Volume 4 – Issue 43
Issued on: 20 May 2023

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064
IJRSP

Rainfall Trends Analysis in context of Climate Change in Imam Turki Bin Abdullah Royal Nature Reserve (ITBA) – Saudi Arabia

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Abstract

Rainfall trend analysis, on different spatial and temporal scales, has been used during the past century as the indicate of global climate change by the scientific community. According to some recent studies, the Nature Reserve (ITBA) has been suffering a rainfall decrease, especially in the second half of the studied period (1993-2018). The aim of the present study is to analyze the rainfall trends using the time series of 52 years in five rain stations (Linah, Rafha, Ha'il, Dawmat Al Jandal and Hafr Al Batin) surrounding the Nature Reserve of (ITBA) that extended on area of about 91500 km^2 in the Northeast of Saudi Arabia. The trends analysis of annual rainfall, rainy days, shows that the fluctuations or variations in climatic parameters is a recurring phenomena in the studied stations. Inter-annual variability of the rainfall and the actual mean of daily rainfall are characterized by the high coefficients of variation, varying from 0.73 (Linah) to 0.83 (Ha'il) and from 0.53 (Linah) to 1.09 (Rafha), respectively. The variance test of $F_{max\text{-}ratio}$ method indicates the homogeneous annual rainfall distribution at Linah, Rafha and Ha'il, the homogenous rainy days distribution at only Ha'il and the homogeneous distribution of the actual mean of the daily rainfall at only Linah. The trends of annual rainfall, rainy days and actual mean of the daily rainfall obtained by using T-student test are significant in Ha'il and Dawmat Al Jandal, in all stations and in only Hafr Al Batin, respectively.

Keywords: Annual rainfall, Rainy days, Actual mean of daily rainfall, Moving averages, Semi-averages, Variance, Statistical tests.

1. Introduction

Climate change can affect significantly the variability in surface water resources with a decreased rainfall and high temperature and evaporation (Wang et al. 2020). So, the rainfall variability is considered as the most important hydro-meteorological component of the water cycle and Its variability is highly correlated with flood and drought, especially in arid zones (Wang et al. 2017).

The rainfall trends are directly related to the climate change they have a several acute impacts on the environment, society, economy and agriculture. Their impact can caused the psychological disorders, economic disruption, biodiversity loss, loss of crop production, malnutrition, livelihood disruption, decreased social-cultural function, environmental degradation (Miah et al. 2017; Hossain et al. 2019). Therefore, over the last four decades, the estimation of long-term rainfall variability and trend has become the main active research worldwide (Sun et al. 2018; Praveen et al. 2020; Wang et al. 2020). In this context, many studies have been used several methods for estimating the long-term rainfall trend and variabilities, especially Mann-Kendall test, Spearman's rho, Şen-Theli estimator, and linear regression (Mann 1945; Furl et al. 2014; Cui et al. 2017; Tosunoğlu 2017; Sanikhani et al. 2018; Ahokpossi 2018; Al Balasmeh et al. 2019; Caloiero 2020; Gao et al. 2020; Wang et al. 2020).

Rainfall modeling or rainfall trend is used in assessment for the water balance in Saudi Arabia (Al Sarmi and Washington 2011; Al-Ahmadi and Al-Ahmadi 2013a; Almazroui et al. 2015). Many previous literature on global climate change reported Saudi Arabia as a highly water-scarce region (Rahman and Islam 2019). Saudi Arabia is considered as a rainfall deficit region. The studies and researches using the rainfall to detect climate change are rare (El Kenawy and McCabe 2016).

Hence, before proposing any environmental management plans in (ITBA), it is of paramount importance to detect rainfall trends and their distribution characteristics in recorded data. Previous literature reported that many statistical techniques are available for trend detection. In the present study, Moving averages and Semi-averages methods were used to detect the variability and trends of the annual rainfall, rainy days and actual mean of the daily rainfall data for the period 1697-2018 (52 years).

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064
IJRSP

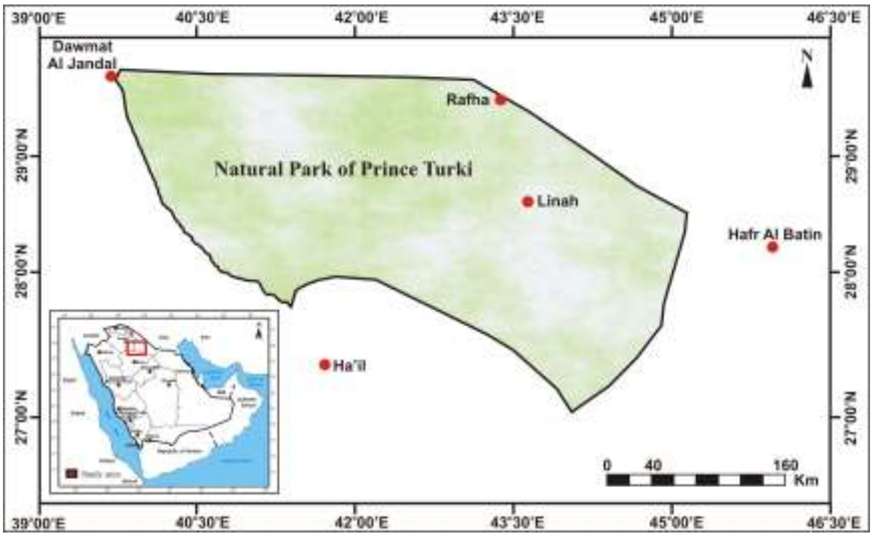
The present study area, the Imam Turki Bin Abdullah Royal Nature Reserve (ITBA), is arid region of Saudi Arabia and very limited study on the rainfall has been conducted. The future trend of rainfall in the Nature Reserve of (ITBA) needs to be known for long-term sustainable planning. So, no studies have been analyzed the long-term rainfall trends and variability in the study area. Therefore, the present study is the first to use in the study area, the coefficient of variation (CV), Standardized Anomaly Index (SAI) for analyzing the variability of the rainfall data, Hartley's index for analyzing the homogeneity of the semi averages method and T-student for determining the performance of the Semi averages method. The findings of the present study would help to update the rainfall trends detected in the study area by finding the best methods for estimating accurate rainfall trends. These objectives would help to propose high-precision and accurate plans for water resources and environment management in the Imam Turki Bin Abdullah Royal Nature Reserve (ITBA)

2. Materials and Methods

2.1. Study area

The study area is located in Northeastern of Saudi Arabia, covered a geographical area of about 91500 km^2 (Fig. 1). are known as Imam Turki Bin Abdullah Royal Nature Reserve (ITBA)

Figure 1: Geographic location of study area.



