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Analysis of Meteorological Drought in Tihama Plain, Yemen Using Standardized Precipitation Index (SPI)

Analisis Kemarau Meteorologi di Dataran Tihama, Yaman Menggunakan Indeks Piawai Kerpasan

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Abstract

Meteorological drought occurs when precipitation rate is less than usual for a period of time in affected areas. This article aims to analyse the meteorological drought in the Tihama Plain, as one of the most important agricultural areas in Yemen contributing 42 percent to the total agricultural production in the country. The study attempts to find out if the plain is currently facing drought conditions through analysing the rainfall data obtained from five meteorological stations for the past 30 years (1980-2010). The Standardized Precipitation Index (SPI) method normally gives best results regardless of other climatic parameters such as humidity, minimum and maximum temperature, potential evapotranspiration and sun hours as it gives accurate result using only precipitation data. The reason beyond using SPI method is that its results are effective and they are similar to the actual drought situation with some exception of the extreme condition of severe drought. SPI was calculated using 3 months' time scale from the monthly precipitation record. Then, the results were classified to determine the severity of drought (mild, moderate, severe and very severe) based on the SPI values. The results showed that the region faces the risk of drought, where the percentage of drought severity reached 47.43 percent in all the categories (mild 39.12%, moderate 5.41%, severe 1.84%, and very severe 1.06%). It was found that the eastern part of the region is more vulnerable to drought.

Keywords meteorological drought, precipitation, drought conditions, Standardized Precipitation Index (SPI), drought severity, Tihama Plain

Abstrak

Kemarau meteorologi berlaku apabila kadar hujan adalah kurang daripada nilai biasa untuk tempoh masa mencukupi bagi ketakseimbangan dalam kitaran hidrologi di kawasan yang terlibat. Artikel ini bertujuan untuk menganalisis kemarau meteorologi di Dataran Tihama, yang merupakan salah satu kawasan pertanian yang paling penting di Yaman yang menyumbang kira-kira 42 peratus daripada jumlah pengeluaran pertanian di negara ini. Dalam tahun-tahun kebelakangan ini, Dataran Tihama menghadapi perubahan dalam musim hujan, yang memberi kesan negatif terhadap pertanian dan air bawah tanah. Tujuan kajian ini adalah untuk mengenalpasti keadaan kemarau dengan menganalisis data hujan yang diperoleh daripada lima stesen meteorologi untuk 30 tahun yang lalu (1980-2010) dengan menggunakan Indeks Piawai Kerpasan (SPI), iaitu satu indeks paling boleh dipercayai untuk mengukur tempoh, keterukan dan keruangan kemarau. Keputusan SPI menganalisis untuk tempoh masa keseluruhan 30 tahun (1980-2010) menunjukkan bahawa rantau ini menghadapi risiko kemarau, iaitu peratusan kemarau adalah sebanyak 47.43 peratus dalam semua kategori (ringan 39.12%, sederhana 5.41%, yang teruk 1.84%, dan sangat teruk 1.06%). Kajian ini membuktikan bahawa bahagian timur rantau ini adalah lebih terdedah kepada kemarau meteorologi.

Kata kunci kemarau meteorologi, kerpasan, keadaan kemarau, Indeks Piawai Kerpasan, keterukan kemarau, Dataran Tihama

INTRODUCTION

Drought is a serious threat to livelihoods and sustainable development in many regions of the world, especially in the areas located in the arid and semi-arid territories (Schwabe & Connor, 2012). It is the result of a normal decrease in the quantity of rainfall through a long period of time, typically a season or over (Mishra & Singh, 2010). Other climatic elements like rising temperatures rate, high rate evaporation, high winds, and low of moisture are often correlated with drought. These elements can perform and substantially exacerbate the intensity of drought events (Wilhite, 2000). Drought happens in both high and low rains regions in a temporary dry period unlike aridity which is a permanent feature of climate and is limited to low rainfall regions (Maliva & Missimer, 2012).

Since the mid-twentieth century, especially in early 1980, rapid warming of the atmosphere has contributed significantly to the universal drying (Trenberth et al., 2014). Aridity and drought regions have already increased significantly and still expected in many zones over the coming decades, with obvious traces for too large numbers of population in arid and semi-arid (Middleton & Sternberg, 2013). Compared to other natural disasters, drought is the most damage and higher costly that causes a rate of $6-8 billion of universal losses by natural catastrophes yearly; it affects the livelihood of a large number of people more than the effect of any other type of natural disasters (Keyantash & Dracup, 2004).

