend detection of the autocorrelated data. Extreme precipitation trend was examined using Man-Kendall (MK) and four indexes: The annual count of rainy days (RR1), the annual count of days with precipitation larger than 20mm (R20), the highest 5-day precipitation amount for each year (R5D), and simple precipitation intensity index (SDII).

2. STUDY AREA

Middle East and North Africa region comprises of 20 countries, in the northern hemisphere and thus, characterized with dry, hot summer and mild winter.

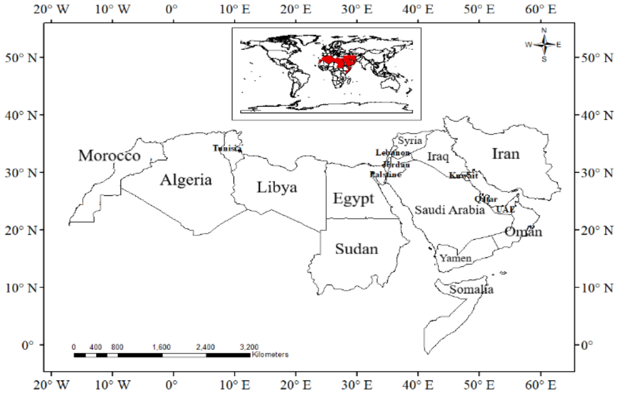

Fig 1 Middle East and North Africa (MENA) map

3. DATA AND METHOD

The long-term monthly precipitation data CRU TS 4.03 (Climate Research Unit) over the period of 118 years (1901-2018) has been used in the present study. In climate research, they are widely accepted as reference datasets given on high-resolution (0.5x0.5 degree) and had been used in some literatures without bias correction[6,11]. The data can be downloaded from Centre of Environmental Data Archival (https://crudata.uea.ac.uk/cru/data/hrg/)[12].

(1) Serial correlation and trend detection

Serial correlation may lead to an erroneous rejection of the null hypothesis in trend detection[13]. Using Durbin Watson (DW), serial correlation was checked for the time series in order to detect any autocorrelation in the data prior to applying the Man-Kendal trend test. The **modified Mann-Kendall** test can be employed for an autocorrelated series[14,15]. the autocorrelation between ranks of the observations ρk are evaluated after subtracting a non-parametric trend estimate such as Theil and Sen's median slope from the data. Only significant values of ρk are used to calculate variance correction factor n\n*S, as the variance of S is underestimated when data are positively autocorrelated:

$$\frac{n}{n*s} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1}(n-K)(n-K-2)pk \quad (1)$$

The corrected variance is then computed as

$$V^*(S) = V(S) \times \frac{n}{n*S} \quad (2)$$

where,

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18} \quad (3)$$

The standardized test statistic Z (N (0, 1)) is computed by

$$ZMK = \begin{cases} \frac{s-1}{\sqrt{Var(S)}} when\ S > 0 \\ 0 \ldots when\ S = 0 \\ \frac{s+1}{\sqrt{Var(S)}} when\ S < 0 \end{cases} \quad (4)$$

where,

$$S = \sum_{i=1}^{n-1} \sum_{i+1}^{n} sgn(xj - xi) \quad (5)$$

The slope estimates of N pairs of data are computed by

$$Q_i = \frac{xj - xi}{j - i} \quad \text{for } i = 1, \ldots.., N \quad (6)$$

(2) The MODAWEC model and extreme indices

The gridded monthly CRU was converted to daily using MODAWEC model in order to investigate extreme precipitation trend. This model converts monthly precipitation (in mm) and maximum and minimum temperature (C) to daily values while preserving the monthly totals and averages. The input data, average minimum and maximum temperature and wet days (tmin, tmax, wet days) were obtain from the (CRU TS 4.04) available at 50 × 50 km spatial resolution for (1901–2019). More details on the MODAWEC model and can be found in [16)].

For all four extremes indices, higher values indicate more extremes on precipitation. R5d, R20, RR1, SDII express the intensity or frequency of heavy precipitation. The daily precipitation from the model was used to calculate the indices and Mann-Kendal is used to test and analyze the trend for each index.

