The Homogeneity Analysis of Rainfall Time Series for Selected Meteorological Stations in Iraq

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Abstract

In the present research, the homogeneity tests were conducted for 36 meteorological stations records throughout Iraq. For this purpose, monthly and annual total rainfall records at stations operated by Iraqi meteorological organization and seismology (IMOS) from 1981 to 2010 were considered. Four methods namely standard normal homogeneity test (SNHT), Buishand range test, Pettitt test, and von Neumann ratio tests were chosen to detect the inhomogeneity of the rainfall time series. The results of each of the testing methods were evaluated separately at a significance level of 95% and the inhomogeneous years have been determined. With the application of the four mentioned methods, inhomogeneity was detected at 30% of stations (11 stations) and 70 % of stations (25 stations) were found to be homogeneous. The results of the different tests are condensed into three classes: 'useful', 'doubtful' and 'suspect'. A qualitative interpretation of this classification is given, 31 stations were assigned as useful, two stations were labeled as doubtful and three stations were assigned as suspect.

Key words: Homogeneity tests; standard normal homogeneity tests; Buishand range test, Pettitt test; Von Neumann ratio test; rainfall; Iraq.

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تحليل التجانس للسلاسل الزمنية للامطار لمحطات الانوائية في العراق

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الخلاصة

تم في هذه الدراسة اجراء اختبارات التجانس لتسجيلات الامطار في 36 محطة انوائية بالعراق. ولهذا الغرض تم استخدام المعدلات الشهرية والسنوية للامطار والمتوفرة في الهيئة العامة للانواء الجوية والرصد الزالزالي ولفترة 30 سنة (1980-2010). اربع اختبارات للتجانس تم استخدامها في هذه الدراسة للكشف عن تجانس السلال الزمنية للامطار وهي اختبار معيار التجانس الطبيعي ،واختبار مدى بويشند، اختبار بيتيت واختبار نسبة فون نيومان. نتائج كل طريقة اختبار تم تقييمها بشكل منفصل وبمستوى ثقة 95% وايضا تم تحديد السنوات الغير المتجانسة في كل طريقة ومن خلال تطبيق اختبارات التجانس اظهرت النتائج ان 30% من المحطات (11 محطة) وجدت غير متجانسة بينما كانت 70% من المحطات (25 محطة) كانت متجانسة. نتائج الاختبارات الاربعة تم تقسيمها الى ثلاث اصناف: مفيدة ، مشكوك بها ، مشتبه بها. التقييم النوعي لهذا التصنيف اظهر ان 31 محطة كانت مفيدة ومحطتين فقط مشكوك بها بينما كانت ثلاث محطات مشتبه بها.

الكلمة المفتاحية: اختبارت التجا نس،اختبارمعيار التجا نس الطبيعي، اختبار مدى بويشند، اختبار بيتيت، اختبار نسبة فون نيومان، العراق

Introduction

The accuracy and reliability of climate change, flood and drought modeling, water resources planning, determination of rainfall-runoff relationship, and river flow estimation models vary according to the quality of the data used. The factors such as method of gauging and data collection, the conditions around the station, station relocation, and the reliability of the measurement tool affect the homogeneous precipitation records. For this reason, the data recorded at gauging stations should be tested and checked for reliability and homogeneity prior to their use in the research studies, [1]. A homogeneous time series is define as one in which variations are caused only by the weather and the climate. The factors causing variations on the long-term time series are, location of the stations, instruments, formulae used to calculate means, observing practices and station environment [2].

The homogeneity tests of time series may be classified in two groups as 'absolute method 'and 'relative method'. In the first method, the test is applied for each station separately. In the second method, the neighboring (reference) stations are also used in the testing [3]. Szalai and Szalai *et al*. (summarize the application of different methods that are used in European countries [4,5].This method purposely used to detect a single systematic change in mean in an independent time series. This test is similar with standard normal homogeneity test (SNHT) proposed. Wang et al. proposed a penalized maximal *t* test (PMT) to detect the undocumented mean shifts in climate data series [6]. It takes account the position of each station change-point to reduce the effect of unequal sample sizes. They compared the performance with SNHT and found that PMT is powerful in detecting all the change-points that are not too close with the end of series. However, this test is weak in detecting the change-points that are near to the end of series. Costa et al. also proposed a technique which used the residuals from a seemingly unrelated regression equation (SUR) model [7, 8]. Meanwhile Seleshiand Camberlin used multiple analyses of series for homogenization (MASH) technique in Ethiopia [9].