In many Arab countries, droughts have become a more frequent and a serious bluster to humanitarian safety. Over the past three decades, nearly 50 million people have been affected in the Arab region by climatic disasters events, with losses estimated at $11.5 billion (World Bank, 2012). It is a very hazardous problem which will increase causing serious threat on various aspects of life including humanitarian disasters, economic losses, and stresses on natural ecosystems (Kaniewski et al., 2012). Taking into account that most of the Arab states are suffering from crispness of their ecosystems, and facing intense risks of deterioration of vegetation cover, soil, and depletion of water resources on per day continuously (El Kharraz et al., 2012). This is coupled with the rushing increase in population growth accompanied by an increase pressure on natural resources in this region (ACSAD, 2001). For instance, according to a report by the World Bank (2012), Morocco witnessed drought events that involved large amounts of cereals (e.g., 5 million tons of wheat) to face the people needs.

In recent years, Yemen has faced several periods of drought, 1979-81, 1983-84, 1990-91 and 2007-2009, which caused a lot of damages on Yemeni economy, which largely relies on agricultural resources (U.S, 1982; World Bank, 1986; UNDESA/ESCWA, 2013; Miyan, 2015). For instance, in 1990-1991 drought had a significant effect on the socio-economic situation in Yemen. This caused wide agricultural losses and increased a number of poor households in rural zones, lower revenue contribution of the agricultural production in the gross domestic product of the country (UNDESA/ESCWA, 2013). According to ESCWA (2005), irrigated agriculture like vegetables registered a decline in production by 16 percent, as cereals yields dropped sharply, where production decreased both of millet, sorghum and barley by 33 percent, 34 percent, and 38 percent respectively. Livestock have witnessed a marked decrease by 11 percent as a result of the lack of pasture and forage because of drought. About 43 percent of the population live below the poverty line, as estimated in 2009. It is expected to increase the number of hungry people in Yemen between 80,000-270,000 people by 2050, as a result of the severity of frequency of droughts and changing climate (Wiebelt et al., 2011). What makes the matter worse is the water shortage as stated by Noaman et al. (2013) (under 1000 cubic meters per year).

The study area has faced drought events that have occurred over the past years like other regions in Yemen. But the effect of the drought was more pronounced in the study area due to conditions that helped increase the frequency of drought doubling its effects. The study area lies within arid and semi-arid climate region which are characterized as high temperature, lack of rainfall and increase evaporation rates. Therefore, due to the dominance of this type of climate, a lot of environmental problems emerged, among which drought comes first and reflects its effects on various elements of the natural environment and human activities in the area. For instance, drought has led to the deterioration of vegetation which reduces its capacity to protect soil which became under drought becoming more active in the form of sandstorms which can be transformed from one place to another. As a result, the sand dunes are formed over large areas of the region nearly (319.784) hectares (Dhaifallah, 2012).

According to Alkatany (2010), the periods of the eighties and nineties and the first five years of the twenty-first century are among the most drought periods impact on the Tihama Plain (the study area). The study reported that the vegetation, soil, and groundwater are the most affected factors by drought. While another study about desertification in a part of Tihama Plain reported that drought is the most important factor which causes desertification and land degradation in the region (Dhaifallah, 2012).

As noted above, it is clear that Yemen, including the study area, severely suffers from frequent drought, and also numerous social, environmental and economic problems resulted by low precipitation rates and frequent droughts. In contrast, according to the researcher's knowledge and based on previous studies (Miyan, 2015; Bogan, 2014; UNDESA/ESCWA, 2013), there is no integrated scientific study of the drought in Yemen in general and in the study area (Tihama Plain) in particular. Furthermore, there is a lack of study that accurately describes how the study area is affected by drought (Miyan, 2015). Therefore, the current study tries to bridge such a gap and as a first step to highlight the drought conditions in Yemen as an attempt to beat the alarm bell to alert the dangers left behind by this serious phenomenon on the environment, economy, and society.

Drought indicators are generally used to indicate the beginning and intensity of drought, and to monitor its spatial and temporal styles. Year by year, many drought indicators have been developed. There are more than 150 drought indicators have been proposed (Niemeyer, 2008), and lately more indicators appeared (Cai et al., 2011; Karamouz et al., 2009; Vasiliades et al., 2011). Among these indicators, Standardized Precipitation Index (SPI) (McKee et al., 1993) is the most frequently used because it can be used for both agricultural and hydrological droughts (Ntale & Gan, 2003). It can track drought on multiple time scales, (i.e. 1, 3, 6, 9, 12, 24 and 48 months); at the same time SPI is flexible with respect to the selected period space (McKee et al., 1993).

The salient advantages of SPI are that it can be computed for different time scales and it can also provide early warning of drought and help assess drought severity (WMO, 2012). Besides, this index is less complex than the Palmer and it has the ability of recording when one number/has historical context and the data can be calculated even with missing data in the input (McKee et al., 1995). However, despite what has been mentioned above, SPI has some minor disadvantages such as it bases on precipitation only and it does not take temperature, evapotranspiration, and runoff as supplementary parameters (Shah et al., 2015).