Table 1. Extremes indices description

Index	Definition	Unit
R5D	The highest 5-day precipitation amount for each year	mm/5day
R20	The annual count of days with precipitation >20mm	day
RR1	The annual count of rainy days >1mm	day
SDII	Total precipitation divided by the number of wet days	mm/day

4. RESULTS AND DISCUSSION

Using Durbin Watson, the autocorrelation in the time series data over the period (1901-2018) was estimated. The p-value was less than 0.0001 for all series which cause the rejection of the null hypothesis (H0) against the alternative hypothesis (Ha). The values of DW are less 2 which indicate the availability of positive autocorrelation.

Table 2. The MMK test results (Annual Precipitation)

Annual Precipitation			
Country	Z-value	P-value	Sen's Slope
Algeria	-1.16	0.24	-0.04
Bahrain	-0.12	0.9	-0.01
Egypt	-3.42	0.01	-0.08
Iran	-2	0.04	-0.16
Iraq	-1.57	0.12	-0.1
Jordan	-3.42	<0.0001	-0.25
KSA	-2.64	<0.0001	-0.04
Kuwait	-0.63	0.39	-0.05
Lebanon	-3.46	<0.0001	-1.48
Libya	-2.69	0.02	-0.06
Morocco	-2.25	0.03	-0.39
Oman	-3.16	<0.0001	-0.25
Palestine	-2.9	<0.0001	-1.23
Qatar	-0.83	0.39	-0.06
Somalia	1.5	0.22	0.2
Sudan	-2.17	0.25	-0.2
Syria	-2.54	0.01	-0.36
Tunisia	0.78	0.49	0.12
UAE	-2.09	0.04	-0.08
Yemen	-7.65	<0.0001	-1.4

(1) Trend Analysis (Annual and Seasonal)

To avoid the influence of serial correlation, the Modified Man-Kendall test was employed for trend detection at significant level 5% and confidence interval 95%. Table. 2 shows the results of MMK test for annual precipitation over MENA region. Most countries in the region exhibit significant negative trend. The highest significant negative trend appeared in Yamen, Lebanon, and Palestine especially in annual and winter series Fig. 2. Spring (MAM), Summer (JJA), and Autumn (SON) showed less significant trend compared to the estimated trend in winter (DJF).

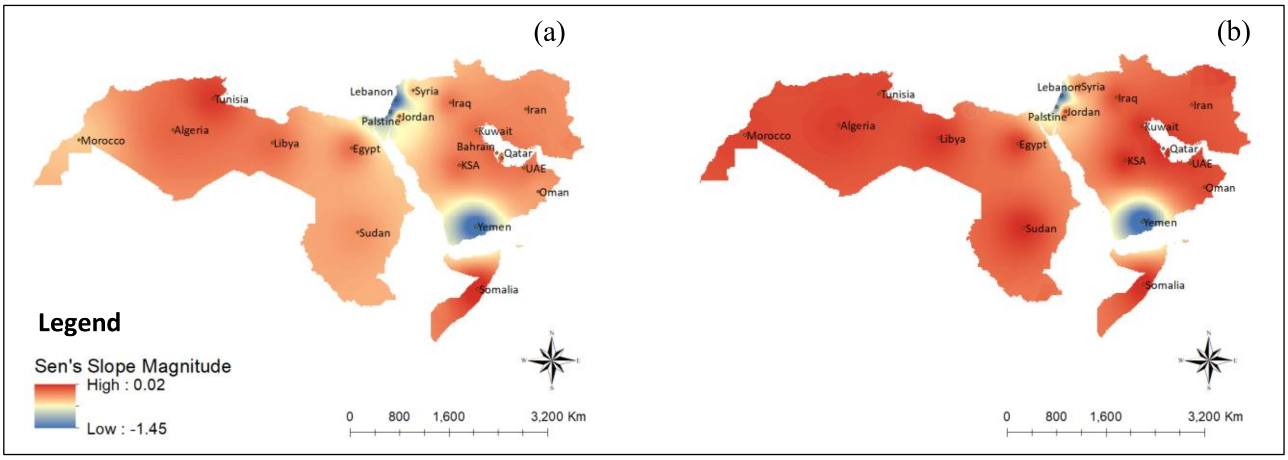

Fig 2. Sen's slope magnitude for (a): annual, (b): winter precipitation trend

The detected decreasing trends for northern Africa are consistent with those found in other studies[2,17,18,19)] and for the Middle East[3)]

