Spatial and Temporal Variation in Rainfall and Groundwater Levels in Kumadvati Watershed in Western Karnataka, India

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Abstract:- **The climate change along with increasing population has increased the pressure on freshwater resources across the world. Therefore, an attempt has been made in the Kumadvati watershed in western Karnataka, India to know the trends in rainfall and groundwater level. Daily rainfall data of 32 water years from 1984-85 to 2015-16 and monthly groundwater level for the same period has been collected from Government departments, GoK. The Mann-Kendall test along with Sen's slope estimator is used to determine the trends and slope magnitude. The annual and season wise result shows there are increasing and decreasing trends in rainfall. However, the groundwater level shows only decreasing trend in the study area. There is a good correlation between rainfall and groundwater level. The rates of decrease or increase in rainfall and groundwater level in the study are discussed.**

Key words: Rainfall trend, Groundwater level, Mann-Kendall statistics, Sen's Slope,

INTRODUCTION

In recent times, climate change is a global phenomenon. Due to climate change, changes in precipitation regimes have affected the availability of water resources in space and time. This has led to damage to agriculture, ecology, and infrastructure, disruption of human activities, injury, and loss of life (Coates, 1996). Rainfall is one of the climatic elements that play an important role in the economic development of a country.

The rainfall intensity and duration vary with space and time. Rainfall analysis carried out by various researchers across the globe has shown an increasing and decreasing trend in rainfall at the regional and local scale (Haylock and Neville, 2000; Brunetti et al., 2000; Gadgil, 2003; Krishna Kumar et al., 2004; Guhathakurta and Rajeevan, 2008; Jain et al., 2013; Gocic and Trajkovic., 2013; Meersmans et al., 2016). Rainfall received in a watershed is an important factor in determining the amount of water available to meet various sectors. If the intensity of precipitation increases can cause flash floods, increase in soil erosion, which often associated with reservoir sedimentation (Suppiah and Hennessy., 1998). On the other hand, if the precipitation decreases, it can deplete the availability of water resources and likely to increase water demand. Changes in precipitation also influence water availability and water quality.

In the context of climatic change and spatial and temporal variability in rainfall, dependence on groundwater has increased. Groundwater is under stress due to an increase in agricultural land and domestic water requirement. The annual water table fluctuation in a water year reflects the volume of groundwater recharge and discharge if the water-bearing properties of the aquifer are known (CGWB, 2009). If recharge exceeds discharge, the volume of water in storage will increase and water levels will rise, if the discharge exceeds recharge, the volume of water in storage will decrease, and water levels will fall. Since recharge and discharge are not distributed uniformly in space and time, groundwater levels rise or fall to adjust to the resulting imbalances. Water levels in wells follow a cyclic pattern that mimics seasonal variations in recharge and discharge. High water levels occur in the rainy season and low water levels occur during the dry summer. The rainfall pattern and its characters are a major controlling factor in the depth of water levels and its annual, seasonal, or decadal fluctuations.

In a hydrological unit, the variability of rainfall in continuum will affect the water table fluctuation. In the hard-rock region, the groundwater resource is less influenced by external factors, unlike surface water resources. Due to over-exploitation of groundwater, the water table is declining at a faster rate (Kulkarni et al., 2004; Panda et al., 2012; Machiwal and Jha, 2014). The porous geological formation where the groundwater gets collected has to be preserved to maintain the existing groundwater regime (Singh and Kasana, 2017). Otherwise, the primary or the secondary porosity in the geological formations is lost or decreases due to external forces, which leads to a decrease in groundwater storage. This results in the loss of freshwater resources due to low groundwater recharge and high surface runoff.

In India, to estimate the volume of groundwater recharge, the water table fluctuation method is adopted (CGWB, 2009). The study of rainfall patterns is very important in understanding spatial and temporal variations in water levels. The impact of temporal variation in rainfall on groundwater level in Shimoga district in the state of Karnataka has not been studied in detail. Hence, a study has been undertaken in Kumadvati watershed to know the trends in rainfall and water level fluctuation.