Wijngaad et al. employed four homogeneity tests, named SNHT, Buishand range (BR) test, Pettitt test and Von Neumann ratio (VNR) test to the European Climate [3]. The results are categorized into three classes, which are useful, doubtful and suspect according to the number of tests rejecting the null hypothesis. Three testing variables were used, each consists of annual values. For temperature, the two testing variables are annual mean of diurnal temperature range and annual mean of the absolute day-to-day differences. Meanwhile for rainfall, the annual number of wet days (threshold 1mm) is employed. Many countries have used the same homogeneities tests to detect the inhomogeneities of data. Stepanek et al. used SNHT, bivariate test and Easterling and Peterson test to detect inhomogeneities of air temperature and precipitation series of Czech Republic [10]. Meanwhile, Gonzalez-Rouco et al. used SNHT to evaluate the homogeneity of precipitation series in Iberian Peninsula, southern France and northern Africa [11].

In present study the method of Wijngaard et al. [3] was adopted to assess the homogeneity series in annual means of rainfall values for 36 stations in Iraq. The missing values of monthly rainfall recorded were completed by using the normal ratio method. Absolute tests are used because the stations are randomly distributed with different rainfall patterns and geographical location. The relative tests, on the other hand, are not encouraged because of absence of high positive correlation among stations investigated.

Material and Methods

Homogeneity Tests.

Four homogeneity tests are used to test the homogeneity of the rainfall data. Standard normal homogeneity test (SNHT), Buishand range (BR) test, Pettitt test, and Von Neumann ratio (VNR) test are selected. Under null hypothesis, the annual values *Yi of* the testing variables *Y* are independent and identically distributed and the series are considered as homogeneous. Meanwhile under alternative hypothesis, SNHT, BR test and Pettitt test assume the series consisted of break in the mean and considered as inhomogeneous. These three tests are capable to detect the year where break occurs.

Meanwhile VNR test is not able to give information on the year break because the test assumes the series is not randomly distributed under alternative hypothesis. There are some differences between SNHT, BR test and Pettitt test. SNHT is sensitive in detecting the breaks near the beginning and the end of the series. BR test and Pettitt test are easier to identify the break in the middle of the series. Besides, the SNHT and BR test assumed *Yi* is normally distributed, whereas Pettitt test does not need this assumption because it is a non-parametric rank test. The detail of these four absolute test methods are explain as following .

1. Standard Normal Homogeneity Test

Alexndersson describes a statistic $T(k)$ to compare the mean of the first k years of the record with that of the last $n-k$ years [12]:

$$T(k) = kz_1^2 + (n-k)kz_2^2 \qquad k = 1, \ldots\ldots, n \tag{1}$$

where

$$\bar{z}_1 = \frac{1}{k}\sum_{i=1}^{k}(Y_i - \bar{Y})/s \quad and \quad \bar{z}_2 = \frac{1}{n-k}\sum_{i=k+1}^{n}(Y_i - \bar{Y})/s \tag{2}$$

If a break is located at the year, then $T(k)$ reaches a maximum near the year $k = K$. The $T(k)$ is depicted in the graphs representing the results of this test. The test statistic T_0 is defined as:

$$T_0 = \max_{1 \le k < n} T(k) \tag{3}$$

The test has further been studied by Jaruskova [13]. The relationship between her test statistic $T(n)$ and T_0 is

$$T_0 = \frac{n\left(T(n)\right)^2}{n-2+\left(T(n)\right)^2} \tag{4}$$

The null hypothesis will be rejected if T_0 is above a certain level, which is depedent on the sample size.