The spatial distribution of mean annual and seasonal rainfall over MENA region are shown in Fig. 3 (a-e). It is clearly noticeable from the figures that most of the Middle East and North African countries are laying in the category of low-rainfall affected areas. The most affected season is summer with average rainfall between (1-10 mm/ month) hitting most of the countries in the region. Spring, on the other hand got better amount of precipitation per season. The north parts of Algeria, Tunisia and Morocco, the Southern Sudan, western Iran and Somalia have different wetter conditions compared to arid conditions characterizing the areas surrounds.

(2) Trend Analysis (Extreme Precipitation)

a) Model validation and trend detection

The monthly CRU TS 4.04 gridded data was converted to daily records using MODAWEC model in order to analyze extreme precipitation events over the region. The output from the model has been proven reliable as it gave a good correlation (R^2=0.876) with the available Oman daily observed data Fig. 4.

The trend of maximum precipitation for all countries were estimated using MMK test Table 3. There is no specific trend for almost all the countries except for Qatar where it exhibits positive trend. There is no such a strong signal towards a decrease or an increase of extreme precipitation over the area. This finding is consistent with what was found in other studies conducted for some parts of the region like Algeria, Morocco, and Tunisia[4)]. Despite the stationary general trend, topography and climate process can cause different magnitude and spatial distribution of extreme precipitation at smaller scale[18)]

