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An Analysis of Dry Spells Patterns Intensity and Duration in Saudi Arabia

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Abstract: This study aims to investigate the patterns of drought in Saudi Arabia by drawing upon precipitation data taken from 20 meteorological stations throughout the country over a period of thirty five years. The mean precipitation was taken and then the SPI was determined for every year at every station to determine whether that region experienced a wet spell or dry spell for that year. The average dry spell index (ADSI), which is a parameter derived from SPI, was used to classify drought pattern in Saudi Arabia. It was found that the localities around 8 of the stations suffered from extreme drought, 5 from severe drought, 6 from moderate drought and only one from mild drought conditions. Several drought parameters, such as longest dry spell duration (LDSD), drought tendency (DT) and average dry spell duration (ADSD), were represented using contour charts. The result was that every area of Saudi Arabia, without exception, has been suffering from drought and this has been the case for 10 years or more for most of the country. This startling fact has gone unheeded up to now. The most significant drought is found in areas of the highest rainfall amounts in southwesterly region, they are experiencing extreme drought. On the other hand there is undetectable extreme drought in the areas of very little rainfall, such as the areas of less than 50 mm annual rainfall.

Key words: Climate · Drought · Environment · Frequency · Intensity · Saudi Arabia

INTRODUCTION

The term drought is used in hydrology to describe the complex natural phenomenon of levels of precipitation in a given region remaining below the mean over a determined period of time.

Drought has been defined in several disciplines such as meteorology, agricultural studies and hydrology. There are numerous definitions of drought and conditions in a region might be defined as a drought according to one definition but not according to another. For example, a meteorological drought is the period during which monthly or annual rainfall is below normal, while a hydrological drought is defined in terms of the effect of dry spells on surface or groundwater, where water resources fail to meet the demand of a given water management system. On the other hand, agricultural drought may be defined in terms of the sensitivity of crops at different stages to water requirements in terms of rainfall, irrigation, soil moisture content and evapotranspiration [1].

In general, drought as defined by the International Negotiating Committee of the Convention to Combat Desertification (INCD) is the naturally occurring phenomenon that exists when rainfall is significantly below normal recorded levels, causing a serious hydrological imbalance that adversely affect land resources production systems [2].

In recent years, the rhythms of change in the natural and social environment have become more and more rapid and the effects of those changes become increasingly severe, complex and permanent. Drought generally results from a combination of natural factors, but can be enhanced by anthropogenic influences. The primary cause of any drought is a deficiency in precipitation, particularly with respect to its intensity, timing and distribution. Human activity plays both active and passive roles in this process.

In the last few decades, the damaging consequences of drought have become more obvious [3]. Russel [4] provided a framework on water supply management that is related to drought analysis. The article analyzes

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drought in terms of cost and losses, in addition to water demand and its relationship to the adjusted level of drought. This was discussed by providing practical examples from municipal planning in Massachusetts. Previous studies in Jordan Aty [5] showed wet and dry spell cycles of precipitation using a probabilistic methodology. The article confirms that Jordan's rainfall has high variability. Sen [6] proposed a probabilistic formulation of spatio-temporal drought pattern. The study suggests that in spite of the fact that drought occurrence is random in any instance with respect to time and locality, nevertheless, its scientific quantification is possible by probabilistic methods.

Wendland [7] analyzed a case study of the 1988 drought in Illinois State. The article deals with several definitions of drought, such as the hydrological, meteorological and agricultural definitions. The study compares the monthly precipitation of 1988 as a percent of the mean for 1951-1980. The response of soil moisture, river flow, lakes, reservoir and groundwater to the deficit of precipitation are calculated, taking into consideration the time response for each type.

McKee proposed a well known standardized precipitation index SPI to monitor drought in the USA [8]. The study explains the characteristics of this index and its applicability for testing some hydrological variables, such as soil moisture and groundwater, in any region. The article discusses the duration and frequency of drought and its relation to the time scale.

Guttman [9] made a comparison between the Palmer drought index (PDI) and SPI. The study explains the characteristics of each one. PDI and its variations were designed to be standardized so that index values would have comparable meaning at all locations and times, otherwise, a comparison might lead to erroneous conclusion by users of PDI. On the other hand, PDI calculations require observations based on the monthly water balance, which involves soil moisture, evapotranspiration and runoff. The same study assumes that SPI gives a better representation of wetness and dryness than PDI.

In Sen and Eljadid [10] the duration and frequency of wet and dry spells in northern Libya are analyzed. In addition, droughts are analyzed for different truncation levels above and below the mean. The percentages of wet and dry spells were found for each truncation level. The outcome of this study shows that the duration of the dry spells at all meteorological stations were longer than that of the wet spells.

Finally, one may ask, what is the advantage of studying drought in an arid region such as that typified by Saudi Arabia? The importance of this study is to measure how far rainfall patterns are changing and determine whether they are changing for the worse. It is hoped that the results of this study may contribute to a better understanding of rainfall phenomena in general. In this study, the intensity, patterns, duration and frequency of droughts in Saudi Arabia are analyzed and presented in contour charts.

Synoptic Climatology of Rainfall in Saudi Arabia: Saudi Arabia occupies an area of approximately 2,000,000 km^2 between 16° N and 32° N. The majority of this region is under the influence of a subtropical high pressure belt, where most of the world's deserts are located.

Climatologically, the global pressure systems around the world oscillate north and south through the seasons. An example of oscillating pressure system is the Equatorial low pressure system, or monsoon which affects Saudi Arabia in summer, i.e. the equatorial trough is shifted from equator to approximately 30° N latitude. The extension of equatorial trough to the north causes very hot and dry summer in Saudi Arabia, except the southwestern areas. These areas are influenced by the sea track of the maritime air mass over the Indian Ocean through the Red Sea, i.e, these areas enjoy wet monsoon season [11].

In winter season the low pressure system travels again towards the equator, besides that the sub-tropical high pressure system will be dominant over Saudi Arabia. The middle and northern parts enjoy cold nights and moderate temperature during daytimes Synoptically, in winter, the rainfall in the northern and middle of Saudi Arabia is affected by the cyclogensis over east Mediterranean Sea, such as Cyprus low. Sometimes deep depressions travel further to the south to affect north and some interior parts of Saudi Arabia [12, 13].

