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Rainfall Fluctuation for Exploring Desertification and Climate Change: New Aridity Classification

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Abstract

The research community in Jordan is basically relying on universal defined aridity classifications, which do not consider the local conditions of Jordan and climate change effects on Jordan. The present study aims at producing a customized aridity classification that better fits the conditions of Jordan. Monthly rainfall data for the period between 1961-2012, for 22 weather stations covering the whole country, were obtained from Jordanian Meteorological Department (JMD). A ten-year moving average was calculated and used for conducting a historical trend analysis and generating aridity spatial maps. Monthly, annual, and ten years moving average aridity trends were tested using Tukey test, Mann-Kendall rank, and a simple linear regression. According to the historical trend analysis, rainfall across the country is significantly (< 0.0001) spatially and temporally distributed, where 90% of the country falls within arid to semi-arid classes. Climate change impacts in Jordan resulted in a shorter rainy season with lower amounts of precipitation and the number of rainfall events. The overall annual rainfall tended to decrease significantly ($P<0.05$) by time with an average reduction rate of 1.1 mm per year. Although the overall trend for most of the rainfall stations was decreasing, individual annual rainfalls analysis indicated the possibilities of extreme events to occur at some locations. The overall trend showed that more frequent drought seasons are expected. According to the new generated aridity classification maps, the country is suffering from a severe shifting to lower rainfall means. The southern and the northern-eastern parts shifted from strongly arid (100-150 mm) into hyper arid class (< 100). Moreover, west-middle part also shifted to moderately arid class (150 – 200 mm). On the other hand, the most obvious shift occurred at the semiarid classes especially the slightly and moderately subclasses. Currently, the wettest two classes (sub-humid and slightly semi-arid) are not present in the map and shifting towards a strongly semi-arid class.

Keywords: Aridity, desertification, climate change, rainfall variability, Jordan

1. Introduction

Dry lands form about one third of the world lands with insufficient rainfall that supports only sparse vegetation and a limited population of people and animals. They are generally threatened by land degradation mainly linked to the low amounts of mean annual precipitation, such as desertification, loss of biota, drought, etc. Aridity, in general, is thrived by climate change since it usually results in lower precipitation amounts with increasing the opportunity of extreme events. Aridity is very important in water resources management issues, where it has a basic role in determining spatial location of water deficit and extreme shortage of water supply.

Defining aridity is crucial to understand the motivators for many aspects of land degradation, and there are many aridity indices used by research community (Middleton and Thomas, 1997; Noin and Clarke, 1998), with many techniques to derive them. Most classifications rely on some combination of the number of days of rainfall, the total amount of annual rainfall, evapotranspiration, temperature, humidity, or other factors.

It is hard to distinguish between aridity and drought since they have almost the same effects. The conceptual difference between them is equivalent to that between climate and weather. In the case of aridity, the lack of rainfall depends on the local climate and represents a permanent or seasonal condition. While drought is a transitory phenomenon related to the meteorological variability and, as such, it can strike everywhere and at any time with levels of intensity and persistence which cannot be determined a priori (Cook et. al., 2004). Aridity and drought, however, represent two sides of the same coin; along with the long-term trends triggered by climate change there has been a tight recurrence of drought episodes that had affected areas previously not prone to such phenomena, as well as other areas suffering from water shortage (Salvati et. al., 2013).

In the Mediterranean region the rainfall seasonality strengthens the effects and impacts of climate change (Salvati, 2009; Toreti et. al., 2010). Trends in climate aridity and the increasing frequency in drought events can lead to desertification (UNCCD, 2010). That said, it is necessary to investigate intensity, spatial distribution, and temporal evolution of water shortage caused by aridity.

Jordan, located in an arid region, suffers highly from

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water deficit. Globally, Jordan is ranked among the first three countries with water scarcity. Jordan water resources are very scarce and mainly rely on rainfall. Therefore, any reduction in annual rainfall will in turn affect the water status and hence all sectors that use water, i.e., agriculture and industry. Change in intensity of precipitation has been used as an indicator for anticipated climate change. There is evidence that a climate change is changing the behavior of precipitation, especially, the extremes (MoE, 2009; Trenberth, 2011). The spatial distribution of rainfall has also been observed to change. Generally, throughout the subtropics dry areas becoming drier and wet areas becoming wetter especially in the mid to high latitudes (Trenberth, 2011).

In Jordan, most studies on precipitation were focused on trends in mean daily, monthly and annual rainfall (Al-Qudah and Smadi, 2011). The reduction in the total rainfall and the number of rainy days was reported in Jordan (Smadi and Zghoul, 2006). Despite the crucial importance of trends in maximum and intensity of precipitation to indicate climate change, still they are not fully understood yet (Al-Qudah and Smadi, 2011). In general, the results of most previous research were not able to statistically find a significant trend (Freiwan and Kadioglu, 2008; Ghanem, 2011).

