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Drought Analysis Using Standard Precipitation Index Method for Vaijapur Block of Aurangabad District, Maharashtra

M.L.Dhumal[1] and K.R. Aher[2*]

Department of Mathematics, Deogiri College, Aurangabad-431005, India
Groundwater Surveys and Development Agency, Aurangabad-431005, India
**Email-kailashgis@gmail.com*

Abstract

Maharashtra is a drought-prone state; almost seventy percent of the states geographical area lies in semi-arid region rendering it vulnerable to water scarcity. Drought is a natural hazard that has significant impact on economic, agricultural, environmental, and social aspects. This study analyzes drought characteristics in the Vaijapur block of Aurangabad based on meteorological and hydrological variables. The frequent occurrence of drought is due to poor and untimely monsoon and various other unfavorable meteorological conditions. The standard precipitation index (SPI) has several characteristics that are an upgrading over other indices, with its simplicity and flexibility. The standardized precipitation index (SPI) method is used for observing and describing drought based on sixty-nine year precipitation data of Vaijapur block of Aurangabad district.

Keywords: Drought analysis, standard precipitation index, Precipitation, Vaijapur block, Aurangabad

Introduction

Like many states in India, the state of Maharashtra comes under the grip of severe drought conditions regularly which deal a crippling blow to economy of the state and country as well. There is an opinion prevalent that these droughts are becoming more and more frequent. The state experience extremes of rainfall ranging from more than 6000 mm over the Ghats to less than 500 nm in Madhya Maharashtra (CGWB, 1993). Agriculture in India, or gambling with monsoons, as it’s often called, is dependent on such weather. A monsoon failure leads to droughts and the rural Indian farmers are the worst affected, making drought identification, monitoring and characterization at the village level crucial for drought proofing in rural areas (Sreedhar et al, 2012). Drought is not only a physical occurrence that can be defined by the weather conditions. A drought is defined as an extended period of unusually dry weather that causes water shortages and crop damage. The Irrigation Commission of India defines drought as a situation occurring in any area where the annual rainfall is less than 75% of normal rainfall. In general there are three types of droughts based on relevance, duration and time of occurrence. Drought is having certain characteristics such as they usually take an elliptic profile. Being of slow start it is difficult to determine the beginning and end of the drought event. The duration may vary from months to years and the core area or epicenter changes over time. The impacts are non-structural and not easy to compute. It is a creeping phenomenon. The impacts of drought are increasing and the effects expand when events continue from one season or year to the next. It does not have a sharp ending (Shah et al, 2015). According to Dracup et al. (1980), droughts are related to precipitation (meteorological), stream flow (hydrological), soil moisture (agricultural) or any combination of the three. A similar classification can be found in Wilhite and Glantz (1985), where four categories are identified: meteorological drought, agricultural drought, hydrological drought, and socio-economic drought. The first three groups could be defined as environmental indicators, the last group as a water resources indicator. The causes of droughts could be attributed to natural phenomena but studies in certain places have indicated that water sources which are under the impact of human (e.g. rivers and groundwater) are two times more vulnerable than sources with less human interference, example is snow cover and precipitation (Shaban, 2009; Edossa et al, 2010). Drought is a disastrous natural phenomenon that has significant impact on socio-economic, agricultural, and environmental spheres. It differs from other natural hazards by its slow accumulating process and its indefinite commencement and termination. Being a slow process although drought often fails to draw the attention of the world community, its impact persists even after ending of the event. A single definition of drought applicable to all spheres is difficult to formulate since concept, observational parameters and measurement procedures are different for experts of different fields. Beside, the concept of drought varies among regions of differing climates (Dracup et al., 1980; Bhuiyan,2004). Precipitation is considered as principal source of water. Precipitation is the meteorological phenomenon that has the greatest impact on human activities and the most important environmental factor limiting the development of the semi arid regions. The success or failure of crops particularly under rain fed conditions is closely related with the rainfall patterns. The impact of rainfall deficiency on water resources varies markedly on a temporal scale for different water storage components of the hydrologic system, while soil moisture responds to precipitation anomalies on a relatively short scale, groundwater, stream flow, and reservoir storage reflect longer-term precipitation anomalies (Kipkorir, 2002; Palchaudhuri and Biswas, 2013; Dhumal and Aher, 2019; Yeola, 2020). The objective of the present paper is to analyze the drought index using standard precipitation index (SPI) method for Vaijapur block of Aurangabad district, Maharashtra state of India.

