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Quantification of Drought in the Kingdom of Saudi Arabia

Qassem Y. Tarawneh

Prince Sultan Institute for Environmental Water & Desert Research,
King Saud University, P.O.Box 2454 Riyadh 11451, Saudi Arabia

Abstract: In order to get spatial pattern of drought, interpolation of standardized precipitation index (SPI) was done. Annual rainfall data of 20 stations are calculated from monthly records from 1970-2005. Each drought event characterized by three correlated attributes: severity, frequency and duration. Several parameters derived from SPI to analyze drought. The output of parameter's calculations is constructed by charts using surfer software programming. The study determined drought pattern in the Kingdom of Saudi Arabia (KSA). The average dry spell index (ADSI) is a parameter derived from SPI to classify drought patterns in the KSA. It is found that 8 stations suffer from extreme drought, 5 stations have severe, 6 have moderate and one has mild. Several drought parameters such as longest dry spell duration (LDSD), drought tendency (DT), average dry spell duration (ADSD) are depicted using contour charts. Some stations have long continuous drought of nine years or more. Drought frequency of multi-time intervals is calculated as probability.

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

INTRODUCTION

Drought has been defined in several disciplines such as meteorological, agricultural and hydrological studies. There are numerous definitions of drought, while one definition may be applied to a given region, at the same time it cannot be extrapolated to other regions with different climate features. For example, meteorological drought from meteorological point of view is the period during which monthly or annual rainfall is below normal, while the hydrological drought which is defined in terms of the effect of dry spells on surface or groundwater, where flow during this spells fails 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 the 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 Convention to Combat Desertification (INCD) is the naturally occurring phenomenon that exists when rainfall is significantly below normal recorded levels, causing serious hydrological imbalance that adversely affect land resources production system [2]. In the last period of time it can be clearly recognized that the rhythm of the changes in the natural and social environment becomes more and more rapid and the effects of the changes become increasingly bright, complex and permanent. Drought generally results from a combination of natural factors that can be enhanced by anthropogenic influences. The primary cause of any drought is the deficiency in precipitation and in particular, the intensity, the timing and distribution. All these processes influence the everyday and future human life more and more directly compared to previous time. Dryness and drought is the resultant of the special interaction between natural and social environment. Man and society play active as well as passive roles in this process, which influences the global development of a region. In the last few decades it became also obvious that effects of drought can cause damages [3].

Russel *et al*. [4] have framework on water supply management especially that is related to drought analysis. The article analyzes drought in terms of cost and losses, in addition to water demand, its relation to drought adjustment level were also discussed by providing practical examples from municipal planning in Massachusetts. Previous studies in Jordan Aty [5] showed the wet and dry spell cycles of precipitation in

Corresponding Author: Qassem Y. Tarawneh, Prince Sultan Institute for Environmental Water & Desert Research, King Saud University, P.O.Box 2454 Riyadh 11451, Saudi Arabia.

Jordan using probabilistic methodology, the article confirms that the Jordan's rainfall has high variability. Şen [6] proposed probabilistic formulation of spatio-temporal drought pattern. The study suggests that drought occurrence along time and space takes place randomly and therefore, their 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 hydrological, meteorological and agricultural drought. The study compares the monthly precipitation of 1988 as a percent of the mean 1951-1980. The response of soil moisture, river flow, lakes and reservoir and groundwater to the deficit of precipitation is calculated, taking into consideration the time response for each type. McKee *et al*. [8] proposed a well known standardized precipitation index SPI to monitor drought in the USA. 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] compared between Palmer drought index (PDI) and SPI. The study explains the characteristics of each one. The PDI and its variations were designed to be standardized so that index values would have comparable meaning at all locations and times, other wise, comparison may lead to erroneous conclusion by users of PDI. On the other hand, the PDI calculations require observations based on the monthly water balance which involves soil moisture, evapotranspiration and runoff. The same study assumes that the SPI gives better representation of wetness and dryness than PDI. Şen and Eljadid, [10] analyzed the wet and dry spells in Libya. The article shows the duration and frequency of dry and wet spell in north Libya. On the other hand, the droughts are analyzed for different truncation levels above and below the mean. The percentages of wet and dry spells are found for each truncation level. The out- come of this study shows the duration of dry spells in all stations which are longer than that of wet spells.