International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

The study area extends from 26°45' to 30°15' North latitudes and 40° to 45° East longitudes in the Northeastern of Saudi Arabia. It is bordered to the Northewest by the regions of Al-Jawf, in the North by the Northern borders, in the South by Ha'il , in the South by Al Qasim area and in the east by the Eastern Province. Consequently, the Nature Reserve (ITBA) is classified under a hot desert climate (BWh) of the Köppen-Geiger climate classification, with hot summers and cool winters. It has a somewhat milder climate than other Saudi sites due to its higher altitude.

Geologically, Nature Reserve (ITBA) is extended over Four main administrative regions; Ha'il, Northern boundaries, Al Qasim area and Al Jawf. In general, the study area is dominated by two air masses, namely, the Polar Continental that occurs from December to February and Tropical Continental that occurs in summer from June to September. Both systems are affected by minor incursions of Polar Maritime and Tropical Maritime air (Fisher & Membery, 1998).

All of the climatic conditions, soil properties and relief topography are clearly contributed to the presence of abundant plant diversity. So, At-Taysiah and Al Hijra plateaus are famous for the widespread of (*Dianthus cyri*). While the (*Haloxylon salicornicum*), *Calligonum comosum*), (*Ephedra alata*) and (*Panicum turgidum*) are the main plants of the sand dunes environment. However, (*Suaeda*) is the most wide spread plant clans in the Sabkhas environment.

In the plateaus environment, two major plants clans, namely (*Rhanterium epapposum*) and (*Haloxylon salicornicum*) are widely spread. The water courses are also an important environment for a number of plants mainly (*Lycium shawii*) and (*Acacia gerrardii*). In addition, the main agricultural activity of the population in west ITBA is the date production and vegetable cultivation. These two sectors are undergoing considerable development as it is the fundamental resource of several farmers. At the same time, these activities include camels breeding and livestock.

2.2. Data used

Datasets of rainfall were obtained from 5 rain stations for the period of 1967-2018 (Tab. 1 & Fig. 2). The dataset is summarized in the tables 2, 3 and 4.

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064
IJRSP

Table 1: Geographic coordinates of studied rain stations.					
Station	Latitude (N)	Longitude (E)	Height (m)	Code	Station No.
Ha’il	27°15'	41°34'	990	101 H	191
Hafr Al Batin	19°51’	41°34’	360	203 EP	152
Rafha	29°35’	43°29’	450	201 EP	151
Linah	29°48’	3^{9o}52’	650	103 SK	598
Dawmat Al Jandal	28°46’	43°45’	500	106 EP	149

Figure 2: Geographic location of studied stations.

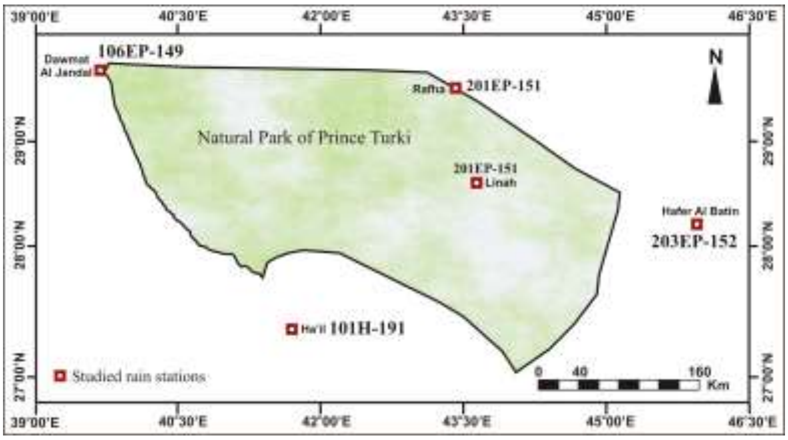


Table 2: Annual recorded rainfall at the rain studied stations..											
Year	**Linah**	**Rafha**	**Ha’il**	**Dawmat Al Jandal**	**Hafr Al Batin**	**Year**	**Linah**	**Rafha**	**Ha’il**	**Dawmat Al Jandal**	**Hafr Al Batin**
1967	105.9	92.7	110.6	149.8	107.6	1993	247.9	121.3	90.8	30.9	168.5
1968	43.4	38.4	101.3	45.9	35.4	1994	66.6	79.2	120.3	39.1	118.7
1969	33.9	37.9	89.2	81.9	48.8	1995	66.5	79.1	42.4	45.7	76.6
1970	51.9	54.9	70.4	101.0	53.6	1996	87.8	104.5	37.5	30.9	131.0
1971	91.1	56.0	65.9	32.5	110.0	1997	20.6	24.5	62.7	58.3	94.0
1972	83.6	120.2	156.5	64.5	155.7	1998	24.8	29.5	140.8	40.5	57.0
1973	73.5	20.4	52.2	32.5	11.4	1999	41.2	49.0	47.0	22.7	51.5
1974	80.9	163.8	158.4	123.7	87.5	2000	57.2	68.0	0.4	43.6	52.7
1975	95.0	30.6	101.7	67.0	102.2	2001	15.0	15.0	9.0	43.0	75.0
1976	94.3	79.7	256.1	48.8	174.6	2002	63.6	75.7	44.0	14.0	37.0