In the transition season spring and autumn, tropical maritime airmass associated with Red Sea trough affects many parts of Saudi Arabia, especially southwestern region, causing heavy showers of rainfall associated with thunderstorm activity. The spatial distribution of rainfall in these seasons depends on the axis of the trough, when the axis of the Red Sea is tilted to north east, the interior parts of Saudi Arabia will be under the effect of rainfall [14].

Table 1: Stations of the studying area, Note: station number appears on the charts

Stn. No.	Name/Area	Code No.	Long. Deg. E	Lat. Deg. N	Elevation M	Rainfall mm
1	Zulfy/Riyadh	455	44.48	26.17	670	108
2	Alaflaj/ Riyadh	454	46.44	22.17	730	44
3	Turbah/Makkah	628	41.40	21.11	1126	43
4	Factories/ Riyadh	452	46.43	24.34	564	78
5	Tayef/Makkah	627	40.27	21.41	1530	154
6	Alhanakia/Madina	368	40.31	24.50	849	58
7	Madina/Madina	366	39.35	24.31	590	54
8	Mlaky/Jazan	496	42.57	17.03	190	360
9	Alkhosh/Jazan	498	41.53	19.00	350	197
10	Bishah/Aseer	64	42.36	20.01	1020	67
11	Alnamas/Aseer	15	42.09	19.06	2600	357
12	Alqateef/Alsharqya	138	50.00	26.30	5	83
13	Um aqla/Alsharqya	169	47.22	26.22	450	47
14	Harth/Alsharqya	165	49.10	24.04	300	27
15	Hayel/Hayel	186	41.38	27.28	1010	83
16	Tabuk/Tabuk	769	36.35	28.22	737	25
17	Tayma/Tabuk	770	38.29	27.38	820	28
18	Almandaq/Albaha	61	41.15	20.10	2400	245
19	Oqlat asqur/Alqassim	787	42.11	25.50	740	55
20	Tabarjal/Aljoof	594	38.17	30.31	566	18

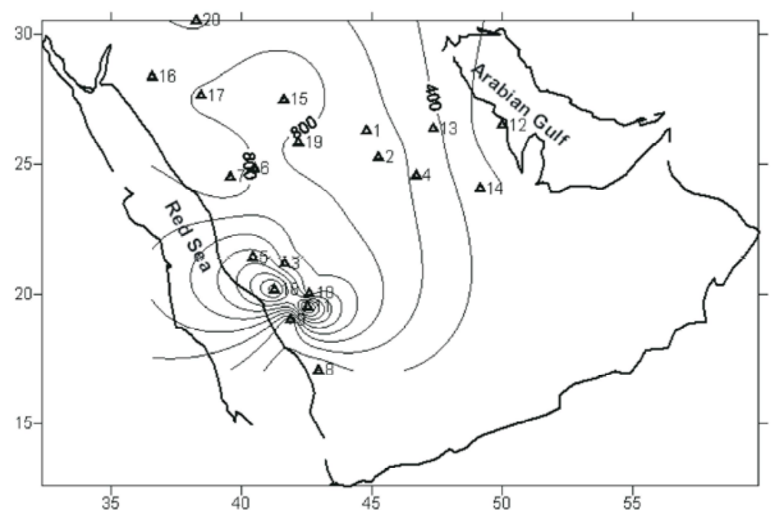


Fig. 1: Stations of the studying area, with their elevations in meter above mean sea level

Methodology and Techniques: In this study, framework techniques were used to quantify drought characteristics like severity, duration and spatial extent in 20 stations in Saudi Arabia, Fig. 1 and Table 1. Various methods and techniques have been used to study drought, among these is the Standardized Precipitation Index SPI. This was proposed by [8] and various interpolation methods were explored in detail to find the optimum technique for interpolating SPI from multi-time scale data. . In addition, Kemp and Ikeda provide a quantification of SPI patterns through a detailed workflow analysis to quantify precipitation deficits on a variety of timescales that reflect the impact of drought on the availability of different water resources [15, 16].

SPI may be defined as a coefficient of variation, specifically the difference between annual precipitation and long-term mean precipitation (in this study, 35 years), divided by the standard deviation for the period of time. Drought occurs when the SPI assumes a negative value and ends when it becomes positive again.

$$SPI = (Q - \overline{Q}) / \sigma_j \quad (1)$$

where, Q represents annual precipitation $\overline{Q}$ and represents annual mean rainfall over a longer period of time and σ_j represents the standard deviation. In this study, dry and wet spells are analyzed using techniques introduced by [16-19]. Their various techniques analyzed the dry and wet spells in terms of dry spell duration, drought intensity and dry spell frequency. These terms are discussed below.

Dry Spell Duration: Water resources projects require long-term planning from a climatic and hydro- meteorological standpoint, especially with respect to water requirements for irrigation and dam sizing. For this purpose, an analysis of the duration of dry and wet spells is required.

In this study when annual precipitation falls below the average (SPI < 0), the year is consider dry (D). On the other hand when SPI > 0, the year is considered wet (W). The longest dry spell duration (LDSD) is the maximum summation of any successive dry spells that take place once through the record *N*, which is 35 years in this study.

$$LDSD = \sum_{i}^{N} D_i,\ \ i = 1, 2, ...N \tag{2}$$

If *LDSD* = N, this implies a zero frequency of wet spells, meaning the whole record is dry. Maximum value of N=35 years.

The concept of drought tendency (DT) is the ratio between of the total number of dry spell cases to the total numbers of wet spells and can be written as:

$$\text{DT} = \sum D / \sum w \tag{3}$$

where, the average dry spell duration (ADSD), can be written as

$$\text{ADSD} = \sum D / N \tag{4}$$

ADSD is the summation of dry spells cases (D) divided by the number of dry spell events (N). For example, if three successive dry spells are followed by one wet spell and one further dry spell - which would be represented as D, D, D, W, D - this would mean that the summation of dry spell cases is 4; however the number of dry spell events (N) is 2, since the uninterrupted sequence of several cases of (D) constitutes a single dry spell event.

Drought Intensity: Drought intensity measures how far the rainfall is below the average. Several researches have dealt with drought intensity using different indices, such as the Palmer drought index (PDI). The use of SPI is more acceptable, because PDI requires measured data on soil moisture, evapotranspiration and runoff, for which records are not available for a sufficient number of years in Saudi Arabia. Drought intensity is introduced in this study using the SPI framework proposed by McKee *et al*. [8]. The same techniques are used by Tarawneh S. [17] to demonstrate the intensity, duration and frequency in Jordan, according to Table 2, Mckee *et al*. [8].