Study area

Vaijapur block of Aurangabad district, located in the heart of the drought-prone interior of Maharashtra state and situated at the latitude of 19°40’ to 20°15’ north and longitude of 74°35’ to 75°00’ east covering an area of approximately 1510.5 sq. km and fall in Survey of India Toposheet No. 46 L/16. The average annual rainfall in Vaijapur block is 540.85mm. About 83% of annual rainfall is received during June to September. Geologically entire study area is covered and surrounded mainly by basaltic lava flows belonging to the Deccan volcanic province that flooded during upper Cretaceous to Eocene age. The prominent geological units observed in the study area are the horizontally disposed basaltic lava flows and each flow has distinct two units. The upper layers consist of vesicular and amygdule zeolitic basalt whiles the bottom layer consists of massive basalt. This basaltic lava flows are the only water bearing formations in the area (CGWB, 2010; Deshpande and Aher, 2012; Aher, 2017; CGWB, 2019; Aher et al, 2020; Deshpande et al, 2020).

Annual Rainfall in Vaijapur block of Aurangabad District

The risk of drought in the semi-arid zone imposes on the farmers a meteorological-agricultural frontier situation, in which they struggle to obtain a reasonable yield, as the arid frontier changes in makeup and position from year to year (Dietz, et al, 1998). For the present study, rainfall data from Rainfall recording and analysis, Department of Agriculture Maharashtra State, Pune (Maharain, 2020) and Long sequence data available with Indian Meteorological Department (IMD,2020) have been collected and analyzed. The annual average rainfall in the Vaijapur block from 1952 to 2020 is 529 mm. However, the last 10 years (2011-2020) average value is 556.59 mm. Out of these ten years, the rainfall was above normal (normal rainfall 540.85mm) in four (2016, 2017, 2019 and 2020) years and in the year 2012, 2014, 2015 and 2018 the rainfall was below 500 mm. Figure 1 depicts the distribution of annual rainfall in Vaijapur block from 1952 to 2020. The linear line in Figure 1 shows an upward trend in the annual rainfall. The highest annual rainfall was 1096.9 in the year 2020 and the lowest was 150 mm in the year 1985. Long term monsoon rainfall over the area is very much fluctuating and shows DPAP signatures. Long term monsoon rainfall shows rising trend at the rate of 0.773 mm/year). Out of 69 years, above normal rainfall (540.85 mm) was recorded for 29 years and the remaining 40 years the rainfall was below normal. The annual rainfall was below 400 mm for 16 years. The multiyear droughts were recorded with a large spatial extension and a high rainfall deficit. As per Agro-climatic Zones, Vaijapur block falls under drought prone area characterized by low and unpredictable rainfall of 500 to 700 mm/year in 40-45 days Common dry spells will last from 2 to 10 weeks (CGWB,2019). Delayed onset and early cessation of south-west monsoon is very common, about 18% Moderate and 6% severe droughts observed from 1952 to 2020.