The research community in Jordan is basically relying on the universal defined aridity classification, which does not consider the local conditions of Jordan and the way it is affected by climate change. Therefore, the present work aims to produce a new customized aridity classification that fits the conditions of Jordan. The proposed new classification will emphasize more on regions with low rainfall, and will generate a spatial map that shows temporal rainfall changes, thus, providing a powerful tool for researchers to understand climate change effects and investigate food security issues, etc.

2. Materials and Methods

2.1. Study Area

Jordan is located about 80 km to the east of the Mediterranean Sea with a predominant Mediterranean climate; hot and dry summers and wet and cool winters. Jordan is also characterized by a unique topographic nature, where the western part represents the world lowest valley that lies north-south between two mountain ranges with a length of about 400 km and a width varies from 10 km in the north to 30 km in the south and elevation between 170-400 m below Mean Sea Level (MSL). The Jordan River passes through this valley from north to south down to the Dead Sea. Just to the east of the Jordan Valley the north-south mountain range reaches about 1150 m above MSL in the northern parts and about 1500 m above mean sea level in the southern parts of Jordan. To the east of this mountain range, a semi desert plateau extends to cover approximately 80% of the total area of the country.

According to the geographic and topographic characteristics, Jordan is divided into three main climatic regions (FAO, 2012): the Ghor Region (lowlands), Highlands, and the Badia and Desert region (Figure 1).

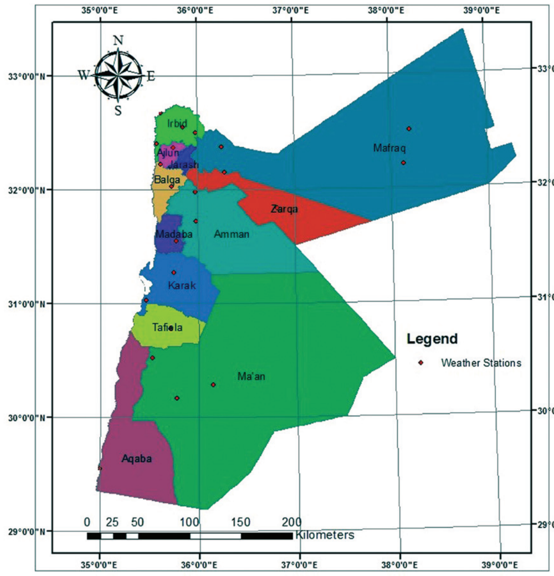

Figure 1. Study area and the location of weather stations

The Ghor (Lowlands) is part of the Great Rift Valley with a length of about 400 km extending from north to south. The Ghor consists of three parts: the Northern Jordan Valley, the Dead Sea (The lowest elevation on earth) and Wadi Araba. The elevation of the Ghor ranges from 197 m below MSL in the north to more than 400 m below MSL at the Dead Sea. The width of the Ghor is approximately 15 km in the north expanding gradually to about 30 km in the south. The area of the Ghor east of River Jordan and Dead Sea is about 3000 km^2.

The Highlands and Marginal Scarpment Region extends north-south to the east of the Ghor. The mountainous region extends from the Yarmouk River in the north to Ras El-Naqab in the south; the mountain ranges are dissected at several locations by valleys such as Zerqa River, WadiMujib and Wadi El-Hasa. The elevation of the peaks of these mountains varies from 1150m above MSL in the north (RasMuneef) to about 1365m above MSL in the south (Al-Shoubak), some peaks exceeds 1500m above MSL (El-Qurain). The total area of the mountains regions is about 7900 km^2. The marginal steppes region stretches from north to southeast of the mountainous region, from the Syrian borders in the north to Ras Al-Naqab in the south. It has an area of 9000 km^2 that represents most potential rangeland of Jordan.

The Badia and desert region extends north-south from the foot of the highlands eastward. The total area of the Badia and the desert is about 70000 km^2, with an elevation of about 600-750 above MSL, the annual rainfall of the Badia ranges from 50 to 100 mm. The south-east of the region is true desert with annual rainfall less than 35 mm; the total area of the Jordanian Desert is 30000 km^2.

2.2. Rainfall Stations Data

Monthly rainfall data for the periods of (1961-2012) for 22 weather stations were obtained from Jordanian Meteorological Department (JMD) distributed across the countryto represent all the topographic and climatic regions and to cover larger parts of the country (Figure 1). The annual rainfall magnitudes for each station were calculated.The robustness of local data time series is one of the major constrains and limitations for assessing the climate variables and indices future projections, thus a ten-year Moving Average (MA) was calculated for each station point. Both the individual rainfall and the ten years MA data were used for conducting historic trend analyses and spatial mapping for aridity.

