International Journal of Environment and Climate Change

Volume 13, Issue 9, Page 1145-1157, 2023; Article no.IJECC.102637
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Trend Analysis of Groundwater Levels in Kalpathypuzha Sub-Basin of Bharathapuzha, Kerala in India

K. K. Rabeea Assainar [a++*], Asha Joseph [a#] and S. Sajeena [a†]

[a] *Department of Irrigation and Drainage Engineering, KCAET Tavanur, Malappuram-676305, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i92340

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/102637

Original Research Article

Received: 16/05/2023
Accepted: 06/07/2023
Published: 15/07/2023

ABSTRACT

Groundwater is one of the most precious and significant sources of water in the world. The understanding of groundwater level variability and trend is crucial for water resources planning in a region. The present study was conducted in the Kalpathypuzha sub-basin of Bharathapuzha. The variability of ground water levels was analyzed using various descriptive statistics such as mean, standard deviation, coefficient of variation, skewness and kurtosis. The groundwater level trend was estimated using the Mann-Kendall test and Sen's slope estimator. Twelve observation wells evenly distributed in the blocks of Kuzhalmannam, Palakkad, Malampuzha and Chittur blocks of Palakkad districts in Kerala were selected for the study. The results of variability analysis showed that, the highest mean monthly groundwater level of 139.1 m was found for the well 139 of Chittur block in September and the lowest mean monthly groundwater level of 61.5 m was found for the well 129 of Palakkad block in September. The highest mean annual groundwater level was 138.9 m in the year 2007 for the well 139 of Chittur block and the lowest was 62.1 m in the year 2016 for the well 129 of

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[++]*Research Scholar;*
[#]*Professor;*
[†]*Associate Professor;*
**Corresponding author: E-mail: rabeea4u@gmail.com;*

Palakkad block. The results of trend analysis showed a decreasing pre-monsoon groundwater level trend in three wells viz. well 129 of Palakkad block and wells 133 and 142 of Malampuzha block while decreasing post-monsoon groundwater level trend was observed in well 139 of Chittur block. There was no significant trend in the rest of the wells for both the pre-monsoon and post-monsoon periods.

Keywords: Groundwater level; mann-kendall; sen's slope estimator; trend; variability.

1. INTRODUCTION

Water is the most essential natural resource which supports life on the globe. The demand and needs for water are growing exponentially. Ever-increasing demands for water for irrigation, domestic, industrial and livestock sectors have created water scarcity worldwide [1]. Groundwater represents the terrestrial subsurface component of the hydrologic cycle. Groundwater is the only reliable source of water, which is now becoming scarce in almost all parts of the hard rock terrain of the country. There are many reasons for this condition such as over-exploitation of groundwater, decrease in infiltration rate, deforestation etc. There is currently a serious groundwater crisis in India as a result of excessive groundwater extraction and contamination, which affects nearly 60% of the country's districts and poses a threat to the population's access to safe drinking water [1].

The groundwater level is an indication of groundwater flow, availability of groundwater and the aquifer's or groundwater system's physical properties. Any event that causes an aquifer's pressure to change will cause the groundwater level to be altered. The groundwater level is affected by the quantity of storage, the amount of discharge and recharge, the variance of stream stages, and evaporation. Hence, understanding the groundwater level variability and trend is crucial for water resources development and management in a region. The method for trend evaluation of groundwater level is an efficient tool for groundwater conservation measures. Time-series analysis is used in groundwater level trend assessment to provide a greater knowledge of long-term changes in groundwater levels. It can assist in figuring out whether an aquifer's groundwater storage is steady, increasing, or decreasing. Several researchers have evaluated how groundwater levels have changed over time using trend analysis approaches [2,3,4].

The Mann-Kendall test is the most common non-parametric method for analyzing groundwater level trends, recharge and different climatic parameters. A non-parametric method for detecting groundwater level trend in Ghat Prabha River Basin, India was applied [5]. Modified Mann-Kendall and Sen's slope estimator at a 5% significance level were used for the groundwater level trend analysis during the period from 1998 to 2012 for 13 data sites in Uttar Pradesh, India [6].

Kumar and Rathnam [7] investigated the monthly, yearly, and seasonal groundwater fluctuation patterns of the forty observation wells in the Warangal district (2000–2015) using a non-parametric Mann-Kendall approach. With the help of Sen's slope estimator, trend magnitudes were calculated. According to the findings, three observation wells on a monthly time series showed substantial positive trends (positive Z-statistics), while other wells among forty showed significant negative trends. The monthly, seasonal, and annual median trend slopes for groundwater levels were all negative. A decreasing trend in the seasonal trend slope was observed in the pre-monsoon season. The annual variation in trend slope ranged between -0.4 and +0.4 millimetres per year. 8. Halder et al. [8] investigated groundwater degradation to examine the seasonal trend in their groundwater levels using Mann-Kendall test statistics between 1996 and 2018. About twenty wells from a river basin in West Bengal were chosen for study. It was found that 60 % of wells showed a drop-in water level, especially in the post-monsoon season.

Noori and Singh [9] applied the nonparametric Mann-Kendall test at a significance level of 0.05 to evaluate seasonal spring (March to May), summer (June to August), fall (September to November), winter (December to February), and annual trends of groundwater-table for all observation points, which is a part of the Kabul basin of Afghanistan.

Kalpathypuzha, a sub-basin of Bharathapuzha coming under the Palakkad district of Kerala is a severe drought-prone area. The area contains over-exploited, critical and semi-critical classes of groundwater exploitation [10]. Ground water development in some parts of the area has reached a critical stage which results in the decline of ground water levels. Thus, there is a need to adopt an integrated approach for the development of ground water resources in Kalpathypuzha sub-basin. Given the above facts, the present research paper aims to analyze the spatio-temporal groundwater level variability and trend in the Kalpathypuzha sub-basin of Bharathapuzha, so that the major hotspots can be identified and necessary water resources management practices can be adopted.