According to several recent studies SPI is the most common and widely used by many studies in order to assess and analyze the drought conditions through using rainfall data to classify the drought severity (e.g. Hayes et al., 1999; Livada & Assimakopoulos, 2007; McRoberts & Nielsen-Gammon, 2012; Palchaudhuri & Biswas, 2013; and Shah et al., 2015). Thus, it could be stated that the main objective of this study is to analyze the meteorological drought in the Tihama Plain using the Standardized Precipitation Index (SPI) based on the rainfall data for the period from 1980 to 2010.

STUDY AREA

Tihama Plain is located on the west part of Yemen between latitude 12º.5 - 16º.5 north of the Equator and between longitude 42º.5 - 43º.5 east of Greenwich, and lies about 226 km of the capital city, Sana'a. The study area covers a total area of 25,314 sq km (Figure 1).

The study area is a corrugated flat plain with a little steep (less than one degree) slowly tilted in the direction of the sea. The area height starts from sea level in the west to about 250 m in the east, except for some peaks and mountain ledges which range in height between 400 km. The various morphologies and their heights affect the quantity of annual rainfall in the region, where the range of rain to rise from about 50 mm at the coast in the west to more than 600 mm in the eastern parts, depending on the gradual rise of the surface area above sea level (Alkatany, 2010).The surface of the study area is penetrated by watercourses of the most important main valleys in Yemen (Moore, Surdud, Rmaa, Zabid, and Siham) from east to west, which made this region the most important agricultural areas in Yemen.

The study area has arid and semi-arid climate, the rains in the region as low overall, ranging between 50-600 mm per year, because of its location within trough of the Red Sea as well as the low level of the surface compared to the neighbouring mountain blocks. Also, the rains are fluctuated from year to another depending on the conditions of the various pressures over the land areas and adjacent surface water bodies. According to the yearly precipitation factor, the study area is often divided into three rainfall regions; arid region (western Part) the average rainfall between 50-200 mm per year, Semi-arid region (middle part) the annual rainfall 200 - 400 mm, and semi-wet region (eastern part) 400 - 600 mm annually (Alkatany, 2010).

Almost the rains in the study area are falling over all the months; however, the heavy rains fall in the months (July, August and September) because these months are the summer months which represents the main rainfall season over most land in Yemen. For this reason the greatest quantity of rains fall on the study area occurs during the summer season. As for temperatures are ranging 37ºc in summer and 24ºc in winter (Assage, 1998).

METHODOLOGY

Method of Data Collection

The monthly rainfall data of 5 meteorological stations for the time period 1980-2010 were acquired from the Public Authority of Agricultural Research, which covered the study area as shown in Figure 1.

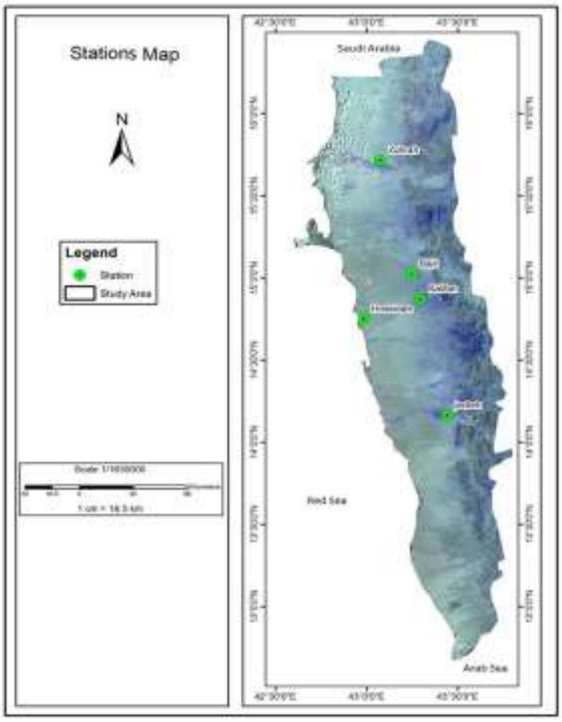


Figure 1 Distribution of meteorological stations in the study area

To determine the drought years, Standard Precipitation Index (SPI) was calculated using SPI calculator software obtained from the National Drought Mitigation Centre (NDMC) of the University of Nebraska, Lincoln using the following link: http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx. The SPI was calculated using 3 months' time scale which is appropriate for the determination of meteorological drought. The results were then transferred to Excel spread sheet, in order to calculate the frequency of drought, identify drought years and draw some graphs to explain the severity of drought.

The formula for determining drought years as used in this research is:

X= Number of months in drought
Rainfall in the study area = 12 month
Heavy Rainfall = 3 month (July, August and September)
Normal dry = 12 - 3 = 9 = No Drought
When X = 10 or above = Drought year

Usually, under normal circumstances Yemen Experience 3 months of heavy rainfall in July, August and September. Therefore, any year with a total of 9 dry months is considered as a normal situation. On the other hand, any year with more than 9 dry months is considered as a drought year. This means that, at least one month out of July, August or September did not receive sufficient rainfall as it used to be, thereby aggravating the drought condition already existing in the country.