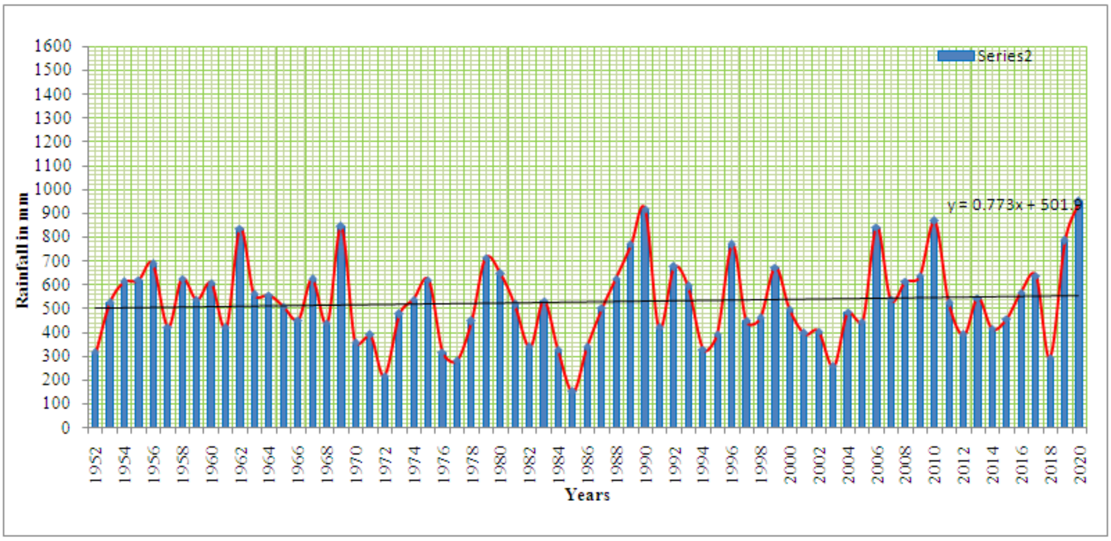


Figure 1. Long term annual Rainfall (mm) from 1952 to 2020 of Vaijapur block

Methodology

Meteorological drought is analyzed using the standard precipitation index **(**SPI) method. The SPI can be calculated for time scales that are important to water managers. Moving total time series is constructed from the observed precipitation data and then used for the SPI computation. The first step in the calculation of the SPI is to determine a probability density function that describes the long-term series of precipitation data. Once this distribution is determined, the cumulative probability of an observed precipitation amount is computed. The inverse normal (Gaussian) function is then applied to the probability. The gamma distribution function is selected to fit the precipitation data in this study

$$G\ (x) = \frac{1}{\beta^{\alpha}\tau^{\alpha}} x^{a-1} e^{-x/b} \tag{1}$$

Where, $\alpha > 0$, α is a shape factor, $\beta > 0, \beta$ is a scale factor.

$$r\ (\alpha) = \int_{0}^{\propto} y^{a-1} e^{-y} \tag{2}$$

Where, $r\ (\alpha)$ is the gamma function.

Computation of the SPI involves fitting a gamma probability density to a given frequency distribution of precipitation total for a station. From Thom (1966), the maximum like hood solutions are used to optimally estimate $\alpha\ and\ \beta$

$$\alpha = \frac{1}{4A}(1 + \sqrt{1 + \frac{4A}{3}} \tag{3}$$

$$\beta = \frac{x}{\alpha} \tag{4}$$

$$A = In\, x \frac{\sum In\ (x)}{n} \tag{5}$$

Where, n = number of precipitation observations.
The cumulative probability is given by

$$\text{G (x)}=\int_0^x g(x)dx = \frac{1}{\beta^{\alpha}{}_{\tau}{}^{\alpha}} \int_0^x x^{a-1} e^{-x/b} \tag{6}$$

letting $t = \frac{x}{\beta}$

$$G(x) = \frac{1}{r\alpha} \int_0^x t^{a-1}\, e^{-t}\text{dt} \tag{7}$$

The gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes

$$H(x) = q + (1 - q)G(x) \tag{8}$$

Where q is the probability of a zero. If m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/n. The cumulative probability, H(x), is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. SPI is categorized based on their range values is shown in table 1.

Table 1. Category of standard precipitation index (SPI) based on range values

Sr.No.	SPI Range	Category
1	+ 2 to more	Extremely wet
2	1.5 to 1.99	Very wet
3	1.0 to 1.49	Moderately wet
4	-0.99 to 0.99	Near normal
5	-1.0 to-1.49	Moderately dry
6	-1.5 to-1.99	Severely dry
7	-2 to less	Extremely dry