2. Buishand rang test

In this test, the adjusted partial sums are defined as

$$S_0^* = 0 \; and \; S_k^* = \sum_{i=1}^{k}(Y_i - \bar{Y}) \qquad k = 1, \ldots\ldots, n \tag{5}$$

When a series is homogenous the values of S_k^* will fluctuated around zero, because no systematic deviations of the Y_i values with respect to their mean will appear. If a break is present in year$K$, then S_k^* reaches a maximum (negative shift) or minimum (positive shift) near the year $k = K$. The $(S_k^*/s)/\sqrt{n}$ is depicted in the graphs representing the results of this test. The significance of the shift can be tested with the rescaled adjusted rang R, which is the difference between the maximum and minimum of the S_k^* values scaled by the sample standerd deviation:

$$R = (\max_{0 \le k < n} S_k^* - \min_{0 \le k < n} S_k^*)/s \qquad (6)$$

Buishand gives critical values for R/n [14].

3. Pettitt test

This test is no-parametric rank test. The ranks $r_1, \ldots\ldots, r_2$ of the $Y_1, \ldots\ldots, Y_n$ are used to calculate the statistics:

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1) \qquad k = 1, \ldots\ldots, n \qquad (7)$$

The X_k is depicted in graphs representing the results of the test.

If a break occurs in year E, then the statistic is maximal near the year $k = E$:

$$X_E - \max_{1 \le K < n} |X_K| \qquad (8)$$

The significance level is given by Pettitt [15].

4. Van Neumann ratio

The Van Neumann ratio N is defined as the mean square successive (year to year) difference [16]:

$$N = \sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2 / \sum_{i=1}^{n}(Y_i - \bar{Y})^2 \qquad (9)$$

When the sample is homogeneous the expected value is $N=2$. If the sample contains a break, then the value of N tends to be lower than this expected value [17]. If the sample has rapid variations in the mean, then values of N may rise above two [18]. This test gives no information about the location of the shift.

Homogeneity tests classification

The outcomes of the four tests for the rainfall series are grouped together. As in Schonwiese and Rapp ,a classification is made depending on the number of tests rejecting the null hypothesis. The following categories are distinguished [19]:

Class 1: 'useful' — one or zero tests reject the null hypothesis at the 5% level.

Class 2: 'doubtful' — two tests reject the null hypothesis at the 5% level.

Class 3: 'suspect' — three or four tests reject the null hypothesis at the 5% level.

The qualitative interpretation of the categories is as follows:

Class 1: 'useful'. No clear signal of an inhomogeneity in the series is apparent. Hence, inhomogeneities that may be present in the series are sufficiently small with respect to the inter-annual standard deviation of the testing variable series that they will largely escape detection. The series seems to be sufficiently homogeneous for trend analysis and variability analysis.

Class 2: 'doubtful'. Indications are present of an inhomogeneity of a magnitude that exceeds the level expressed by the inter-annual standard deviation of the testing variable series. The results of trend analysis and variability analysis should be regarded very critically from the perspective of the existence of possible inhomogeneities.

Class 3: 'suspect'. It is likely that an inhomogeneity is present that exceeds the level expressed by the inter-annual standard deviation of the testing variable series. Marginal results of trend and variability analysis should be regarded as spurious. Only very large trends may be related to a climatic signal.

Study area and available data

Iraq, with a total area of 438 320 km^2, is bordered by Turkey to the north, the Islamic

Republic of Iran to the east, the Arabian gulf to the southeast, Saudi Arabia and Kuwait to the south, and Jordan and the Syrian Arab Republic to the west. Topographically, Iraq is shaped like a basin, consisting of the Great Mesopotamian alluvial plain of the Tigris and the Euphrates rivers (Mesopotamia means, literally, the land between two rivers). This plain is surrounded by mountains in the north and the east, which can reach altitudes of 3550 m above sea level, and by desert areas in the south and west, which account for over 40 percent of the land area.