Drought occurs when the SPI is negatively on an on-going basis, and its severity up to -1.0 or less, and ends when the SPI becomes positively (McKee et al., 1993). Therefore, each phenomenon of drought has a period to be determined by its beginning, end, and severity, in every month the drought continues Table1. Thus, the total positive SPI for all months which is taken by drought might be called the "intensity" of drought (WMO, 2012).

Table 1 Classification of drought based on the SPI index

SPI value	Classification
2.00 to more	Extreme wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderate wet
0 to 0.99	Mild wet
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.00 or less	Extreme drought

Source: Ceglar et al., (2008)

The SPI was calculated from the monthly precipitation record. The classification system proposed by McKee et al. (1993) was used to determine the severity of drought (mild, moderate, severe and very severe) based to SPI value, according to specific standards for any phenomenon of drought on any of time scales. As shown in Table 2.

Table 2 Classification of the SPI values and drought category

SPI value	Drought Category
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.00 or less	Extreme drought

Source: McKee et al., (1993)

Therefore, SPI is designed to fit several time scales for analysing rain. These standards reflect the impact of the drought on the availability of different water sources. For instance, soil moisture conditions (agricultural) are responsive to variations in the quantity of precipitation on a relatively short timescale, 1-6 months, while waterways flow and underground water are responsive to variations in the longer-term precipitation on a time scale ranges between 6 months and 24 months or longer (Al-Timimi & Monim, 2014). Therefore, it should examine the SPI in a period of 1 month or 3 months for the drought in the meteorological conditions, anywhere, and 1, 3, 6 months for agricultural drought and 6 or 12 months or more for the analyses and applications of hydrological drought. For this reason, the SPI value is calculated for periods of 3, 6, 12 and 24 months depending on the purpose of the analysis (WMO, 2012).

As has been mentioned earlier, the SPI was chosen for this study due to its many advantages over other drought indicators, such as its simplicity which depends on rainfall data available, being used in the spatial analysis of the drought better than using precipitation rates. This may be due to the possibility of comparison between the different stations in different climatic zones, even if their normal precipitation rates are different, as well as its ability to quantify different types of drought. In addition, many Arab studies have used SPI as an indicator to monitor, forecasting and analyse the drought, for instance (Michel & Shefa, 2010; Rasheed, 2010; Zhang et al., 2012; Shadeed, 2013; Qassem & Tarawneh, 2013; Shatanawi et al., 2013; Almedeij, 2014; Al-Timimi & Monim, 2014; Mossad & Alazba, 2015), and it was determined to be an effective drought index for East Asia droughts (Al-Timimi & Monim, 2014). In this research the Standardized Precipitation Index is calculated over 3- months to analyze the meteorological drought in the short term.

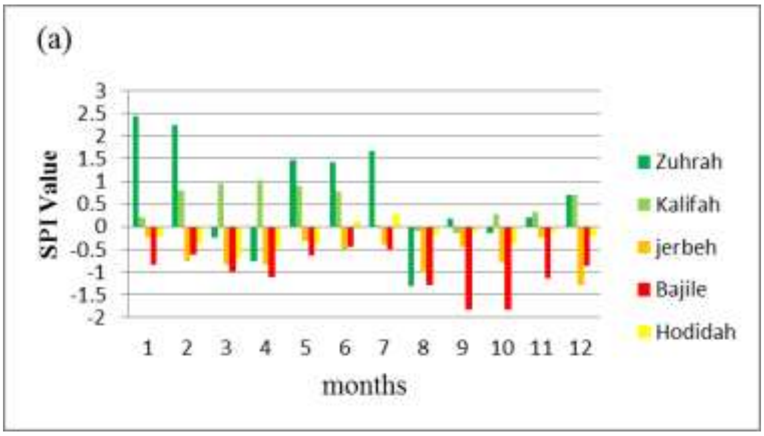
RESULTS AND DISCUSSION

Through the analysis of SPI 3, it is clear that the study area faced severe drought years, where the SPI values were less than (-1) during the years (1984.1991, 2002.2004, 2005.2006). This is well illustrated by looking at Figure 2 which shows the drought years in the study area. It displays that the year 1991 was the worst drought year. Moreover, based on SPI results, the highest drought values recorded in that year was (- 4.22). As it is clear from Figure 2 (b), the Kalifah station is drier than other stations because dry values were recorded throughout the whole months. These values of a very severe drought (- 4.22, - 3.83, -3.15) appeared in September, October and November respectively, while severe drought values (-1.53, -1.85, -1.52) were in July, August and December respectively. As for the rest of months, they had a mild drought values, where the highest value (-0.86) was recorded in April and the lowest value (-0.19) was in May.