In this study, the severity of a dry spell is determined using the concept of Standard Total Accumulative Dry Spell (STCD). This represents the total cumulative ΣSPI value of 35 years. The more severe the dry spell, the larger the STCD. The other concept which is used to quantify the severity of a dry spell is the Average Dry Spell Index (ADSI) used by Tarawneh S. [17].

$$\text{ADSI} = \text{STCD}/\ \text{N} \tag{5}$$

N: as explained in the previous example of the ADSD parameter.

Dry Spell Frequency: Dry spell frequency duration (DFD) is an important criterion in planning for water resources projects, because it measures the probability of drought frequency. For example, a high probability of five-year drought frequency (DFD5) implies severe extended drought which affects the groundwater reservoir, soil moisture and ecosystem of that region. DFD5 refers to five dry spell frequencies, *i.e*, how many times successive five-year dry spells take place during the time period under study, then the probability of DFD5 for example can be written.

$$\text{DFD5} = (\ (\text{F x D5/N}))\ \text{x}\ 100\ \% \tag{6}$$

where F is the frequency of drought, D5 is the 5-years continuous dry spell and N is the length of the record, which is 35 years in this study. The frequency of dry spells of various durations is presented in contour charts in order to compare the frequency with other regions in Saudi Arabia, Table 3 and 4, show example of calculation for one station.

Applications: This study introduces a framework of methodologies for the assessment of drought occurrences as well as the identification of various drought characteristics, such as magnitude, duration intensity and frequency techniques. The results are presented in contour charts using Surfer software programming in order to compare the drought parameters with other regions of Saudi Arabia.

Table 2: Drought categories

SPI value	Drought category
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ 2	Extreme drought

Table 3: Almadina station No. 7, example of calculation with Table 4,

Year	Rainfall	SPI	CASE	SPI	
1970	34.8	-0.42	D	-0.42	
1971	98.4	0.93	W		
1972	38.3	-0.35	D	-0.35	LSYD
1973	2.5	-1.11	D	-1.11	
1974	87.6	0.70	W		
1975	17.4	-0.79	D	-0.79	LDSD
1976	52.5	-0.05	D	-0.05	
1977	9.0	-0.97	D	-0.97	
1978	6.3	-1.02	D	-1.02	
1979	36.6	-0.38	D	-0.38	
1980	13.8	-0.87	D	-0.87	
1981	31.0	-0.50	D	-0.50	
1982	212.0	3.33	W		
1983	41.6	-0.28	D	-0.28	
1984	37.5	-0.36	D	-0.36	
1985	80.2	0.54	W		
1986	57.3	0.06	W		
1987	35.8	-0.40	D	-0.40	
1988	24.1	-0.65	D	-0.65	
1989	94.1	0.84	W		
1990	30.3	-0.52	D	-0.52	
1991	36.9	-0.38	D	-0.38	
1992	37.2	-0.37	D	-0.37	
1993	212.4	3.34	W		
1994	97.7	0.91	W		
1995	65.4	0.23	W		
1996	29.6	-0.53	D	-0.53	
1997	86.6	0.68	W		
1998	39.6	-0.32	D	-0.32	
1999	39.5	-0.32	D	-0.32	
2000	73.3	0.39	W		
2001	62.5	0.17	W		
2002	34.5	-0.43	D	-0.43	
2003	19.8	-0.74	D	-0.74	
2004	12.5	-0.89	D	-0.89	
2005	79.5	0.53	W		

Dry Spell Duration: The dry spell duration is analyzed in terms of three parameters, LDSD, ADSD and DT. The first parameter, LDSD is calculated using Eq. 2. For each station, the chart is presented as in Fig. 2, to show the spatial distribution of LDSD through the study area. The most important result of the LDSD analysis is that, the stations of historically high rainfall amounts such as Jazan No. 8, Albaha No. 18 have 9 and 10 years of continuous drought respectively. The annual rainfall in these stations is 360 mm and 245 mm respectively, the continuous long term of drought which is expressed by LDSD is significant in these stations. On the other hand, the stations of very little amount of rainfall, the high LDSD in these stations does not have large effect on water recourses. Stations of high LDSD and little rainfall such as No. (19) Alqassim; LDSD is 12 years, No. (14) Harth 11 years, No. (13) Um Aqla in Al-Sharqya 10 years and No. (3) Turba in Makkah 11 years. Three stations in northwest of Saudi Arabia station have an LDSD value of 9 years. They are: No. (16) Tabuk, No. (17) Tyma and No. (20) Al-Joof, which reflects a homogenous rainfall regime. These three stations are affected by the same weather system in the winter, when deep depressions from the eastern Mediterranean Sea; such as (Cyprus low) moves to the south and southeast of the sea.

In spite of the fact that the south westerly region has high rainfall in comparison to other regions in the country, the figure shows that station No. (18) Al-mandaq/Al-baha in the southwest region had 10 years of continuous drought. This result is very important and must be taken into consideration in any environmental study for this area.

Drought tendency (DT) is derived from drought duration Eq. 3, which measures the tendency of a region to suffer from dry spells. The output of this calculation is presented in a contour chart in Fig. 3. The figure shows that station No. (14) Harth/Alsharqya and No.(3) Turba/Makkah had a drought tendency of more than 2, which is the maximum for all stations in the study. This reflects that dry spells were two times as frequent as wet spells. The figure shows station No. (1and4) Riyadh, No.(7) Alhanakiya/Almadina, No. (17) Tyma/Tabuk has a DT of more than 1.5.

The ADSD is different from LDSD. It is the number of drought years divided by the number of drought duration of different lengths (Eq. 4). The result of these calculations shows a maximum value of ADSD in stations No. (3, 8, 18 and 9) Fig. 4. This result must be considered for water resources planning in this area. On the other hand, station No. (10) Bisha/Asseer has a minimum ADSD.

Dry Spell Intensity: In this study, dry spells intensity is expressed by several parameters, such as STCD, ADSI, Largest Multi-Year Drought (LMYD) and Largest Single Year Drought (LSYD). The STCD is the cumulative of the SPI values during 35 years; the quantity is derived from SPI techniques, which expresses the severity of dry periods. The intensity of drought is presented in Fig. 5, which shows a maximum STCD in the southwest region.