Finally, one may ask, what is the advantage of studying drought in arid region; such as the KSA? !. The importance of this study is measure how far the rainfall records below the normal, in other words, are the rainfall patterns are changing?. The output of this study may enlighten and contribute in better understanding rainfall phenomena. In this study, drought intensity, patterns, duration and frequency are analyzed and presented in contour charts for the KSA.

Studying Area and Data: The Kingdom of Saudi Arabia (KSA) is located southwest of Asia and occupies an area of 2000,000 km^2. The KSA is bounded by seven countries and three bodies of water. To the north, it is bounded by Jordan, Iraq and Kuwait, to the East, the Arabian Gulf states Qatar, Bahrain and the United Arab Emirates, to the West, the Gulf of Aqaba and the Red Sea which form very long coastal border and to the south Yemen and Oman. The tree bodies of water; namely, Indian Ocean, Red Sea and Arabian Gulf play an important role in rainfall climatology of the KSA. The main topographical parts of Saudi Arabia ; Prince Sultan Research Center ATLAS [11]):

- The Hijaz and Asir: The western coastal escarpment can be considered two mountain ranges separated by a gap in the vicinity of Makkah. The northern range in the Hijaz seldom exceeds 2,100 meters and the elevation gradually decreases toward the south to about 600 meters around Makkah. The rugged mountain wall drops abruptly to the sea with only a few intermittent coastal plains. The eastern slopes are less steep and are marked by dry river beds (wadis) that trace the courses of ancient rivers and continue to lead the rare rainfalls down to the plains.
- East of the Hijaz and Asir lies the great plateau area of Najd. This region is mainly rocky plateau interspersed by small, sandy deserts and isolated mountain ridges. The best known of the mountain groups is the Jabal Shammar, northwest of Riyadh and just south of the An Nafud desert.
- Northern Arabia: The area in the north of the An Nafud is geographically part of the Syrian Desert. It is an upland plateau scored by numerous wadis, most tending northeastward toward Iraq. This area, known as Badiyat ash Sham and covered with grass and scrub vegetation, is extensively used for pasture by nomadic and seminomadic herders.
- Eastern Arabia: East of the Ad Dahna lies the rocky As Summan Plateau, about 120 kilometers wide and dropping in elevation from about 400 meters in the west to about 240 meters in the east. The area is generally barren, with a highly eroded surface of ancient river gorges and isolated hills.
- The Great Deserts: Three great deserts isolate Najd from north, east and south as the Red Sea escarpment does from the west. In the north, the An Nafud--sometimes called the Great Nafud because An Nafud is the term for desert--covers about 55,000 square kilometers at an elevation of

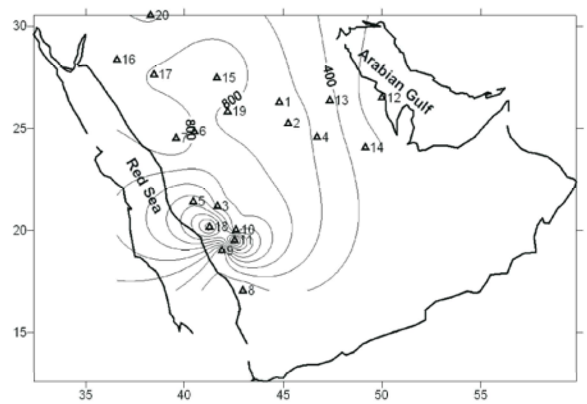

Fig. 1: Stations of the studying area, with their elevations in meter above mean sea level.

Table 1: Stations of the studying area.