As can be seen in Figure 2, months of the year in Jerbeh station have recorded dry values except for the months of April and May, which reported moderately wet values (1.20) and mild wet (0.39). As for the values of dry, it is evident that the highest very severe drought value (-2.74) was in August, followed by (-2.23) in both September and October. But the rest of months have recorded moderate drought values (-1.04, -1.46, -1.11) for each of March, November, and December respectively, and the values of mild drought (- 0.25, - 0.98, - 0.34) were for the months January, February and July respectively.

Furthermore, all months in Zuhrah station have dry values, except for February and March where the mild wet values (0.24, 0.21) were recorded in these months. Regarding the dry values, it is clear that the severe drought values reported in September (-1.85), followed by (-1.52) in October, while moderate drought values were recorded in August and November (-1.3, -1.13) and the values of mild drought (-0.17, -0.56, -0.22, -0.75) were in the months of January, May, June, December, respectively.

In Hodidah station, it is clear from the Figure that the months are divided into dry and wet months equally, where the mild drought values recorded (-0.2, -0.12, -0.37, -0.12, -0.08, -0.34) during the months August, September, October, November, December, January respectively. Whereas, the moderately wet values (1.1, 1.22) were recorded in the months of March-April, at the same time; the mild wet values (0.93, 0.27, 0.51, 0.77) were in February, May, June, and July respectively. Bajile Station, as is shown in the Figure is the only wet station among the other stations where all months recorded mild wet values (0.75, 0.84, 0.89, 0.89, 0.91, 0.93, 0.85, 0.72, 0.16, 0.14, 0.06) from January to December respectively.



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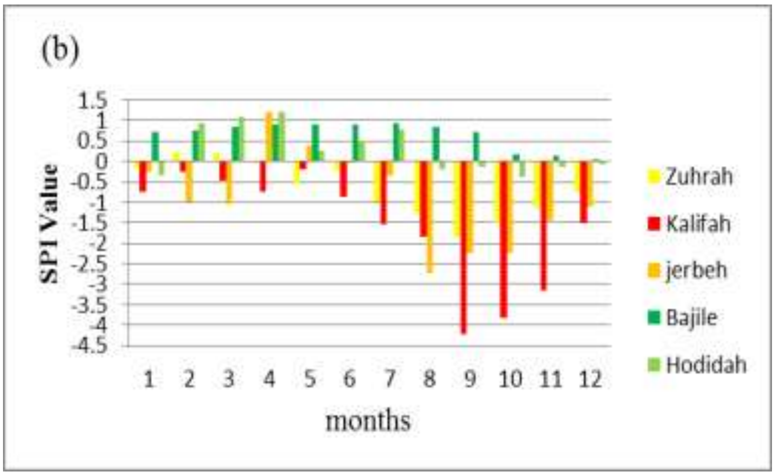
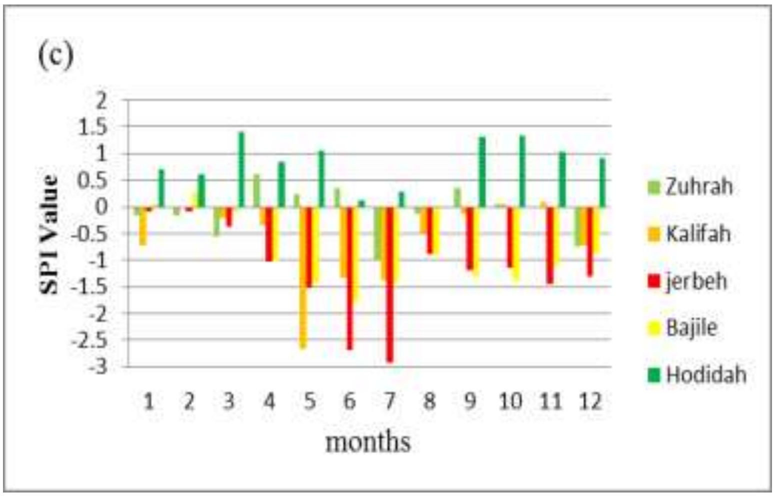
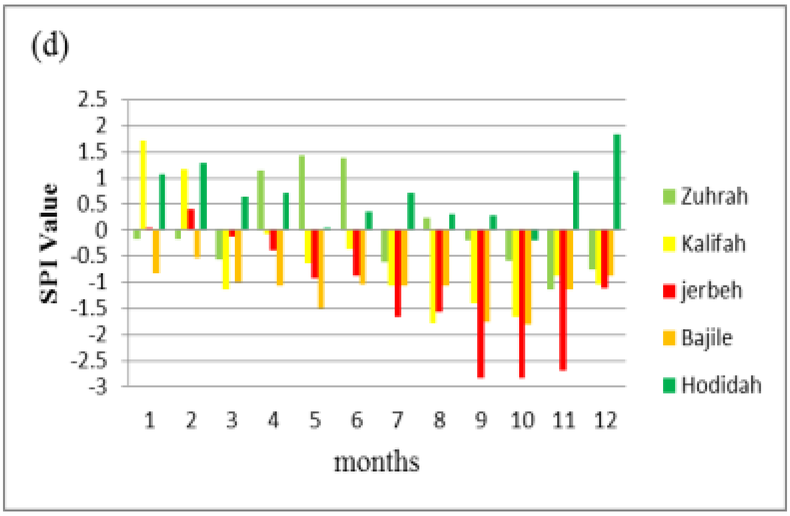