LOCATION DESCRIPTION:

The Kumadvati watershed a tributary of the Tungabhadra River lies between $14^0 08'00''$ and $13^0 46'00''$ N latitude

and 75^{0}12'00'' and 75^{0}28'30''E longitude (Fig. 1). The watershed covers an area of 455 km^2 and drains in Thirthhalli, Hosanagara, and Shivamogga taluks in Shimoga district of Karnataka State, India. The elevation of the watershed varies from 522 to 955 m above mean sea level. The 32 years annual average rainfall of over the watershed is 1830 mm. During the southwest monsoon

season, the watershed receives 83% of the annual rainfall and the remaining during the rest of the year. On average, there are 92 rainy days. The rainfall decreases from the southwest towards the northeast direction of the watershed. The spatial variation in annual rainfall in the watershed is shown in Fig. 2.
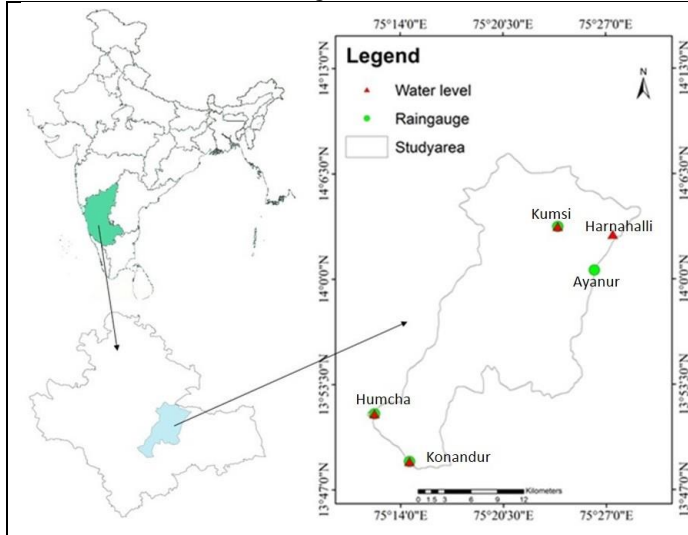

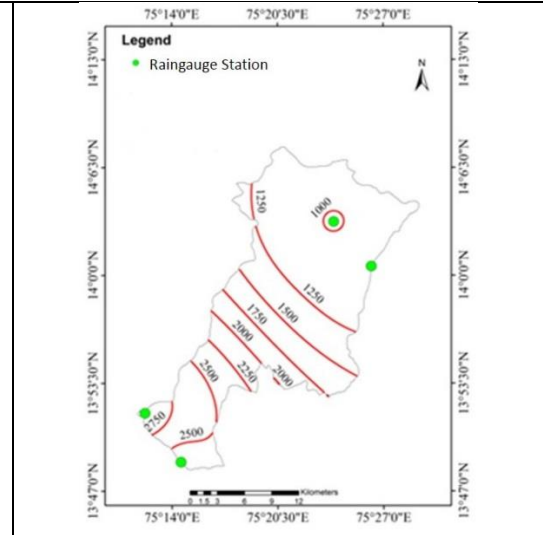| Fig. 1:Location map of Kumadvati Watershed | Fig. 2:Spatial variation in annual average rainfall |

DATA USED

Daily rainfall data for rain gauge stations situated in and around the Kumadvati watershed are collected from the district statistical office, GoK for the period from 1984-85 to 2015-16. The Groundwater Division of Dept. of Mines and Geology, GoK monitor the monthly groundwater level in observation wells. The groundwater level data of the observation wells located within the watershed are collected for the period from 1984-85 to 2015-16. The depth to the water table (m) is measured below the ground surface.

DATA PREPARATION

The annual (Jan –Dec) rainfall and water level data is rearranged to water year (Jun – May). There were some rainfall data missing in some of the stations that were filled in by the average of its neighbouring station method. By the double mass curve method, consistency of the data was checked and found to be consistent. Further, the data has been divided into three seasons, namely monsoon (June – Sept), post-monsoon (Oct. – Jan) and pre-monsoon (Jan – May). The monthly, seasonal, and annual totals were computed and significant statistical parameters are determined for both rainfall and water level fluctuation data.

METHODOLOGY

Trend analysis

In statistics, there are many techniques are available to detect the trend within the time series. WMO (1988) has suggested Mann-Kendall method for assessing trends in meteorological data. According to Hirsch et al., (1991), Mann-Kendall test is preferred when testing different

station in the single study. Studies carried out by researchers in India have used Mann-Kendall rank statistics to know the temporal change in annual and season rainfall (Krishna Kumara et al 2004; Jain et al 2013; Mondal et al 2012). Hence, Mann-Kendall test (Mann, 1945; Kendall, 1975) also known as the MK test method is used to study the temporal trend in time series of rainfall and water level data.

The MK test statistic S is calculated using the equation (1).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (1)$$

Where, x_j and x_k are the data values in time series j and k (j>k), and n is the number of data points.

Each of the data point x_j is taken as a reference point, which is compared with the rest of the data points x_k. The sign ($x_j - x_k$) is the sign function calculated using the equation (2).

$$sgn(x_j - x_k) = \begin{cases} +1, & if \ x_j - x_k > 0 \\ 0, & if \ x_j - x_k = 0 \\ -1, & if \ x_j - x_k < 0 \end{cases} \quad (2)$$

The variance statistic S is computed using the equation (3).