Table 4: Sample of calculations of drought parameters, depending on Table 3

Contraction	Meaning	Calculation
D	Dry spell	23
w	Wet spell	13
DT	Drought tendency	DT=∑D/∑W=23/13= 1.76
LDSD	Longest Dry Spell Duration	Period from 1975-1981=7 years
N	Number of dry spell events	For example, if three successive dry spells are followed by one wet spell and one further dry spell – which would be represented as D,D,D,W,D – this would mean that the summation of dry spell cases is 4; however the number of dry spell events (N) is 2, since the uninterrupted sequence of several cases of (D) constitutes a single dry spell event.
ADSD	Average Dry Spell Duration	ADSD= ∑D/N =23/9= 2.55
STCD	Standard Total Cumulative Drought, from 1970-2005*	*STCD= ∑SPI=-12.63 SPI of the whole years
ADSI	Average Dry Spell Index	ADSI=STCD/N= 12.63/9=1.4 (Moderate Drought)
LMYD	Largest Multi-Year Drought Maximum of any successive years**	**LMYD= ∑SPI= -4.58 Period from 1975-1981=7 years
LSYD	Largest Single-Year Drought	Maximum SPI value of single year

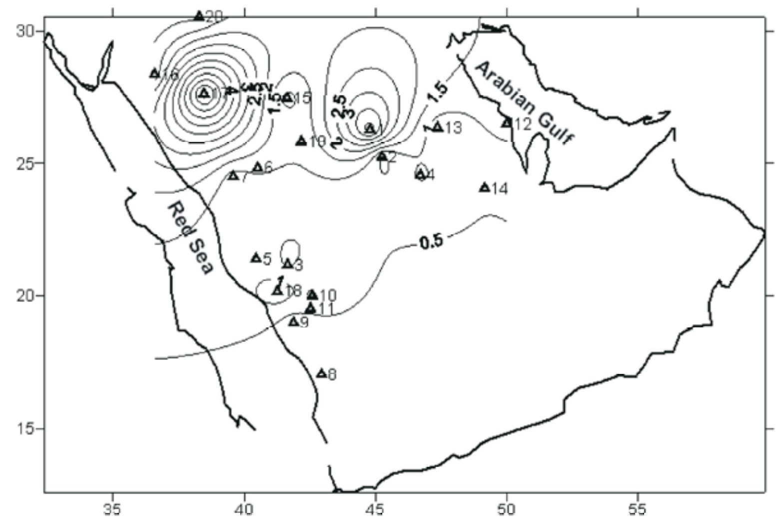


Fig. 2: Longest dry spell durations in years, LDSD

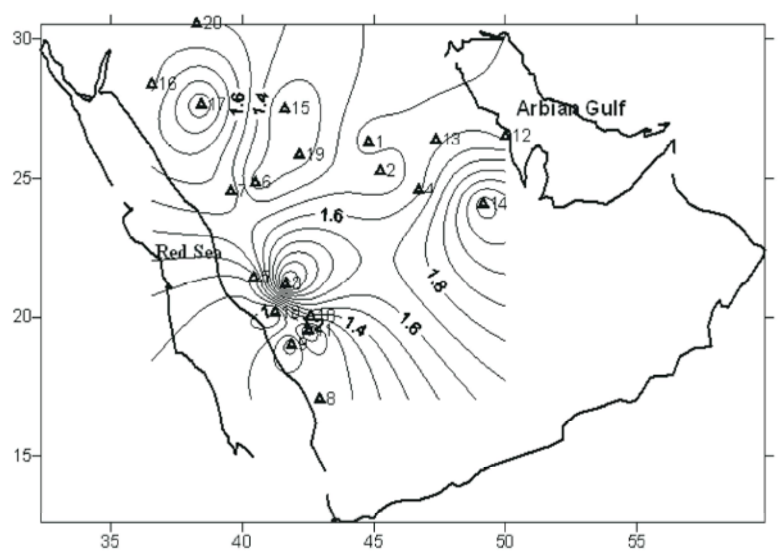


Fig. 3: Drought tendency, DT

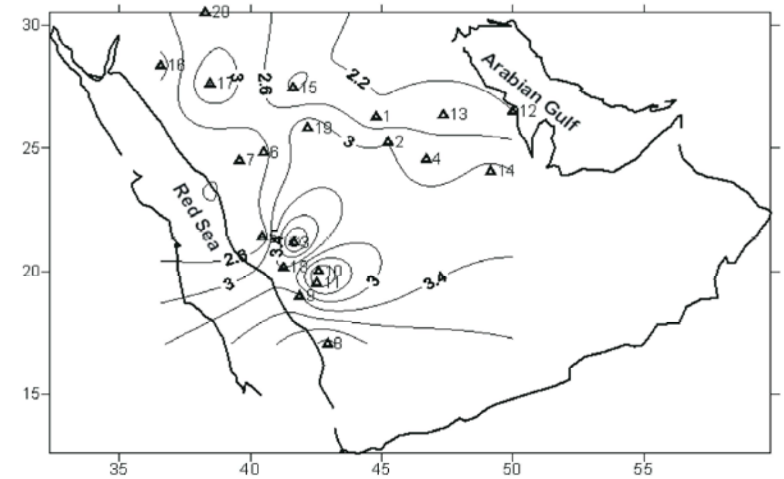


Fig. 4: Average dry spell duration, ADSD

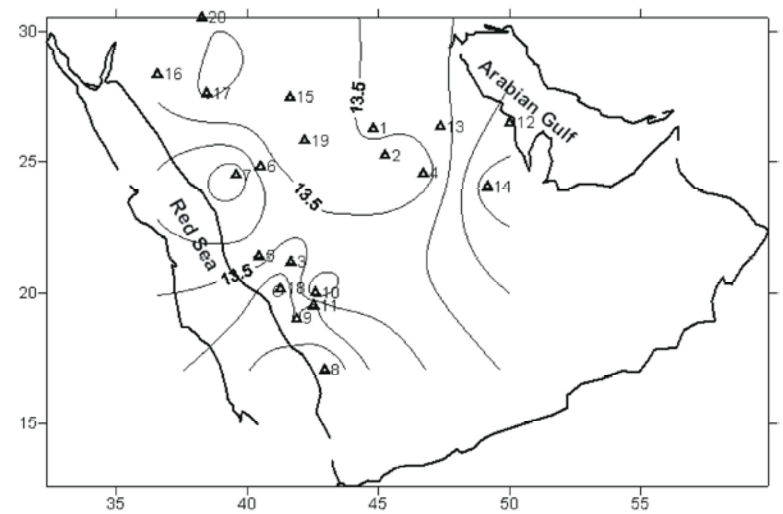
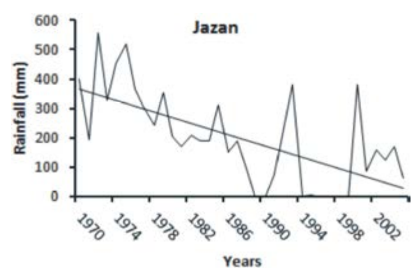