1977	102.4	148.8	101.9	13.6	82.7	2003	33.2	39.5	25.0	14.5	42.5
1978	33.8	30.7	42.4	5.0	69.5	2004	61.8	73.5	24.0	22.2	110.0
1979	41.0	12.1	63.6	9.8	34.9	2005	70.6	84.0	65.0	24.5	76.0
1980	34.0	49.4	55.0	19.0	58.8	2006	4.0	12.0	76.0	57.5	11.8
1981	108.4	103.2	81.4	3.4	77.4	2007	7.3	8.7	12.0	13.8	8.5
1982	201.4	94.6	108.6	70.9	104.2	2008	76.0	37.0	65.6	38.0	55.5
1983	35.5	17.2	69.0	17.5	32.7	2009	21.0	42.5	65.5	49.2	59.0
1984	43.3	68.3	227.8	32.3	47.8	2010	67.0	31.0	13.0	12.0	4.0
1985	70.3	83.6	145.7	60.7	35.6	2011	56.0	26.6	10.0	10.5	9.0
1986	30.3	36.0	131.2	72.3	52.3	2012	55.0	51.5	35.0	16.0	24.0
1987	7.2	8.6	58.4	58.9	22.2	2013	88.0	129.5	63.0	42.7	114.0
1988	77.0	49.2	4.4	60.3	11.5	2014	105.0	127.5	31.0	23.0	66.4
1989	188.5	55.9	173.6	17.0	18.3	2015	127.0	137.5	34.0	7.5	125.0
1990	66.5	21.3	29.4	25.0	9.9	2016	29.5	48.0	16.0	1.0	18.0
1991	107.0	0.4	103.7	38.9	89.5	2017	6.7	8.0	72.8	15.0	7.8
1992	74.0	87.5	37.6	17.9	61.0	2018	211.5	251.6	347.3	2.0	246.5

Table 3: Rainy days recorded at the rain studied stations.

Year	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin	Year	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin
1967	13	11	13	20	15	1993	25	16	22	6	21
1968	25	29	17	21	14	1994	7	10	24	6	12
1969	19	23	16	13	28	1995	10	14	8	6	13
1970	16	29	11	4	21	1996	8	11	10	9	15
1971	27	19	12	12	24	1997	5	7	15	11	16
1972	27	37	28	14	34	1998	2	3	9	6	8
1973	5	2	10	3	6	1999	3	5	5	7	12
1974	14	3	26	19	22	2000	9	13	1	9	9
1975	14	2	15	10	21	2001	3	2	2	42	7
1976	8	6	22	13	22	2002	4	6	6	5	7
1977	11	16	18	6	12	2003	5	7	25	2	5
1978	4	5	7	4	8	2004	8	12	4	4	5
1979	6	15	9	7	4	2005	6	9	10	3	3

Volume 4 – Issue 43
Issued on: 20 May 2023
International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064
IJRSP

1980	4	11	17	7	9	2006	1	1	11	8	1
1981	7	8	18	3	11	2007	6	9	12	3	8
1982	15	23	38	11	14	2008	11	9	7	5	4
1983	2	14	13	6	5	2009	3	8	12	5	2
1984	4	26	16	6	6	2010	8	8	2	4	2
1985	14	21	21	9	8	2011	9	6	5	1	3
1986	7	10	30	10	8	2012	8	8	3	3	6
1987	4	6	16	10	3	2013	13	13	12	6	13
1988	13	14	5	13	3	2014	15	14	12	2	9
1989	21	17	26	7	4	2015	20	10	9	2	8
1990	7	11	14	5	2	2016	4	8	8	1	2
1991	17	2	31	5	11	2017	1	2	4	1	2
1992	7	13	14	3	14	2018	10	14	18	1	12

Table 4: Actual mean of the daily rainfall recorded at the rain studied stations.

Year	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin	Year	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin
1967	8.1	8.4	8.5	7.5	7.2	1993	9.9	7.6	4.1	5.2	8.0
1968	1.7	1.3	6.0	2.2	2.5	1994	9.7	7.9	5.0	6.5	9.9
1969	1.8	1.6	5.6	6.3	1.7	1995	6.9	5.7	5.3	7.6	5.9
1970	3.2	1.9	6.4	25.3	2.6	1996	11.7	9.5	3.8	3.4	8.7
1971	3.4	2.9	5.5	2.7	4.6	1997	4.3	3.5	4.2	5.3	5.9
1972	3.1	3.2	5.6	4.6	4.6	1998	12.1	9.8	15.6	6.8	7.1
1973	14.7	10.2	5.2	10.8	1.9	1999	12.0	9.8	9.4	3.2	4.3
1974	5.8	54.6	6.1	6.5	4.0	2000	6.4	5.2	0.4	4.8	5.9
1975	6.8	15.3	6.8	6.7	4.9	2001	5.0	7.5	4.5	1.0	10.7
1976	11.8	13.3	11.6	3.8	7.9	2002	15.5	12.6	7.3	2.8	5.3
1977	9.3	9.3	5.7	2.3	6.9	2003	6.9	5.6	1.0	7.3	8.5
1978	8.5	5.6	6.1	1.3	8.7	2004	7.5	6.1	6.0	5.6	22.0
1979	6.8	0.8	7.1	1.4	8.7	2005	11.5	9.3	6.5	8.2	25.3
1980	8.5	4.5	3.2	2.7	6.5	2006	4.0	12.0	6.9	7.2	13.8
1981	15.5	12.9	4.5	1.1	7.0	2007	1.1	0.9	1.0	4.6	1.1
1982	13.4	4.1	2.9	6.4	7.4	2008	6.9	4.1	9.4	7.6	13.9

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

1983	17.8	1.2	5.3	2.9	6.5	2009	7.0	5.3	5.5	9.8	29.5
1984	10.8	2.6	14.2	5.4	8.0	2010	8.4	3.9	6.5	3.0	2.0
1985	4.9	4.0	6.9	6.7	4.5	2011	6.2	4.4	2.0	10.5	3.0
1986	4.4	3.6	4.4	7.2	6.5	2012	6.9	6.4	11.7	5.3	4.0
1987	1.8	1.4	3.7	5.9	7.4	2013	6.8	10.0	5.3	7.1	8.8
1988	5.9	3.5	0.9	4.6	3.8	2014	7.0	9.1	2.6	11.5	7.4
1989	9.0	3.3	6.7	2.4	4.6	2015	6.4	13.8	3.8	3.8	15.6
1990	9.5	2.0	2.1	5.0	5.0	2016	7.4	6.0	2.0	1.0	9.0
1991	6.3	0.2	3.3	7.8	8.1	2017	4.9	4.0	18.2	15.0	4.6
1992	10.6	6.7	2.7	6.0	4.4	2018	22.1	18.0	19.3	2.0	20.7

2.3. Methodology analysis

The methodology analysis used several statistical analysis as follows:

(1)- Rainfall variability analysis

1.1. Coefficient of variation (CV)

The coefficient of variation (CV) determines the variability of the rainfall in specific region. A high value of (CV) indicates that the rainfall variability is greater, where a lower value means the opposite. The (CV) is computed by the following equation:

$$CV = \frac{\sigma}{\mu}$$

Where (σ) is the standard deviation and (μ) is the mean of chosen temporal scale. (CV) is used to classify the degree of variability events into three categories : (Asfaw et al., 2018).