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] (3)$$

Where, n is the number of data points, q is the number of tied groups and t_p denotes the number of values in the pth group. A tied group is a set of sample data having the same value.

The standard normal test statistic Z is calculated using S and Var(S) values in the following equation (4).

Published by :

http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 06, June-2020

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if \ S > 0 \\ 0 & if \ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if \ S < 0 \end{cases} \quad (4)$$

By evaluating the Z value, we can find the presence of a statistically significant trend. A positive (negative) value of Z indicates an upward (downward) trend. A statistic Z has a normal distribution. To test for either an upward or a downward monotone trend (a two-tile test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from standard normal cumulative distribution tables. In MAKESENS the tested significance level alpha are 0.001, 0.01, 0.05 and 0.1.

SEN'S SLOPE ESTIMATOR

The second method of non-parametric procedure for estimating the true slope of an existing trend is developed by Sen's (1968). This method can be used in studies where the trend can be assumed to be linear. This means that f(t) in equation (5) is

f(t) = Qt + B   (5)

where, Q is the true slope and B is a constant. To get Q in the above equation (5), first we have to calculate the slopes of all data value pairs using an equation (6).

$Q_i = \frac{x_j - x_k}{j - k}$ for $i = 1, 2, 3, 4 \ldots\ldots N$ (6)

Where, j > k, x_j and x_k are the data values at times j and k respectively. The median of these N values of Q_i is represented as Sen's estimator of slope.

If there are n values, x_j is the time series, we get as many as N = n(n-1)/2 slope estimates Q_i. The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is computed as:

$Q = Q_{\left[\frac{(N+1)}{2}\right]}, \ if \ N \ is \ odd$

$\qquad\qquad\qquad\qquad\qquad\qquad (7)$

$Q = \frac{1}{2}\left(Q_{\left[\frac{N}{2}\right]} + Q_{\left[\frac{N+2}{2}\right]}\right)$, if N is even

By the non-parametric technique based on the normal distribution, Q_{med} is computed by a two sided test at 100(1-α)% confidence interval and the true slope is obtained. This is valid for n as small as 10 unless there are many ties.

If Q_i value is positive, it indicates an upward or increasing trend and if Q_i values are negative, it indicates downward or decreasing trend in the time series.

Change magnitude of trend as percentage of mean
The percentage change is computed using the equation (8) by approximating it with a linear trend.

Percentage change (%) $= \frac{Q \times length \ of \ year}{mean} \times 100$

$\qquad\qquad\qquad\qquad\qquad (8)$

RESULTS AND DISCUSSIONS:

Rainfall Trend Analysis
The rainfall record at different stations in the watershed is analysed individually and the results of statistical analysis are shown in Table 1. Lowest annual precipitation of 758 mm is recorded in Ayanur station in the year 2001-02 and highest rainfall of 5153 mm records in Humcha station in the year 1994-95. The annual spatial rainfall distribution map (Fig.2) shows that the southwest portion of the watershed receives the highest rainfall and decreases towards the northeast direction in the watershed. On average, the watershed receives 1830 mm of rainfall annually.

The variation of annual rainfall at four rain gauge stations of the study area is shown using Box and Whisker plots (Fig.3). From the figure, it is evident that the annual rainfall at Humcha and Konandur stations is more than the average rainfall of the watershed. These stations are located in the southern part of the watershed where the forest cover is more. At Kumsi and Ayanur stations, it is less than the annual average rainfall of the watershed. These stations are located in the northern part of the watershed. The rainfall distribution at Kumsi and Ayanur stations is low, whereas at Humcha and Konandur it is more.
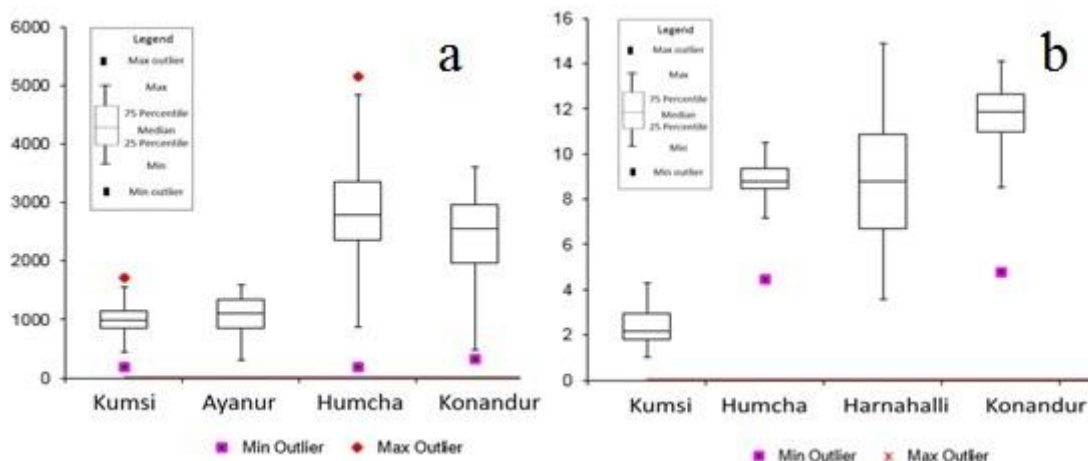

