Time Series Analysis of Rainfall Variability at North Jordan: A Case Study at Yarmouk River Basin

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Abstract. Water represents a key challenge to sustain the progress of Jordan. Providing healthy drinking water, along with current scarcity is one of the most major constraints in the water sector. This paper pursues to investigate the Spatio-temporal distribution of rainfall variability for time slice 1985-2014 over the Yarmouk River Basin (YRB) – Jordan side. Ten rainfall gauges were selected within the basin over the observation period. Applying two nonparametric statistical tests; Mann-Kendall to detect the rainfall trend in YRB, and Kolmogorov–Smirnov to detect the variations of rainfall distribution. Besides, the GIS spatial analyst tool was utilised to create interpolated rainfall map using the Thiessen polygons method. The results indicated that YRB will witness a potential decline in annual rainfall in most stations. Further, a shift in rainy season timing 2 and 58 days was observed at late in the start of the season (SoS) and 2 to 48 days for an early end of the season (EoS) on a decade's basis accompanied by the significant uptrend in the long-term.

1. Introduction
The climate in Jordan is typically semi-arid, with a relatively annual rainfall of less than 200mm falling upon 92\% of the country’s area, makes Jordan the second water-poorest country in the world. The annual inequalities of rainfall distribution are bonded to its location as a hot spot (Rahman, et al. 2015). The actual water supply delivered to the population, on average, approximately 61 liters per person per day (MWI, 2016). This is well below 2 700 litres/day per person of the international water poverty line (FAO, 2016). However, the demand effects have outpaced the water sector due to stressors (e.g. climate change, rapid population growth, and refugees).

Analyzing climatic variables and trends is vital to understand and evaluate the current climate change status and its effects on water resources (Al-Mashagbah and Al-Farajat, 2013). In Jordan, some research on rainfall variability has been conducted. Aladaileh et al. (2019) analyzed the historic rainfall trend for time span from 1979/1980 to 2016/2017, revealing drought incidents. The MK analysis outcome of the study showed a decrease in rainfall in most regions, whilst standardized rainfall index (SPI) indicated no probability for recurrent drought at a regional level. Tarawneh and Kadioğlu (2003) analyzed rainfall periodicity over Jordan for data periods between 17 to 75 years using harmonic analysis/ times series. The results showed high variance in rainfall over the mountains and the winter season had the highest amount of rainfall, especially in January, while the southwestern regions witnessed less rainfall. This was consistent with the results of Rahman et al. (2015), who examined the variability in rainfall during 1970-2013. The statistical analysis disclosed a declining trend in southwestern areas and high variation in northern mountainous areas. Nevertheless, most of the prior efforts focused on annual variations, while this research keen to adopt seasonality and shifting in seasons. Further analysis was conducted in this study to investigate rainfall variability across Jordan’s Yarmouk River Basin (YRB) for a 30-year period (1985-2014).
2. Study Area

The Yarmouk River Basin is a transboundary catchment located north of Jordan shared with Syria, with a total area of 1392 km² (Figure 1). The basin lies within the Jordan boundary between 32° 20’ to 32° 45’ N and 35°42’ to 36°23’ E. It is one of the important basins with a withdrawal rate of 54MCM/year (MWI, 2015). The multi-terrane zone is 1187m above sea level (ASL) and 213m below sea level (BSL) (Batayneh, 2010) as shown in figure 2. B2/A7 is the primary aquifer and the main geological formations of volcanic origin are therefore calcium and chert (Zumlot, 2012). Due to its location in a semi-arid region, the annual rainfall varies, on average, from 140mm east at Jaber Mughayyir station to 600mm west at Ras Muneif station.