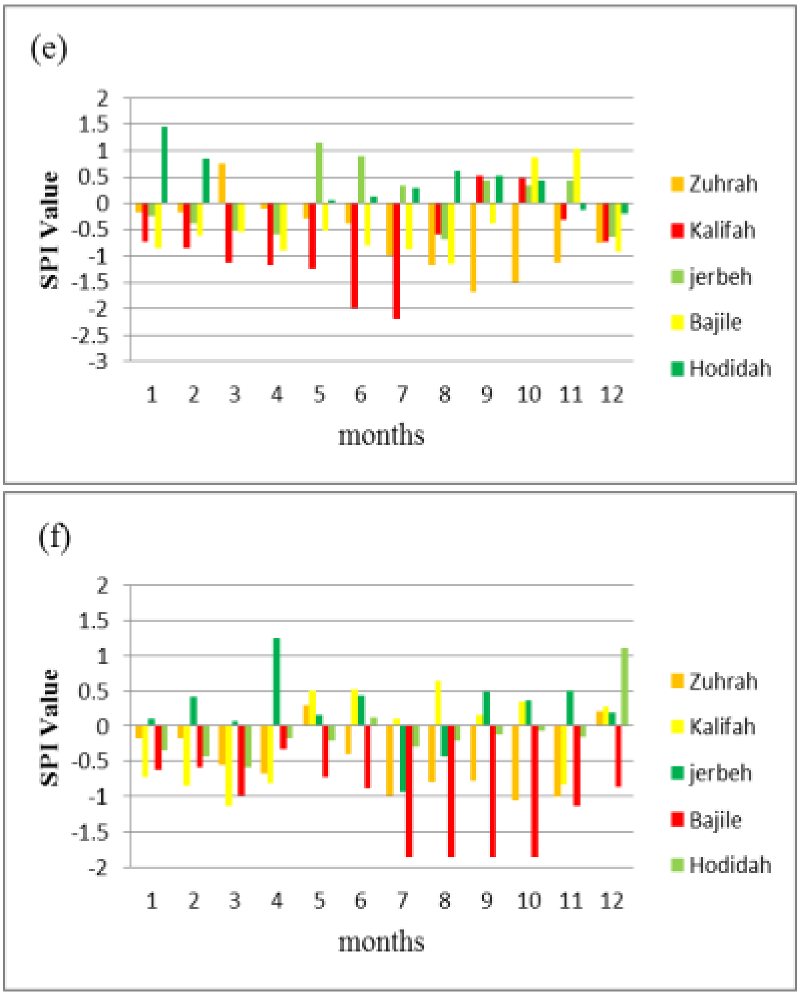


Figure 2 Drought years (a) 1984 (b) 1991 (c) 2002 (d) 2004 (e) 2005 (f) 2006

The drought categories frequency was classified based on Table 1, through which we got the results shown in Table 3 which represents a summary for the frequencies of all drought categories in all stations of the study area. Through Table 2, it is clear that the near normal category (NN) has a high frequency value. The maximum moderate drought (MD) frequency was 33 and its percentage was 32 percent in Bajile Station. While in Hodidah station, the minimum frequency was 1 and its percentage was 0.97 percent. The maximum severe drought (SD) frequency was 12 at a percentage of 34 percent in Bajile; whereas, the minimum frequency was 1 by 2.77 percent in Hodidah. Additionally, the category of extreme drought (ED) frequency was 13 by 63 percent in Jerbeh station, while the minimum frequency was at zero level in Zuhrah and Hodidah stations Figure 3.

Table 3 Frequencies of drought categories for the meteorological stations in the study area

Classes / Stations	EW	VW	MW	NN	MD	SD	ED
Zuhrah	12	14	32	295	16	5	0
Kalifah	6	12	32	277	30	11	7
Jerbeh	4	9	36	282	23	7	13
Bajile	8	7	43	266	33	12	1
Hodeidah	11	18	27	310	1	1	0