Fig. 5: Standard total cumulative drought, STCD

In this study, 8 stations are suffering from extreme drought, three of them; (No. 8 Malky/Jazan, No. 9 Jazan/ Alkhosh and No. 18 Almandaq/Albaha) are in the southwesterly region, they have annual rainfall 360 mm, 197 mm and 245 mm respectively, which are the highest among the whole stations. The remaining stations of extreme drought all have annual rainfall amounts less than 50 mm Table 5, the drought in these stations is not significant and difficult to be detectable. This result must be taken in consideration in southwest region because it is climatologically the wettest region in the country. Figure (6) from (1-20) shows the time series of rainfall trends of all stations in the study, the trend in the stations 8, 9 and 18 is decreasing. On the other hand, stations in the northwest No. (20, 19, 17 and 15) have a high value of STCD, which indicates the severity of drought of this region. Figure 6 shows that increasing trends in the areas



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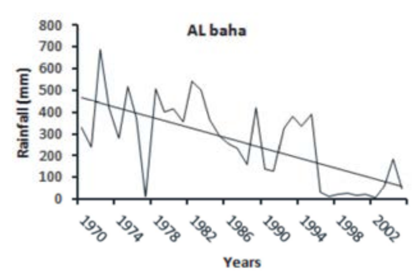

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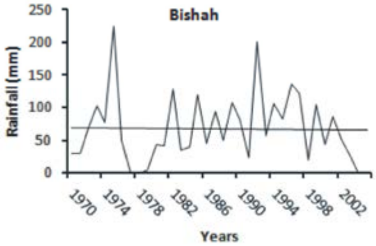

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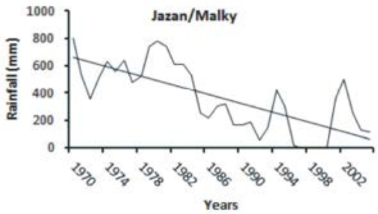

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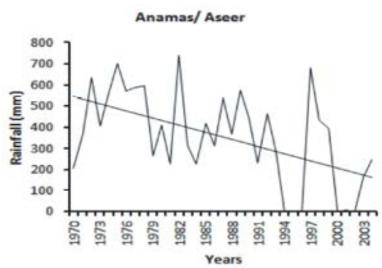

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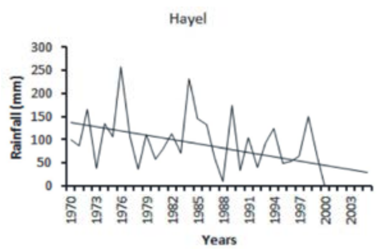

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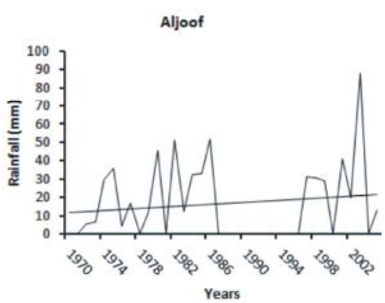

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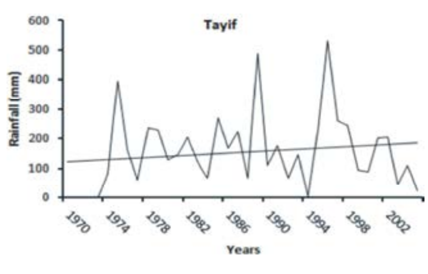

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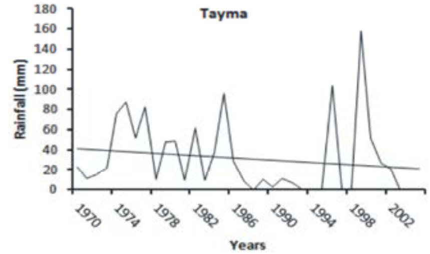

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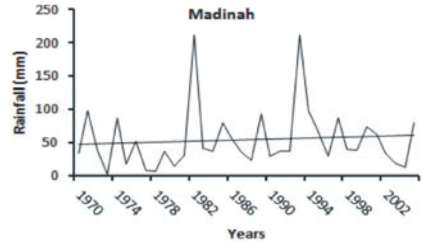

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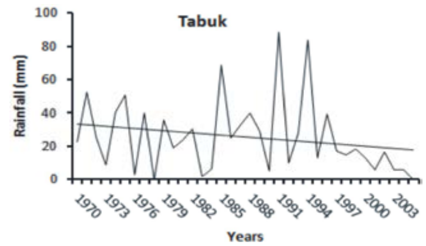

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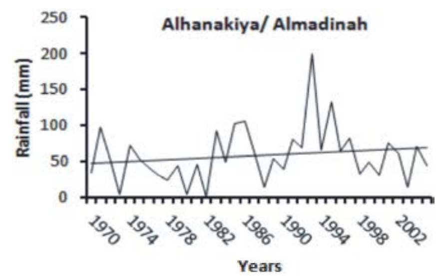

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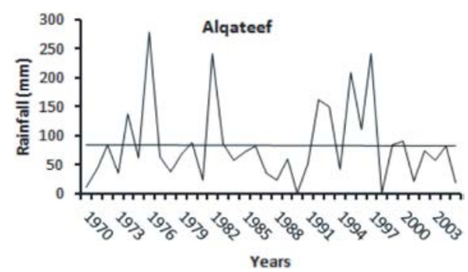

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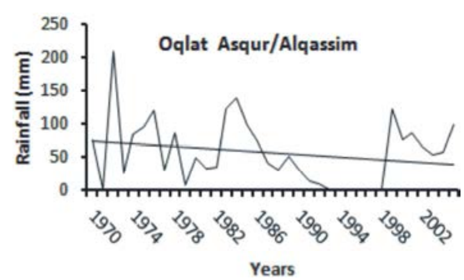