2. MATERIALS AND METHODS

2.1 Study Area

The Kalpathypuzha watershed which is one of the principal tributaries of the Bharathapuzha River and the most water-stressed regions of the river basin was selected for the study. The area of the Kalpathypuzha watershed is shared between Tamil Nadu and Kerala and only the part coming under the Kerala region was taken for this study. The study area covers the Kuzhalmannam, Palakkad, Malampuzha and Chittur blocks of the Palakkad district. It is located between 10.939443 °N and 10.684076 °N latitude and 76.428872 °E and 76.900910 °E longitude. The geographic area of the study portion is 759 km^2. The elevation of the study area ranges from 24 to 2028 m. The area falls under a tropical dry and wet climate. The average annual rainfall is about 2400 mm. The average maximum and minimum temperatures are 32.45 °C and 23.50 °C respectively. The average annual relative humidity is about 72% and the average annual wind speed is about 5.75 km/hr. Physiographically the study area has high and mid land and the main soil type of the area is laterite and alluvial soil. The location map of the study area is shown in Fig. 1.

The location of different wells selected for the study is shown in Fig. 2. Twelve observation wells evenly distributed in four blocks Kuzhalmannam, Palakkad, Malampuzha and Chittur of Palakkad district was selected for the study. The ground water level data of three wells, 160 PKD-12, PKD S-3 and PKD S-4 in Kuzhalmannam block, three wells 128, 129 and 160 PKD-8 in Palakkad block, four wells 133, 140, 142 and PKD S-15 in Malampuzha block and two wells 139 and PKD S-7 in Chittur block was taken for analysis of variability and trend. The wells were denoted by the same ID number given by the Groundwater Dept. office in Palakkad.

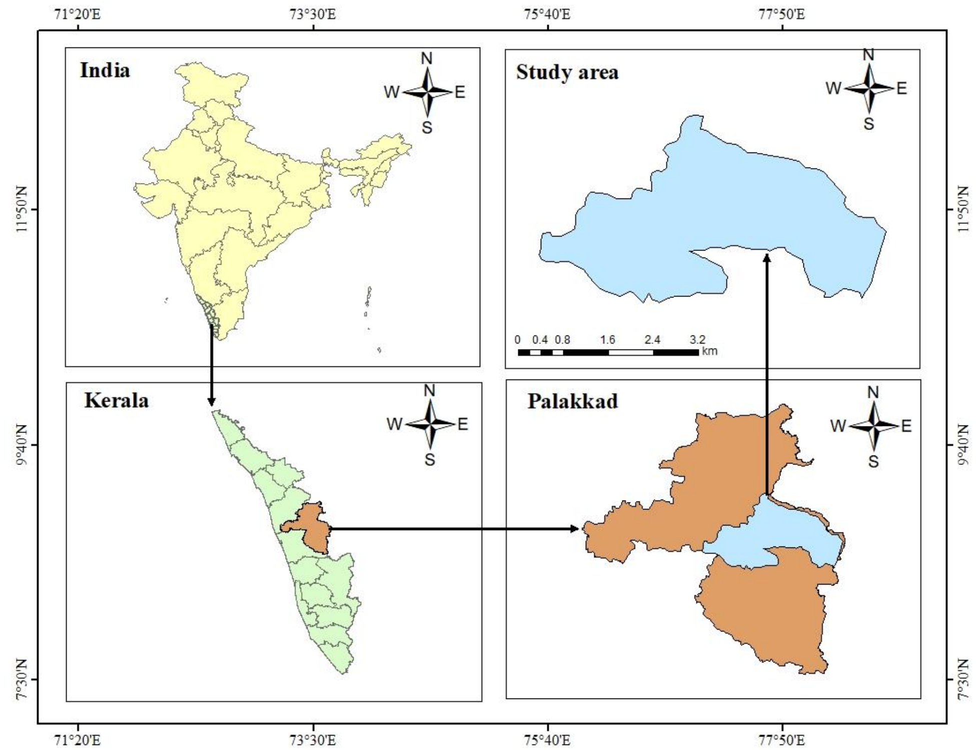

Fig. 1. Location map of the study area

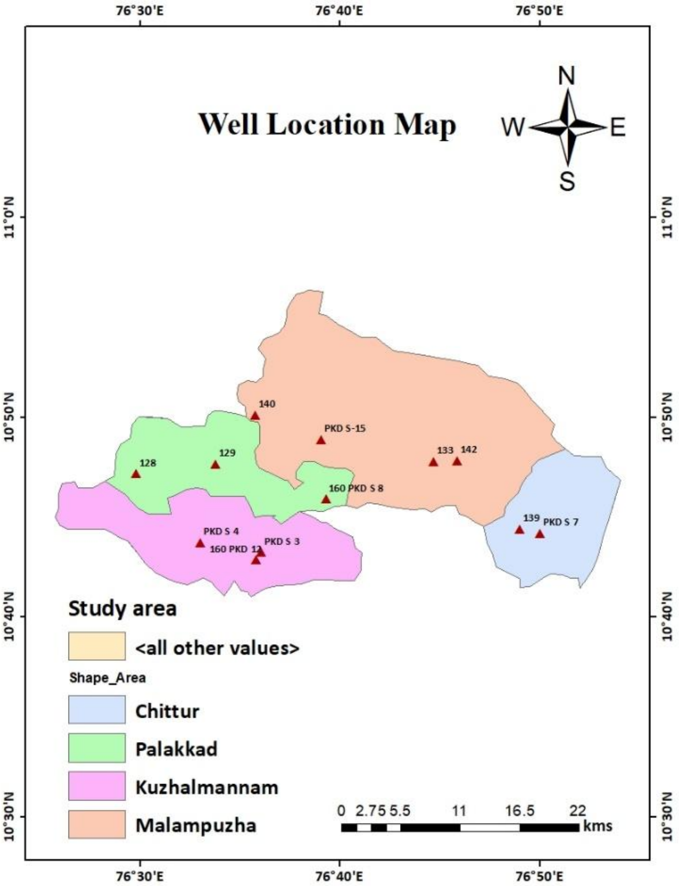

Fig. 2. Map showing the location of wells in the study area

2.2 Data

The well location data and monthly groundwater level data was collected from the District Groundwater Department, Palakkad for a period of 15 years (2007-2021). Out of the twelve wells, seven were dug wells and six were borewells. Dug wells are shallow, manually excavated wells with larger diameters whereas borewells are deep, machine-drilled wells with smaller diameters. Details of the wells are shown in the Table 1.

