



Water quality index method in assessing groundwater quality of Palakonda mandal in Srikakulam district, Andhra Pradesh, India

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Abstract

Clean, safe and acceptable fresh water is fundamental to the existence of life. There is still a serious problem with adequate availability of fresh and quality of water for human consumption. This study, therefore, assesses the relevance of groundwater in the selected sites of villages of Palakonda mandal in the Srikakulam district of Andhra Pradesh, India, for consumption, based on different indices of water quality. Groundwater is the principal source for domestic and irrigation purposes in this region. In order to assess the quality of groundwater, 39 groundwater samples were collected during pre- and post-monsoon season from 2013 to 2016. The concentrations of physicochemical parameters such as pH, electrical conductivity, total dissolved solids, total hardness (TH), Ca(II), Mg(II), fluoride (F⁻), chloride (Cl⁻), dissolved oxygen, total alkalinity and nitrite (NO₂⁻) were analyzed to compute Water Quality Index (WQI). The results of the concentrations were interpreted and compared with WHO (2012) and BIS (2012) standards. Correlation between various parameters was also computed, and the results were presented. The results of WQI computation infer that the groundwater of the selected sites in Palakonda mandal is rated as 'good' for human consumption.

Keywords Water quality index · Correlation matrix · Srikakulam · Palakonda (PLKD)

Introduction

Water is an imperative asset on earth. All life as well as human being relies upon water. Due to its characteristics, water has numerous applications for living beings (Morhit and Mouhir 2014). Being a sustainable natural resource, groundwater is the most important and biggest reserve of potable for the human populace (Madhav et al. 2018). Safe potable is not solely an elementary demand of all living organisms, however, conjointly a human right (Jackson et al. 2001). Universally, approximately 33% of the human populace utilize the groundwater for potable (Kumar et al. 2018). Groundwater is favored over surface water as a result

it appears to be less contaminated by means of anthropogenic pollutants (Belkhiri and Mouni 2012; Kumari et al. 2014; Kumar et al. 2015a, b). Due to deficiency of fresh water people were compelled to use spring water for meeting their needs. Groundwater's characteristics over southern India are strongly structured over bedrock geology and local weather, but may additionally also keep impacted in components by means of pollution its quality has been changed by various anthropogenic sources like agricultural wastes, unplanned urbanization, industrial pollutants, improper disposal of flawed matter, etc. Groundwater within the arid and semiarid regions (Bhunja et al. 2018) plays a crucial role for drinking and irrigation (Roy et al. 2018) purpose in rural India (Kumar et al. 2015a, b). In some parts of Asian countries, the rural population has to travel half a mile to access to drinking water since they lack the necessary infrastructures for the water purification (Kumar 2004).

An impure groundwater resource might initiate water-borne diseases, cholera, typhoid, and protozoan infection (Alley 1997). However, once groundwater is sufficiently secured and well processed, it might be a good source of potable water. The principal threat to groundwater quality embodied household and industrial wastes in addition to the

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use of agricultural composts and pesticides (Ofodile 2002). These pollutants may cause contamination by penetrating into aquifers through the stream. Nitrate is hazardous to infants; it affects a disease called ‘methemoglobinemia’ (Ahamad et al. 2018; McCasland et al. 2007). Within the coastal areas, an intrusion of saltwater is also polluting the groundwater resources (Taiwo 2012). The viral pathogens also can cause a major threat to the spring water.

Groundwater is utilized in residential as well as in industrial water supply systems throughout the world. As a result the quick development of populace and the quick pace of industrialization (Subba Rao 2018) in the recent decades, the demand for fresh water has increased enormously. Most of the advanced horticultural practices involve in the extreme usage of fertilizers causing unhygienic and unsanitary conditions, as a result human health becomes vulnerable (Ramakrishnaiah et al. 2009).

Fast urbanization, particularly in growing nations like India, has affected the provision of quality of water because of its over exploitation and ill-advised waste transfer, particularly in urban zones (Sharma et al. 2017). As per WHO, around 80% of the considerable number of ailments peoples are affected by the water. Once the underground water is defiled, its quality cannot be reestablished by preventing the contamination from the resource. It thus becomes necessary to observe the groundwater quality frequently and find methods to ensure this.

The WQI is one of the foremost efficient tools to convey data on water quality to the affected residents as well as policymakers. In this way, it changes into an authoritative parameter for the appraisal and administration of the groundwater. The WQI is characterized as a grading (Chaurasia et al. 2018) mirroring the combined impact of various parameters present in the groundwater quality (Jamshidzadeh and Barzi 2018). The WQI is computed from the perspective of the appropriateness of groundwater for individual utilization.