The climate in Iraq is mainly of the continental, subtropical semi-arid type, with the north and north-eastern mountainous regions having a Mediterranean climate. Rainfall is very seasonal and occurs in the winter from December to February, except in the north and northeast of the country, where the rainy season is from November to April. Average annual rainfall is estimated at 216 mm, but ranges from 1200 mm in the northeast to less than 100 mm over 60 percent of the country in the south. Winters are cool to cold, with a day temperature of about 16 °C dropping at night to 2 °C with a possibility of frost. Summers are dry and hot to extremely hot, with a shade temperature of over 43 °C during July and August, yet dropping at night to 26 °C [20].

The monthly and annual means data (1981-2010) used in present study were provided by the Iraqi meteorological organization and seismology (IMOS). The data belong to 35 meteorological stations distributed all over in Iraq as shown in figure 1.Monthly total rainfall values were obtained by summing up daily rainfall data observed by the stations. Similarly, the annual total rainfall data were calculated by adding monthly total precipitation data. Table (1) summarizes the basic descriptive statistical measures of annual rainfall data and missing data of the selected stations. From the table it can be inferred that the mean annual rainfall of Iraq is 265.39 mm/year and the median is 623 mm. northern stations have a high values of rainfall, the high standard deviation values can be easily correlated with the high rainfall range (northern region). To test whether the annual rainfall data follow a normal distribution, the skewness was computed. Skewness is a measure of symmetry, or more precisely, the lack of symmetry. The data set is said to be symmetric if it looks the same to the left and right from the center point. The skewness for a normal distribution is zero, and any symmetric data should have skewness near zero. Negative values for the skewness (Salahaddin and Fao stations) indicate that data are skewed to the left and positive values for the skewness indicate that data are skewed to the right. The missing frequency of rainfall data ranged between (0% Mosul station to 11.6 Fao station).

The total annual rainfall at stations with missing data was calculated after completing the missing data. The missing values were completing by using the method of normal ratio, in this method the missing rainfall values at a site can be estimated from concurrent observations that are located as close to and evenly spaced from the missing data station as possible, known as index station [21]. The normal ratio method is:

$$\frac{P_x}{N_x} = \frac{1}{n}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \dots\dots\dots\frac{P_n}{N_n}\right) \quad (10)$$

Where

P_x: missing precipitation for station x

P_1,P_2,P_3, P_n: precipitation at neighboring station for the concurrent period.

N_x: normal long-term precipitation at station x.

N_1,N_2,N_3,N_n: normal long-term precipitation for neighboring station.

Results and Discussion

As stated above, the homogeneity of the annual total rainfall time series of the stations throughout Iraq were tested by using the four tests, Standard normal homogeneity test (SNHT), Buishand range (BR) test, Pettitt test, and Von Neumann ratio (VNR) test. As a result of the analysis explained in the previous section, annual total rainfall values for 36 stations were obtained. In the application of homogeneity methods, observation series of each station were considered separately. The results of each method were evaluated for a significance level of 95% and the inhomogeneities were detected. Critical values taken from

Wijngaard et al. (2003) for SNHT, BR test, Pettitt test and VNR test are 7.56, 1.50, 107 and 1.42 respectively.

Table (2) shows the results of the four homogeneity tests for each station, based on the results, 69.44 of station appear homogenous since the null hypothesis for the SNHT, BR test and Pettitt test are not rejected at 5% level of significance. The results also indicated that 30% of the stations were rejected the null hypothesis at 5% level of significance for one or more test of the four homogeneity tests.72.7% of the inhomogeneous station were rejected by the Von Neumann ratio (VNR) test, 45.4% of the station were rejected by the Pettitt test and Standard normal homogeneity test (SNHT) and one station was rejected by Buishand range (BR) test. The table also shows that most inhomogeneous stations were rejected in the period between (1994-1998) except one station which was rejected at (2007).

Figure 2 illustrate the geographical distribution of homogeneous and inhomogeneous stations on Iraq map, 54.4% of the inhomogeneous station(6 station) located in the western part of Iraq, while the other inhomogeneous station are distributed in the north and south parts of Iraq.