Results and Discussion

Standard precipitation index is used to measure the intensity of meteorological drought in an area, which takes into account the characteristics of the rainfall such as the inert-annual variability in rainfall in the region. Thus SPI unlike other criteria used for assessing the intensity of drought, enable us to compare drought intensities spatially between two regions, which experience two different degrees of variation in rainfall, even while having the same magnitude of mean annual rainfall. The reason is in terms of rainfall magnitude, what is normal for one location may be abnormal for another location. Mathematically the SPI is estimated on the basis of the cumulative probability of occurrence of a given rainfall at a station. Based on the historical rainfall data, an analyst can then tell what is the probability of the rainfall being less than or equal to a certain amount. Thus the probability of rainfall being less than or equal to an amount much smaller than the average will be also be lower (0.2, 0.1, 0.01 etc., depending on the amount). Therefore if a particular rainfall event gives a low probability on the cumulative probabilities function, then this is indicative of a likely drought event. Alternatively a rainfall event which gives a high probability on the cumulative probabilities function is an abnormally wet event. Some of the advantages which can be derived from the SPI are as follows. Plotting a time series of the years against SPI gives a good indication of the drought history of a particular station (GSDA. 2015; Aher and Dhumal, 2021). In order to estimates the SPI values for different rainfalls, the mean value and standard deviation of the rainfall record is to be first estimated. Then the deviation of the annual rainfall from the mean value is estimated and expressed in terms of number of standard deviations by diving by the SD value. The standardized precipitation index (SPI) was estimated to determine that rarity of a drought in Vaijapur block based on sixty nine (69) years (1952-2020) rainfall data available (Table 2). The results were evaluated and found that the results of SPI and actual climatic condition have quite similar results as per their respective categories. For example (-2 to less) categories indicates (extremely dry) drought years include 1985. The second category-1.5 to-1.99) indicates (severely dry) drought years include 1977, 2003 and 1972. The third category (-1.0 to-1.49) indicates (moderately dry) drought years include 1970, 1982, 1986, 1984, 1994, 1976, 1952 and 2018. The fourth category (-0.99 to 0.99) indicates (Near normal) indicate normal condition years include 1983, 2011, 1953, 1981, 1965, 1987, 2000, 2004, 1973, 1998, 2015, 1966, 1997, 1978,2005, 1968, 1957, 1961, 1991, 2014, 2002, 2001, 1995, 1971 and 2012. The fifth category (1.0 to 1.49) indicates (moderately wet) wet years include 2019, 1989, 1996, 1979, 1956, 1992, 1999, 1980, 2017, 2009, 1988, 1958, 1967, 1955, 1975, 2008, 1954, 1960, 1993, 2016, 1963, 1964, 2013, 2007, 1974 and 1959. The sixth category (1.5 to 1.99) indicate (very wet) wet years include 2010, 1969, 2006 and 1962 whereas the Seventh category (+ 2 to more) indicate (extremely wet) wet years include 2020 and 1990 for Vaijapur block of Aurangabad district (Table 2 and 3). SPI values suggest that out of last 69 years, 2 were extremely wet (SPI + 2 to more), 4 were very wet (SPI 1.5 to 1.99); 26 moderately wet (SPI 1.0 to 1.49); 25 were near normal (SPI 0.99 to-0.99); 8 were moderately dry (SPI-1.0 to-1.49); 3 were severely dry (SPI-1.5 to-1.99); and 1 were extremely dry (SPI-2 and less) years (Fig.2).