Stn. No.	Name/Area	Code No.	Long. Deg. E	Lat. Deg. N	Elevation M
1	Zulfy/Riyadh	455	44.48	26.17	670
2	Alaflaj/ Riyadh	454	46.44	22.17	730
3	Turbah/Makkah	628	41.4	21.11	1126
4	Factories/ Riyadh	452	46.43	24.34	564
5	Tayef/Makkah	627	40.27	21.41	1530
6	Alhanakia/Madina	368	40.31	24.5	849
7	Madina/Madina	366	39.35	24.31	590
8	Mlaky/Jazan	496	42.57	17.03	190
9	Alkhosh/Jazan	498	41.53	19	350
10	Bishah/Aseer	64	42.36	20.01	1020
11	Alnamas/Aseer	15	42.09	19.06	2600
12	Alqateef/Alsharqya	138	50	26.3	5
13	Um aqla/Alsharqya	169	47.22	26.22	450
14	Harth/Alsharqya	165	49.1	24.04	300
15	Hayel/Hayel	186	41.38	27.28	1010
16	Tabuk/Tabuk	769	36.35	28.22	737
17	Tayma/Tabuk	770	38.29	27.38	820
18	Almandaq/Albaha	61	41.15	20.1	2400
19	Oqlat asqur/Alqassim	787	42.11	25.5	740
20	Tabarjal/Aljoof	594	38.17	30.31	566

about 1,000 meters. South from the An Nafud in a narrow arc is called Ad Dahna, a narrow band of sand mountains also called the river of sand. The southern portion of the Ad Dahna curves westward following the arc of the Jabal Tuwayq. At its southern end, it intercept with the Rub al Khali, one of the truly forbidding sand deserts in the world and, until the 1950s, one of the least explored. The topography of this huge area, covering more than 550,000 square kilometers, is varied. In the west, the elevation is about 600 meters and the sand is fine and soft; in the east, the elevation drops to about 180 meters and much of the surface is covered by relatively stable sand sheets and salt flats.

In this study 20 station Fig. 1 are chosen in order to cover the diversity of different regions in the KSA, besides, they have long and continuous data Fig. 1. The stations in figure one is given identification numbers, their names and locations are given in Table 1. The annual rainfall is calculated from the monthly data to analyze the drought patterns in the KSA.

Climatology and synoptic of rainfall in Saudi Arabia: Saudi Arabia is located approximately between 16°N and 32°N. The majority of this region is located under the influence of subtropical high pressure belt; where most of the world's deserts are located. The high pressure system in general is characterized by descending motion which means no upward motion, no clouds and consequently no precipitation.

Climatologically, the global pressure systems around the world oscillate north and south through the seasons depending on the position of the sun with respect to latitude circles. When the sun is over the north hemisphere, the starting of spring in the north hemisphere, all pressure systems are shifted to the north following the sun. An example of traveling 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 the Kingdom of 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 [12].

In winter season the sun will be over the south hemisphere, 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, with few wet days due to the passage of extra-tropical cyclone over the Mediternean Sea. The transition season spring and autumn are consider as a combination of transition period between summer and winter. Since our concept to discuss the dry and wet spells, the rainfall regime must be explained in terms of synoptic situations [13].

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. These depressions cause rainfall and drop in temperature especially in winter and early springs. These depressions usually associated with upper troughs or cold air aloft ; at height of approximately 500 geopotential meter or 500 mb surface pressure chart. On the other hand the activity of rainfall over the southwestern parts is also affected by the deepening of the upper trough that coincides with extension of moist maritime air mass from over the Indian Ocean as Red Sea trough [14].

In 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 [15].

In summer season, Saudi Arabia is affected by tropical continental hot and dry monsoon, while the southwestern parts enjoy wet monsoon from over the Indian Ocean, this result due to shifting of inter tropical convergence zone to the north in summer season.

Methodology and Techniques: Drought has been studied by several methods and techniques. Among these is the Standardized Precipitation Index SPI, which is proposed by McKee *et al*. [8]. Various interpolation methods were explored in detail to find the optimum technique for interpolating SPI from multi-time scale data. The frame work techniques is used to quantify drought characteristics like severity, duration and spatial extent. In addition, quantification of SPI pattern through details workflow to quantify precipitation deficits on multi-time scales that reflect the impact of drought on the availability of different water recourses is given by Kemp [16] and Ikeda *et al*. [17].