2.3 Analysis of Groundwater Level Variability

To study the variability of groundwater level, the statistical parameters viz. mean, standard deviation, coefficient of variation, skewness and kurtosis were computed for the groundwater level data.

2.4 Trend Analysis of Groundwater Level

Trend analysis of groundwater level data was statistically examined in two phases. The non-parametric Mann-Kendall test was applied in the first phase. The normalised test statistic (Z) value was used to determine the upward or downward trend. In the second phase, the non-parametric Sen's slope estimator was used to calculate the rate of trend, rise or fall [4]. Thus, annual groundwater level data was subjected to trend analysis using the Mann-Kendall test and Sen's Slope estimator to determine whether there was an upward or downward trend.

2.4.1 Mann-Kendall test (M-K)

A non-parametric test called the M-K test is used to identify trends and the non-linear trend that results from Kendall test statistics. Based on the normalised Z statistics value, the monotonic trend (increasing or decreasing) in the annual groundwater level time series was examined. The groundwater level's decreasing trend is represented by the Z statistic's negative value, and its rising trend is shown by its positive value. In contrast to the alternative hypothesis (H1), which predicts an increasing or declining monotonic trend, the null hypothesis (H0) is that there is no trend or serial correlation among the population under study [11,12]. The Mann-Kendall statistics (S) is given by the equation (1)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad (1)$$

Where,

sign $(x_j - x_i) = 1$, if $(x_j - x_i) > 0$
sign $(x_j - x_i) = 0$, if $(x_j - x_i) = 0$
sign $(x_j - x_i) = -1$, if $(x_j - x_i) < 0$

S values that are positive or negative represent an upward or downward trend; respectively.To determine the significance of the trend, statistical analysis is required. Kendall describes the normal approximation test technique (1975). This test assumes that the dataset only contains a small number of tied values. The variance (S) is calculated by the equation (2)

$$Var\,(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)] \quad (2)$$

The normal Z- statistics is computed as follows:

$$Z = \frac{S-1}{\sqrt{Var\,(S)}}, \text{ if } S > 0$$

$$Z = 0, \text{ if } S = 0$$

$$Z = \frac{S+1}{\sqrt{Var\,(S)}}, \text{ if } S < 0$$

If Z is negative and the computed Z-statistics is higher than the Z-value corresponding to the 5% level of significance, the trend is considered to be falling. If Z is positive and the computed Z-statistics is higher than the Z value corresponding to the 5% level of significance, the trend is considered to be rising. There is no trend if the calculated Z-statistics is smaller than the Z-value equivalent to the 5% level of significance.

2.4.2 Sen's slope estimator

The median of the pair-wise slopes between each pair of points in the dataset is used to determine Sen's slope. Each slope (m_{ij})is estimated using equation (3)

$$mij = \frac{(Y_j - Y_i)}{(j-i)} \quad (3)$$

where,

i = 1 to n-1 and j = 2 to n,

Y_j and Y_i are data values at time j and i (j > i), respectively.

If there are n values of *Yj* in the time series, there will be N = n(n-1)/2 slope estimates. The median slope of these N values of slopes is known as Sen's slope.

The Sen's slope is:

$$m = m_{(\frac{N+1}{2})}, \text{ if n is odd}$$

$$m = \frac{1}{2}(m(\frac{N}{2}) + m(\frac{N+1}{2})), \text{ if n is even}$$

Sen's slope suggests a rising trend when it is positive, while Sen's slope reveals a declining tendency when it is negative.

Table 1. Details of wells selected for the study

Sl. No	Well (ID as per state GW Dept. norms)	Block	Latitude (Decimal degrees)	Longitude (Decimal degrees)	Well type	Elevation (m)
1	160 PKD-12	Kuzhalmannam	10.715	76.597	Bore well	70
2	PKD S-3	Kuzhalmannam	10.721	76.601	Dug well	74
3	PKD S-4	Kuzhalmannam	10.729	76.550	Dug well	67
4	128	Palakkad	10.787	76.497	Dug well	68
5	129	Palakkad	10.795	76.563	Dug well	71
6	160 PKD-8	Palakkad	10.765	76.655	Bore well	92
7	133	Malampuzha	10.797	76.745	Dug well	113
8	140	Malampuzha	10.835	76.596	Bore well	90
9	142	Malampuzha	10.797	76.764	Bore well	113
10	PKD S-15	Malampuzha	10.815	76.651	Dug well	93
11	139	Chittur	10.741	76.817	Bore well	152
12	PKD S-7	Chittur	10.737	76.837	Dug well	152

Groundwater department, Palakkad

3. RESULTS AND DISCUSSION

3.1 Variability of Groundwater Level

3.1.1 Mean monthly groundwater level w.r.t Mean Sea Level (MSL) in (m) from 2007 to 2021

The mean monthly groundwater level was highest in the post-monsoon months (August and September) and lowest in the pre-monsoon months (April and May) which is indicated by rise of water level in the post-monsoon period and fall of water level in pre-monsoon. The rise might be due to the recharge of rainfall in monsoon and the fall might be due to the lowering of the water table in the pre-monsoon period because of decreased recharge and increased abstraction. The maximum mean monthly groundwater level of 151.3 m was observed for the well PKD S-7 in September and the minimum mean monthly groundwater level of 61.5 m was observed for the well 129 in May as shown in Fig. 3a.