Source: SPI Results

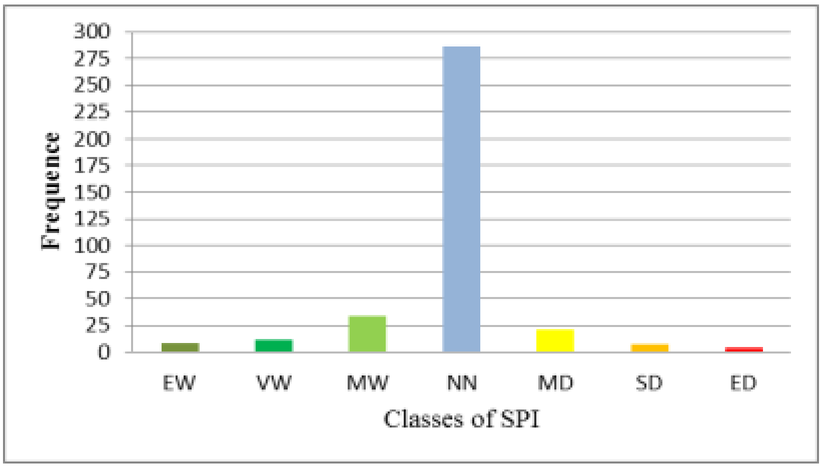


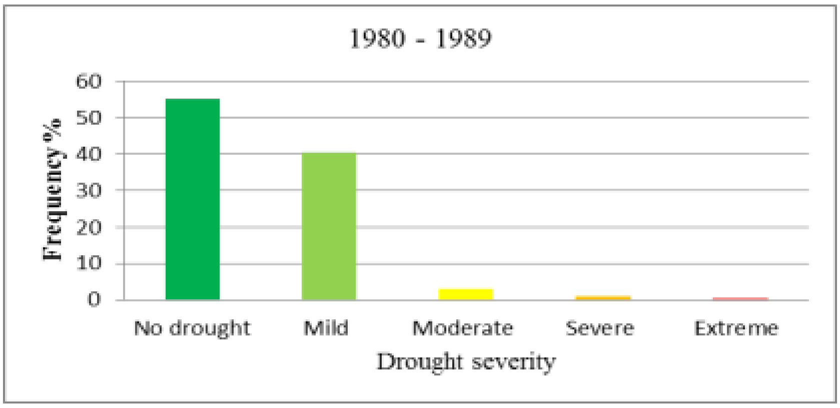
Figure 3 Frequency of mean annual of SPI classes

For determining the severity of drought in the study area stations, the study period of 30 years (1980-2010) was divided into three time periods (1980-1989) (1990-1999) (2000-2010). Each period represents 10 years in order to facilitate measuring the change that occurred in drought categories during those periods. By referring to Table 4 and Figure 4, it could be found that the drought categories have varied between a time period and other. In the first period (1980-1989), the severity of drought was interpreted as follows: approximately 55.16 percent were wet months (no drought), 40.34 percent mild drought, 0.3 percent moderate drought, 0.1 percent severe drought and 0.5 percent very severe drought. For the second period (1990-1999), the percentage of no drought was 59 percent in one hand. On the other hand, the drought categories were: mild drought 34 percent, moderate drought 4 percent, severe drought 1.34 percent and very severe drought 1.17 percent. In the final period (2000-2010), it was noted that the increase in drought severity percentage compared to previous periods except for the category of no drought which was decreased to 42.72 percent. The rest of categories were as follows: mild drought 43.18 percent, moderate drought 9.39 percent, severe drought 3.19 percent and very severe drought 1.52 percent.

Table 4 Classification of drought severity in the study area based on SPI

Category / Period	No drought %	Mild drought %	Moderate drought %	Severe drought %	Very severe drought %
1980-1989	55.16	40.34	3	1	0.5
1990-1999	59	34.5	4	1.34	1.17
2000-2010	42.72	43.18	9.39	3.19	1.52
Average all the period 1980-2010	52.57	39.12	5.41	1.84	1.06