Table 2. Rainfall and SPI of study area

Sr.No.	Year	Rainfall	SPI	Sr.No.	Year	Rainfall	SPI
1	1952	312.9	-1.33	35	1986	336	-1.19
2	1953	523.3	-0.10	36	1987	502	-0.23
3	1954	610.4	0.40	37	1988	627	0.50
4	1955	619.4	0.46	38	1989	770	1.33
5	1956	687.4	0.85	39	1990	918	2.19
6	1957	421.6	-0.69	40	1991	418.4	-0.71
7	1958	626	0.50	41	1992	676	0.79
8	1959	537	-0.02	42	1993	593	0.30
9	1960	609.9	0.40	43	1994	328.4	-1.24
10	1961	418.5	-0.71	44	1995	393	-0.86
11	1962	835.1	1.71	45	1996	767.8	1.32
12	1963	557.7	0.10	46	1997	449	-0.53
13	1964	556	0.09	47	1998	460.2	-0.47
14	1965	508.2	-0.19	48	1999	672	0.76
15	1966	452	-0.52	49	2000	497.8	-0.25
16	1967	623	0.48	50	2001	394.7	-0.85
17	1968	439.3	-0.59	51	2002	405	-0.79
18	1969	844	1.76	52	2003	255	-1.66
19	1970	355	-1.08	53	2004	484.4	-0.33
20	1971	389.2	-0.88	54	2005	445.8	-0.55
21	1972	217.3	-1.88	55	2006	843.1	1.76
22	1973	476.7	-0.37	56	2007	538.3	-0.01
23	1974	537.7	-0.02	57	2008	614.9	0.43
24	1975	618.9	0.45	58	2009	635.6	0.55
25	1976	317.2	-1.30	59	2010	868.5	1.91
26	1977	277.7	-1.53	60	2011	523.6	-0.10
27	1978	447.5	-0.54	61	2012	388.6	-0.89
28	1979	713.5	1.00	62	2013	545.8	0.03
29	1980	645.9	0.61	63	2014	414.8	-0.73
30	1981	516.8	-0.14	64	2015	457.3	-0.49
31	1982	336	-1.19	65	2016	569	0.16
32	1983	531.3	-0.06	66	2017	638.6	0.57
33	1984	329.1	-1.23	67	2018	293.1	-1.44
34	1985	150	-2.27	68	2019	786.2	1.43
				69	2020	948.9	2.37

Table 3. Standard precipitation index (SPI) category of study area.

Sr. No.	SPI Range	Category	Year	No. of Years
1	+ 2 to more	Extremely wet	2020, 1990	2
2	1.5 to 1.99	Very wet	2010, 1969, 2006, 1962	4
3	1.0 to 1.49	Moderately wet	2019, 1989, 1996, 1979, 1956, 1992, 1999, 1980, 2017, 2009, 1988, 1958, 1967, 1955, 1975, 2008, 1954, 1960, 1993, 2016, 1963, 1964, 2013, 2007, 1974, 1959	26
4	-0.99 to 0.99	Near normal	1983, 2011, 1953, 1981, 1965, 1987, 2000, 2004, 1973, 1998, 2015, 1966, 1997, 1978,2005, 1968, 1957, 1961, 1991, 2014, 2002, 2001, 1995, 1971, 2012	25
5	-1.0 to-1.49	Moderately dry	1970, 1982, 1986, 1984, 1994, 1976, 1952, 2018	8
6	-1.5 to-1.99	Severely dry	1977, 2003, 1972	3
7	-2 to less	Extremely dry	1985	1