Figure 3: Box and Whisker Plot of 32 years annual rainfall (a) and Water level fluctuation (b)

Table.1: Significant Statistical parameters of Rainfall and Groundwater Level in Kumadvati Watershed

Seasons		Rainfall				Groundwater level			
		Kumsi	Ayanur	Humcha	Konandur	Kumsi	Humcha	Harnahalli	Konandur
Annual	Mean	1022	1106	2847	2471	2.3	8.7	9.1	11.4
	Median	997	1111	2777	2559	2.1	8.8	9.0	11.8
	Standard Deviation	231	288	897	628	0.8	1.1	3.0	2.1
	Minimum	712	604	1078	1313	1.0	4.5	3.6	4.8
	Maximum	1709	1594	5153	3598	4.3	10.5	14.9	14.1
Monsoon(Jun to Sept)	Mean	771	817	2473	2174	1.6	7.0	8.3	10.0
	Median	750	753	2468	2212	1.4	7.4	8.3	10.3
	Standard Deviation	157	192	823	605	0.7	1.7	2.9	2.9
	Minimum	572	559	853	1018	0.5	2.3	3.6	2.7
	Maximum	1138	1189	4489	3380	3.4	9.5	14.6	14.0
Post-Monsoon(Oct to Jan)	Mean	187	193	236	215	1.9	8.1	7.9	10.8
	Median	163	178	210	188	1.8	8.4	7.5	11.2
	Standard Deviation	95	72	125	83	0.7	1.3	3.7	2.2
	Minimum	91	82	100	122	0.4	2.6	1.8	2.3
	Maximum	579	356	607	471	4.1	9.7	15	13.2
Pre-Monsoon(Feb to May)	Mean	98	135	165	121	3.6	10.9	11.2	13.5
	Median	85	135	137	125	3.4	11.1	11.0	13.8
	Standard Deviation	57	64	136	62	1.2	1.0	3.0	1.4
	Minimum	11	42	41	16	1.1	8.5	4.8	9.3
	Maximum	237	285	823	300	5.9	12.6	15.7	15.4

To know the annual rainfall trend in the watershed, the MK test (Z) and Sen's slope estimator has been carried out and the results represent both positive and negative trends (Table 2). From Table 2, Z statistics reveal the rainfall trend during different seasons in different stations. Except Humcha, all other station shows an increasing trend in annual and monsoon rainfall, whereas during post-monsoon and pre-monsoon season shows decreasing trend and increasing trends respectively in all stations. In a study by Naidu et al (1999) also concluded that a positive trend is present in the Kumadvati watershed region by analysing 124 years rainfall data.

During the post - monsoon, decreasing trend in the precipitation records found to be statistically significant at the 10% level at Humcha and 5% significant level at Ayanur and Konandur during pre-monsoon. In other stations, trend in rainfall are not significant. The Sen's

slope estimator of rainfall results shows that the annual change magnitude of trend at Kumsi, Ayanur, Humcha and Konandur is 22.4%, 30%, -16.9% and 10.8% respectively. The change magnitude observed at Humcha is -69.6%, -3.7%, -42.2% and -2.8% during annual, monsoon, post-monsoon and pre-monsoon respectively.

In three stations, namely Kumsi, Ayanur and Konandur, Sen's slope percentage change is positive for annual, monsoon and pre-monsoon seasons, whereas at Humcha show increasing trend only during pre-monsoon and decreasing trend for annual and other two seasons. The annual decrease in rainfall at Humcha station is 19.17mm/year. In Kumsi, Ayanur and Konandur stations, the annual increase in rainfall is 2.7cm/year, 7.4cm/year and 9.0 cm/year respectively (Table 3). The rainfall trend in four stations for annual, monsoon, post-monsoon and pre-monsoon is shown in Fig. 4.