2.3. Aridity Index

There are many techniques to derive an aridity index. Most of the available classifications (e.g., Intergovernmental Panel on Climate Change (IPCC 2007), UNESCO (1979), Thornthwaite, 1948) rely on some combination of the number of days of rainfall, the total amount of annual rainfall, evapotranspiration, temperature, humidity, or other factors. In the present study, using only mean annual rainfall was selected to derive and customize the aridity index due to its reliability, simplicity, and small amount of data needed (only rainfall). Based on the IPCC, 2007 index, areas with less than 250 mm mean annual rainfall is considered arid, areas between 250 and 500 mm are semi-arid, while areas with annual precipitation higher than 500 mm are considered sub-humid and humid. Accordingly, Jordan is mostly arid and semi-arid, therefore the investigation was focused on the low rainfall areas dividing them into subclasses that fit Jordan's conditions using Geographic Information Systems (GIS) spatial analyst platform. Initially, spatial maps were generated using GIS version 10.3 software based on different ranges of rainfall, then the selection of the approved classification was made after visually studying the generated spatial maps and selecting the map with least impurities and that has a reasonable number of subclasses.

2.4.Variability Testing and Trends Analyses

Aridity trends and changes were tested through testing monthly, annual, and ten years Moving Average (MA) rainfall variability using the comparison between means Tukey HSD (Honestly Significant Difference) platform within JMP (2012) statistical software. Tukey HSD test is an exact alpha-level test (usually P = 0.05, where the confidence is 95%) that is based on Least Significant Difference (LSD) similar to t-test; however, it is conservative since it tackle the differences in the sample sizes (Hayter, 1984; Tukey, 1991).

The annual and ten years MA trends of monotonic increase or decrease between the beginning and the end of an available time series was detected using two methods: (1) the linear regression trends (Pearson Product-Moment Correlation), and (2) nonparametric "Mann-Kendall rank trend test" (Bartlett and Kendall, 1946). The trend analysis was made on both year and month basis to assess monotonic changes dominancy over the historic period.

The Pearson product-moment correlation coefficient (r) was calculated using the Multivariate Platform within JMP (2012) statistical software. It measures the strength of the linear relationship between two variables (Equation 1). If there is an exact linear relationship between two variables, the correlation is 1 or -1, depending on whether the variables are positively or negatively related. If there is no linear relationship, the correlation tends toward zero:

$$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x}_i)(y_i - \bar{y}_i)}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x}_i)^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}} \quad (1)$$

The Mann-Kendal Test (τ_b) was performed using Non-Parametric test Platform within JMP (2012) statistical software, where observations are ranked in order according to the value of the first variable. The observations are then re-ranked according to the values of the second variable. The number of interchanges of the first variable is used to compute Kendall's τ_b coefficients. The Kendall's τ_b coefficients range from -1 to +1 and are based on the number of concordant and discordant pairs. A pair of rows for two variables is concordant if they agree in which variable is greater. Otherwise, they are discordant or tied. The Kendall's was computed using Equation (2):

$$\tau_b = \frac{\sum_{i<j}^{n} \mathrm{sgn}(x_i - x_j) x_i \mathrm{sgn}(y_i - y_j)}{\sqrt{\left(\frac{n(n-1)}{2} - \sum\frac{(t_i)(t_i-1)}{2}\right)\left(\left(\frac{n(n-1)}{2} - \sum\frac{(u_i)(u_i-1)}{2}\right)\right)}} \quad (2)$$

where, sgn (z) is equal to 1 if z > 0, 0 if z = 0, and -1 if z < 0.The t_i (the u_i) are the number of tied x (respectively y) values in the ith group of tied x (respectively y) values, n is the number of observations, and Kendall's τ_b ranges from -1 to 1. If a weight variable is specified, it is ignored.

2.5. Spatial Modeling

The individual and 10-year MA rainfalls were spatially analyzed using ordinary interpolation within ArcGIS software (ESRI® version 10.1). ArcGIS Geostatistical Analyst tool was used to interpolate the spatial behavior of rainfall distributions following four stages of analysis: (1) histogram analysis and standardization, (2) autocorrelation using Moran I tests, (3) characterization and selection of best empirical fit to represent the actual spatial variations using semivariogram modeling, and (4) interpolation of rainfalls at unknown locations using kriging techniques.

The semi-variance clouds in all directions were computed using Equation 3 (Selker et. al., 1999), and the best empirical variogram model was selected based upon the lowest root mean square error (RMSE) (Goovaerts, 1997):

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[(Z(x) - Z(x+h)\right]^2 \quad (3)$$

where, g(h) is the semi-variance, z(x) is the value of initial potential at site x, z(x+h) is the value of potential at site (h) distance from (x), and N is the number of sample pairs.

The Ordinary Kriging (OK) technique was used to assess the spatial extent of rainfall quantities. The OK method assumes a constant unknown mean, where the value at the unsampled point can be predicted by a linear weighing of the variation between the surrounding points derived from variogram analyses (Equations (4a) and (4b)):

$$Z(X_0) = \mu + \varepsilon(X_0) \quad (4a)$$

$$Z(X_0) = \sum \lambda_i \ \gamma(x_i), \quad \sum \lambda_i = 1 \quad (4b)$$

where, μ is an unknown constant and $e(X_0)$ is the error associated with an unknown location X_0, $Z(X_0)$ is the estimated value of Z at X_o, and λ_i is the weight that gives the best possible estimation from the surrounding points.