![Figure 1. (A) Map of Jordan Country, (B) Digital Elevation Model of YRB (NASA, 2016).](image)

3. Methodology

3.1. Data Collection

Yarmouk River is the largest surface water resource with 40% of Jordan’s surface water composition (MWI, 2016). Data sets of ten rainfall stations covering the whole area were collected for a 30-year (1985-2014), sourced from local agencies and authorities including the Ministry of Water and Irrigation (MWI) formed by the Water Authority of Jordan (WAJ) and the Jordan Meteorological Department (JMD) (Figure 2). The selection of stations was based on multi-criteria of evaluation, i.e. spatial distribution, data accuracy, reading, and recording through the regularity in observations and the longevity of the station. The Digital Elevation Model (DEM) map was available from NASA Reverb (Figure 1-B).

3.2. Time Series and Trend Analysis

The average monthly rainfall of 30 years period was tested in time series. Seasonal and annual trends were examined using time series, Mann-Kendall (MK), and Sen’s Slope (Q) analyses. The linear regression method observed the annual water year trend for entire stations from Oct/1985 until Sep/2014. MK test was applied for both annual and seasonality trends, while Sen’s slope adopted for annual and winter season only (i.e. November to March).
4. Results and Discussion

4.1. Annual Rainfall Estimation

Ten rainfall stations were chosen to study the annual trend in rainfall over the selected period (Table 1). The GIS interface (Figure 2) was used to create Thiessen polygons and the total annual rainfall of YRB was estimated to be 270.5 mm.

![Thiessen Polygons at Yarmouk River Basin](image)

Figure 2. Thiessen Polygons at Yarmouk River Basin

4.2. Trend Analyses

The overall amount of rainfall and its distribution during the year reflect the variability of the rainy season, i.e. delayed or early rainfall, or intense rainfall events separated by long dry spells (Camberlin, et al., 2009). Table 2 illustrates the results of the times series, MK, and Sen’s slope analyses. The tests unanimously agreed that YRB is subjected to high variability, which contributed to a downward trend in the amount of rainfall over the observation period. In comparison, Mustafa and Rahman’s study (2018) also exposed a downward trend in annual rainfall for the current area – North of Jordan. See Error! Reference source not found. for time series trend results of the rainfall gauges.

Table 1. Average Water Year Rainfall at Yarmouk River Basin.

| Station ID | Station Name | Rainfall Average (mm) |
|------------|--------------|-----------------------|
| AD0002     | Hartha       | 392.61                |
| AD0003     | Kufr Saum    | 427.78                |
| AD0005     | Um Qeis      | 128.85                |
| AD0008     | Kharja       | 402.27                |
| AD0009     | Hawwara      | 357.37                |
| AD0010     | Husn         | 324.95                |
| AD0011     | En Nueiyime  | 266.18                |
| AD0018     | Ibbin        | 511.88                |
| AD0032     | Baqura       | 376.37                |
| AL0002     | Midwar       | 253.83                |

![Thiessen Polygons for YRB](image)

Table 2. The results of time series analysis, MK, and Sen's slope tests for whole stations, as Q refers to Sen's slope test.