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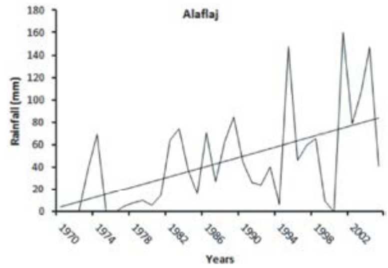

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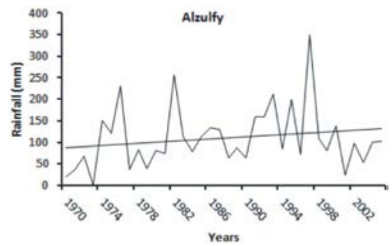

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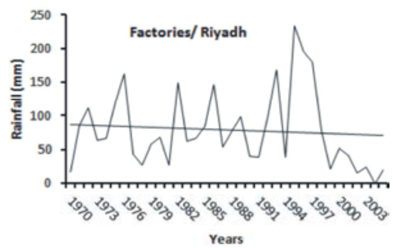
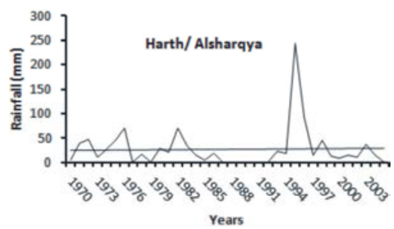
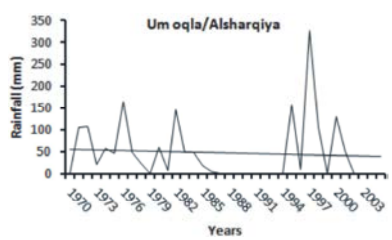


(17)



(18)



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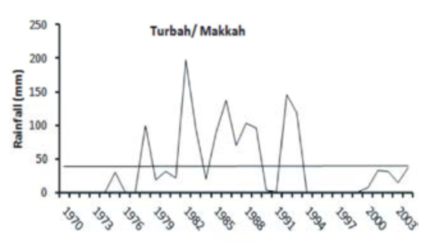

(20)

Fig. 6: Time series of rainfall and the trend for the stations in the study area

typified very low precipitation such as Aljoof, Alaflaj and Al-hanakiya/ Almadina this is due to the sensitivity of the data to severe flooding events; Table 1. If we adjust for these irregularities, these positive trends disappear.

The main purpose of this study is to classify the types of drought in Saudi Arabia. ADSI is calculated and presented as a contour chart to show the categories and types of drought in each region. The chart is constructed depending on drought categories (Table 2). ADSI depicts the severity of drought, the higher the ADSI the more severe the drought (Fig. 7). The extreme drought in the areas of maximum rainfall in the southwest region, such as stations No. (8, 9 and 18) is more significant comparing to the extreme drought in the areas of very little rainfall such as Aljoof; (18 mm), Tyma (28 mm) and Alaflaj. ADSI for the stations No. (8, 9 and 18) is -3.87. -2.40 and -3.04 respectively, Fig. 7.

It may seem a kind of paradox that the region of high rainfall in the country is the same regions that have extreme drought. This is attributed to the fact that the SPI compares the rainfall amounts with the average. Fig. 7 shows another extreme drought in Saudi Arabia, such as station No.(3, 9, 2,19, 20 and 17). The northwest region receive very little amounts of rainfall, although the stations of this region are suffering from extreme drought, such as Aljoof No. 20 and Tyma No. 17, both have ADSI of value - 2.1. Alriyadh /Alflaj No. 2 is suffering from extreme drought of ADSI VALUE -2. Table 5, gives ADSI, type of drought and annual rainfall for each station. This result provides valuable knowledge about the characteristics of the areas, needed to plan for water resources and irrigation projects. These areas should be given more attention. The result of drought severity will be of great importance to decision makers for the future planning of agricultural projects in these areas.

In order to calculate the severity of individual dry periods, two parameters are derived from SPI techniques: LMYD and LSYD. Station No.(18) Almandaq/Albaha in the southwestern region has the largest LMYD through 10 years of continuous drought (Fig. 8). The other area is the Oqlat asqur/Alqassim station No.(19), which shows a large value for LMYD; 12 years of continuous drought. The figure depicts and expresses the severity of multi-year drought. Water resources and indeed every aspect of the environment, are strongly affected in areas with high LMYD values and consequently the region's socio-economic situation is affected.

The LSYD is used to measure the severity of a single-year drought. This parameter is useful when considering the cultivation of crops which cannot survive under severe drought conditions and reach their

Table 5: Type of drought in the KSA and annual rainfall

Stn. No.	Code	Name	ADSI	Type of Drought	Rainfall (mm)
8	496	Jazan/ Malky	3.9	Extreme	360
18	61	Albaha/Almandaq	3	Extreme	245
3	628	Makkah/ Turba	2.9	Extreme	43
9	498	Jazan/ Alkhosh	2.4	Extreme	197
2	454	Riyadh/Alaflaj	2	Extreme	44
19	787	Alqassim/Oqlat asqur	2.4	Extreme	55
20	594	Aljoof	2.1	Extreme	18
17	770	Tyma	2.1	Extreme	28
1	455	Riyadh/ Zulfy	1.6	Severe	108
4	452	Riyadh /Factories	1.8	Severe	78
6	368	Madina/Alhanakiya	1.6	Severe	58
11	15	Asseer/Annams	1.8	Severe	357
15	186	Hayel	1.6	Severe	83
5	627	Tayef	1.4	Moderate	154
7	366	Madina	1.4	Moderate	54
12	138	Alsharqya/ Alqateef	1.4	Moderate	83
13	169	Alsharqya/ Um aqla	1.4	Moderate	47
14	165	Harth	1.2	Moderate	27
16	769	Tabuk	1.2	Moderate	25
10	64	Bisha	0.95	Mild	67