3. Results and Discussion

3.1.Characterization of Current Climatic Conditions

According to the historic meteorological data, rainfall across the country is significantly (< 0.0001) spatially and temporally distributed. Table 1indicates that the major part of the country (90%) is arid to semi-arid, characterized by very low annual precipitation that averages less than 220mm. The annual total precipitation amounts varied sharply from one climatic region to another from a minimum average of 28 mm at the southern Badia region to a maximum average of 573 mm at the upper northern highlands region of RasMuneef. Along the Ghor region, the highest point was at the north where it may reach 280 at Deir-Alla and decreased towards the south till 71 mm at Ghor Safi. In mountains, the average annual precipitation exceeded 573 mm in RasMuneef and 542 mm at Salt mountains, decreasing gradually southward to 333 mm in ErRabbah, and 270mm in Shoubak.

In the steppes region, the amount of rainfall was about 100-200 mm. It was 153 mm in Mafraq and 139 mm in Wadi Dhulail. In the Badia, it was about 75-110 mm in the north decreasing to about 60 mm in the south (57 mm in Azraq south and 97 mm in Qatraneh, 80 mm in Rawaished, and 41mm in Ma'an). In the Jordanian Desert (south east of Jordan) the annual rainfall was less than 30 mm in Al-Jafr till reaching Aqaba with 30 mm annual precipitation.

Sometimes, unstable summer rainfall events might occur due to heat convection from land to atmosphere, uplifting and condensation at mountains, but their quantities are almost negligible.

Table 1. Individual annual mean and mean of 10 years moving average (MA) comparison using Tukey HSD test per station

Station	Available data	Count of years	Individual annual mean		Mean of 10 years MA	
			Mean	Tukey HSD* Rank	Mean	Tukey HSD* Rank
RasMuneef	1960-2012	52	573.0	a	576.5	a
Salt	1961-2012	51	541.9	a	547.5	b
Irbid	1960-2012	52	469.2	b	472.5	c
Baqura	1967-2012	45	382.8	c	390.8	d
ErRabbah	1960-2012	52	333.0	cd	340.8	e
Wadi El-rayyan	1960-2012	52	295.6	de	301.1	f
DeirAlla	1960-2012	52	281.3	def	288.1	fg
Shoubak	1960-2012	52	270.2	def	276.9	gh
Amman Airport	1960-2012	52	260.2	ef	263.0	h
Alhasan/Tafileh	1971-2012	41	229.7	efg	224.4	i
Ramtha	1976-2012	36	220.8	fgh	224.0	i
Q.A.I.Airport	1960-2012	52	166.1	ghi	165.3	j
Mafraq	1960-2012	52	153.0	hij	157.0	jk
WadiDhulall	1968-2012	44	139.2	ijk	140.9	k
Qatraneh	1960-2012	52	97.0	jkl	97.2	l
Rwaished	1960-2012	52	79.6	klm	81.5	lm
Ghor Safi	1974-2012	38	71.4	klm	74.3	m
Safawi	1960-2012	52	71.1	klm	72.0	m
Azraq South	1981-2012	31	57.3	lm	60.2	mn
Ma›an	1960-2012	52	40.8	lm	42.0	no
Al Jafer	1960-2012	52	30.4	m	31.4	o
Aqaba	1960-2012	52	28.2	m	29.4	o

* Levels not connected by same letter are significantly different according toTukey HSD test at 95% confidence level.

The rainy season extends from around October to May of the next year and about 80% of the seasonal rainfall occurs through the months of December to March (Table 2). Maximum rainfall events generally occurred in January, however, it might sometimes occur earlier in November or delayed till late January or February. According to Figure 2, it is observable that the climate change impacted the rainy season considerably through shortening the season, reducing the quantity of rainfall, lowering the number of rainfall events, and shifting the time of occurring. The temporal change indicated that the maximum rainfall started to be more observable in February and, thus, a shift existed with shortening or narrowing the rainy month's extents at both ends (i.e., October-November and April-May rainfalls were becoming rare).

Table 2. Average over years of rainfall quantities for each month for the different stations