3.1.2 Annual mean groundwater level w.r.t MSL (m) from 2007 to 2021

The mean annual groundwater level was lowest in the year 2017 for the majority of wells which might be due to reduced rainfall and recharge in the year. The highest annual mean groundwater level of 150.9 m was observed for the well PKD S-7 in the year 2015 and the lowest of 62.1 m was observed for the well 129 in the year 2016 as indicated by Fig. 3b.

3.1.3 Monthly standard deviation of groundwater level (m)

For the majority of wells, the standard deviation was found to be high in June/July with values varing from 1 to 3.43 m than other months. But the highest standard deviation of 3.81 m was found for well 142 in February and the lowest was 0.17 m for well 160 PKD-12 in July. More variation in the standard deviation of groundwater level was found in the June/July months which may be due to the rise in groundwater level by monsoon rainfall.

3.1.4 Monthly coefficient of variation (%) of groundwater level

The coefficient of variation (CV) of the majority of wells was found highly variable in the monsoon months of June and July with values varying from 21.83 to 93.30 which indicated high groundwater level fluctuation in the respective months due to the arrival of monsoon. The highest CV of 93.30 was found for the well 133 in July while the lowest of 4.32 was for the well 129 in February.

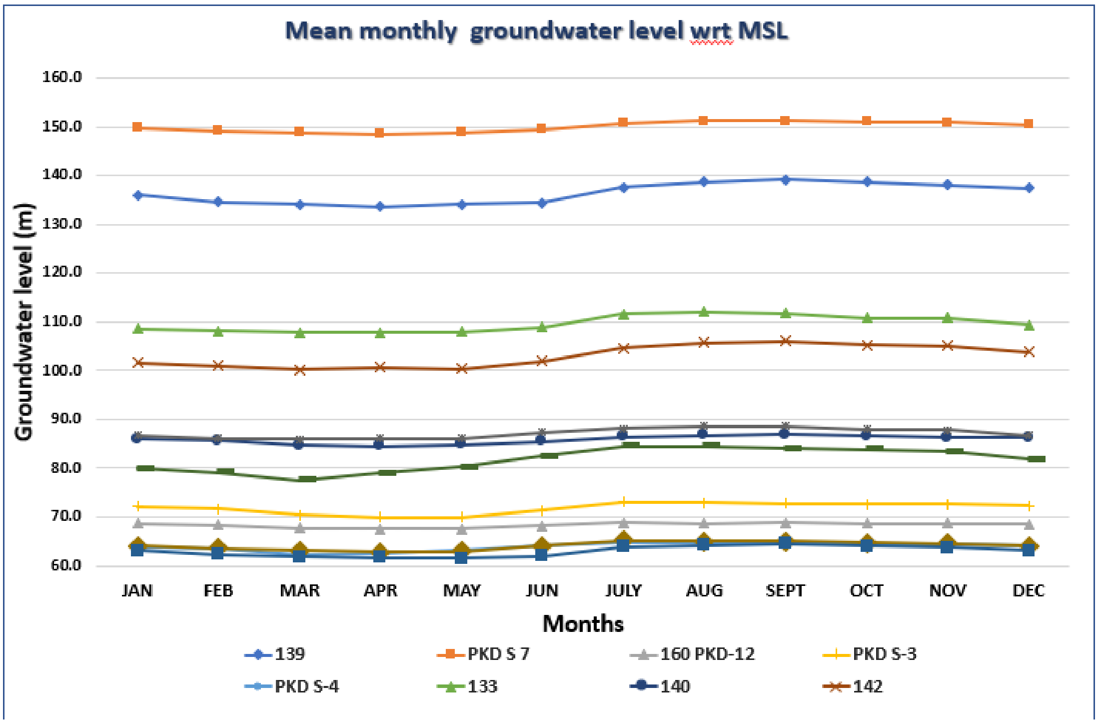

Fig. 3a. Mean monthly groundwater level w.r.t MSL

3.1.5 Skewness of groundwater level

The Skewness value was found between -1.94 to 3.42, some wells showed a negatively skewed distribution whereas other showed a positively skewed distribution. The highest positive skewness of 3.42 was for the well PKD S-3 in February and the highest negative skewness of -1.94 was found for the well 129 in January. The distribution was extremely skewed which indicated that the groundwater level was highly asymmetric from the normal distribution which happens due to the rise and fall in the groundwater level due to the recharge by seasonal rainfall. The Skewness of the groundwater level is represented graphically in Fig. 4.

3.1.6 Kurtosis of groundwater level

The Kurtosis was found between 12.44 to -1.7. Some wells showed a negative value of kurtosis which indicated a light peak in the distribution whereas other wells showed a positive value of kurtosis which indicated a heavy peak. The highest positive kurtosis of 12.44 was observed for the well PKD S-3 in February and the highest negative kurtosis of -1.7 was observed for the well 133 in November. High kurtosis indicated that the groundwater level data was more concentrated around the mean. The kurtosis of the groundwater level is represented graphically in Fig. 5.

3.2 Water Table Contour Map of the Study Area

The water table contour map of the study area was generated during the study period (2007 to 2021) in Arc GIS using the IDW interpolation technique. The average elevation of the well locations was about 96.25 m above MSL. The ground level elevation varied from 67 m at well PKD S-4 of the Kuzhalmannam block to 152 m at wells 139 and PKD S-7 of the Chittur block. The water table contour maps were prepared for pre-monsoon, post-monsoon and annual periods and are shown in Fig. 6. Similar results were obtained in the study conducted by Goyal et al. [13]. The pre-monsoon water table elevation of wells varied from 148.66 m in well PKD S-7 of the Chittur block to 61.66 m in well 129 of the Palakkad block. The post-monsoon water table elevation of wells varied from 151.21 m in well PKD S-7 of the Chittur block to 64.16 m in well 129 of the Palakkad block. The annual water table elevation of wells varied from 150.02 m in well PKD S-7 of the Chittur block to 63.02 m in well 129 of the Palakkad block.