The goal of this work is to examine the appropriateness of groundwater for human utilization in view of processed water quality index values. It is noticeable that the quality of groundwater in the selected area to evaluate whether the water is suitable for different purposes like human consumption, agricultural and industrial use. In this investigation, the author has tried to compare the necessary parameters like the physical, chemical and related to the quality of drinking water.

Study area

Palakonda (PLKD) mandal Fig. 1 is one of the rural mandal in Srikakulam district of Andhra Pradesh state, India. It is located 43 km toward (North) from district headquarters of

Srikakulam. It is a mandal headquarter with latitude 18°36′ 20″ E, and longitude 83° 45′ 30″ N. Agriculture, horticulture and livestock are the main sources of employment, most of them performing forced labor, whereas the main industries include food processing, rice mills, stone crushing and mining.

Materials and methodology

The groundwater samples (39) Table 1 were collected during the period of pre-monsoon and post-monsoon seasons during 2013–2016. The groundwater samples were stored in previously cleaned 1000 ml polyethylene bottles and appropriate preservatives are added for further study. All used chemicals are of AR-Grade (Merck, BDH and Qualigens) and the solutions are made with triple distilled water. All these analyses were carried out using APHA methods (APHA 2012). The electrical conductance and pH of the collected water samples were assessed on the spot by using ELICO PE138 water quality analyzer. Chloride ion concentration present in the water samples was determined by argentometric titration using K_2CrO_4 as an indicator. TH, Ca(II) and Mg(II) in the groundwater were determined by using EDTA titration. Magnesium was estimated as the difference between hardness and calcium with the help of mathematical calculations. Turbidity was measured by using Nephelometer (Model 132, Systronics). The chemical constituent total alkalinity was measured by acid titration. F^- was measured using microprocessor-based bunch PH/Ion meter, Cyber scan 2100, Eutech instruments (USA) with fluoride sensitive electrode; NO_2^- was determined by UV-Visible double-beam spectrophotometer (Model AU-2701, Systronics). The statistical summary of physico chemical parameters and its comparison with BIS standards for groundwater samples in Palakonda mandal (PLKD) during pre- and post- monsoons are presented in Table 2.

Water quality index

Drinking water quality index is thought of as a ranking reflecting the amalgamated effect of different drinking water quality parameters on the entire quality of drinking water. The groundwater quality index was computed from the point of view of the suitability of bore water for human utilization. It is assumed that the weights for various drinking water quality parameters are inversely proportional to the standards for the relevant parameters (Ramakrishna et al. 2009). Weighted arithmetic index method of WQI proposed by Brown (1972) has been applied to evaluate the water quality status of the groundwater (Khan and Qureshi 2018; Brown