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q.A.I.Airport	41.0	36.4	28.1	9.3	2.0	0.1	0.0	0.0	0.1	3.7	14.6	32.0
Al Jafer	5.9	3.7	4.3	3.3	1.2	0.0	0.0	0.0	0.1	3.9	3.3	4.4
Alhasan/Tafileh	57.6	46.7	40.8	15.6	1.7	0.0	0.0	0.0	0.0	3.7	16.3	45.2
Amman Airport	62.3	59.0	43.3	12.7	2.7	0.1	0.0	0.0	0.1	7.2	23.9	48.6
Aqaba	5.5	4.4	3.4	2.9	0.9	0.0	0.0	0.0	0.0	2.2	2.9	6.0
Azraq South	12.8	9.8	9.1	4.1	1.3	0.0	0.0	0.0	0.3	2.8	6.2	9.8
Baqura	92.1	75.6	54.3	20.4	5.4	0.2	0.0	0.0	0.8	14.1	44.9	80.3
DeirAlla	66.2	55.7	42.7	14.9	3.1	0.1	0.0	0.0	0.5	10.2	33.9	54.2
ErRabbah	85.0	74.3	54.3	19.6	3.9	0.0	0.0	0.0	0.1	6.2	28.5	61.7
Ghor Safi	13.7	16.5	11.7	5.1	1.2	0.0	0.0	0.0	0.2	3.1	5.7	14.0
Irbid	104.9	104.4	81.4	24.7	5.7	1.0	0.0	0.0	0.6	14.0	45.6	85.7
Ma'an	8.5	7.2	5.8	3.1	1.5	0.0	0.1	0.0	0.2	4.9	3.8	5.6
Mafraq	34.9	31.5	25.2	7.4	2.1	0.1	0.0	0.0	0.3	6.4	17.8	27.2
Qatraneh	24.7	20.3	16.5	6.5	1.5	0.0	0.0	0.0	0.0	4.1	7.6	18.0
Ramtha	47.9	51.1	37.8	10.4	3.2	0.7	0.0	0.0	0.2	7.8	24.9	39.1
RasMuneef	129.1	127.9	93.1	30.0	7.6	1.0	0.1	0.0	0.6	17.4	64.1	115.0
Rwaished	13.5	14.3	10.0	10.9	3.7	0.2	0.0	0.0	0.3	7.0	9.4	10.8
Safawi	13.7	14.2	9.2	5.4	1.9	0.0	0.0	0.0	0.1	5.1	9.0	11.7
Salt	136.0	124.7	90.3	26.4	3.5	0.1	0.0	0.0	0.2	12.4	50.6	105.6
Shoubak	69.6	55.9	46.4	16.9	4.0	0.1	0.0	0.0	0.2	5.5	19.5	51.3
WadiDhulall	34.6	29.0	21.9	6.9	2.2	0.1	0.0	0.0	0.1	4.7	15.6	24.2
Wadi El-rayyan	70.1	58.8	42.2	13.8	4.4	0.1	0.0	0.1	0.7	14.0	35.5	60.7
Average	**51.8 a**	**46.9 b**	**35.4 d**	**12.4 f**	**3.0 gh**	**0.1 h**	**0.0 h**	**0.0 h**	**0.3 h**	**7.4 g**	**22.2 e**	**41.7 c**

3.2.Rainfall Variability and Trend Analysis

The Mann-Kendall trend and the linear trends of the time series at overall scale and station scale are presented in Table 3. Mann-Kendall results indicatedthat the rainfall at country scale was statistically significant at either 5 percent or the 1 percent confidence levels. The resulted trends are strong evidence of climate change in Jordan during the last 50 years. According to the historic climatic linear analyses, the overall annual precipitation regardless the station tended to decrease significantly ($P<0.05$) by time with a reduction rate of 1.0 to 1.1 mm per year for individual annual and 10-years MA, respectively.

According to the trend analysis for annual and 10-year MA rainfall at station level, a climatic change was obviously apparent and its impact was noticed as indicated by their high significant Kendall and linear regression trends (Table 3). However, very few stations showed a significant increase in precipitation, such as Ras Muneef and Wadi El-Rayyan. Precipitation tended to decrease in number of rainy days, which may be attributed to an increase in the daily rainfall intensity and, thus, an increase in the chance of recording extreme precipitation events. On the other hand, many other stations experienced an increasing number of rainy days associated with decreasing annual precipitation amounts, leading to a decrease in daily rainfall intensity such as Wadi Dhuleil, Irbid and Al-Rabba (Figure 3).

Although the overall trend for most the rainfall stations is decreasing as indicated by the MA; however, individual annual rainfalls showed the variations in wet and drought seasons and, thus, possibilities of extreme events. Figure 4 shows an example of one of the stations where very wet seasons occurred in 1967, 1974, 1980, and 1992, while drought seasons were more frequent and observable at all stations during 1963, 1970, 1973, 1976-1979, 1984, 1986, 1999, 2000, 2004, and 2008.