- Low CV (less than 20%)
- Moderate CV (from 20% to 30%).
- High CV (Above 30%).

1.2. Standardized Anomaly Index (SAI)

The Standardized Anomaly Index (SAI) was introduced by E.B. Kraus in the mid-1970s and was examined closely by Katz and Glantz at the National Center for Atmospheric Research, United States, in the early 1980s. SAI was developed for identifying drought events, especially in areas frequented by drought. The SAI can be computed by applying the follow equation:

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

$$SAI = \frac{X_i - X'}{Sd}$$

Where, (X_i) is the annual rainfall of the particular year, (X') is the long-term mean annual rainfall over a period of observation and (Sd) is the standard deviation of annual rainfall over that period of observation. So, positive value suggests a time of wet situation relative to the period of reference chosen, while the negative value ones imply a drought condition (Table 5).

Table 5 : SAI values classification (McKee et al., 1993).

SAI value	Category
Above 2.0	Extremely wet
1.5 – 1.99	Very wet
1.0 – 1.49	Moderately wet
(-0.99) – 0.99	Near normal
(-0.1) – (-1.49)	Moderately dry
(-1.50) – (-1.99)	Severely dry
(-2) or less	Extremely dry

(2)- Rainfall trend analysis

2.1. Simple Moving Averages (SMA) method

The formula for Simple Moving Average is written as follows:

$$SMA = (A_1 + A_2 + \ldots\ldots\ldots A_n) / n$$

Where A is the average in period n; and **n** is the number of periods.

2.2. Homogeneity of variance test

Hartley (1950) proposed a homogeneity of variances test which is based on a F_{max} statistic used the ratio of the largest variance to the smallest variance as follows:

$$F_{max} = \frac{\sigma^2 max}{\sigma^2 min}$$

The exact distribution of Hartley's F-max statistic is known under homogeneity of variances with equal sample sizes and Hartley has given a table of the upper 5 % points of this statistic. David (1952) gave corrections to this table. This is one of the most popular statistics for comparing the semi averages. In this paper, Hartley's F_{max} statistic for testing the homogeneity of variances used the equal sample sizes for 26 years; with the first part (1967-1992) and the second part (1993-2018) of the time-series. Hartley's F_{max} statistic is not robust when the underlying distribution is not normal or unequal sample sizes (Conover et al., 1981 ; Rivest, 1986). However, the reasons for using F_{max} statistic are as follows. Firstly, the rain data recorded during a continuous and common time series (52 years) available at every studied station. Secondly, the rainfall data is in general, normally distributed. Thirdly, Hartley's statistic is still easy to compute using an equal sample sizes (Gupta, 1987 ; Chu & Sutradhar, 1995). Fourthly, also with the increase of usage and availability of several computer software, it is easier to apply F_{max} ratio with a high accuracy. To apply F_{max} method, the time-series were divided into two equal parts with respect to time. However, the dataset is homogeneous if the computed F_{max} value is smaller than the critical F_{max} value at the level 0.05 and degree of freedom [d.f = n – 1].

2.3. Semi-averages method

To apply the semi-averages method, the time-series were divided into two equal parts with respect to time. And then we compute the arithmetic mean of the two parts. The trend values can then be read from the ratio between the semi-averages of the first and the second parts (X_1', X_2') of every period (T_1, T_2). So, the ratio value greater than 1 indicates the increasing trend and the ratio value less than 1 represents the decreasing trend. The trend indicator "b" was defined as the ratio of the difference between the semi-averages and the difference between the middle of the two parts, expressed as follows:

$$b = \frac{X'_2 - X'_1}{T_2 - T_1}$$

Where, X'_1 and X'_2 are the semi-averages of the first and the second parts (T_1 , T_2) the middle of every part. The estimated straight trend line passes through the two points (X'_1 , X_2').

The level significance of trend can be determined by comparison between the difference of the semi-averages ($X'_2 – X'_1$) and the standard error (SE), expressed as follows:

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

$$S.E\left|X'_1 - X'_2\right| = \left[\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right]^{0.5}$$

Where, (σ_1^2 , n_1) are the variance and the number of time units (years) covered by the first part; (σ_2^2 , n_2) are the variance and the number of time units (years) covered by the second part. So, the T-student test can be computed using the following equation:

$$t = \frac{\left|X'_1 - X'_2\right|}{\left[\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right]^{0.5}}$$

However, the trend is significant at the level 0.05 and degree of freedom [d.f = $(n_1+n_2) - 2$], if : (Gregory, 1970 ; Oliver, 1981).

a- The computed T-student value is greater the critical T value b- The absolute difference IX'_1 – X'_2I > 2 SE or 3 SE, at the same level 0.05 and degree of freedom.

3. Results and Discussion

3.1. Annual rainfall variability

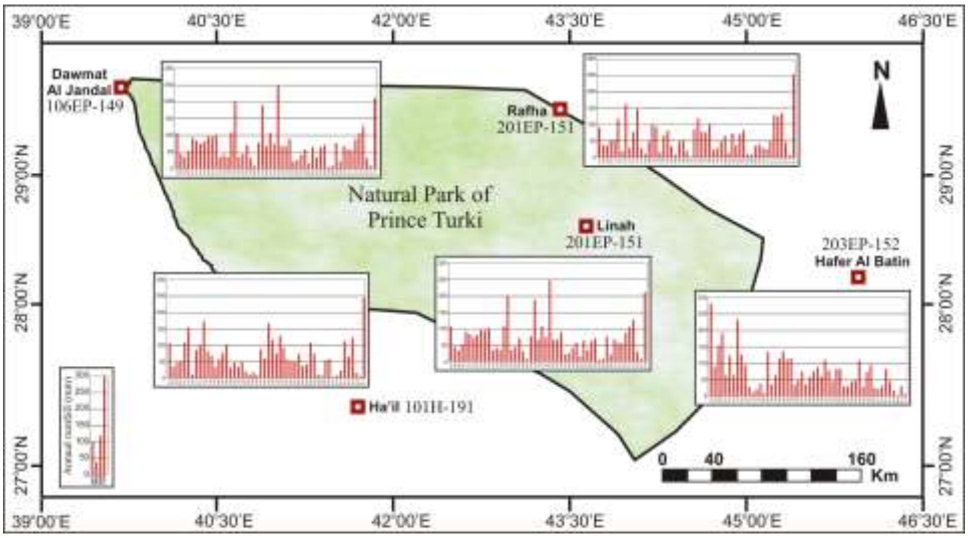
The variability of annual rainfall and rainy days are analyzed using two statistical parameters; coefficient of variation (CV) and standardized anomaly index (SAI).