Table 2: Values of significant trend in Rainfall

Stations	Annual			Monsoon			Post-Monsoon			Pre-Monsoon		
	Test Z	Q	%	Test Z	Q	%	Test Z	Q	%	Test Z	Q	%
Kumsi	1.3	6.91	22.4	1.5	6.11	27.1	-1.1	-2.0	-37.6	1.3	1.8	60.1
Ayanur	1.4	10.11	30.0	1.4	8.06	33.5	-0.2	-0.4	-7.2	2.0*	2.9	71.3
Humcha	-0.7	-14.9	-16.9	-0.8	-12.5	-16.3	-1.9+	-5.8	-87.1	1.6	3.15	64.1
Konandur	0.7	8.25	10.8	0.7	11.54	17.2	-1.1	-1.9	-33.1	2.0*	2.9	83.9

Z - Mann-Kendall test, Q - Sen's slope estimator.*** Statistically significant at 0.1% level of significance. * Statistically significant at 5% level of significance.+ Statistically significant at 10% level of significance.

The MK test trend values obtained for annual rainfall is used to show spatial trend in the watershed using Arc-GIS software (Fig.6a). The highest trend value is 1.65 and the lowest is -0.55. The map shows an increasing trend in

rainfall from south to north. The linear equations obtained from the trend lines of annual rainfall at different stations are shown in Table 3.

Table 3: Linear equations of the trend lines for annual rainfall and groundwater level

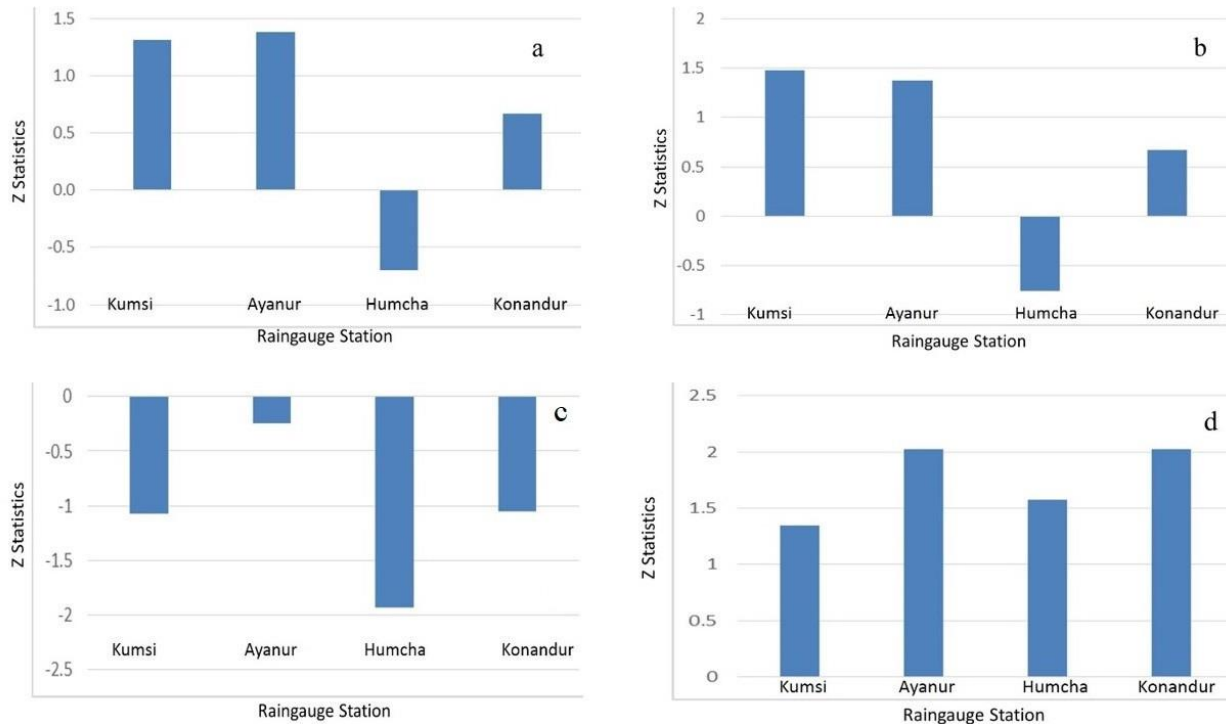| Rainfall	Linear equation	Groundwater Level	Linear equation
Kumsi	y = 2.7602x + 970.6	Kumsi	y = -0.0468x + 3.1225
Humcha	y = -19.166x + 3159.9	Humcha	y = -0.0023x + 8.6078
Ayanur	y = 7.4158x + 964.67	Harnahalli	y = -0.123x + 11.095
Konandur	y = 9.0066x + 2322.2	Konandur	y = 0.00297x + 10.908

Figure 4: Trend of Z for Rainfall – Annual (a), Monsoon (b), Post-Monsoon (c), and Pre-Monsoon (d)

WATER LEVEL FLUCTUATION

The annual groundwater level fluctuation data is shown using Box and Whisker plots (Fig 3). Maximum water level fluctuation observed at Harnahalli station where the high irrigation activity and settlements are located. At Humcha station, the water level fluctuation is less and is located closer to forest land, where irrigation activity and population is less.