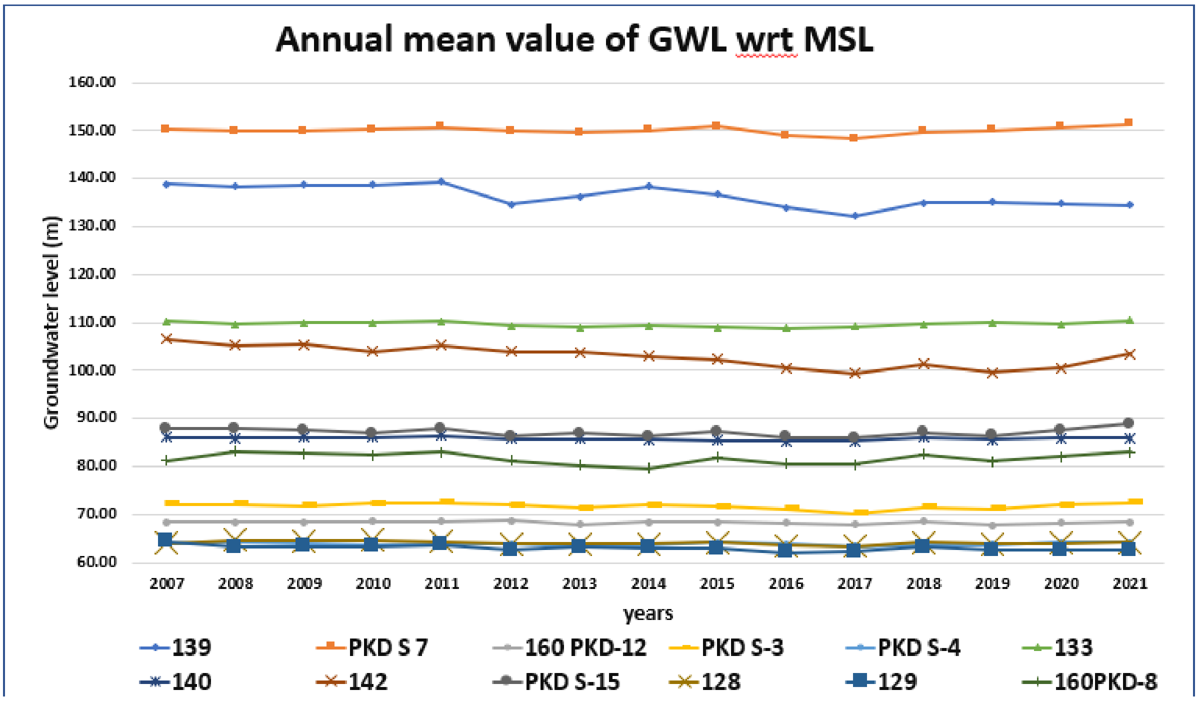

Fig. 3b. Annual mean groundwater level w.r.t MSL

Fig. 4. Skewness of groundwater level by different wells a) 139 b) PKD S-7 c) 160 PKD-12 d) PKD S-3 e) PKD S-4 f) 133 g) 140 h) 142 i) PKD S-15 j) 128 k) 129 and l) 160 PKD-8

3.3 Groundwater Level Fluctuation

Groundwater level fluctuation was calculated as the difference between post- monsoon and pre-monsoon groundwater levels. Groundwater level fluctuation is classified into four different categories viz, 1-2 m, 2-3 m, 3-4 m and 4-5 m. The average annual seasonal fluctuation of groundwater level for the study period is shown in Fig. 7. The major portion of the study area was found to have a groundwater level fluctuation of 2 m to 3 m, which comprises well PKD S-4 of Kuzhalmannam block, wells PKD S-15 and 142 of Malampuzha block. A small portion of the study area was found to have a groundwater level fluctuation of 1 m to 2 m, which comprises wells PKD S-3 and 160 PKD-12 of Kuzhalmannam block, well 129 of Palakkad block, well 133 of Malampuzha and well 139 of Chittur block. The portion with 4 m to 5 m groundwater level fluctuation included wells 140 and 160 PKD-8 of Malampuzha block and well PKD S-7 of Chittur block. Well 128 of Palakkad block showed a groundwater level fluctuation of 3 m to 4 m.

3.4 Groundwater Levels and Annual Rainfall

The annual replenishment of the aquifer primarily depends on rainfall, thus the groundwater level changes might be correlated with the variations in precipitation amounts. Therefore, the Depth to the water table and annual rainfall was plotted against a period as shown in Fig. 8. The effect of heavy rain in the years 2009, 2011, 2013, 2014, 2018 and 2019 on the depth to water table (bgl) was quite visible in the plot with a slight time lag (recharge time). Similiar results were obtained in the study conducted by Minea and Croitoru [12].