Source: SPI Results



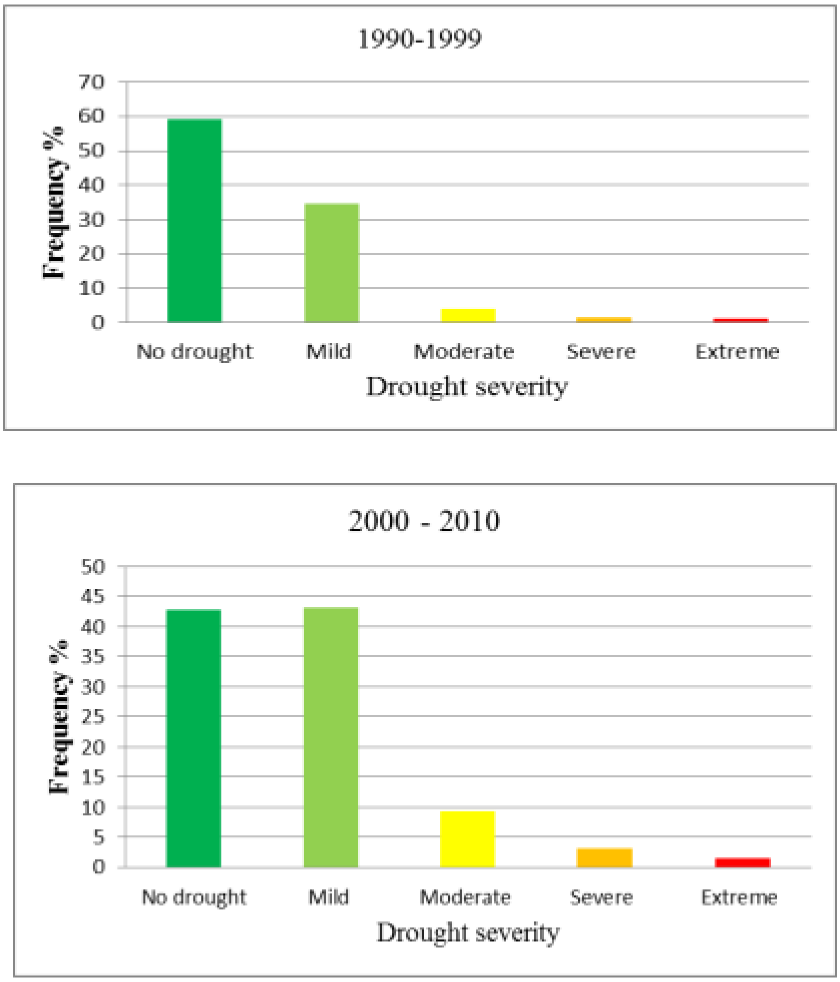


Figure 4 Classification of severity of drought for 3 decade

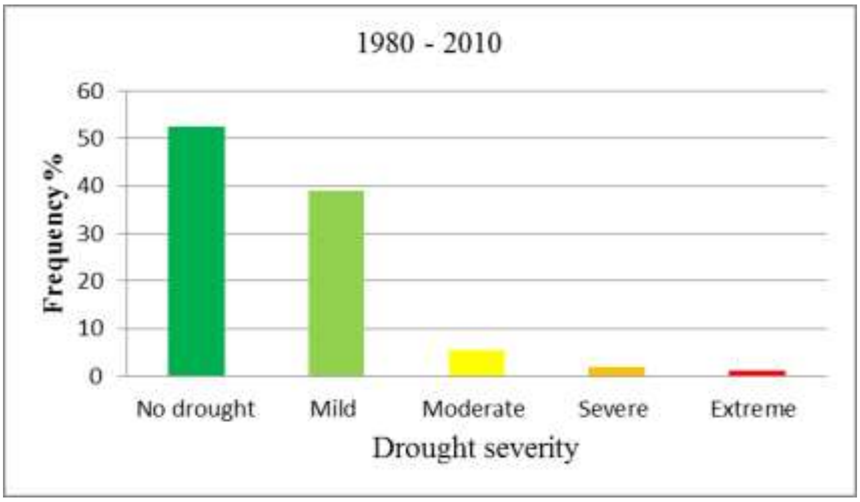


Figure 5 classification of severity of drought categories 1980-2010

As for the entire time period of 30 years (1980-2010), it could be noticed from Table 4 and Figure 5 that the rate of drought period is evenly matched with wet period rate where the percentage of drought severity reaches 47.43 percent in all categories (mild 39.12%, moderate 5.41%, severe 1.84%, and very severe 1.06%), and the wet period (no drought) 52.57 percent.

CONCLUSION

The study area faced severe drought years during the years (1984-1991, 2002-2004, 2004-2006). Therefore, this study aimed to analyse meteorological drought in Tihama Plain. The SPI results of the year 1991 were the worst drought years where the highest drought values (-4.22) recorded in that year. Also, the highest values of the drought was in the summer months (July - August-September), the main season of heavy rains in the study area. Moreover, the meteorological stations in the eastern part of the study area have severe drought compared to other stations. Furthermore, the increasing frequency of drought categories was in the period (2000-2010) compared with the previous periods (1980-1989 and 1990-1999), and finally the rate of drought period is evenly matched with wet period rate, where the percentage of drought periods 47.43 percent and 52.57 percent for the wet periods (no drought), during the study period (1980-2010).

Based on the study results, it is recommended to carry out a similar study on the neighbouring areas. The precipitation used in SPI can be applied to calculate the precipitation deficit for the current period. Moreover, it can be used to calculate the current percentage of the average precipitation for a particular time period of months. Additionally, SPI can calculate other water variables of ground water, stream flow, soil moisture, reservoir and snowpack. In sum, SPI is normally distributed; therefore, it can be used to monitor dry as well as wet periods. It can be an invaluable tool for monitoring climatic conditions, specifically those in drought-prone areas. Throughout this study, we recommend that developing drought monitoring system, using SPI, based largely on climatic and meteorological information, can be a great support for early assessment of drought influences in the study area.

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