The SPI may be defined as a coefficient of variation, or the difference from mean divided by standard deviation of the period of time. The drought occurs when the value of SPI assumes negative value and ends when it becomes positive.

$$SPI = \frac{QJ - \overline{Q}_j}{\sigma_j} \quad (1)$$

where, Q_j and $\overline{Q}_j$ are measured annual and long term annual mean rainfall respectively and σ_j is the standard deviation. In this study the dry and wet spells are analyzed using a techniques introduced by Tarawneh [18], Kemp [16] and Ikeda [17] Keyantash and Darcup [19] and Heim [20]. The techniques analyzed the dry and wet spells in terms of:

Dry Spell Duration: Water resources projects require long-term planning in terms of climatic and hydro- meteorological view points, especially in water requirements for irrigation and dam sizing. For this purpose, the analysis of duration of dry and wet spells is required.

In this study when yearly rainfall below the average the year enjoys dry spell or 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.

$$LDSD = \sum_i^N D_i, \quad 1,2,......., N \quad (2)$$

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

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

$$DT = \frac{\sum D}{\sum W} \quad (3)$$

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

$$ADSD = \frac{\sum D}{N} \quad (4)$$

is the number of dry spell cases divided by the number of dry spell events of different time intervals. For example, if three successive dry spells followed by one wet and one dry spells; D,D,D,W, D, in this case the number of dry spell events is two.

Drought Intensity: Drought intensity measures how far the rainfall is below the average. Several researches dealt with drought intensity using different indices, such as Palmer drought index (PDI). The use of the SPI is more acceptable because PDI requires measured data on soil moisture, evapotranspiration and runoff which are not

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

available for long records in KSA. Drought intensity is introduced in this study using the SPI frame work proposed by McKee *et al*. [8]. The same techniques is used by Tarawneh [18] to adopt the intensity, duration and frequency in Jordan.. The classification of drought as given in Table 2 Mckee *et al*. [8] is used by Kemp [16] and Ikeda [17].

The severity of dry spell is determined in this study using the concept of Standard Total Accumulative Dry spell (STCD). This represents the total cumulative; ΣSPI value of 35 years. The severest the dry spell the largest the STCD. The other concept which is used to quantify the severity of dry spell is Average dry spell index (ADSI) [18].

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

N: Is the number of drought cases of different length during the record under investigation, for example if three years of dry spells followed by wet then dry spells such as D,D,D,W,D. in this example *N* is equal 2.

Dry Spell Frequency: Dry spell frequency duration (DFD) is one of the important criteria in planning for water resources projects. It measures the probability of drought frequency. For example, high probability of five-year drought frequency (DFD5) implies sever extended drought which affects groundwater reservoir, soil moisture and ecosystem of that region. DFD5 refers to five dry spell frequency, i.e, how many times the successive five years of dry spell take place during the record, then the probability of DFD5 for example can be written as:

$$DFD5 = \frac{\text{F x D5}}{\text{N}} \text{ x } 100\% \tag{6}$$

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 multi-time length are constructed in contour charts in order to compare the frequency in the KSA.

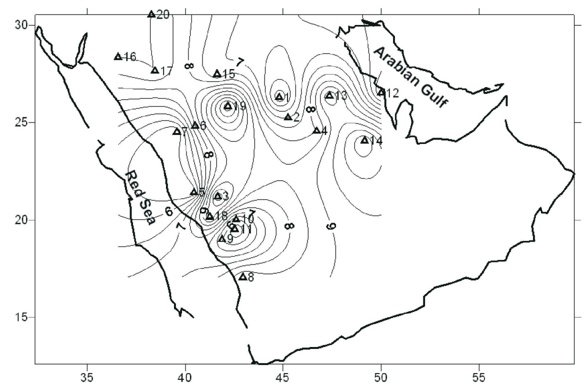

Fig. 2: Longest dry spell durations in years, LDSD.

Applications: The 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 [18]. The results are presented by contour charts using Surfer software programming in order to compare the drought parameters through the KSA regions.