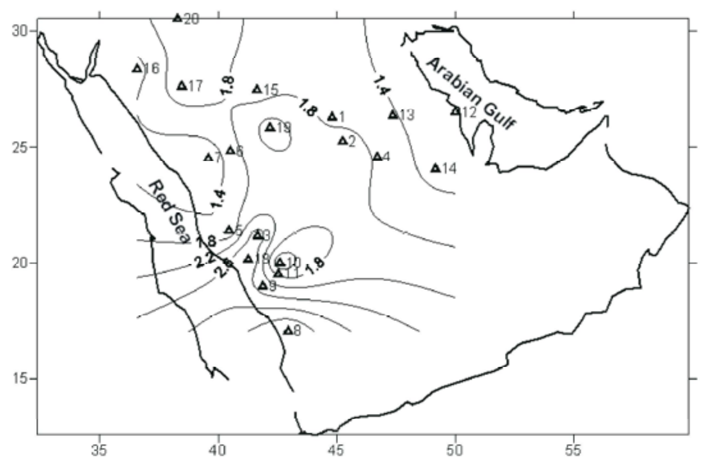

Fig. 7: Average dry spell index, ADSI

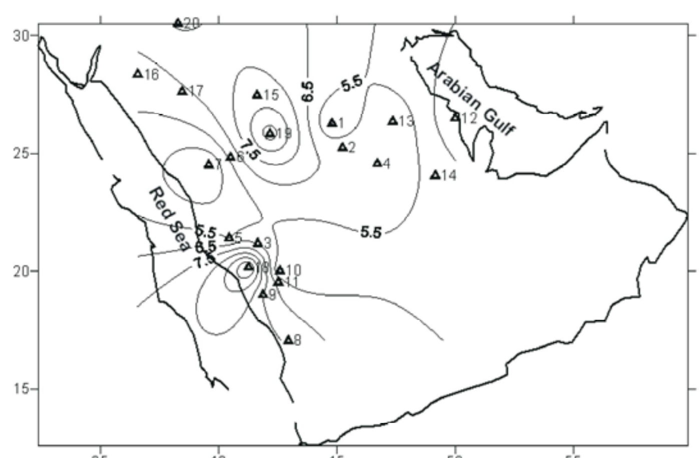

Fig. 8: Largest Multi-year drought, LMYD

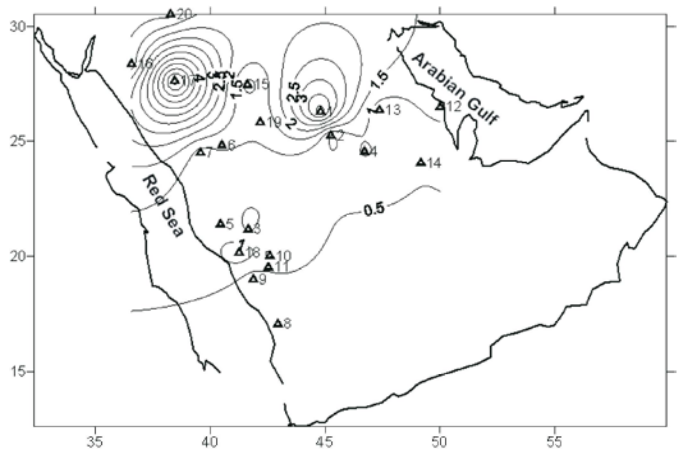

Fig. 9: Largest single-year drought, LSYD

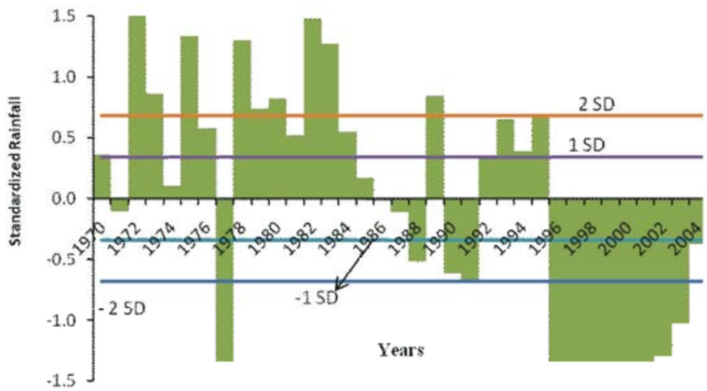

Fig. 10: Intensity, duration and frequency of drought in Al-Baha, extreme drought

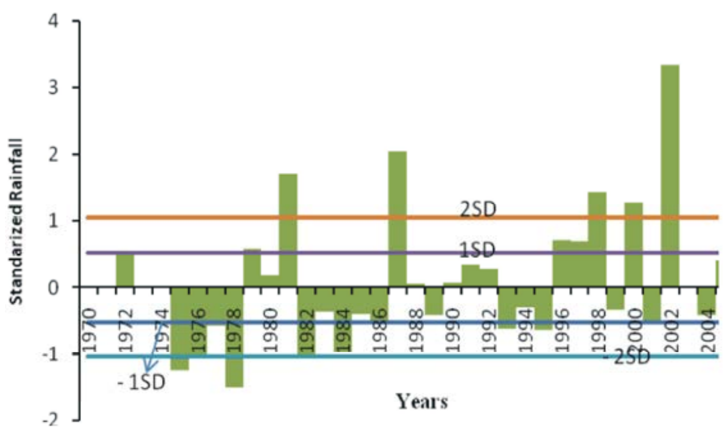

Fig. 11: Intensity, duration and frequency of drought in Al-Zulfy, severe drought

wilting point fast. Station No. (17) Tyma/Tabuk and Zulfy/ Riyadh No. (1) have the maximum LSYD for the stations under study. This means that these areas suffered the severest drought in a single year (Fig. 9). These areas pose difficulties for the cultivation of certain crops and this must be taken in consideration in planning agricultural projects.

Drought intensity, duration and frequency are depicted in one figure for some stations for each drought category. Fig. 10 illustrates an extreme drought measured at the Al-baha station (18). The figure shows a wet period from 1970 - 1985. During this period, there was a stretch of 8 years where precipitation was 2 times the SDV above the mean. The period from 1986-1995 exhibited

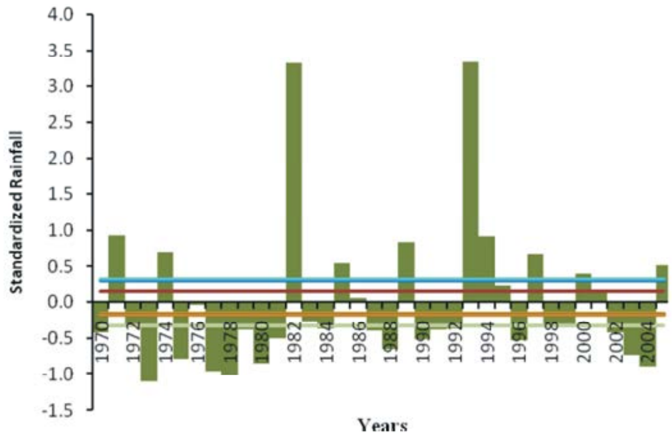

Fig. 12: Intensity, duration and frequency of drought in Al-Madina, moderate drought