1- Coefficient of variation (CV)

The mean annual rainfall varies from 38.2 mm in Dawmat Al Jandal station to 79.7 mm in Ha'il station (Fig. 3). But, the annual rainfall is ranged for extremely dry years from 0.4 mm at Rafha (1991) and Ha'il (2000) to 4.0 mm at Linah (2006) and Ha'il (2010). However, the mean annual rainfall is ranging for relatively rainy years from 149.8 mm (1967) at Dawmat Al Jandal to 347.3 mm (2018) at Ha'il. Interannual variability of rainfall is characterized by the high coefficients of variation, from 0.73 at Linah to 0.83 at Ha'il. So, the range of annual rainfall varies from 158.8 mm to 346.9 mm at Dawmat Al Jandal and Ha'il, respectively (Tab. 6 & Fig. 3).

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

Figure 3: The spatial distribution of the annual rainfall.



To analyze the statistical significance of the annual rainfall variance, the Chi square test was computed. The Chi square values are presented in Table 7. The test Chi square distribution has been used for detecting the statistical significance of the annual rainfall variance. The null hypothesis indicating that the variance data don't have any outliers is accepted if the computed value of Chi square test is greater than the critical value at 0.05 significance level corresponding to the degree of freedom (n-1). While the null hypothesis is rejected and the alternative hypothesis is accepted on the contrary case. So, from the table 7, the Chi square values are greater than the critical values at 0.05 significance level and at the different degrees of freedom in all stations, except Ha'il. This result show that the variance of the annual rainfall is only significant at Ha'il station.

Table 6: Descriptive statistics of the annual rainfall in studied stations.

Staistic parameters		Linah	Rafha	Ha'il	Dwmat Al Jandal	Hafr Al Batin
Annual rainfall (mm)	X'	70.9	63.8	79.7	38.3	68.0
	SD	51.5	48.4	66.3	30.2	50.0
	CV	0.73	0.76	0.83	0.79	0.74
	Maximum	247.9	251.6	347.3	149.8	246.5

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064
IJRSP

	Minimum	4.0	0.4	0.4	1.0	4.0
	Range	243.9	251.2	346.9	148.8	242.5
Rainy days	X’	10	12	14	8	10
	SD	6.8	7.7	8.3	6.8	7.4
	CV	0.01	0.01	0.01	0.02	0.01
	Maximum	27.0	37.0	38.0	42.0	34.0
	Minimum	1.0	1.0	1.0	1.0	0.9
	Range	26.0	36.0	37.0	41.0	33.2
Actual daily of mean rainfall (mm)	X’	8.0	7.2	6.0	5.8	7.8
	SD	4.2	7.9	4.0	4.0	5.8
	CV	0.53	1.09	0.66	0.69	0.74
	Maximum	22.1	54.6	19.3	25.3	29.5
	Minimum	1.1	0.2	0.4	1.0	1.1
	Range	20.9	54.4	18.9	24.3	28.4

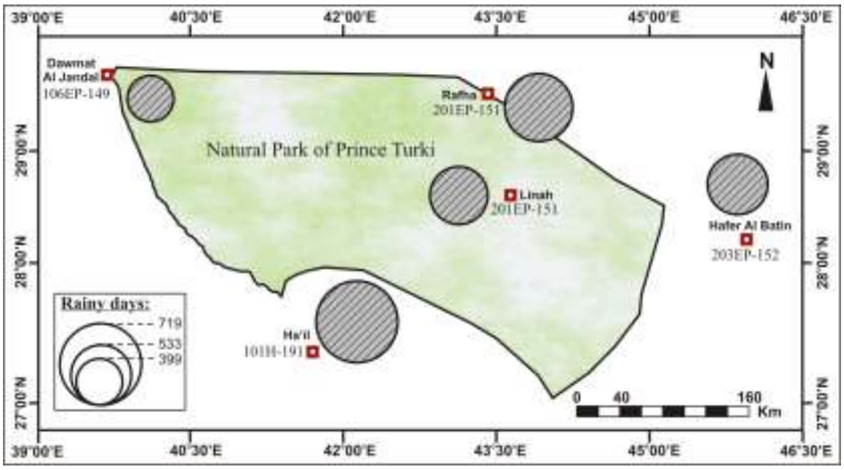
Table 7: Chi square test of annual rainfall variance at the studied stations.

Station	X_c^2	df	N	X_t^2	H = 0
Linah	20.492	3	4	7.815	Accepted
Rafha	24.923	3	4	7.815	Accepted
Ha’il	8.462	3	4	7.815	Rejected
Dawmat Al Jandal	14.923	3	4	7.815	Accepted
Hafr Al Batin	14.000	3	4	7.815	Accepted

In the same context, the cumulative frequency of rainy days during the period of 1967-2018 (52 years) shows that the maximum is observed with 719 days at Ha’il and the minimum with 399 days at Dawmat Al Jandal (Fig. 4).

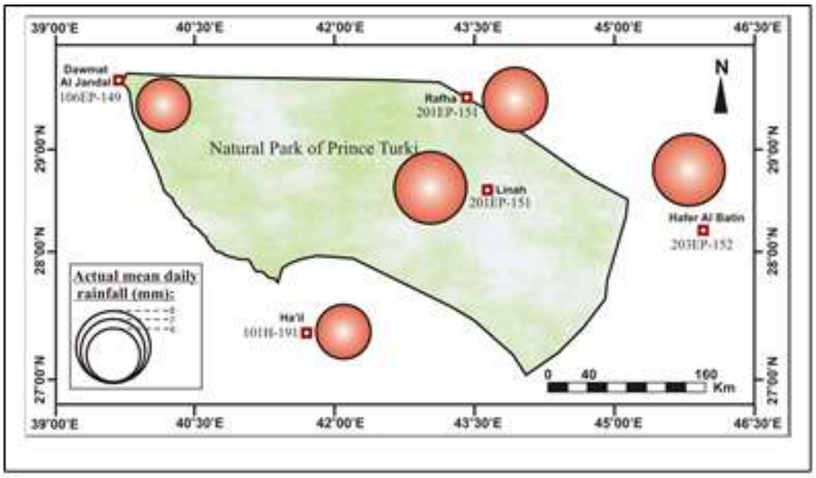
International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

Figure 4: The spatial distribution of the total rainy days.