Dry Spell Duration: The dry spell duration is analyzed in terms of three parameter, the LDSD, ADSD and DT. The LDSD is calculated using Eq^{n} 2, for each station as a point, the chart is constructed in Fig. 2, to show the spatial distribution of LDSD through the KSA. The figure shows that, stations No. (19) Alqassim, (14) Harth and (13) Um Aqla in Al-Sharqya and (3) Turba in Makkah have the maximum LDSD. The fore mentioned stations have LDSD values 12, 11, 10 and 11 year respectively. Station No. (16) Tabuk, (17) Tyma and (20) Al-Joof in the northwest of the KSA have 9 years LDSD. They have a homogenous rainfall regime. These stations in the northwest region are affected by the same weather system in winter season, when deep depressions of east Mediterranean Sea ;such as (Cyprus low) travel to south and southeast of the Sea. On the other hand, the figure shows, only one station; No. (18) Al-mandaq/Al-baha in the southwest region has 10 years of continuous drought; this result is very important if put our consideration that station 18 is located in the region of high rainfall amounts. This station must be taken in consideration in any environmental study.

Drought tendency is derived from drought duration Eq^{n} 3, which measures the tendency of a region toward the occurrences of dry periods. DT is calculated for 20 stations, the output is presented in a contour chart in Fig. 3. The figure shows that station No. (14)

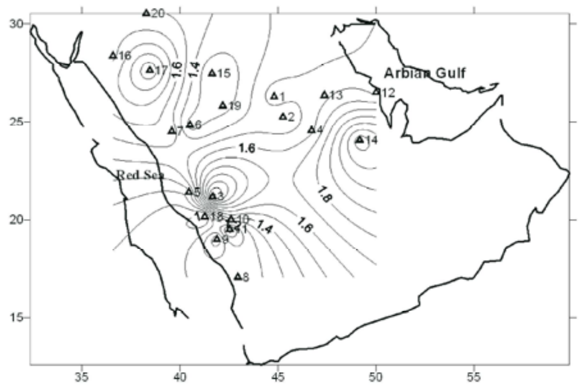

Fig. 3: Drought tendency, DT.

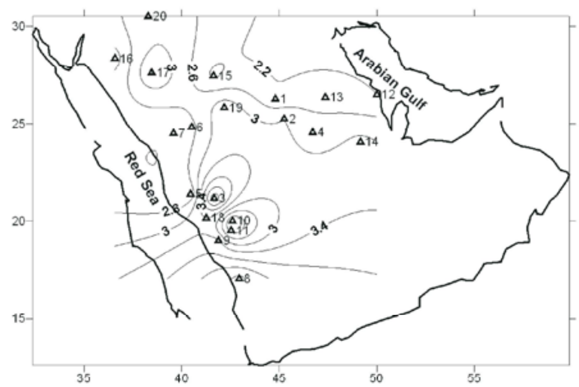

Fig. 4: Average dry spell duration, ADSD

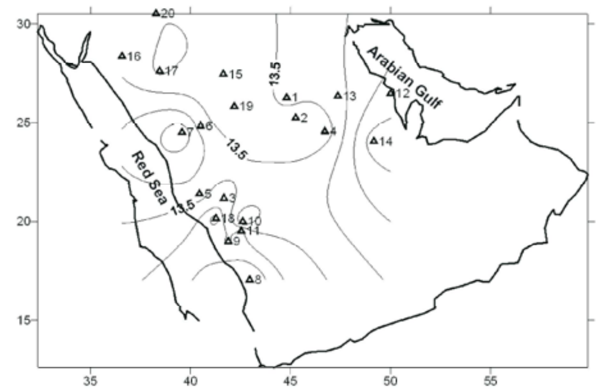

Fig. 5: Standard total cumulative drought, STCD.

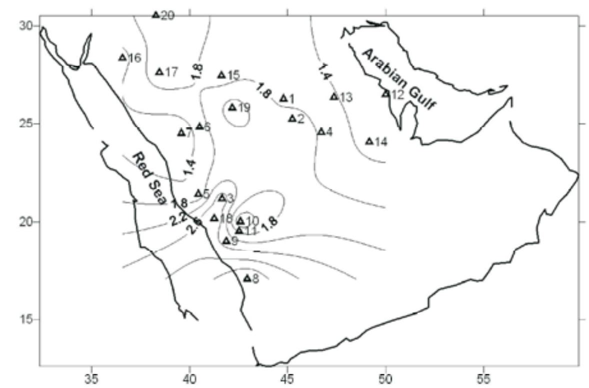

Fig. 6: Average dry spell index, ADSI.