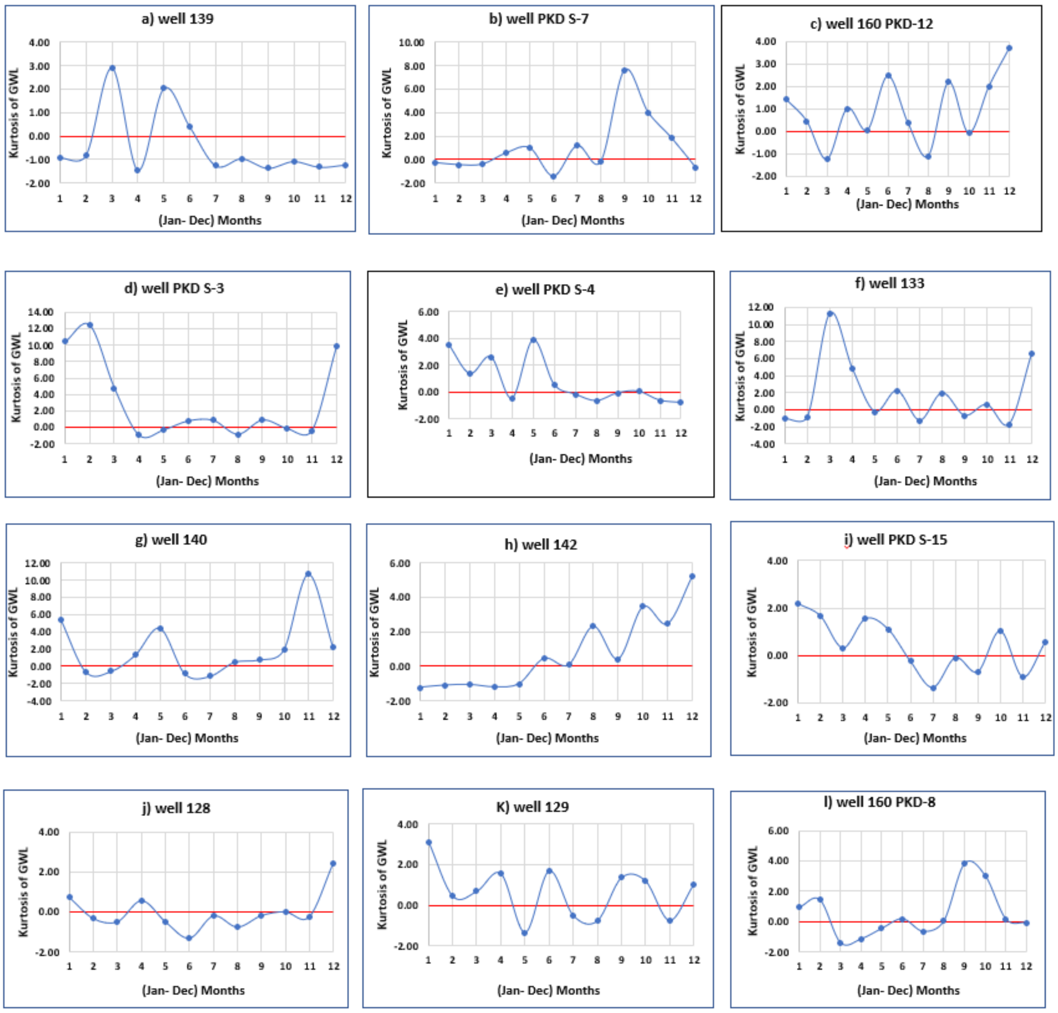

Fig. 5. Kurtosis of groundwater level by different wells a) 139 b) PKD S-7 c) 160 PKD-12 d) PKD S-3 e) PKD S-4 f) 133 g) 140 h) 142 i) PKD S-15 j) 128 k) 129 and l) 160 PKD-8

3.5 Trend Analysis of Groundwater Level

The trend analysis of groundwater levels of all the twelve wells in the study area during the period 2007 to 2021 was carried out for pre-monsoon (March-May), post-monsoon (September-November) and annual period using Mann-Kendall test and Sen's slope estimator. The trend analysis was done using XLSTAT software. If the P value is less than the α value**,** there exists a trend and if the slope is negative the trend is decreasing otherwise increasing [8].

3.5.1 Pre-monsoon, post-monsoon and annual groundwater level trend

The pre-monsoon groundwater level trend analysis showed a decreasing trend in wells 129, 133 and 142 while all other wells showed no trend. The post-monsoon groundwater level trend analysis showed a decreasing trend in well 139 and no trend in all other wells. The annual groundwater level trend analysis showed a decreasing trend in wells 129, 139 and 142 while no trend in all other wells. Declining trend of groundwater is observed mainly in wells coming under areas of more water usage.

3.5.2 Spatial distribution of groundwater level trend in the study area

The spatial distribution of groundwater level trends during pre-monsoon, post-monsoon and annual is shown in Fig. 9. It is clear that during pre-monsoon, two wells 133 and 142 of Malampuzha block and one well 129 of Palakkad block, during post-monsoon, well 139 of Chittur block and during annual period, well 139 of Chittur block, 142 of Malampuzha block and well 129 of Palakkad block showed a decreasing trend, which is mainly due to more water usage in those areas.