Consequently, the mean of rainy days varies from 8 days/year at Dawmat Al Jandal to 14 days/year at Ha'il. But during the extremely dry years, the total of rainy days don't exceed 2 days/year. However, during the relatively rainy years, the total of rainy days is ranging from 15 to 18 days/year at Dawmat Al Jandal and Ha'il, respectively. So, the actual mean of daily rainfall obtained by the ratio of the cumul of annual rainfall and the cumulative frequency of rainy days during the studied period varies from 5.8 to 8.0 mm/day at Dawmat Al Jandal and Linah, respectively. But the maximum of daily rainfall is ranged from 19.3 mm/day (2018) at Ha'il to 54.6 mm/day (1974) at Rafha and the difference between the upper and lower mean varies from 18.9 to 54.4 mm/day at Ha'il and Rafha, respectively. So the actual mean of daily rainfall is characterized by the high coefficients of variation, with 0.53 to 1.09 at Linah and Rafha, respectively (Tab. 6 & Fig. 5).

Figure 5: The spatial distribution of the actual mean daily rainfall.



2- Standardized Anomaly Index (SAI) of rainfall

The computed SAI values are presented in the table 7. Positive values that suggest wet years relative to the period of reference increase from 19 years at Ha'il and Jubbah, 21 years at Linah and Rafha, 22 years at Hafr Al Batin to 23 years at Dawmat Al Jandal. While, the negative ones imply a drought condition during the dry years vary from a station to another with the maximum of 29 years at Dwmat Al Jandal to 33 years at Ha'il.

Table 8: Distribution of SAI positive and negative at the studied stations.

Variable	SAI	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin
Annual rainfall (mm)	Positive	21	21	19	23	22
	%	40.4	40.4	36.5	44.2	42.3
	Negative	31	31	33	29	30
	%	59.6	59.6	63.5	55.8	57.7
Rainy days	Positive	19	21	23	18	22
	%	36.5	40.4	44.2	34.6	42.3
	Negative	33	31	29	34	30
	%	63.5	59.6	55.8	65.4	57.7
Actual mean daily rainfall (mm)	Positive	22	20	21	25	19
	%	42.3	38.5	40.4	48.1	36.5
	Negative	30	32	31	27	33
	%	57.7	61.5	59.6	51.9	63.5

From the table 8, the positive values of the rainy days increase from 18 years at Dawmat Al Jandal, 19 years at Linah, 21 at Rafha, 22 years at Hafr Al Batin to 23 years at Ha'il. While, the negative ones vary from with the maximum of 29 years at Ha'il to 34 years at Dawmat Al Jandal. Consequently, the actual mean of daily rainfall shows the positive values increasing from 19 years at Hafr Al Batin to 25 years at Dawmat Al Jandal and a negative values varying from 27 to 33 years at Dawmat Al Jandal and Hafr Al Batin, respectively. The Standardized Anomaly Index (SAI) was used determine the characteristics of the annual rainfall (Table 9).

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

Table 9: The annual rainfall classification using SAI.						
SAI value	Category	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin
Above 2.0	Extremely wet	4	2	3	3	3
1.5 – 1.99	Very wet	0	2	0	0	1
1.0 – 1.49	Moderately wet	1	4	4	3	3
(-0.99) – 0.99	Near normal	42	37	39	41	36
(-0.1) – (-1.49)	Moderately dry	5	7	6	5	9
(-1.50) – (-1.99)	Severely dry	0	0	0	0	0
(-2) or less	Extremely dry	0	0	0	0	0

From the table 9, the SAI values ranged from (-0.99) to 0.99 indicating the "near normal" class is represented by the most high proportion of the annual rainfall frequency in all selected stations. The frequency of near normal class varies from 36 years at Hafr Al Batin to 42 years at Linah.

3.2. Trends analysis

3.2.1. Moving-averages trends

The trends of annual rainfall were analyzed using the Moving averages method. So, the time-series of dataset was divided into five periods: 1967-76, 1977-86, 1987-96, 1997-2006 and 2007-2018. The table 10 and figure 6 present the moving-averages of the named periods. The analysis of the annual rainfall for 1967-2018, indicates a decrease trends at the selected stations. So, the moving averages vary with the range of 27.8 mm at Dawmat Al Jandal to 66.8 mm Ha'il. The analysis of the rainy days, indicates also a decrease trends at the selected stations (Fig. 7). So, the moving averages vary with the range of 9 days mm at Dawmat Al Jandal to 15 days at Linah. The table 10 shows a contrast of temporal and spatial distributions of the increasing and decreasing trends of the rainfall and the rainy days moving averages. Consequently, that there is no homogeneous trends of the two variables characterizing the same period at all station.

Table 10: the moving-averages of annual rainfall and the rainy days at the studied rain stations.						
variable	Period	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin
Annual	1967-1976	75.4	69.5	116.2	74.8	88.7

rainfall (mm)	1977-1986	70.0	64.4	102.7	30.5	59.6
	1987-1996	98.9	60.7	69.3	36.5	70.7
	1997-2006	39.2	47.1	49.4	34.1	60.7
	2007-2018	70.8	74.9	63.8	19.2	61.5
Rainy days	1967-1976	17	16	17	13	21
	1977-1986	7	15	19	7	9
	1987-1996	12	11	17	7	10
	1997-2006	5	7	9	10	7
	2007-2018	9	9	9	3	6

From these various trends, it is clear the difficulties to determine the main trend of annual rainfall in all stations using the moving-average method. However, the semi-averages method was applied to analyze the annual rainfall trends.

Figure 6: The spatial distribution of the moving averages of the annual rainfall.