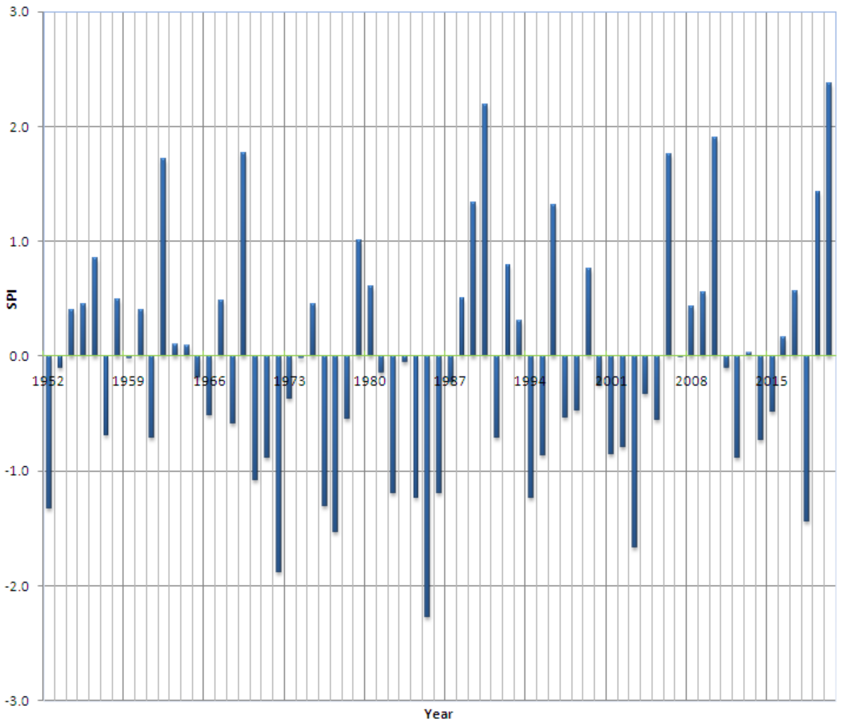
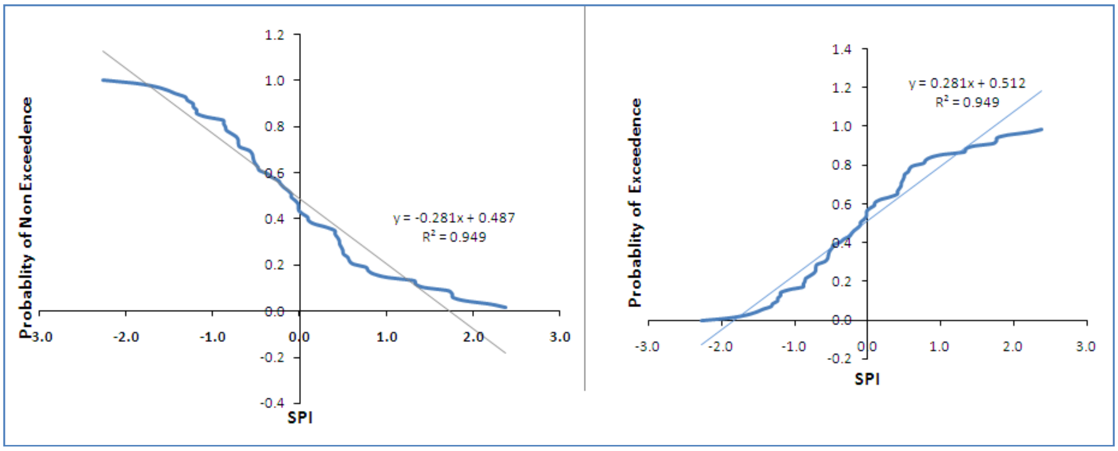


Figure 2: Drought results using SPI method of the study area.

Probability of occurrences of drought of different intensities

The probabilities function was estimated for finding out the cumulative probability of occurrences of a drought of less severe magnitude. For this, the SPI values estimated for the annuals rainfall values were arranged in ascending order and the probability of occurrences of droughts of lesser magnitude were worked out by diving the assigned value by total number of observations. The probability of occurrences of droughts of lesser magnitude was highest for the rainfall with maximum SPI. The cumulative probability of occurrences of a severe (meteorological) drought is very low, nearly 6 percent, however probabilities of occurrences of moderate drought is around 18 percent, whereas probabilities of occurrences of normal 58% and excess rainfall is 18% (Fig.3)



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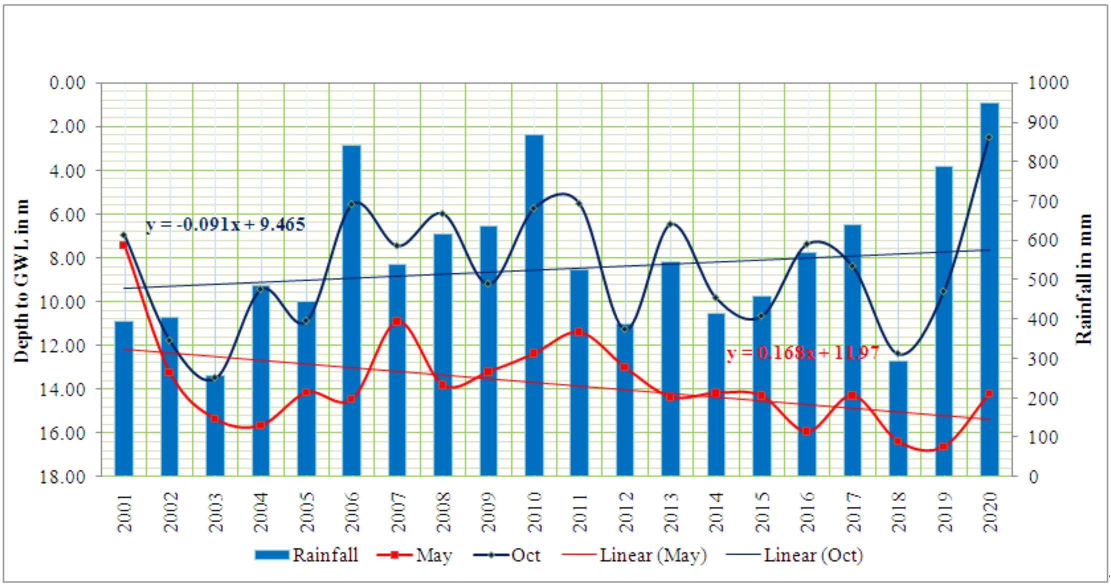