| Stations | Annual Trend | Time series Analysis | MK \(^a\) | Q \(^b\) | MK | Q | MK | Q | MK | Q | MK | Q | MK | Q | Trend |
|----------|--------------|----------------------|------------|---------|-----|----|-----|----|-----|----|-----|----|-----|----|-------|
| Hartha   | -1.4919      | -0.14                | -0.59      | -1.57   | -0.87| 1.32| 1.12| -0.75| -1.04| 0.98| 1.09| 2.58| -1.39| Downward |
| Kufr Saum | -5.2711      | -1.68                | -3.56      | -0.97   | -0.65| -0.14| -0.26| -0.8 | -0.97| -0.59| -1.01| -1.27| -1.16| Downward |
| Um Qeis  | -1.9606      | -1                   | -1.72      | -1.05   | -0.7 | 0.3 | 0.4 | 0   | 0   | -0.57| -0.64| -0.46| -0.4 | Downward |
| Kharja   | -1.3562      | 0                    | 0.25       | -0.36   | -0.15| 0.5 | 0.62| -0.05| -0.04| 0.14| 0.2 | -1.11| -1.18| Downward |
| Hawwara  | 0.9266       | 0.61                 | 1.54       | -0.68   | -0.44| 0.73| 0.5 | -0.8 | -0.71| 0.79 | 1.48| 0.54| -0.38| Upward |
| Husn     | -6.705       | -2.39                | -5.8       | -1.14   | -0.58| -1.13| -0.8 | -1.27| -1.33| -1.66| -1.57| -2.05| -1.38| Downward |
| En Nueiyime | -0.816      | -0.29                | -0.52      | -0.09   | 0    | -0.43| -0.23| -0.2 | -0.09| 0.14| 0.18| -0.87| -0.64| Downward |
| Ibbin    | -2.9746      | -0.7                 | -2.48      | -0.32   | -0.13| -0.43| -0.79| -1   | -1.6 | 0.71| 0.8 | -0.21| -0.23| Downward |
| Baqura   | -5.8173      | -1.94                | -4.3       | -0.5    | -0.4 | 0.32| 0.35| -1.39| -1.37| -0.9 | -1.01| -1.63| -1.09| Downward |
| Midwar   | 5.3703       | 2.03                 | 5.14       | 0.77    | 0.21 | 1.04| 0.92| 1.48| 1.06| 1.45| 1.9 | 0.87| 0.35| Upward |

\(^a\) Slope of Time Series trend line.
\(^b\) Test – Z results of Mann-Kendall (MK) test.
\(^c\) Sen’s Slope values.

As an example for Hartha station, the average monthly rainfall values highly varied from November to March, and the highest records of the rainy season were observed in February (Figure ).
4.3. Rainy Season Duration

Analysis of the rainy season variability in terms of duration requires two variables: rainfall amounts in (mm) and the number of rainy days on a water-year basis. "Kolmogorov-Smirnov" (KS) analysis was conducted to determine the maximum difference between two distributions (F1 and F2) at a specific rainfall station. The "Cumulative Distribution Function (CDF)" is the base of the KS test on a decade's basis. Where F1(x) refers to rainy days in a certain year and F2(x) is the rainy days in the next sample (after 10 years). Using plotting position equation of Sevruk and Geiger (1981), the "Cumulative Distribution Function (CDF)" plots (Figure 4) were derived:

\[
P(\%) = \frac{m - 0.375}{N + 0.25} \times 100\%
\]

Where m is the rank of the rainy day, and N is the total number of rainy days for each function. For example, the CDF plots of En Nueiyime station show:

1. The SoS in 1985 was 15 days earlier than in 1994 (Figure 4-a). In 1985 a longer rainy season was observed while EoS was 2 days later. Meaning that to be the last to cross the threshold line of 100 percent. In 1994, however, rainy days were higher than in 1985.
2. The rainy season in 2004 began later in the second decade (1995-2004), with 15 days delay compared with 1995, as it resulted in a shorter season.
3. The period of the rainy season was higher in 2014 in the third decade (2005-2014) than in 2005, with a declination in the number of rainy days.
4. The rainy season at the station was the longest in the observation period (1985-2014), but fewer rainy days were anticipated on decade basis during the season and thus more dry spells were expected.
5. Variability in the average annual rainfall was noticed through changes in the number of rainy days.

4.4. Shifting in Rainy Season

Rainy season variability was analysed in terms of rainfall temporal distribution of selected stations at YRB. Changes in seasonal timing can help to represent a feature of natural climate variability, which has a notable effect on many hydrological series. Table 3 summarizes the shift in the rainy season depending on its start and end on a decade's basis. The analysis showed a shift in the rainy season for most stations in terms of delaying in SoS between (2) and (58) days, and early onset in EoS between (2) and (48), see table 3 for results. En Nueiyime station was considered as an example of the representative rainfall stations at YRB (Figure 5).
Figure 4. Temporal Distributions of Rainy Days at En Nueiyime Station: (a) 1985-1994, (b) 1995-2004, and (c) 2005-2014.