Harth/Alsharqya, No. (3) Turba/Makkah has the maximum drought tendency more than 2. This reflects that the dry spells is two times the wet spells. The figure shows station No. (1&4) in Riyadh area, No.(7) Alhanakiya/Almadina, No. (17) Tyma/Tabuk has DT 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^n 4. The results of calculations is presented in Fig. 4. The figure shows maximum value of ADSD in stations No (3, 8, 18 and 9). It is an alert to be considered for planning in water resources of this area. On the other hand station No (10) Bisha/Asseer has minim ADSD.

Dry Spell Intensity: Dry spells intensity in this study is expressed by several parameters, such as STCD, ADSI, largest multi-year drought (LMYD) and largest single year drought (LSYD). The STCD is a quantity derived from SPI techniques, which expresses the severity of dry periods. The severity of drought is presented in Fig. 5 which shows maximum STCD in the southwest region station No.(8 and 18). On the other hand stations in the northwest No (20,19,17 and 15) have high value of STCD, which explain that the whole region encounter severe drought.

In order to classify the type of drought in the KSA, the average dry spell index ADSI Eq^n 5 is developed McKee *et al*. [8], Tarawneh [18]. ADSI is presented as a contour chart to show the categories and type of drought in each region. The charts is constructed depending on the drought categories in Table 2. The ADSI Fig. 6 depicts the severity of drought in the KSA. The highest value of the ADSI reflects the severest drought in the region. The figure shows that extreme drought in the southwest region station No (8 and 18) Malky/Jazan and Almandaq/Albaha respectively. This is may be kind of paradox to say that the region of high amounts of rainfall in the KSA, has extreme drought. This attributed to the fact that the SPI index compares the rainfall amounts with the average. Fig. 6 shows another extreme drought through the KSA, such as station No (3, 9, 2,19, 20 and 17), see the names and locations, Table (1)

These stations represent Riyadh area and the northwestern parts of the KSA. This result provides an important knowledge of the characteristics of the area to

Table 3: Types of drought in the KSA.

Stn. No.	Code	Name	ADSI	Type of Drought
8	496	Jazan/ Malky	3.9	Extreme
18	61	Albaha/Almandaq	3	Extreme
3	628	Makkah/ Turba	2.9	Extreme
9	498	Jazan/ Alkhosh	2.4	Extreme
2	454	Riyadh/Alaflaj	2	Extreme
19	787	Alqassim/Oqlat asqur	2.4	Extreme
20	594	Aljoof	2.1	Extreme
17	770	Tyma	2.1	Extreme
1	455	Riyadh/ Zulfy	1.6	Severe
4	452	Riyadh /Factories	1.8	Severe
6	368	Madina/Alhanakiya	1.6	Severe
11	15	Asseer/Annams	1.8	Severe
15	186	Hayel	1.6	Severe
5	627	Tayef	1.4	Moderate
7	366	Madina	1.1	Moderate
12	138	Alsharqya/ Alqateef	1.4	Moderate
13	169	Alsharqya/ Um aqla	1.4	Moderate
14	165	Harth	1.2	Moderate
16	769	Tabuk	1.2	Moderate
10	64	Bisha	0.95	Mild

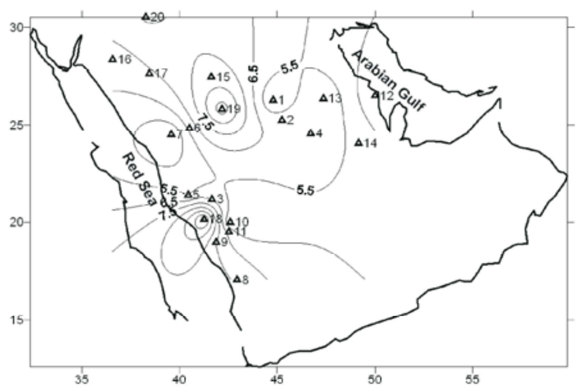

Fig. 7: Largest Multi-year drought, LMYD.

plan for water resources and irrigation projects. This area should be given more prominence in terms of agricultural projects. This result will be of great importance for the decision maker for future planning in these areas. Table 3 shows the type of drought and the ADSI value for each station.