Figure 4: Long term groundwater level trend of study area

Groundwater levels and annual rainfall

As the annual replenishment of the aquifer primarily depends on rainfall, thus the groundwater level changes might be correlated with the variations in precipitation amounts (Goyal et al, 2010). Groundwater is a dynamic resource and it varies from place to place quantativaly and qualitatively. Its quantity is mostly depends on the rainfall data of that particular region, geological terrain, rock type i.e. aquifer, geomorphology and drainage pattern. The groundwater levels have direct bearing to the incidence of rainfall as it is the maximum contributor of water to aquifers. Response of groundwater levels to the incidence of rainfall varies depending on its various hydrodynamics properties. The occurrence of heavy rains results in flood and also improvement in groundwater systems (Varadaraj, 2006; Aher and Kathane, 2015; Kathane et. al, 2015; Singh and Kasana 2017). The Groundwater surveys and Development Agency (GSDA), has been monitoring the groundwater levels since several decades. The recording of depth of groundwater table in meters below ground level is observed during the months of May (pre-monsoon) and October (post-monsoon) (GSDA, 2015). For the present study, pre-monsoon (May) and October (post-monsoon) groundwater table fluctuation data of 141 observation wells were analyzed and interpreted (GSDA, 2021). The rainfall and groundwater level data plots indicate positive correlation and quick response to incidence of rainfall (Fig. 4). The occurrence of heavy rainfall in the year 2020 has resulted in stabilizing the groundwater levels and raised the water levels. Good amount of rainfall helps in stabilizing groundwater levels by enhanced recharge and reduction in groundwater usage. The hydrograph is studied in relation to annual rainfall which shows rising rainfall trend whereas hydrograph shows rising trend in pre-monsoon at the rate of 0.168 mm/year and falling trend in post-monsoon at rate of 0.091 mm/year, The depth of water levels during pre-monsoon varies from 7.45 (2001) to 16.59 mbgl (2019) with average depth 12.13 mbgl and post-monsoon is 2.45 (2020) to 13.48 mbgl (2003) with mean water level 6.62 mbgl. Depletion of water table in the study area was found fluctuating between 0.5 to 11.73 mbgl having average water level fluctuation 5.23 mbgl. The decline may be because the area has experienced increased irrigation draft and number of irrigation wells, indicates over exploiting situations in addition by the erratic behavior of the rainfall.

Conclusion

It is found that standard precipitation index (SPI) is a good indicator of the drought, Drought being a natural hazard refers to the adverse impacts on natural spheres and not to the causes for the impacts. The analysis of drought using SPI from rainfall data is useful to determine the distribution and characteristics of drought in the Vaijapur block of Aurangabad district, Maharashtra, India. The SPI method gives best result without other climatic parameters as it uses only precipitation data and gives accurate result. The results were evaluated and found that the results of SPI and actual climatic condition have quite similar results as per their respective categories. SPI values suggest that out of last 69 years, 2 were extremely wet (SPI + 2 to more), 4 were very wet (SPI 1.5 to 1.99); 26 moderately wet (SPI 1.0 to 1.49); 25 were near normal (SPI

0.99 to-0.99); 8 were moderately dry (SPI-1.0 to-1.49); 3 were severely dry (SPI-1.5 to-1.99); and 1 were extremely dry (SPI-2 and less) years. This method is better for agricultural applications since it is simple and effective, whereas the decline of water level indicates over exploiting situations in addition by the erratic behavior of the rainfall.

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