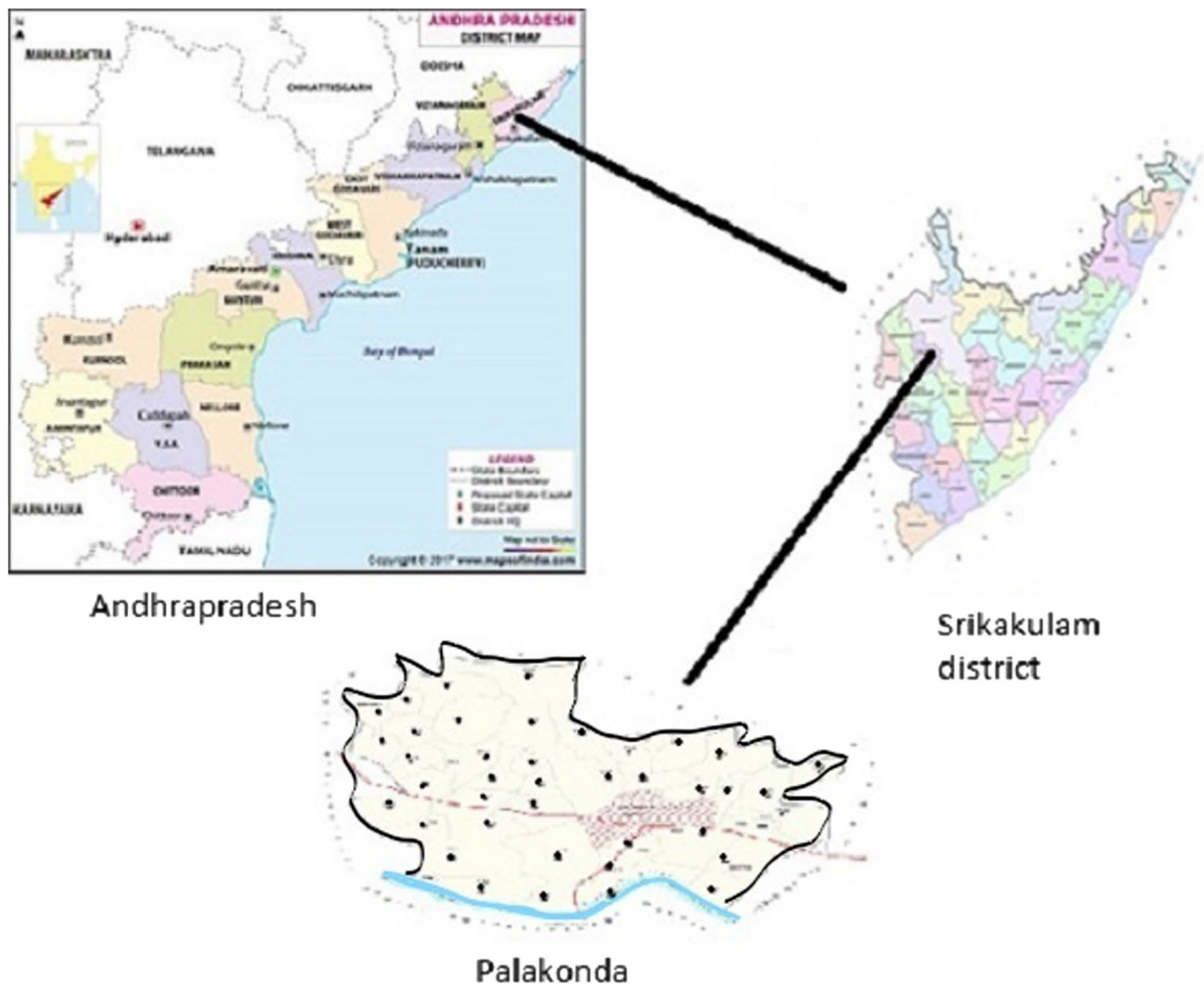


Fig. 1 The geographical location of Palakonda mandal in Srikakulam District of Andhra Pradesh. (Source of these maps are from Google maps)

et al. 1972). Out of 13 parameters analyzed, 10 parameters were taken for calculating WQI (Ramakrishna et al. 2009). Physicochemical parameters including EC, pH, TDS, TH, Ca(II), Mg(II), Cl⁻, F⁻, NO₂⁻ and TA were used to calculate WQI (Table 3) of groundwater in Palakonda mandal. WQI is calculated by using following formula.

$$WQI = \sum QiWi / \sum Wi \tag{1}$$

where *Qi* is the quality rating of *i*th water quality parameter and *Wi* is the unit weight of the *n*th water quality parameter.

The quality rating *Qi* is calculated using the equation

$$Qi = 100 * [(Vi - Vo) / (Vs - Vo)]$$

where *Vi* is the actual amount of *i*th parameter present, *V_i* is the ideal value of the parameter, *V_o* = 0, except for pH

(*V_o* = 7) and *V_s* is the standard permissible value for the *i*th water quality parameter. Unit weight (*Wi*) is calculated using the formula

$$Wi = k / Vi$$

Where *k* is the constant of proportionality and it is calculated using the equation

$$K = 1 / \sum Vs = 1, \quad 2 \dots n$$

Table 1 List of sample stations in Palakonda mandal

Sample	Palakonda mandal		
	Location/villages	Sample	
P ₁	Sirikonda	P ₂₁	Dolamada
P ₂	Velaga vada	P ₂₂	Jamparakota
P ₃	Velaga vada	P ₂₃	Baddumasingi
P ₄	P.R.Rajupeta	P ₂₄	Singupuram
P ₅	Singannavalasa	P ₂₅	Malle veedu
P ₆	Parasurama puram	P ₂₆	Padmapuram
P ₇	N.K.Rajapuram	P ₂₇	Basuru
P ₈	Kondapuram	P ₂₈	V.P.Rajupeta
P ₉	Vadama	P ₂₉	Lovidi Laxmipuram
P ₁₀	Ampili	P ₃₀	Kotipalli
P ₁₁	Annaram	P ₃₁	Gudivada
P ₁₂	Goidapeta	P ₃₂	Garugubilli
P ₁₃	Chinna Mangalapuram	P ₃₃	Lumburu
P ₁₄	PeddaMangalapuram	P ₃₄	Tampatapalli
P ₁₅	Gopalapuram	P ₃₅	Tumarada
P ₁₆	Navagam	P ₃₆	Attali
P ₁₇	Avalangi	P ₃₇	Panukuvalasa
P ₁₈	G.Venkatapuram	P ₃₈	Voni
P ₁₉	Potli	P ₃₉	Chintada
P ₂₀	R.B.R.Peta		