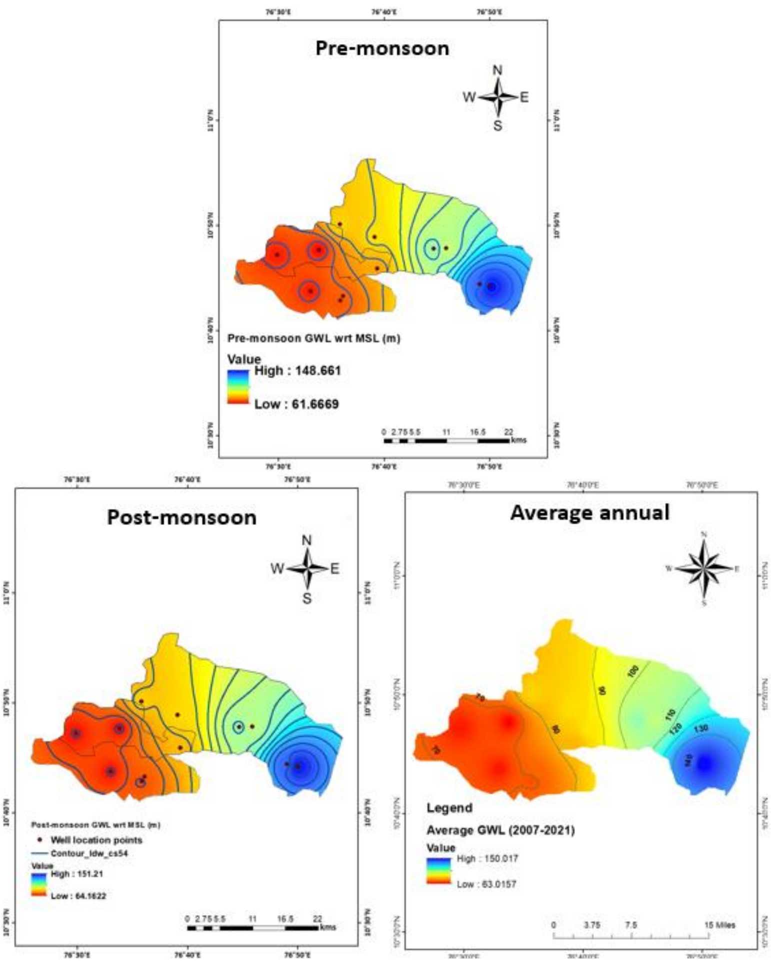

Fig. 6. Pre-monsoon, post-monsoon and annual water table contour map

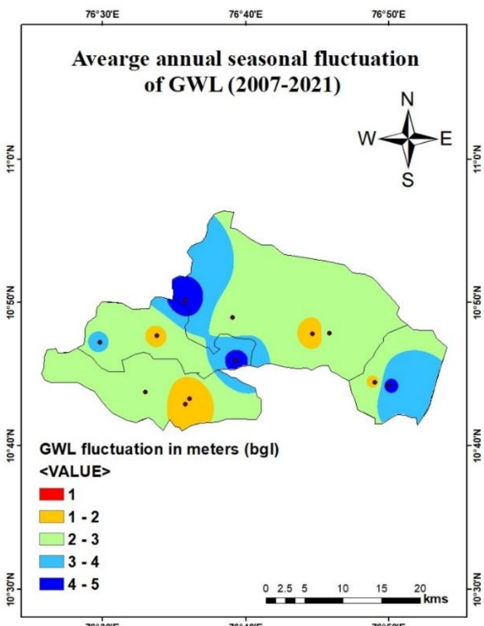

Fig. 7. Average annual seasonal fluctuation of groundwater level

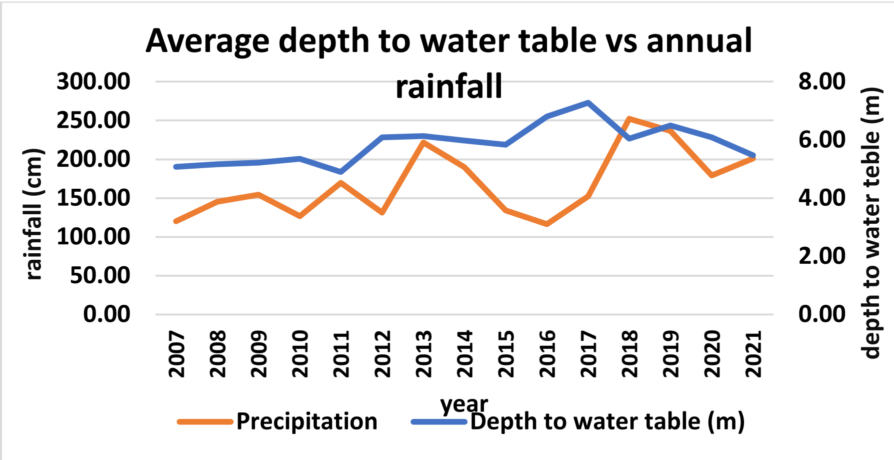

Fig. 8. Trend of average depth to water table with respect to rainfall

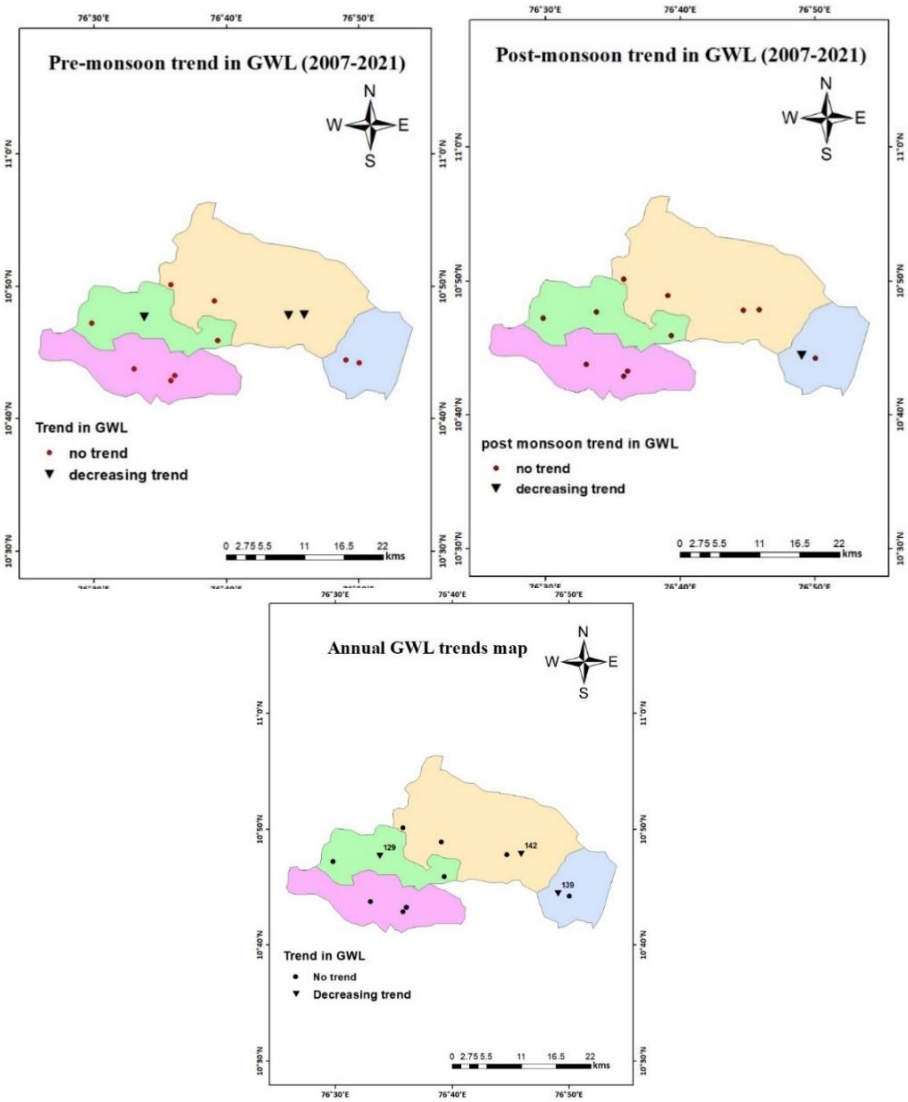

Fig. 9. Spatial distribution of groundwater level trend - pre-monsoon, post-monsoon and annual

Table 2. Results of Mann-Kendall trend analysis for pre-monsoon, post-monsoon and annual

Well ID	S	VAR(S)	P	Slope	Trend
Pre-monsoon					
128	-31	408.333	0.138	-0.073	No
129	-60	407.333	0.003	-0.08	Decreasing
133	-43	408.333	0.038	-0.013	Decreasing
139	-33	408.333	0.113	-0.298	No
140	-21	408.333	0.322	-0.019	No
142	-67	408.333	0.001	-0.605	Decreasing
160 PKD 12	11	408.333	0.621	0.01	No
160 PKD S8	3	408.333	0.921	0.012	No
PKD S3	-11	408.333	0.621	-0.031	No
PKD S7	13	408.333	0.553	0.053	No
PKD S 15	-13	408.333	0.553	-0.003	No
PKD S 4	4	407.333	0.882	0.004	No
Post-monsoon					
128	-23	408.333	0.276	-0.022	No
129	-19	408.333	0.373	-0.05	No
133	-11	408.333	0.621	-0.051	No
139	-46	407.333	0.026	-0.37	Decreasing
140	-29	408.333	0.166	-0.042	No
142	-31	408.333	0.138	-0.149	No
160 PKD 12	-20	407.333	0.346	-0.023	No
160 PKD S8	-14	407.333	0.519	-0.042	No
PKD S3	-39	408.333	0.06	-0.035	No
PKD S7	11	408.333	0.621	0.015	No
PKD S 15	-15	408.333	0.488	-0.044	No
PKD S 4	-32	407.333	0.125	-0.019	No
Annual					
128	-31	408.333	0.138	-0.049	No
129	-59	408.333	0.004	-0.092	Decreasing
133	-9	408.333	0.692	-0.02	No
139	-61	408.333	0.003	-0.382	Decreasing
140	-35	408.333	0.092	-0.045	No
142	-73	408.333	0	-0.471	Decreasing
160 PKD 12	-24	407.333	0.254	-0.02	No
160 PKD S8	-13	408.333	0.553	-0.035	No
PKD S3	-29	408.333	0.166	-0.056	No
PKD S7	-1	408.333	1	-0.001	No
PKD S 15	-17	408.333	0.428	-0.063	No
PKD S 4	-2	407.333	0.96	-0.005	No

Mann-Kendall test results in XLSTAT software

4. CONCLUSION