In order to calculate the severity of individual dry periods two parameters are derived from SPI techniques, LMYD and LSYD. The LMYD Fig. 7 shows Station No(18) Almandaq/Albaha in the southwestern region has the largest LMYD during 10 years; (multi-year) of continuous drought. The other area is Oqlat asqur/Alqassim station No (19) shows large value of LMYD during 12 years of continuous drought, the figure depicts the expresses the severity of multi-year drought. The high values of LMYD affect water recourses, environment and the socio-economic of the region.

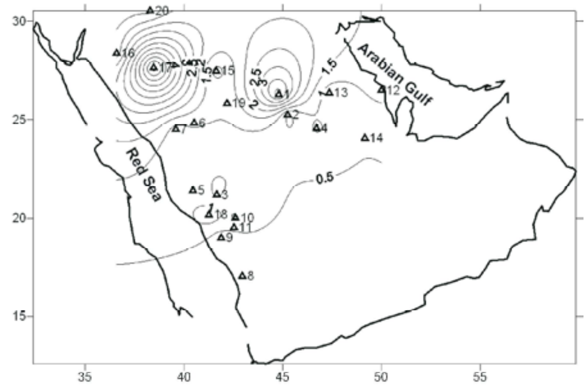

Fig. 8: Largest single-year drought, LSYD.

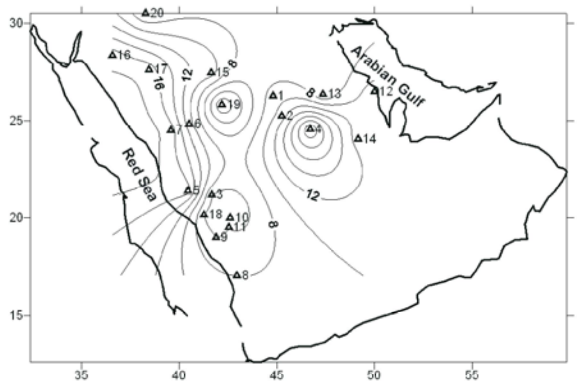

Fig. 9: Probability of the frequency of two years drought.

The LSYD, is used to measure the severity of a single year drought. The important of this parameter is useful for growing some plants which can’t survive under a severe drought and reach its wilting point so fast. Fig. 8 shows station No (17) Tyma/Tabuk and Zulfy/Riyadh No (1) have the largest LSYD i.e, the severest drought of single year. These stations are sensitive for some kind of plants must be taken in consideration in agricultural projects.

Dry Spell Frequency: Occurrence of extreme climatological events such drought periods cause substantial damage to the ecosystem and sometimes such events are regional in nature. Dry spells frequency has great importance for stationary and systematic rainfall process but not for areas of high variability of rainfall. In the KSA the coefficient of variation of rainfall is very high, i.e, the rainfall process is variable. The southwestern region has apprximatley a systematic rainfall systems in summer and spring from the Indian Ocean monsoon,

Table 4: 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			

so that, dry spell frequency analysis may contribute in better understanding in such rainfall regime. The probability of rainfall frequency is calculated Eq^n 6 and the DF2 is taken as example to be presented in Fig. 9. Drought frequency of different periods, such as the frequency of (one, three …… -year) refer to (DF1, DF3,……etc.) were analyzed and the result shown in Table 4. The analysis of drought DFD1 and DED2, respectively shows non-zero probability.