Figure 5. Shifting in Rainy Season at En Nueiyime Station (1985-2014).
### Trend analysis was applied to determine the time-shifting of the rainy season. Both Mann-Kendall and Sen's Slope test were used on a decade's and annual basis at En Nueiyime, see Figure and Figure . Two parameters were calculated: test-Z and Sen's Slope (Q), with confidence limits at a probability level of 95% (}

#### Table 3. Shifting in rainy season results at YRB Stations (1985-2014)

| Station Name | Parameter | Decade (1) | Decade (2) | Decade (3) |
|--------------|-----------|------------|------------|------------|
|              |           | 1985-1994  | 1995-2004  | 2005-2014  |
| Hartha       | SoS       |            |            |            |
|              | Shifting (Days) in SoS | 16-Oct-84 | 31-Oct-93  | 16-Oct-94  | 10-Nov-03 | 0          | 21-Oct-13  |
|              | EoS       | 22-Apr-85  | 01-Apr-94  | 03-Apr-95  | 03-Apr-04 | 0          | 09-May-14  |
|              | Length of Season | 189 154  | 170 145    | 0          | 201       |            |
|              | No. of Rainy Days | 34 37    | 29 35      | 0          | 21        |            |
| Kafr Saum    | SoS       | 16-Oct-84  | 31-Oct-93  | 01-Nov-94  | 02-Oct-03 | 0          | 18-Oct-13  |
|              | EoS       | 22-Apr-85  | 25-Mar-94  | 03-Apr-95  | 03-Apr-04 | 0          | 09-May-14  |
|              | Length of Season | 189 146  | 154 185    | 0          | 204       |            |
|              | No. of Rainy Days | 29 34    | 33 38      | 0          | 23        |            |
| Um Qeis      | SoS       | 16-Oct-84  | 05-Nov-93  | 10-Oct-94  | 10-Nov-03 | 29-Oct-04 | 03-Nov-13  |
|              | EoS       | 22-Apr-85  | 01-Apr-94  | 18-Apr-95  | 22-Apr-04 | 0          | 04-May-05  |
|              | Length of Season | 189 127  | 191 165    | 188        | 188       |            |
|              | No. of Rainy Days | 28 28    | 35 42      | 34        | 17        |            |
| Kharja       | SoS       | 16-Oct-84  | 11-Nov-93  | 05-Nov-94  | 10-Nov-03 | 0          | 18-Oct-13  |
|              | EoS       | 22-Apr-85  | 01-Apr-94  | 18-Apr-95  | 03-Apr-04 | 0          | 09-May-14  |
|              | Length of Season | 189 142  | 164 146    | 0          | 204       |            |
|              | No. of Rainy Days | 31 27    | 38 36      | 0          | 16        |            |
| Hawwara      | SoS       | 16-Oct-84  | 17-Oct-93  | 17-Oct-94  | 02-Oct-03 | 29-Oct-04 | 18-Oct-13  |
|              | EoS       | 22-Apr-85  | 01-Apr-94  | 18-Apr-95  | 16-Apr-04 | 04-May-05 | 30-Mar-14  |
|              | Length of Season | 189 167  | 169 198    | 188        | 163       |            |
|              | No. of Rainy Days | 28 34    | 42 45      | 40        | 23        |            |
| Hasn         | SoS       | 16-Oct-84  | 18-Oct-94  | 16-Oct-94  | 02-Oct-03 | 17-Nov-04 | 19-Oct-13  |
|              | EoS       | 22-Apr-85  | 01-Apr-94  | 18-Apr-95  | 21-Apr-04 | 0          | 04-May-05  |
|              | Length of Season | 189 166  | 185 203    | 169        | 203       |            |
|              | No. of Rainy Days | 30 46    | 23 40      | 38        | 26        |            |
| En Nueiyime  | SoS       | 16-Oct-84  | 31-Oct-93  | 16-Oct-94  | 03-Dec-03 | 17-Nov-04 | 19-Oct-13  |
|              | EoS       | 22-Apr-85  | 01-Apr-94  | 18-Apr-95  | 19-Apr-04 | 04-May-05 | 09-May-14  |
|              | Length of Season | 189 151  | 183 168    | 168        | 202       |            |
|              | No. of Rainy Days | 28 36    | 31 36      | 32        | 16        |            |
| Jbin         | SoS       | 16-Oct-84  | 16-Oct-93  | 09-Oct-94  | 28-Oct-03 | 29-Oct-04 | 03-Nov-13  |
|              | EoS       | 22-Mar-85  | 01-Apr-94  | 18-Apr-95  | 03-Apr-04 | 0          | 04-May-05  |
|              | Length of Season | 158 168  | 176 157    | 188        | 188       |            |
|              | No. of Rainy Days | 36 52    | 51 40      | 35        | 16        |            |
| Baqura       | SoS       | 16-Oct-84  | 16-Oct-93  | 09-Oct-94  | 28-Oct-03 | 29-Oct-04 | 03-Nov-13  |
|              | EoS       | 22-Mar-85  | 01-Apr-94  | 18-Apr-95  | 03-Apr-04 | 0          | 04-May-05  |
|              | Length of Season | 158 157  | 192 159    | 188        | 188       |            |
|              | No. of Rainy Days | 36 52    | 51 40      | 35        | 16        |            |
| Midwar       | SoS       | 16-Oct-84  | 13-Dec-93  | 11-Oct-94  | 10-Nov-03 | 29-Oct-04 | 31-Oct-13  |
|              | EoS       | 12-May-85  | 25-Mar-94  | 08-Apr-95  | 18-Apr-04 | 0          | 04-May-05  |
|              | Length of Season | 209 103  | 180 161    | 188        | 191       |            |
|              | No. of Rainy Days | 24 24    | 40 35      | 34        | 12        |            |
The results were as follows:

1. En Nueiyime station witnessed an uptrend indicated by the positive slope $Q$ (1.67) in figure (6). This increase was significant since the $P$-value (0.044) was less than $\alpha$ (0.05) according to MK test at 95% probability level for the first decade (1985-1994).

2. There was a modest increase in the trend in the second decade (1995-2004).

3. The observed trend in the time shift in the rainy season during the third decade (2005-2014) was slightly less, with a negative slope (-1.33) value.

4. Figure (7) displays an uptrend of time-shifting in the rainy season at the station over the period (1985-2014). However, this uptrend is considered significant at 95% probability level as the $P$-value (0.036) was less than $\alpha$ (0.05) according to MK test.

Besides, the annual analysis at En Nueiyime station revealed a significant trend in a continuous 30-year period, whilst the decadal analysis showed insufficient evidence of the trend, as the trend varied from decade to decade.

5. Conclusions

This paper aims to study the rainfall variability of the proposed YRB catchment. Time series and trend analyses were performed to find out potential trends in rainfall. The study reached the following conclusions:

1. The basin experienced a decreasing trend in the annual rainfall, with high variability in rainfall values, as the maximum rainfall was observed in Februarys over a 30-year time slice.

2. In terms of duration, the rainy season ranged from (127) to (205) days with a decrease in the number of rainy days.
3. The onset of the rainy season at YRB was more variable than its end, while the start of the season changed on a decade’s basis for 15 days on the western side of YRB.
4. The average annual shift in the rainy season on a decade’s basis fluctuated between 2 to 58 days in case of delayed SoS and 2 to 48 days in early EoS.
5. It was better to predict the annual trend of temporal changes in the rainy season in a continuous period of 30 years than in an intermittent period; say 10-year. However, the long-term trend showed a substantial increase in the rainy season shift in YRB rainfall gauging stations.

Appendix
This section includes times series trend analysis results for the adopted rainfall gauges, as most of the station were subjected to declination trend over time slice (1985-2014).
Figure A1. Times series trend analysis for the adopted rainfall gauges A-J over (1985-2014).
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