Results and discussion

Physicochemical parameters

pH

It is one of the important factors of groundwater. For successful purification with chlorine, the pH ought to ideally be under eight; in any case, bringing down pH of water (<7) will probably be destructive. Inability to limit consumption can bring about the defilement of drinking water and an antagonistic impact on its taste and the appearance (Singh and Hussian 2016). The pH fluctuates between slightly acidic and slightly alkaline in the mandal. The hydrogen ion concentration ranges in Palakonda mandal from 6.18 to 7.32 with an arithmetic mean value of 6.76 in pre-monsoon and 6.25–7.7 with a mean value of 6.87 during the post-monsoon season, which is within the WHO (WHO 2012) guidelines (6.5–8.5) for drinking water. The variation in pH is attributed to hydro-geochemical factors in the area under study. The variation in pH is represented in Fig. 2.

Electrical conductivity (EC)

The electrical conductance of water samples in Palakonda mandal ranges from 326 to 3839 μS/cm with an average value of 1428.46 μS/cm and 330–3845 μS/cm with an arithmetic mean value of 1434.31 μS/cm during pre-monsoon

Fig. 2 Seasonal variation of pH in selected sample locations in Palakonda mandal

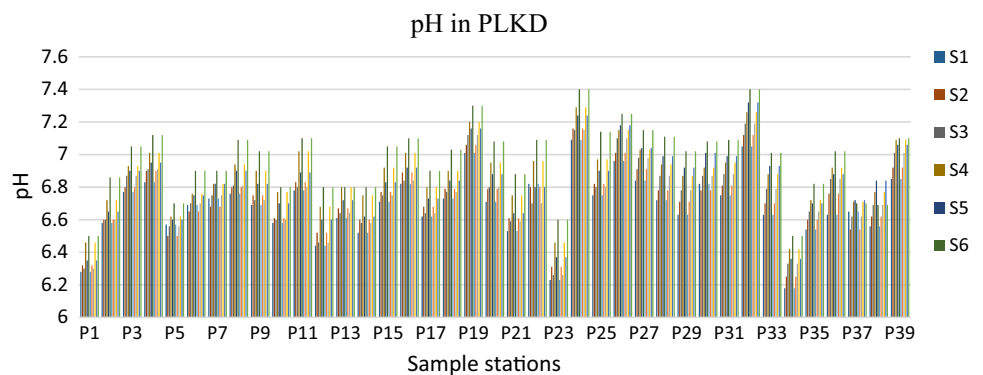


Fig. 3 Seasonal variation of EC in selected sample locations in Palakonda mandal

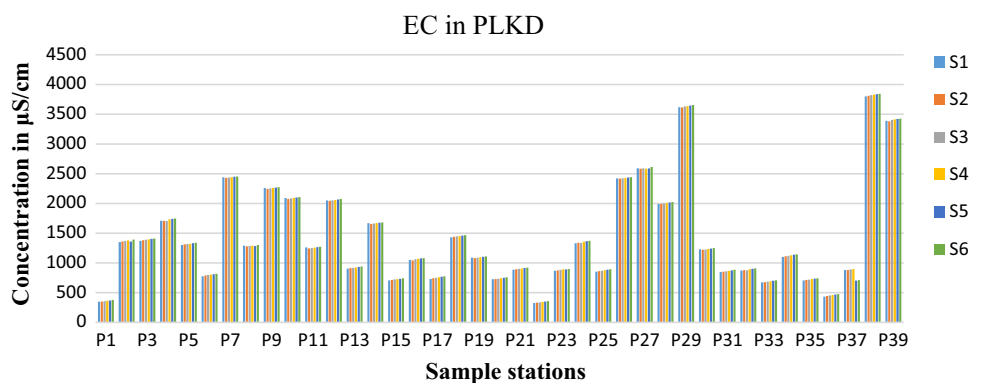
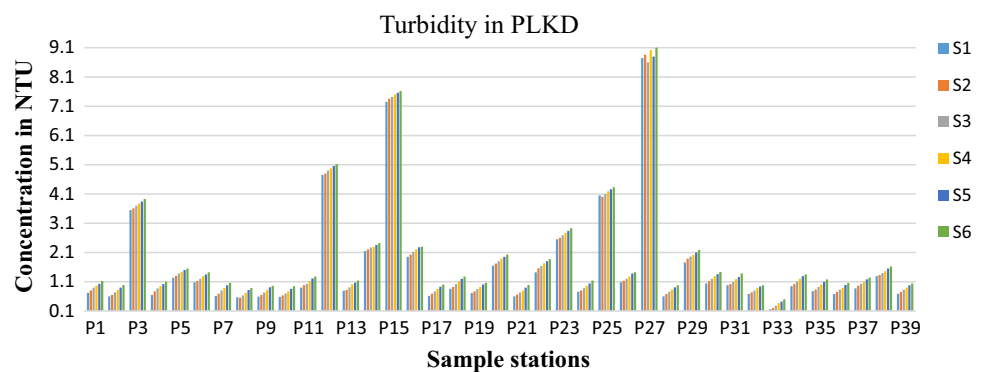


Table 2 Statistical summary of physicochemical parameters and its comparison with BIS standards for groundwater samples in Palakonda Mandal (PLKD) during pre- and post-monsoons

PLKD Parameter	Pre-monsoon				Post-monsoon				BIS
	Mean	Max	MIN	SD	Mean	Max	MIN	SD	
pH	6.76	7.32	6.18	0.22	6.87	7.7	6.25	0.24	6.5–8.5
EC	1428.46	3839	326	860.71	1434.31	3845	330	859.56	500
TURB	1.72	8.8	0.16	1.78	1.80	9.18	0.2	1.80	5
TDS	969.26	2820	222	635.31	977.02	2827	230	632.91	500
TH	450.68	1536	148	249.22	449.60	1526	142	246.57	300