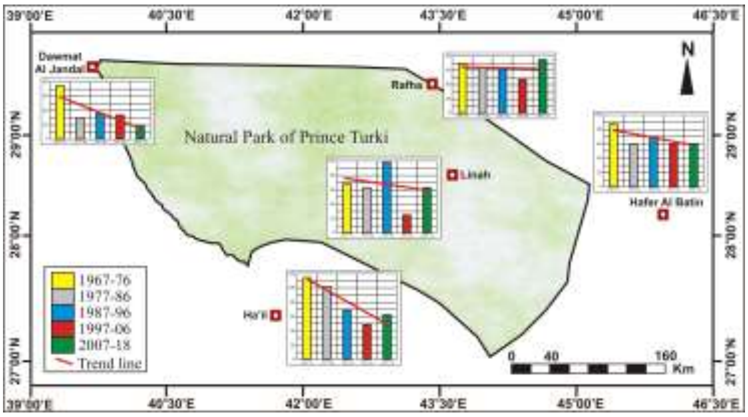
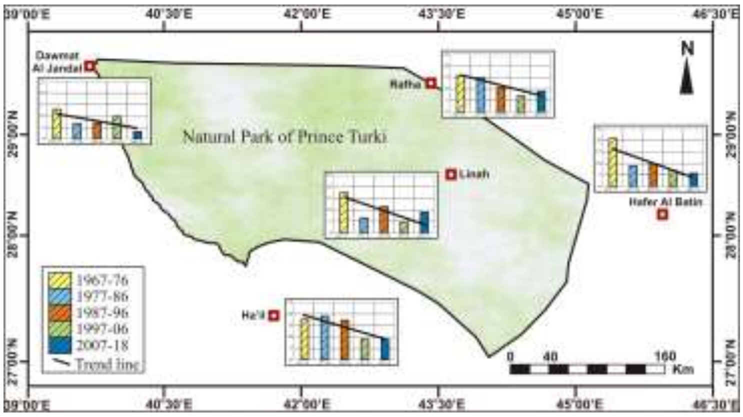


Figure 7: The spatial distribution of the moving averages of the rainy days.



International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064
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3.2.2. Homogeneity of variance

The variance is homogeneous if the calculated F_{cmax} value is small than the critical F_{tmax} value at the degree of freedom (n-1) and significance level 0.05. It is clear from the data of table 11 that the calculated F_{max} values are greater than the critical F_{max} value 1.67 at the statistical significance level 0.05 and the degree of freedom 51. The results of this test indicate that the variance of the annual rainfall is homogeneous at only Linah, Rafha and Ha'il. While, the variance of the rainy days is only homogeneous ay Ha'il and the variance of the actual mean of daily rainfall is only homogeneous at Linah.

Table 11: Results of F_{max}-Hartley's test.

Variable	Station	S_1^2	S_2^2	F_{max-c}	Variance
Annual rainfall (mm)	Linah	2033.6	3324.5	1.63	Homogeneous
	Rafha	1804.6	2943.5	1.63	Homogeneous
	Ha'il	3526.1	4607.2	1.31	Homogeneous
	Dawmat Al Jandal	1347.0	280.3	4.81	Not homogeneous
	Hafr Al Batin	1838.8	3244.8	1.76	Not homogeneous
Rainy days	Linah	54.9	31.2	1.76	Not homogeneous
	Rafha	88.2	16.5	5.35	Not homogeneous
	Ha'il	63.6	43.4	1.46	Homogeneous
	Dawmat Al Jandal	27.2	61.2	2.25	Not homogeneous
	Hafr Al Batin	73.0	26.8	2.73	Not homogeneous
Actual mean daily rainfall (mm)	Linah	19.3	17.2	1.12	Homogeneous
	Rafha	112.0	14.0	8.02	Not homogeneous
	Ha'il	7.8	24.7	3.17	Not homogeneous
	Dawmat Al Jandal	21.9	10.8	2.03	Not homogeneous
	Hafr Al Batin	4.5	53.0	11.81	Not homogeneous

3.2.3. Semi-averages trends

Trend analysis of a series of observed annual rainfall, rainy days and actual mean of daily rainfall using the semi-averages method can indicate if these variables pattern and distribution are changing in due course of time or remains stable (Borse & Agnihorti, 2017).

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

Various researchers have contributed to the study of climate change over Saudi Arabia using rainfall and temperature trends. So, the analysis of different time series data has proved that rainfall trend is decreasing (Al Sarmi & Washington, 2013). The rainfall has a direct impact on the scarcity of the surface water resources over Saudi Arabia (Amin et al., 2016).

In this study, the whole data of rainfall, rainy days and actual mean of the daily rainfall is divided into equals periods (parts): (1967-1992) and (1993-2018). After the average (arithmetic mean) of each part is calculated in order to obtain 2 semi averages (Table 12).

Table 12: Statistical parameters of semi-averages trends at the studied stations.

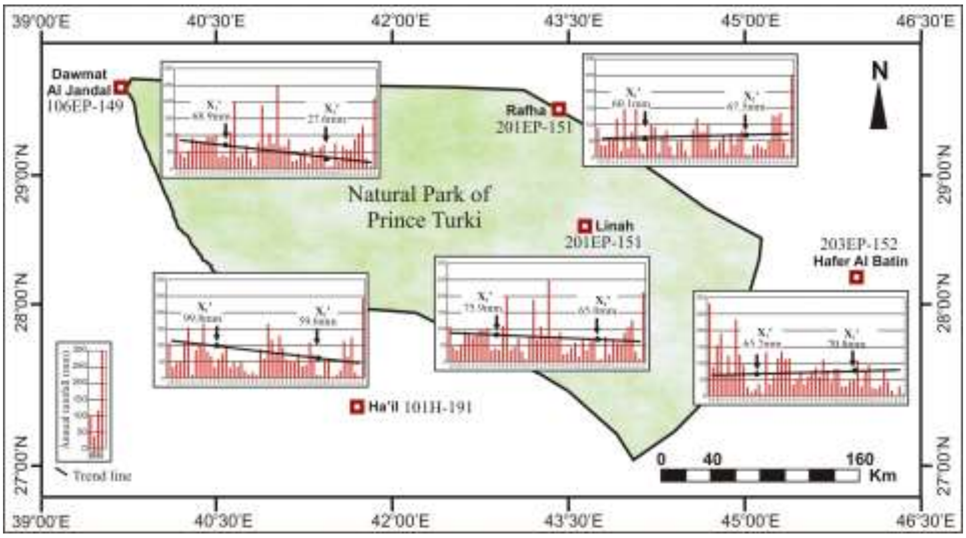
Variable	Statistical parameters	Linah	Rafha	Ha'il	Dawmat Al Jandal	Hafr Al Batin
Annual rainfall (mm)	X'_1	75.9	60.1	99.8	48.9	65.2
	X'_2	65.8	67.5	59.6	27.6	70.8
	T'_1	1979.50	1979.50	1979.50	1979.50	1979.50
	T'_2	2005.5	2005.5	2005.5	2005.5	2005.5
	b	-0.39	0.29	-1.55	-0.82	0.21
	SE	14.4	13.5	17.7	7.9	14.0
	2SE	28.7	27.0	35.4	15.8	28.0
	$IX_1'-X_2'I$	10.1	7.4	40.2	21.2	5.6
	T-student	0.705	0.549	2.274	2.684	0.399
	df	50	50	50	50	50
	$T_{t0.05}$	1.697	1.697	1.697	1.697	1.697
	H=0	Accepted	Accepted	Rejected	Rejected	Accepted
Rainy days	X'_1	12.0	14.4	17.8	9.3	12.7
	X'_2	7.8	8.7	9.8	6.1	7.9
	T'_1	1979.50	1979.50	1979.50	1979.50	1979.50
	T'_2	2005.5	2005.5	2005.5	2005.5	2005.5
	b	-0.16	-0.22	-0.31	-0.12	-0.18
	SE	1.8	2.0	2.0	1.8	2.0
	2SE	3.6	4.0	4.1	3.7	3.9
	$IX_1'-X_2'I$	4.1	5.7	8.0	3.2	4.8
	T-student	2.273	2.837	3.924	1.731	2.446
	df	50	50	50	50	50
	$T_{t0.05}$	1.697	1.697	1.697	1.697	1.697
	H=0	Rejected	Rejected	Rejected	Rejected	Rejected