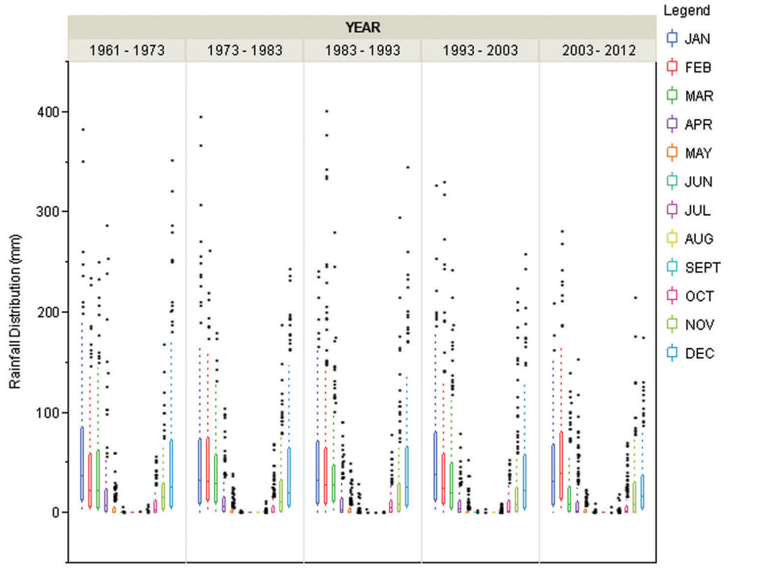

Figure 2. Temporal change in rainfall distribution around the year

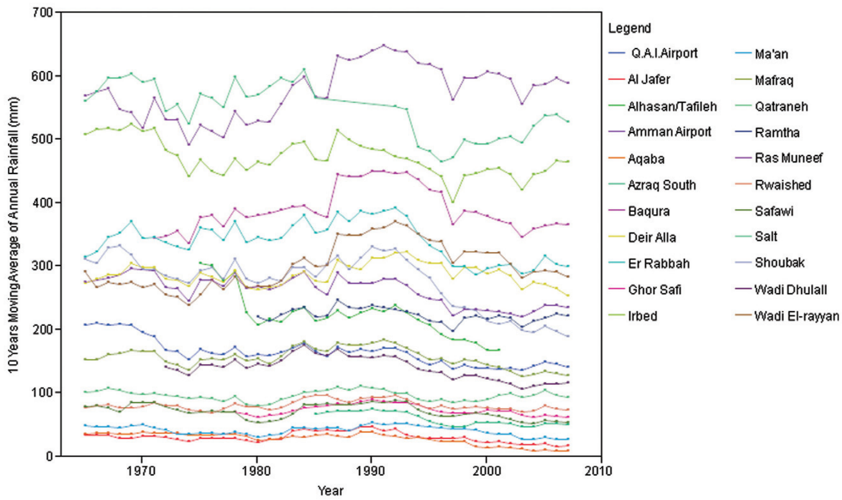

Figure 3. 10 years moving average annual rainfall distribution per station

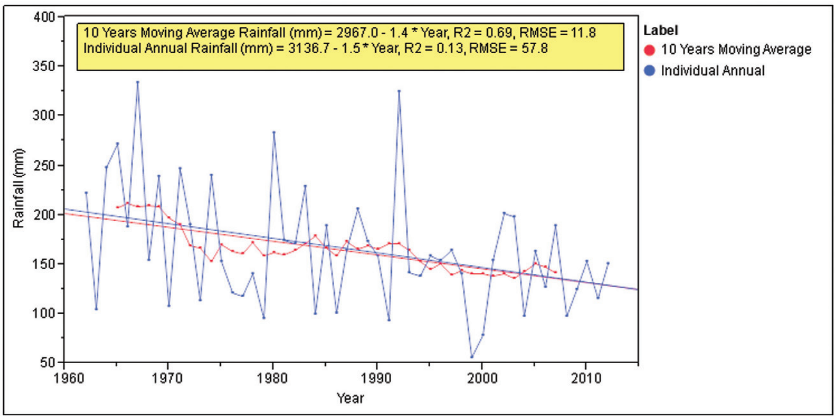

Figure 4. Example for moving average and individual annual rainfalls for Q.A.I. Airport station

Table 3. Mann-Kendall and Pearson trend statistics of individual annual and 10-years moving average (MA) rainfall by station