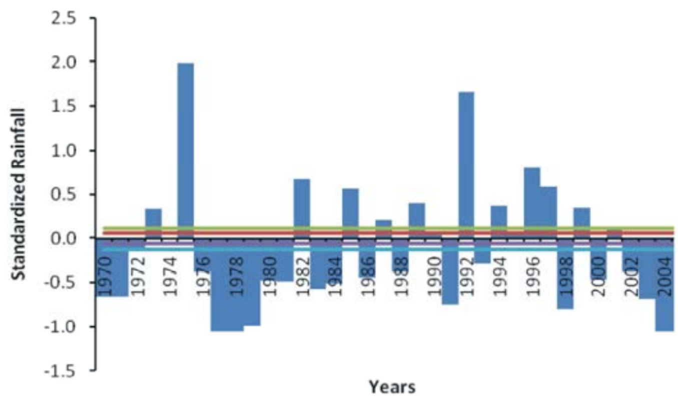

Fig. 13: Intensity, duration and frequency of drought in Bisha, mild drought

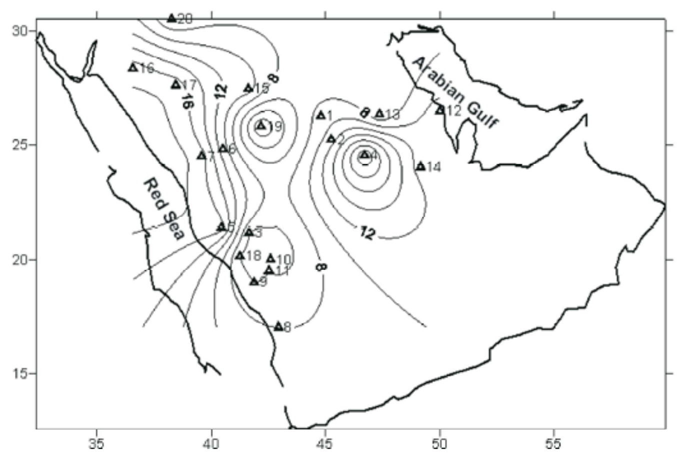

Fig. 14: Probability of the frequency of two years drought

small variations around the mean; 5 years were wet and more than the SDV above the mean. The remaining period, from 1996 - 2005 was dry. The figure shows a continuous 10-year drought with more than two times the SDV below the mean.

An example of a severe drought is found in the region of Al- zulfy station (1), Fig. 11 The figure shows 22 years of drought out of 35 years. The drought years exceed -2 SDV thresholds, which expresses the severity of drought. The figure shows some wet years far exceed + 2 SDV, which gives an indication that the area is subjected to severe winter storms. Fig. 12 and 13 represent the moderate and mild drought in Al- Madina station (7) and Bisha station (10), respectively.

Table 6: Percentage of probability of drought frequency for multi-time intervals

St. No.	Code	DF1%	DF2%	DF3%	DF4%	DF5%	DF6%	DF7%	DF8%	DF9%	DF10%	DF11%	DF12%
1	455	6	9		11					29			
2	454	6	11		22			19					
3	628	3	6	8	22								
4	452	6	22		14			22					
5	627	8	17	17									
6	368	11	11	17					22				
7	366	8	17	17	17								
8	496	3	8			14				25			
9	498	6	6			14	33						
10	64	22	4	8			17						
11	15	14	6		11	14							
12	138	14	11	8		28							
13	169	17	6		11					28			
14	165	8	11	8	11							31	
15	186	14	11	8				19					
16	769	19	17							25			
17	770	19	17					19		25			
18	61	3	6	8							28		
19	787	11			11								33
20	594	6	6	9	11					25			

Dry Spell Frequency: The occurrence of extreme climatological events, such as long drought periods, cause substantial damage to the ecosystem and sometimes they can affect a very large region. Dry spells frequency is important for stationary and systematic rainfall processes, but not for areas of high rainfall variability. In Saudi Arabia, the coefficient of variation of rainfall is very high. The southwestern region has an approximately systematic rainfall system in the summer and spring on account of the Indian Ocean monsoon, so that dry spell frequency analysis may contribute to better understanding the rainfall regime. The probability of rainfall frequency is calculated using Eq. 6. DF2 is presented as an example in Fig. 14. Drought frequencies of different periods (such as one year, three years ……, N years) , are referred to as (DF1, DF3,……,DFN). These were analyzed and the results shown in. Table 6. The analysis of DF1 and DF2 shows a non-zero probability of drought.

CONCLUSION

The analysis of drought in Saudi Arabia reveals important facts. In spite of the aridity of the region, the output of the analysis of dry spells in 20 locations over a period of 35 years shows all locations are suffering from various type of drought. The study shows 8 stations out of 20 have extreme drought and 5 have severe, 6 have moderate and only one has mild drought. The study confirms that no location is typified by wet conditions. This result assures that there is a change in the rainfall regime and a process by which rainfall is produced. It is important to reassess these results with respect to the affects of climate change in future studies. To conclude that Saudi Arabia has no wet location over a period of 35 years is very important, because the effect of drought on such an arid environment is subtle and therefore difficult to determine. Nevertheless, it is possible to support changes in the rainfall process or system by the fact that the localities of 8 stations suffered from more than a 9 years continuous dry spell and one further locality for 12 years. This means that a new normal pattern for rainfall could emerge. The analysis of the frequency of drought does not explain a systematic process of rainfall, which is attributed to a high variability of rainfall. The study reveals new facts and may help in understanding drought and its effect on the study area, where there is a paucity of studies and investigations in this field.

The most important result of this study is to conclude that the southwesterly region, which historically has received the most rainfall, has been suffering from extreme drought for the past 10 years. Areas which have historically has received moderate rainfall are experiencing severe drought, while the areas that are experiencing low levels to minimal levels of drought are areas which historically have received very little rainfall. In some cases, these areas even show an increasing trend for the 35 years under study. However, due to the low levels of rainfall in these areas, the statistics are more sensitive to rare episodes of extreme flooding, which can affect the accuracy of the resulting trend.

Finally, areas of extreme drought must be taken in consideration in developing and implementing any agricultural project and such conditions require issuing of drought emergency declarations. This result of drought analysis confirms our conclusion about a change in the rainfall process. The study recommends the need for more investigations and research in this region.

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