The statistical results according to the classification system outlined in Section (2.5) are shown in table 3. The results shows a very high percentage of 'useful' station series (86.11%),only a two series are assigned to the 'doubtful' class (Tuz and Amara).Three stations (Emadiyah, Sumeel and Hella) assigned to the suspect class, two of them located in the north part of Iraq.

Figure 3 shows the time series of rainfall for the three suspect stations (Emadiyah, Sumeel and Hella), in the three stations the null hypothesis were rejected in the period between (1996-1998)

Historical of the station relocation, observing practices and instruments used are important in analyzing the homogeneity of the stations. Unfortunately, these data are not available in the stations that we studied. Therefore it does not have evidence to evaluate the breaks detected and correct the series. In future, it is encourage to involve historical metadata to investigate the causes of the break occurs.

Conclusions

In this work, four homogeneity tests were employed successfully for the rainfall time series of meteorological stations operated by IMOS throughout Iraq. For this purpose 36 station having records for the period of 1980-2010 were examined and analyzed. Homogeneity tests were applied for examining the reliability of the data using SNHT, BR, Pettitt and VNR tests, after employing the four homogeneity tests, the observation records were evaluated separately at significant level of 95% and the inhomogeneous time series were determined, and according to this level of confidence the inhomogeneous structure was detected in 11 station (30% of considered station in present work). The results were assessed by classifying the stations into 3 categories, which are useful, doubtful and suspect, there are 31 stations labeled as useful and 2 station assigned as doubtful while 3 stations labeled as suspect.

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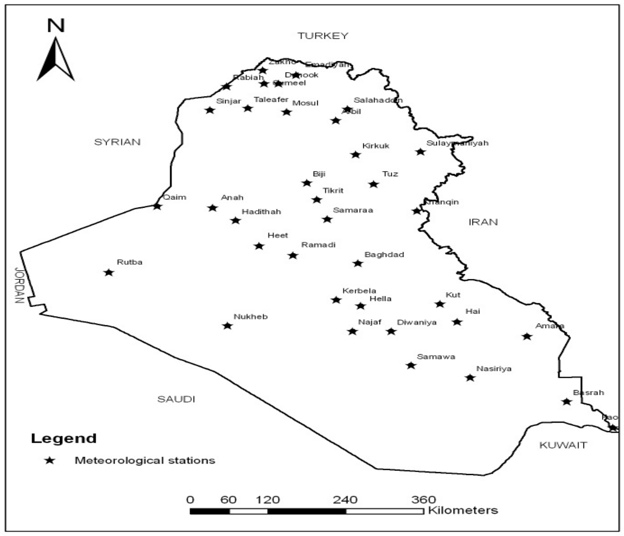

Figure 1: The geographical distribution of selected stations in the study.

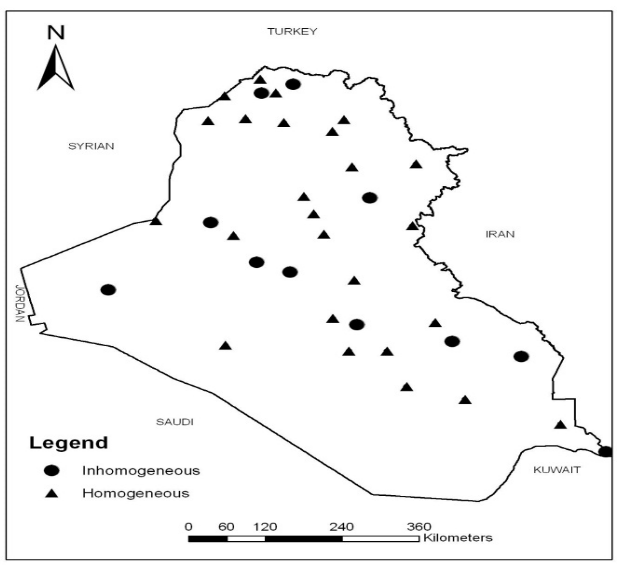

Figure 2: The geographical distribution of homogenous and inhomogeneous stations in Iraq.