CONCLUSION

Saudi Arabia is mainly considered as a sub-tropical arid region, although, the analysis of drought reveal important facts. In spite of the aridity of the region, the study shows 8 stations out of 20 have extreme drought and 5 stations have severe. This result assures that there is a change in the rainfall regime and process. The effect of such drought on the environment can't be detectable in arid region. On the other hand the change in rainfall process or systems may be supported by the fact that, 8 stations have more than 9 years of continuous dry spell, one of them has 12 years. This yields to new normal of rainfall records. The analysis of the frequency of drought may not explain a systematic process of rainfall, This is attributed to high variability of rainfall. The study reveals new facts and may help in understanding the drought and its effect on studying area, where there is a lack of studies in the KSA in this field.

On the other hand, the areas of extreme drought must be taken in consideration in any agricultural project. Drought monitoring would benefit from the information which indicates the status of rainfall, water supply and demand. Two stations in the southwest region have extreme drought, this region receives the highest amount of precipitation in the KSA. This result confirms our conclusion about a change in rainfall process. The study recommends the need for more investigations and researches in this region.

REFERENCES

1. Tarawneh, S., 2000. Drought analysis of selected rainfall stations in Jordan. Dirasat, 27: 77-95.
2. Dambe, D.D., 1997. Agrometeorological inputs in measures to alleviate the effect of drought and to combat Desertification. *WMO*-TD, No. 836., Geneve
3. Naginders S. Sehmi and Zbiniew W. Kundzewicz, 1997. Sustainability of Water Resources under Increasing Uncertainty (Proceedings of Rabat Symposium S1, April 1997). IAHS Publ., 240: 57. Water,

4. Russel, C.S., D.G. Arey and R.W. Kates, 1970. Drought and Water Supply, Implication of Massachuesttes Experience for Municipal Planning. The Johns Hopkins Press, Baltimor and London.
5. Aty, S.H., 1976. On the distribution of rainfall sequences with application to actual data Dirasat, Jordan Univ., 3: 15-25.
6. Şen, Z., 1998. Probabilistic formulation of the spatio-temporal drought pattern. Theor. Appl. Clim., 61: 197-206.
7. Wendland, W.M., 1990. Hydrological aspects of the 1988 drought in Illinois. American Water Resources Asso, 26: 913-920.
8. McKee, T.B., N.J. Doesken and J. Kleist, 1993. The relationship of drought frequency and duration to time scale. 8th Conference of Applied Climatology, Boston, Massachusetts, Jan., pp: 17-22.
9. Guttman, N.B., 1998. Comparing the Palmer drought index and standardized precipitation index. J. of Amer. Water Res. Asso., 34: 113-121.
10. Şen, Z. and A.G. Eljadid, 1999. Rainfall distribution function for Libya and rainfall prediction. Hydro. Sci., 44(5): 665-680.
11. Prince Sultan Research Center for Environment Water and Desert, 2007. Space Image Atlas of Kingdom of Saudi Arabia.
12. Abdullah, M.A. and M.A. Al-Mazroui, 1998. Climatology study of the southwest of Saudi Arabia, Rainfall analysis. Clim. Res., 9: 213-223.
13. Shehadeh, N., 1991. The climate of Jordan, Al-basheer Press. Amman.
14. Tarawneh, Q. and M. Kadioglu, 2003. An analysis of precipitation climatology in Jordan. Teore. & Appl. Clim., 74: 123-136.
15. Almazroui, M., 2010. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009, Atmos. Res. doi:10.1016/j.atmosres.2010.11.006
16. Kemp, D.D., 1991. Global Environmental Issues. A climatological Approach, London and New York.
17. Ikeda, S.E., E. Suzuki, E. Uchida and M. Yoshino, 1980. Statistical Climatology Development in Atmospheric Science. Elsevier Scientific Publishing Company, Amsterdam.
18. Tarawneh, S., 1999. Drought Analysis of desert and Badia of Jordan. Abhath Al-Yarmouk, 8: 117-145.
19. Keyantash, J. and J.A. Darcup, 2002. The Quantification of drought: An analysis of drought indices. Bull. of American Met. Soc. 83(8):1167-1180.
20. Heim, Jr. 2002. A review of twentieth century drought indices in the united states. Bull. of American Met. Soc., 83(8): 1149-1165.