Ca	61.66	114.87	13.46	23.37	59.05	109.31	20.2	20.11	75
Mg	93.05	350.12	19.01	57.77	88.78	341.21	25.22	56.62	30
F ⁻	0.47	1.65	0.01	0.34	0.58	1.77	0.05	0.36	1.5
Cl ⁻	249.62	800	34	176.37	260.68	813	46	175.32	250
DO	8.11	15.5	2.52	3.71	8.08	15.43	3.12	3.66	–
TA	457.29	897	118	181.60	463.94	903	123	181.55	200
Nitrite	0.04	0.45	0	0.11	0.042	0.48	0	0.11	0.02

All units except pH and electrical conductivity are in mg/l, min—minimum, max—maximum, arithmetic mean, *SD* standard deviation

Fig. 4 Seasonal variation of turbidity in selected sample locations in Palakonda mandal



and post-monsoon season, respectively. The variation in EC is represented in Fig. 3.

The measured EC was found to be very high in both seasons. As per the WHO standards (WHO 2012), the acceptable limit of EC in groundwater is 500 mg/L. In Palakonda, 36 samples (92.3%) in both seasons are not within the permissible limit, except P1, P22 and P36; remaining all samples are not within the + limit. It may be due to contamination of the water sample. The EC of groundwater is a direct function of its TDS (Harilal et al. 2004). It is therefore an index representing the total concentration of soluble salts in water (Purandara et al. 2003).

Turbidity

The turbidity of the groundwater is caused by the suspended matter and silt. Recent research has established a correlation with high turbidity and gastrointestinal infections (Singh and

Table 3 Relative weight of parameters in the study area

Parameter	Standards of BSI	Wi
pH	8.5	0.058415
EC	500	0.000993
TDS	500	0.000993
TH	300	0.001655
Ca	75	0.00662
Mg	30	0.016551
F ⁻	1.2	0.413774
Cl ⁻	250	0.001986
Total alkalinity	200	0.002483
Nitrite	1	0.496529
		$\sum W_i = 1$

Hussian 2016). The turbidity of the water samples in the research area has been observed in pre-monsoon within the range of 0.16–8.8 NTU with the mean value of 1.72 NTU

and 0.2–9.18 NTU with an average of 1.80 NTU during the post-monsoon of Palakonda mandal. Variation in the values of turbidity is represented in Fig. 4.