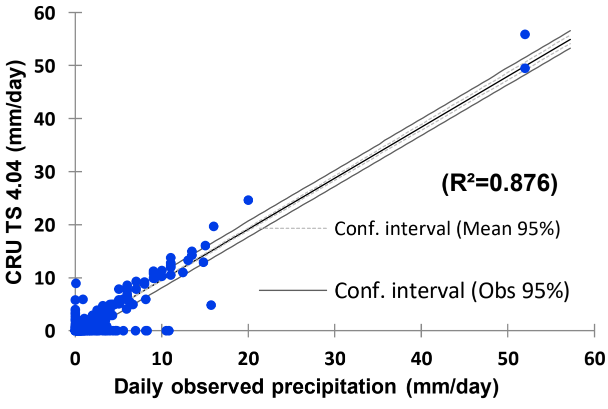

Fig 4. Model validation, Oman observed data vs CRU

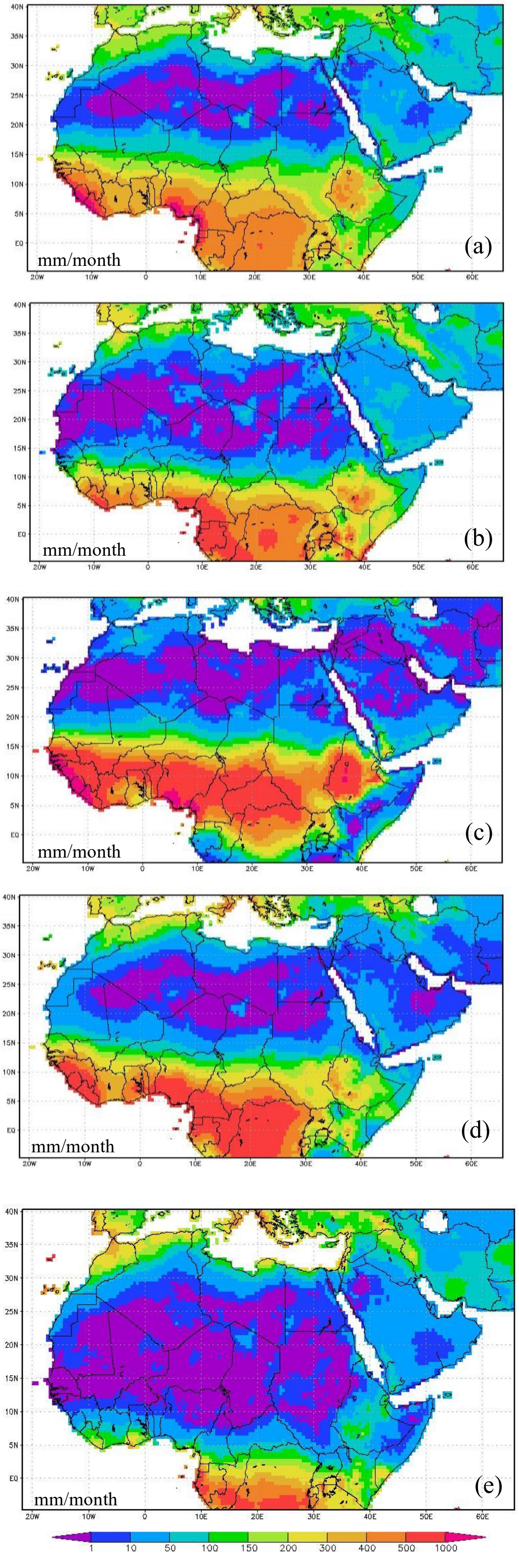

Fig 3 (a-e). Spatial distribution of average precipitation (a: Annual, b: Spring, c: Summer, d: Autumn, e: Winter).

(3) Extreme Indices

The trend test results for (R5d, R20, RR1, and SDII) are presented in Fig. 5, showing the trend for each country and each index, if they are significant. All the countries in the Middle East except for Bahrain, Iran, KSA and Lebanon have shown significant decrease in RR1 while the trend in the North African side remain stationary except for Egypt. Tow countries are severely affected by a negative trend in two indices, Palestine (RR1, R20), Lebanon (R20, SDII). On the other hand, there are some increasing trend, Kuwait exhibited positive trend in (R5D and SDII), Qatar in (R20 and SDII). The indices trend results showed a huge variability and inconsistency but if we classify the area into three zones (Eastern Middle East, Western Middle East, and North Africa) then the eastern side of Middle East exhibited an increasing trend in some indices, the western side showed a decrease in general, and North Africa has shown no specific trend. In other study for the same area, 1960s found to be wetter than any of more recent decade[4]) that was also found when analyzing the extreme precipitation series for all countries and indices Fig 5. The 1960s seems to be the changing point where the trends afterwards show the tendency towards either positive or negative condition. This trigger the need for a smaller scale investigation to understand the factors and climate process responsible to cause the shift in the trend. The different response in the three zones also require to be linked with regional climate characteristics and other factors like topography.

Table 3. The MMK test results (Extreme Precipitation)

Extreme Precipitation (Daily maximum precipitation of the year)			
Country	Z-value	P-value	Sen's Slope
Algeria	-0.182	0.856	-0.001
Bahrain	1.055	0.287	0.033
Egypt	-1.317	0.185	-0.011
Iran	0.298	0.765	0.004
Iraq	0.663	0.504	0.012
Jordan	-0.155	0.878	-0.003
KSA	-1.550	0.118	-0.016
Kuwait	1.823	0.066	0.077
Lebanon	-0.470	0.636	-0.032
Libya	-0.692	0.486	-0.006
Morocco	-0.679	0.494	-0.030
Oman	1.868	0.060	0.200
Palestine	-0.333	0.737	-0.021
Qatar	2.023	0.041	0.061
Somalia	1.627	0.100	0.064
Sudan	0.084	0.934	0.010
Syria	0.243	0.808	0.006
Tunisia	1.035	0.296	0.031
UAE	0.831	0.404	0.042
Yemen	1.804	0.069	0.025