The study entitled “Trend Analysis of Groundwater Levels: Kalpathypuzha Sub-Basin of Bharathapuzha, Kerala in India” was focused to study the variability and trend analysis of the groundwater level of the region. Twelve observation wells, evenly distributed in the Kuzhalmannam, Palakkad, Malampuzha and Chittur blocks of the Palakkad district were selected for the study. The data on groundwater level was acquired for a period of 15 years from 2007 to 2021. The groundwater level variability was analyzed by various descriptive statistics like mean, standard deviation, coefficient of variation, skewness and kurtosis. The groundwater level trend was estimated by Mann- Kendall test and the Sens slope estimator.

The results of variability analysis showed that, the highest mean monthly groundwater level of 139.1 m was found for the well 139 of Chittur block in September and the lowest mean monthly groundwater level of 61.5 m was found for the well 129 of Palakkad block in May. The highest mean annual groundwater level was 138.9 m in the year 2007 for the well 139 of Chittur block and the lowest was 62.1 m in the year 2016 for the well 129 of Palakkad block. Results of trend analysis showed a decreasing pre-monsoon groundwater level trend in three wells 129 (Palakkad block), 133 and 142 (Malampuzha block) and decreasing post-monsoon groundwater level trend in well 139 (Chittur block), while no trend in all other wells for both seasons. The annual groundwater level trend showed a decreasing trend in wells 129 (Palakkad Block), 139 (Chittur block) and 142 (Malampuzha block). By this study the critical areas of groundwater depletion can be identified and necessary water management practices can be adopted according to the area.

ACKNOWLEDGEMENT

I express gratitude to major advisor Dr. Asha Joseph, advisory committee members Dr. Rema KP, Dr. Sajeena S, Dr. Josephina paul and also thankful to Dept. of Irrigation and Drainage engineering, Kelappaji College of Agricultural Engineering and Technology, Kerala Agricultural University Tavanur, Malappuram, Kerala, India for providing necessary facilities and assistance in conducting research work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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