Actual mean of daily rainfall (mm)	X'_1	7.8	6.9	5.6	5.6	5.6
	X'_2	8.2	7.6	6.4	6.0	10.0
	T'_1	1979.50	1979.50	1979.50	1979.50	1979.50
	T'_2	2005.5	2005.5	2005.5	2005.5	2005.5
	b	0.02	0.03	0.03	0.02	0.17
	SE	1.2	2.2	1.1	1.1	1.5
	2SE	2.4	4.4	2.2	2.2	3.0
	$IX_1'-X_2'I$	0.4	0.7	0.8	0.4	4.4
	T-student	0.360	0.340	0.698	0.361	2.975
	df	50	50	50	50	50
	$T_{t0.05}$	1.697	1.697	1.697	1.697	1.697
	H=0	Accepted	Accepted	Accepted	Accepted	Rejected

On the graphic of data distribution, every point is plotted against the middle of each part. Then, the straight line joining these 2 semi-averages points gives the trend line. So, the table 12 and figure 8 summarize the annual rainfall trends using the semi-averages method. From the data of Table 12, we find that the annual rainfall amounts have decreasing trends in Linah, Ha'il and Dawmat Al Jandal, with the simple negative regression values of (-0.39), (-1.55) and (-0.82) respectively. While the annual rainfall amounts have increasing trends in Rafha and Hafr Al Batin, with the simple positive regression values of 0.29 and 0.21, respectively. The statistical significance was determined using the standard error method S.E$|X'_1-X'_2|$ for the two semi-averages. There are a significant decreasing trends of the annual rainfall at the 5% significance level only in Ha'il and Dawmat Al Jandal. These two trends are statistically significant because the probability of their occurrence exceeds 5%. For the difference to be statistically significant and therefore substantial and real, it is required that it exceed (2S.E) or (3S.E). Otherwise it is considered statistically insignificant and rejected (Gregory, 1970; Crowe, 1971). Student's t-statistic test of the difference between the semi-averages also confirmed these results. The calculated "t" values are greater than the critical "t" value (1.697) at the significance level 0.05, at the degree of freedom (n-2) 50 in Ha'il and Dawmat Al Jandal.

Volume 4 – Issue 43
Issued on: 20 May 2023
International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

Figure 8: The spatial distribution of the semi-averages trends of annual rainfall



And on the contrary, the T-student value of the rainy days trends is greater than the critical value (1.697) in all the studied stations. Consequently, the null hypothesis was rejected and the decreasing trends of the rainy days are significant in the study area, In the other hand, the T-student value of the actual mean of the daily rainfall is smaller than the critical value (1.697) in all the stations, except Hafr Al Batin. So, the increasing trends of the actual mean of the daily rainfall are not significant in the study area, except Hafr Al Batin.

4. Conclusions

This study applied the Moving averages and Semi-averages methods to evaluate trends in the annual rainfall, rainy days and the actual mean of the daily rainfall using the data recorded from 1967 to 2018 at five rain stations. So, the main results obtained can be summarized in the following:

1- The annual rainfall variability was characterized by the average varying from 148.8mm at Dawmat Al Jandal to 346.9mm at Ha'il and the variability of the rainy days characterized by the average varying from 8 days/year at Dawmat Al Jandal to 14 days/year at Ha'il. As a result, the actual mean of the daily rainfall varies from 5.8 mm/day at Dawmat Al Jandal to 8.0 mm/day at Linah. The SAI analysis shows that the main category of the annual rainfall distribution was the "Near Normal" category, with the frequency of 36 years at Hafr Al Batin and 42 years at Linah. The highest annual rainfall was recorded with an amount of 347.3 mm (2018) at Ha'il.

International Journal of Research and Studies Publishing
المجلة الدولية لنشر البحوث والدراسات
ISSN: 2709-7064

2- Regarding the variance, Chi square test shows that the variance of the annual rainfall was not significant in all of the studied stations. The Fmax-ratio shows the homogenous variance of the annual rainfall at Linah, Rafha and Ha'il, the homogeneous of the variance of the rainy days at only Ha'il and the homogeneous variance of the actual mean of the daily rainfall at only Linah.

3- As for the trends analysis, the T-student test shows the significant decreased trends of the annual rainfall at only Ha'il and Dawmat Al Jandal, the significant decreased trends of the rainy days in all of the studied stations and the significant increased trends of the actual mean of the daily rainfall at only Hafer Al Batin.

From the foregoing, it is difficult to infer the general trends of the annual rainfall as an indicate for confirming the aspects of the climate change in the study area. So, it is recommended to comparing these results with the rainfall trends in more rain stations and auditing the results of the obtained trends by adding the analysis of more climatic variables over Saudi Arabia.

5. Acknowledgment

The study's targets come in line with the relentless efforts made by the Imam Turki bin Abdullah Reserve Development Authority in managing this reserve, as it exerted tremendous efforts through which it sought to re-develop environment in an attempt to bringing it to its fertile past again when the environmental -balance was dominant in all its parts.

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