The results of groundwater level trends in all four stations during annual, monsoon and pre-monsoon seasons show a positive trend at Humcha, and Konandur stations, whereas at Kumsi and Harnahalli wells show a negative trend (Table. 4 and Fig. 5). The negative trend is mainly because the groundwater recharge during the monsoon season has decreased in the watershed due to change in LULC. The large area has been brought under irrigation in the recent times and in addition, during the post-monsoon season, groundwater extraction has increased in the watershed for irrigation and domestic water supply. Earlier people in the watershed use to grow rain-fed crops like paddy during monsoon season only. Now they have switched over to plantation crops due to labour problem. These plantation crops require irrigation during other seasons also. Hence, the groundwater shows declining trend.

The MK test (Z) and the Sen's slope estimator has been carried out to know the groundwater level trend and is tabulated in Table 4. The Z statistics reveal that the groundwater level shows a decreasing trend in all the observation wells except during pre-monsoon season. At Kumsi station, the trend found to be statistically significant at the 0.1% level of significance during annual, monsoon, and pre-monsoon seasons. In post-monsoon season statistically significant at 10% level of significance. At Harnahalli station, the trend found to be statistically significant at the 0.5% level of significance during annual, post-monsoon, and pre-monsoon.

Table 4: Values of significant trend of water level fluctuation

1984-2015	Annual			Monsoon			Post-Monsoon			Pre-Monsoon		
	Test Z	Q	%	Test Z	Q	%	Test Z	Q	%	Test Z	Q	%
Kumsi	-3.7***	-0.05	-69.6	-3.62***	-0.05	-100	-1.67+	-0.02	-33.7	-3.45***	-0.08	-71.1
Humcha	-1.1	-0.01	-3.7	-0.89	-0.03	-13.7	-0.79	-0.02	-7.9	0.23	0.01	2.9
Harnahalli	-2.1*	-0.12	-42.2	-1.35	-0.08	-30.8	-2.29*	-0.14	-56.7	-2.35*	-0.15	-42.9
Konandur	-0.4	-0.01	-2.8	-0.50	-0.04	-12.8	-0.31	-0.01	-3.0	1.14	0.02	4.7

Z - Mann-Kendall test, Q - Sen's slope estimator.*** Statistically significant at 0.1% level of significance. * Statistically significant at 5% level of significance. + Statistically significant at 10% level of significance
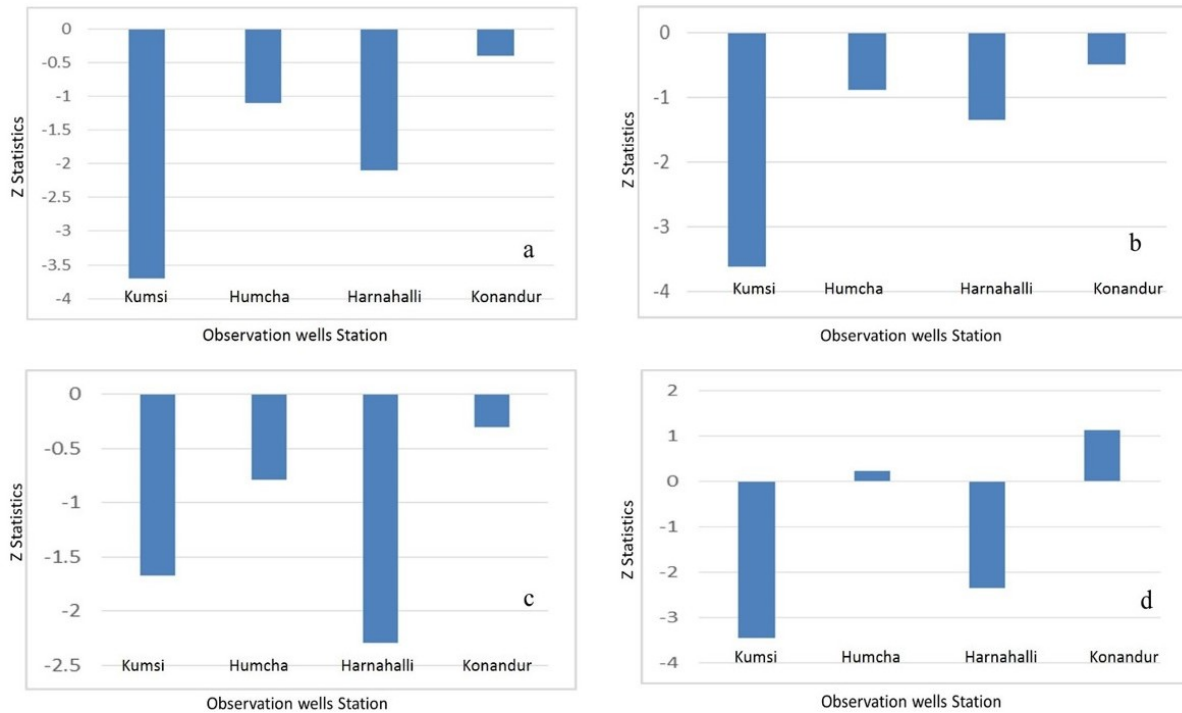
Figure 5: Trend of Z for Water level - Annual (a), Monsoon (b), Post-Monsoon (c), and Pre-Monsoon (d)