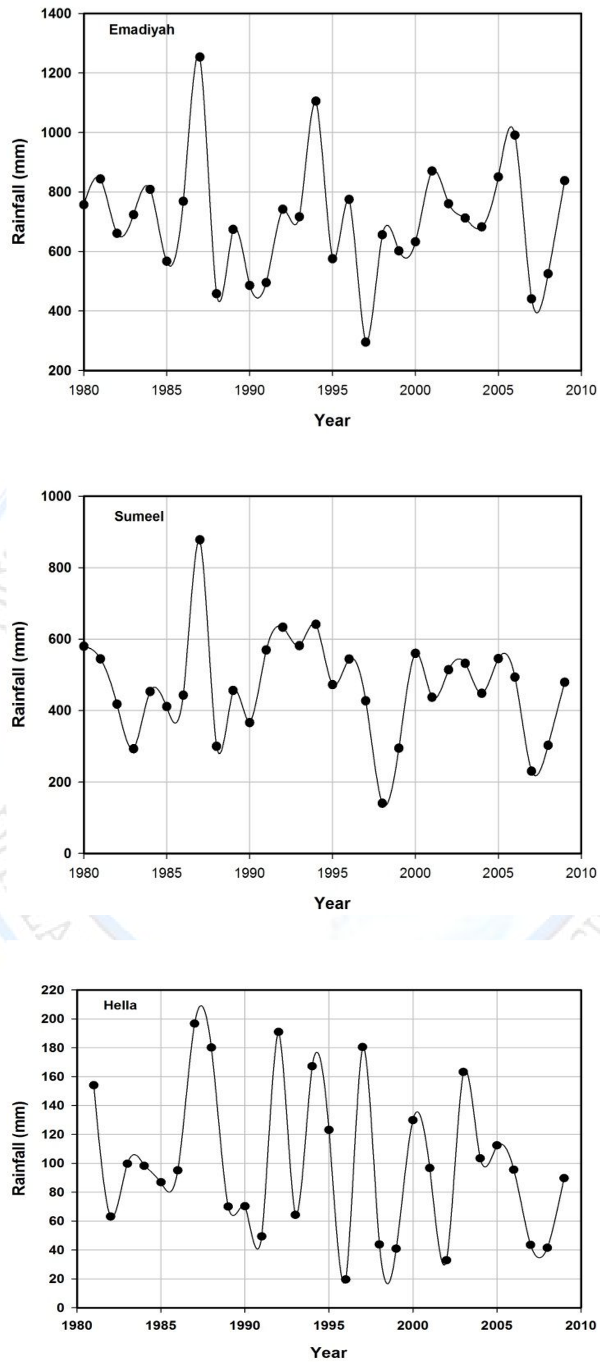

Figure 3: The rainfall time series for the three suspected stations (Emadiyah, Sumeel and Hella).

Table 1: Geographical information, descriptive statistics and percentage of the missing data of the stations