No.	Station name	Individual annual			10 years MA			10 years MA rainfall trend			
		Kendall τ	Prob>|τ|	R	Kendall τ	Prob>|τ|	r	Trend Equation	R^2	RMSE	Prob> F
1	Q.A.I.Airport	-0.2376	0.0139*	-0.3680	-0.6035	<.0001**	-0.8771	= 2967.0 - 1.41 * Year	0.6960	11.85	<.0001**
2	Al Jafer	-0.1911	0.0503	-0.2233	-0.2935	0.0055**	-0.3958	= 435.1 - 0.20 * Year	0.1009	7.71	0.0379*
3	Alhasan/Tafileh	-0.2034	0.0857	-0.4115	-0.5556	<.0001**	-0.8747	= 7521.3 - 3.67 * Year	0.6519	21.71	<0.0001**
4	Amman Airport	-0.1576	0.1026	-0.2055	-0.5127	<.0001**	-0.8217	= 3010.4 - 1.38 * Year	0.5887	14.70	<0.0001**
5	Aqaba	-0.3392	0.0004**	-0.4348	-0.6700	<.0001**	-0.8796	= 1282.6 - 0.63 * Year	0.7016	5.23	<0.0001**
6	Azraq South	-0.2000	0.1140	-0.2719	-0.5494	0.0002**	-0.9023	= 2617.7 - 1.28 * Year	0.7010	5.81	<0.0001**
7	Baqura	-0.0081	0.9376	0.0119	0.0601	0.6009	0.1447	= -384.7 + 0.39 * Year	0.0153	34.30	0.4652
8	DeirAlla	-0.0510	0.5975	-0.0754	0.0122	0.9084	0.0468	= 1832.0 + 0.05 * Year	0.0016	17.04	0.8017
9	ErRabbah	-0.0510	0.5975	-0.1219	-0.1849	0.0805	-0.4810	= 2380.4 - 1.03 * Year	0.1733	28.50	0.0055**
10	Ghor Safi	-0.1964	0.0827	-0.2281	-0.1908	0.1387	-0.4200	= 624.7 - 0.28 * Year	0.0787	8.47	0.1331
11	Irbid	-0.1341	0.1649	-0.1501	-0.4219	<.0001**	-0.6942	= 3288.8 - 1.42 * Year	0.3901	22.53	<.0001**
12	Ma'an	-0.1859	0.0542	-0.2155	-0.2447	0.0207*	-0.4282	= 460.3 - 0.21 * Year	0.1294	6.94	0.0178*
13	Mafraq	-0.0886	0.3587	-0.1231	-0.2182	0.0392*	-0.4024	= 1027.1 - 0.44 * Year	0.1219	14.94	0.0217*
14	Qatraneh	-0.0259	0.7887	-0.1279	-0.1185	0.2628	-0.2143	= 256.3 - 0.08 * Year	0.0157	8.07	0.4241
No.	Station name	Individual annual			10 years MA			10 years MA rainfall trend			
		Kendall τ	Prob>|τ|	R	Kendall τ	Prob>|τ|	r	Trend Equation	R^2	RMSE	Prob> F
15	Ramtha	0.0032	0.9783	-0.0459	-0.2698	0.0439*	-0.5002	= 1255.6 - 0.52 * Year	0.1592	9.97	0.0354*
16	RasMuneef	0.0149	0.8774	0.0720	0.3178	0.0027**	0.6382	= -3206.1 + 1.90 * Year	0.3277	34.67	<0.0001**
17	Rwaished	-0.0086	0.9288	-0.0810	-0.0831	0.4325	-0.0313	= 122.8 - 0.02 * Year	0.0012	7.77	0.8286
18	Safawi	-0.1937	0.0448*	-0.2821	-0.3245	0.0022**	-0.5429	= 905.7 - 0.42 * Year	0.2173	10.12	0.0016**
19	Salt	-0.0828	0.4225	-0.1797	-0.4084	0.0004**	-0.7783	= 5056.1 - 2.27 * Year	0.5215	29.78	<0.0001**
20	Shoubak	-0.2675	0.0056**	-0.3678	-0.4640	<.0001**	-0.7908	= 5163.2 - 2.46 * Year	0.5286	29.53	<0.0001**
21	WadiDhulall	-0.1534	0.1425	-0.2394	-0.4159	0.0004**	-0.6721	= 2177.1 - 1.02 * Year	0.3516	14.86	<0.0001**
22	Wadi El-rayyan	0.0298	0.7576	0.0813	0.3577	0.0007**	0.5873	= -2708.5 + 1.52 * Year	0.2823	30.70	0.0002**
Overall mean		-0.0584	0.0052**	-0.0891	-0.0537	0.0195*	-0.1055	= 2289.7 - 1.04 * Year	0.0057	165.47	0.0261*

* sign indicates significant trends at the 5 percent confidence level, and
** sign indicates significant trends at the 1 percent confidence level

The trend statistical analysis of precipitation on a monthly basis indicated that the reduction is highly significant during the whole rainy season except for February where the rainfall tended to increase by a rate of 0.25 mm per year (Table 4). On the other hand, summer rainfall events tended to increase insignificantlyduring the dry seasons of June, July August, and September.

Table 4. Historical trend analysis for average monthly rainfall

Month	Linear Model	Mann-Kendall τ	Prob>|τ|	R^2	RMSE	Prob> F
Jan	= 560.45 - 0.26 * Year	-0.0194	0.3504	0.0045	55.69	0.0303*
Feb	= -442.9 + 0.25 * Year	0.0498	0.0167*	0.0042	55.16	0.0352*
Mar	= 813.8 - 0.39* Year	-0.1175	<0.0001**	0.0187	41.22	<0.0001**
Apr	= 430.8 - 0.21* Year	-0.1260	<0.0001**	0.0167	23.51	<0.0001**
May	= 80.5 - 0.04 * Year	-0.0065	0.7726	0.0069	6.79	0.0072**
Jun	= -5.7 + 0.003 * Year	0.0057	0.8193	0.0008	1.48	0.3468
Jul	= -0.3 + 0.0002 * Year	0.0180	0.4772	0.0002	0.17	0.6692
Aug	= -0.7 + 0.0004 * Year	0.0083	0.7430	0.0008	0.18	0.3458
Sep	= -13.4 + 0.007 * Year	0.1158	<0.0001**	0.0063	1.25	0.0096**
Oct	= 48.9 - 0.02* Year	-0.0247	0.2544	0.0007	11.87	0.4080
Nov	= 115.7 - 0.05 * Year	-0.0678	0.0013**	0.0004	33.51	0.5090
Dec	= 1028.7 - 0.50 * Year	-0.0660	0.0015**	0.0187	52.44	<0.0001**