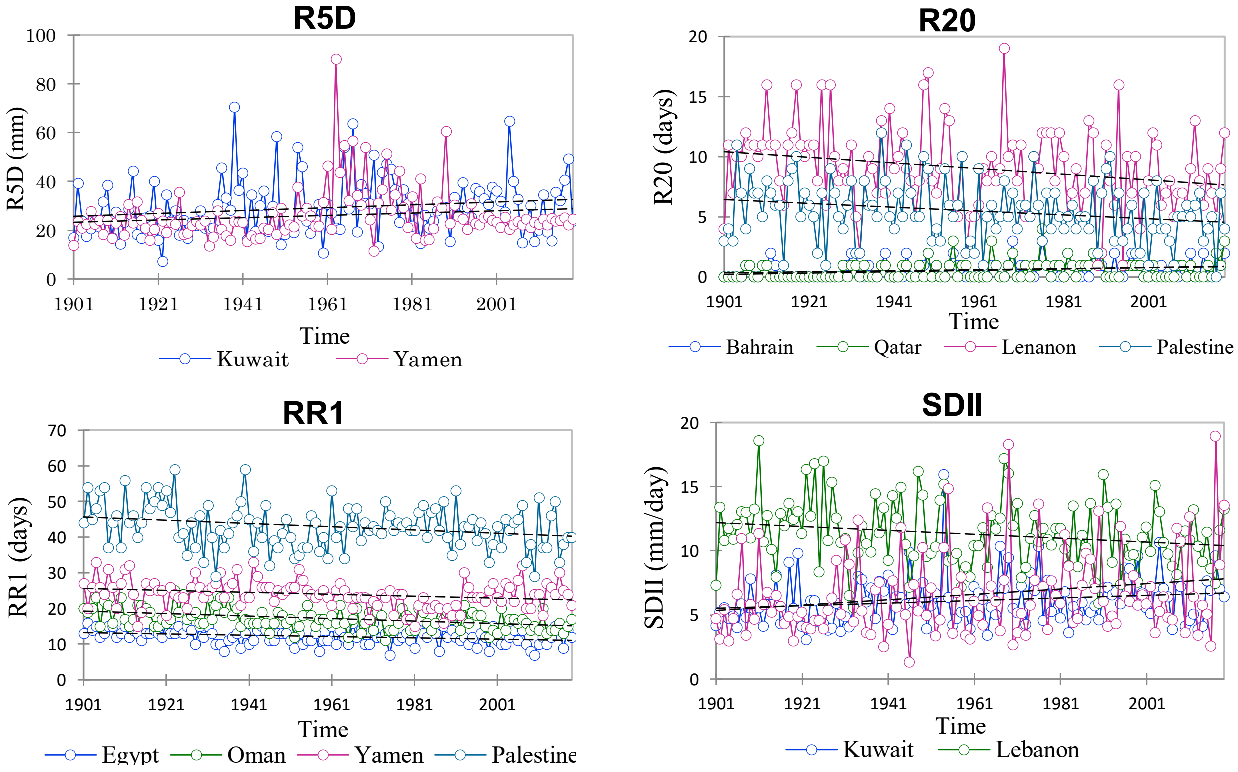

Fig 5. Extreme indices trend over MENA region during the period (1901-2019)

5. CONCLUSION

Using CRU (Climatic Research Unit) data, trend of the annual, seasonal and extreme precipitation over MENA have been analyzed using non-paramedic Man-Kendal, Sen's slope and four climate indices (R5D, R20, RR1, and SDII). Most of the countries in the region exhibit significant negative trend in the annual and winter precipitation with highest decline estimated for Yamen, Lebanon and Palestine. In contrast the area showed less negative trend in Spring, Summer and the least in Autumn. Yamen which showed significant negative trend in annual, Spring, Autumn, and Winter, has got significant increase in the trend for Summer. No specific trends were estimated when analyzing extreme precipitation. Nevertheless, increasing trend were detected for some countries in the eastern part of Middle East in R5D, R20, and SDII indices, other countries like Lebanon and Palestine showed decreasing trend in R20 and RR1. North Africa on the other hand, exhibit stationary trend where no specific response neither positive nor negative. Looking at these results, there is there is a noticeable shift towards drier condition with negative trends in mean precipitation affecting most of the countries in the region, but the increase trend in some indices needs further investigation especially when different zones responded differently (Levant, Arabian Peninsula, and North Africa). The increase in the intensity and frequency of extreme precipitation in some areas has to be link with the local factors and climate process to understand the cause and possible future scenarios

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