	Stations	Longitude (Degree)	Latitude (Degree)	Elevation (Meter)	Mean(mm)	S.D(mm)	Skewness	Missing of Data %
1	Emadiyah	43.30	37.05	1236	697.39	211.12	0.38	3%
2	Salahaddin	44.20	36.38	1075	606.04	193.44	-0.11	10%
3	Sulaymaniyah	45.45	35.53	843	699.12	221.61	0.21	3%
4	Sinjar	41.83	36.32	583	365.60	136.63	0.76	9.5%
5	Duhook	43.00	36.87	554	548.83	188.10	0.39	8%
6	Zakho	42.72	37.13	433	593.52	187.35	1.13	1.6%
7	Arbil	44.00	36.15	420	422.50	152.18	0.76	2%
8	Rabiah	42.10	36.8	382	354.98	118.22	1.53	9.8%
9	Taleafer	42.48	36.37	373	316.42	112.97	0.59	13%
10	Kirkuk	44.35	35.47	331	353.62	136.95	0.17	8%
11	Nukheb	42.28	32.03	305	80.62	47.71	0.70	9.4%
12	Dukcan	44.95	35.95	276	736.21	220.05	0.41	8.8%
13	Sumeel	42.75	36.87	250	466.28	143.16	0.23	2%
14	Mosul	43.15	36.31	223	355.38	128.36	0.68	0%
15	Rutba	40.28	33.03	222	111.13	68.41	1.70	7%
16	Tuz	44.65	34.88	220	275.68	112.80	0.42	2.25%
17	Qaim	41.02	34.38	178	129.30	62.08	0.74	9%
18	Anah	41.95	34.37	175	134.92	56.80	0.84	10%
19	Biji	43.53	34.9	116	197.96	77.67	0.79	2%
20	Hadithah	42.35	34.13	108	122.24	70.35	1.23	9.1%
21	Tikrit	43.70	34.57	107	173.61	65.79	0.89	4.3%
22	Samaraa	43.88	34.18	75	167.21	68.57	0.45	3.9%
23	Heet	42.75	33.63	58	119.49	74.50	1.67	10.5%
24	Najaf	44.32	31.95	53	81.61	45.30	1.17	9%
25	Ramadi	43.32	33.45	48	113.42	54.35	1.20	11%
26	Baghdad	44.40	33.3	32	111.96	48.93	0.26	8%
27	Kerbela	44.05	32.57	29	89.68	45.13	0.73	1%
28	Hella	44.45	32.45	27	99.19	51.11	0.48	1%
29	Kut	45.75	32.49	21	131.74	43.95	0.71	24%
30	Diwaniya	44.95	31.95	20	102.19	55.82	0.83	1.5%
31	Hai	46.03	32.13	17	124.26	53.71	0.74	1%
32	Samawa	45.27	31.27	11	94.97	57.12	1.64	9.8%
33	Amara	47.17	31.83	9	169.17	76.23	0.55	2.6%
34	Nasiriya	46.23	31.02	5	122.75	52.46	0.50	10.3%
35	Basrah	47.78	30.52	2	138.14	54.15	0.95	3.25%
36	Fao	48.50	29.98	1	147.13	38.98	-0.14	11.6%

Table 2: The results of the four homogeneity tests for the rainfall time series of the selected station

	station	Petti.	SNHT	BR	VNR
1	Arbil	-	-	-	-
2	Duhook	-	-	-	-
3	Emadiyah	1997(123)	1997(7.89)	-	X*
4	Khanqin	-	-	-	-
5	Kirkuk	-	-	-	-
6	Mosul	-	-	-	-
7	Rabiah	-	-	-	-
8	Salahaddin	-	-	-	-
9	Sinjar	-	-	-	-
10	Sulaymaniyah	-	-	-	-
11	Sumeel	1998(121)	1998(8.12)	-	X
12	Taleafer	-	-	-	-
13	Tuz	2007(117)	2007(7.72)	-	-
14	Zakho	-	-	-	-
15	Amara	1993(132)	1993(11.25)	-	-
16	Anah	-	-	-	X
17	Baghdad	-	-	-	-
18	Basrah	-	-	-	-
19	Biji	-	-	-	-
20	Fao	2008(113)	-	-	-
21	Hadithah	-	-	-	-
22	Hai	-	-	-	X
23	Heet	-	-	-	X
24	Kut	-	-	-	-
25	Qaim	-	-	-	-
26	Ramadi	-	-	-	X
27	Samaraa	-	-	-	-

28	Tikrit	-	-	-	-
29	Diwaniya	-	-	-	-
30	Hella	-	1996(8.45)	1996(1.67)	X
31	Kerbela	-	-	-	-
32	Najaf	-	-	-	-
33	Nasiriya	-	-	-	-
34	Nukheb	-	-	-	-
35	Rutba	-	-	-	X
36	Samawa	-	-	-	-

Table 3: The useful, doubtful and suspect stations percentage according to the classification system.

period	Class1(useful)	Class 2(doubtful)	Class 3 (suspect)	Total number of station time series
1980-2010	31(86.11)	2(5.55)	3(8.33)	36 (100%)