* sign indicates significant trends at the 5 percent confidence level, and
** sign indicates significant trends at the 1 percent confidence level

3.3. Spatial Modeling and Aridity

According to the spatial analysis for the 10 years MA annual rainfalls, the semi-variogram suggested anisotropic rainfall behavior with an orientation of 24 degrees. In general, the aridity of the country was spatially and temporally obvious and increased over time. Several aridity classifications were investigated and the most appropriate was chosen and applied as in (Table 4). The western northern part of the country and across all the years received the highest rainfall (> 400 mm), while the eastern and southern parts were the most arid (<100 mm) (Figure 5). The country is suffering from shifting to lower rainfall means. A strongly arid class existed at the southern and the northern-eastern parts from year 1960 till 2000 disappeared and turned into hyper arid class. Moreover, west- middle part are slightly arid class that used to receive 200 to 250 mm, currently it shifted to be under moderately arid class with range of 150-200 mm. before year 2000.

On the other hand, it is obvious that the climate change impact was more effective on the semi-arid classes, especially the slightly and moderately subclasses. Currently, the two wet classes have disappeared from the map and have shifted towards strongly semi-arid.

The results of moving average clearly showed that the period 1970 to 1980 was the most wet period, and the rainfall amount exceeded 500 mm was during this period only (Fig. 5).

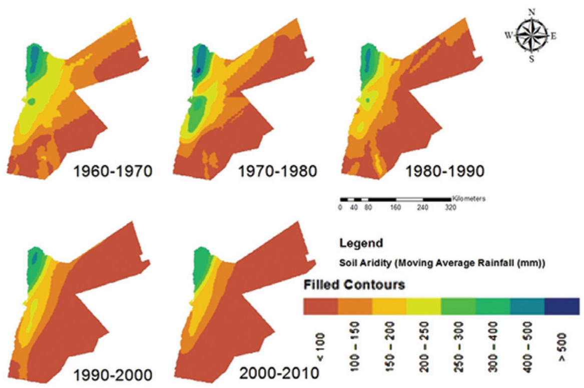

Figure 5. Spatial and temporal distribution of MA annual rainfall across the country with adopted aridity classification

Table 5. Recommended aridity subclasses customized to Jordan conditions

Class	1 Hyper arid	2 Strongly Arid	3 Moderately Arid	4 Slightly Arid	5 Strongly Semi arid	6 Moderately Semi arid	7 Slightly Semi arid	8 Subhumid
Mean annual rainfall (mm)	< 100	100 – 150	150 - 200	200 - 250	250 - 300	300 - 400	400 - 500	>500

4. Conclusions

The use of spatial and temporal statistics of rainfall was helpful in identifying the extent of aridity classes in Jordan. In the present study, the rainfall index was enough to illustrate and visualize the extent of aridity change across the country. Statistical trend analyses of monthly, annual, and ten years moving average rainfall using Tukey HSD, Mann-Kendall rank, and Pearson Correlation Coefficient of Linear Regression for 22 weather stations indicated clear evidence on the severity of global warming and, thus, the desertification impact. The rainfall variability over the past 50 years was highly significant that is temporally and spatially variable.

The climate change had considerablyimpacted the rainy season through shortening the season, reducing the quantity of rainfall, lowering the number of the rainfall events, and the shifting time of occurring. Temporal analyses revealed a shift in the maximum rainfall to be more observable at February with narrowing the rainy month's magnitudes at both ends. The rainfall linear trend analysis suggested a significant decrease ($P<0.05$) by about 1.1 mm per year and, thus, acerbating the pressurized demand on water for various sectors. On the other hand, very few stations showed a significant increase in precipitation, such as RasMuneef and Wadi El-Rayyan that could be used for further strategic planning as surface water catchments.

In terms of sever events, the monthly and annual individual trend analyses indicated an increase in the possibility of both wet and drought seasons where the drought phenomenon is more observable across the country. Although the wet season's temporal and spatial magnitudes are still unpredictable, their existence is evident and increasing over time and, thus, should be taken seriously in the future strategic planning under the theme of flood risk assessments.

Although the major part of the country (90%) is arid to semi-arid and characterized by a very low annual precipitation that averages less than 220mm, the aridity of the country is increasing over time. The adopted aridity classification was able to visualize the existing shifts occurred over the past 50 years using the temporal and spatial modeling tools within GIS.The shift was clearer at the semi-arid classes, especially the slightly and moderately subclasses that changed towards a strongly semi-arid class. In addition, strongly arid classes within southern and the northern-eastern parts of the country are changing into a hyper arid class. Moreover, a slightly arid class at west-middle parts was shifted to a moderately arid class.

The results of the present study vitally and critically urge the need for National Adaptive Management Action Plans (NAMA) in all related sectors especially water and agriculture. Future scenarios for natural resources management at a local scale should incorporate projects that demonstrate the actual aridity status and change with the adopted new classification.

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