The trend values obtained from MK test for water level are used to show the trend in water levels in the watershed (Fig. 6b).The maximum and minimum decrease trend in water level in the watershed varies from -1.3 to -5.2m. This decreasing trend increases from the southern part towards the northern part of the watershed. The higher values of a decreasing trend in the northern part are due to increase in irrigation activity and population. The annual water level fluctuation trend line equations for the observation wells are given in Table 3. The decrease in water level at Harnahalli is 12 cm/year and Kumsi it is 5 cm/year. In other two stations, the decrease in groundwater level is negligible.
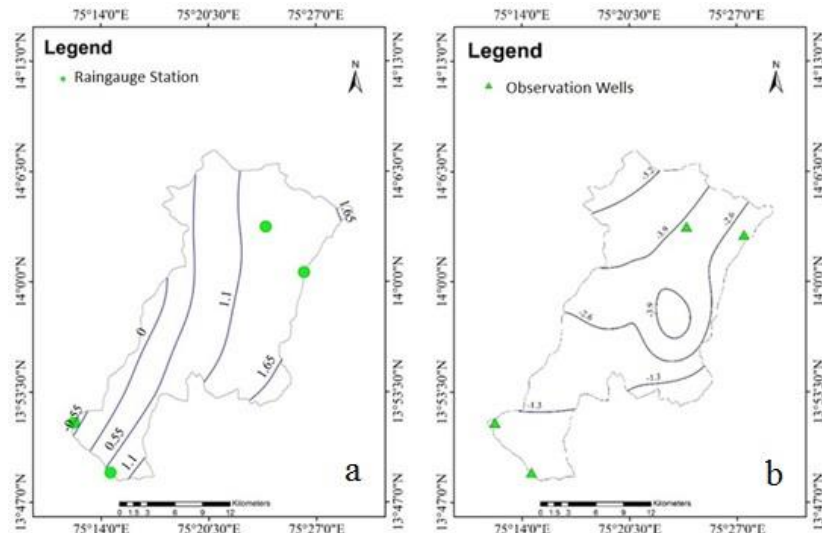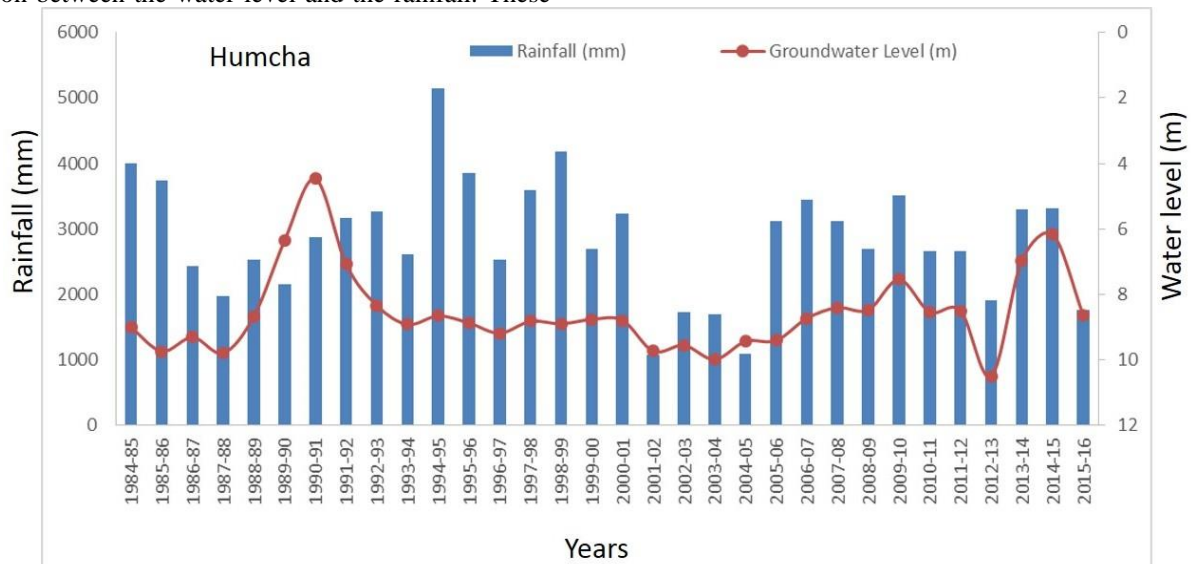
Figure 6: The spatial trend in rainfall (a) and groundwater level (b) in Kumadvati watershed

GROUNDWATER LEVEL IN RELATION TO RAINFALL

To know the relationship between rainfall and groundwater levels of the observation wells in the study area, 32 years annual rainfall and groundwater levels are plotted for three stations (Fig 7). The rate of increase in water level in the wells depends on the intensity and duration of the rainfall. If both intensity and duration is more, the groundwater recharge will be more, the water level increases quickly. Otherwise, if the duration of rainfall is less even if the annual rainfall is equal to average rainfall, the rate of recharge decreases and in turn increase in water level is also less.

The Humcha, and Konandur stations shows a good correlation between the water level and the rainfall. These two stations are located in the southern side of the watershed and they are close to forestland. At these stations, the ground slope is high since they are located along the foothills of the Western Ghats. Hence, in-spite of receiving high rainfall, groundwater recharge is moderate. The annual fluctuation in these stations is very low due to less population and irrigation activity. The observation wells at Kumsi and Harnahalli are in the northern part of the watershed where the slope is less and recharge is more. Hence, in these observation wells, the groundwater level reaches close to the ground surface during monsoon season. The yearly water level fluctuation in these observation wells is more due to unsustainable withdrawal of groundwater for domestic and irrigation purposes.
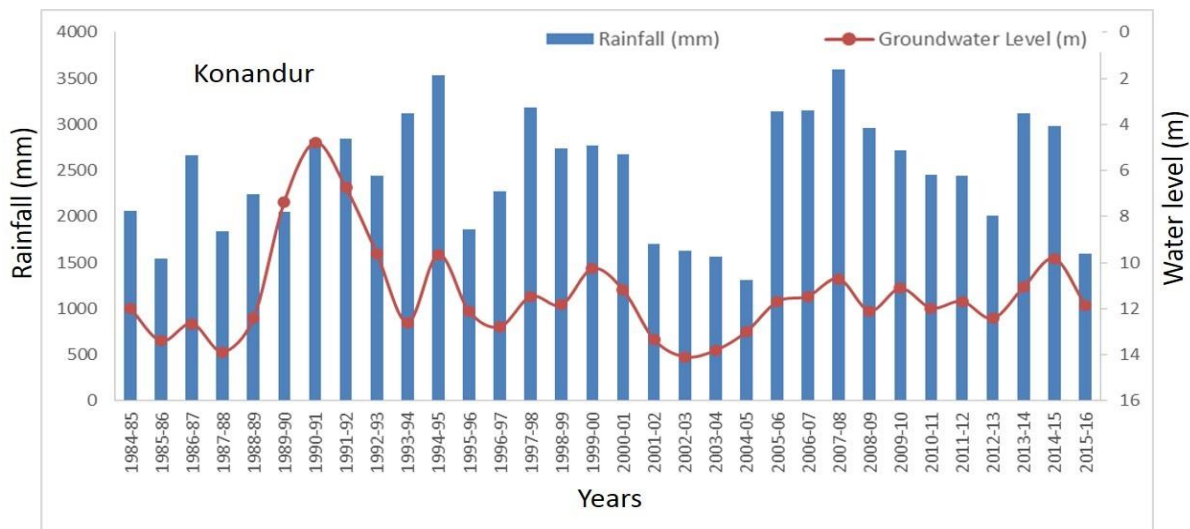
Fig 7: Relationship between rainfall Vs groundwater level at Humcha and Konandur stations in Kumadvati watershed

CONCLUSIONS

In the present study, analysis of 32 years of rainfall and groundwater level in Kumadvati watershed for the period from 1984-85 to 2015-16 has been analysed to know the spatial and temporal trend. The Mann-Kendall test used to know the trend in annual rainfall shows there is an increasing and decreasing trend in the stations. The rainfall increases from south towards the north. At Humcha the annual, monsoon and post-monsoon season shows decreasing trend. At Kumsi, Ayanur and Konandur stations show an increasing trend in rainfall for annual, monsoon, and pre-monsoon. In general, the groundwater level in the study area shows a decreasing trend annually. The spatial maps show-decreasing trend in rainfall and groundwater levels in the study area. The relationship between rainfall and water level show a good correlation at Humcha and Konandur stations. The decrease in water level during the study period at Kumsi and Harnahalli is due to increase in irrigation area and population in the northern part of the watershed.

ACKNOWLEDGEMENT:

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