For drinking water as per the BIS (2012) standards, one NTU is the acceptable limit and if there is no alternative source available, five is the permissible limit. In this analysis, 94.8% of the Palakonda groundwater samples were well within the permissible limit, except P15 and P27 samples of Palakonda mandal (Table 1).

Total dissolved solids

Total dissolved solids (TDSs) are measured as inorganic salts and tiny quantities of the organic substance existing in the water. The amount of TDS is one among various key aspects as a standard of potable water. As per WHO (2012), the taste of the water may be effected by the presence of dissolved solids. Moreover, the palatability of drinking water could also be categorized as pleasant (< 300 mg/L), good (300–600 mg/L), fair (600–900 mg/L), poor (900–1200 mg/L) and unsuitable (> 1200 mg/L). In

this analysis, the TDS of analyzed samples is in the range of 222–2820 mg/L with a mean value of 969.26 mg/L in pre-monsoon season and 230–2827 mg/L with a mean value of 977.02 mg/L during post-monsoon. Accordingly only 33 (84.6%) samples of pre-monsoon and 35 (89.7%) post-monsoon samples are showing values greater than 500 mg/L. The variation of TDS is shown in Fig. 5. The water containing high solids may cause laxative or constipation effects (APHA 2012).

Total hardness

The amount of total hardness (TH) in the groundwater is due to minerals containing the Ca²⁺ and Mg²⁺ ions. Hardness of water is due to the contamination caused by dominant presence of limestone, dolomite and chalk mixed in calcium and magnesium carbonates and bicarbonates. The TH is measured as the summation of the hardness contributed by calcium and magnesium ions. In the present analysis, the total hardness of analyzed samples was observed in the range of 148–1536 mg/L with a mean value of 450.68 mg/L (as

Fig. 5 Seasonal variation of TDS in selected sample locations in Palakonda mandal

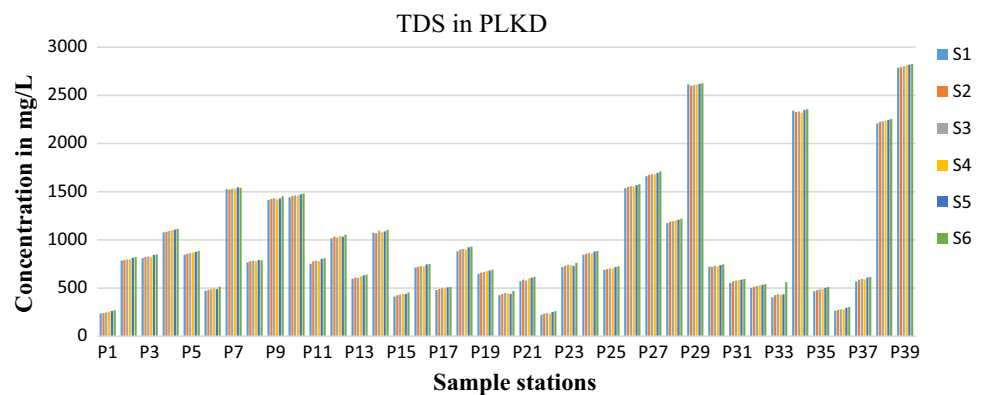


Table 4 Correlation of physicochemical parameters in Palakonda Mandal in December 2013

	EC	pH	Turbidity	TDS	TH	Ca	Mg	F ⁻	Cl ⁻	DO	Total alkalinity	Nitrite
EC	1.00											
pH	0.12	1.00										
Turbidity	0.10	0.00	1.00									
TDS	0.89	-0.06	0.05	1.00								
TH	0.79	-0.05	-0.02	0.66	1.00							
Ca	0.06	-0.29	0.16	0.20	0.33	1.00						
Mg	0.82	0.00	-0.05	0.65	0.98	0.15	1.00					
F ⁻	0.24	0.13	0.20	0.16	0.03	-0.30	0.09	1.00				
Cl ⁻	0.97	0.02	0.07	0.89	0.81	0.16	0.82	0.17	1.00			
DO	0.22	0.11	-0.06	0.34	0.06	0.23	0.02	0.05	0.29	1.00		
Total alkalinity	0.70	0.47	0.18	0.47	0.41	-0.35	0.49	0.42	0.54	-0.05	1.00	
Nitrite	0.75	0.05	0.10	0.71	0.62	0.09	0.63	0.18	0.70	0.30	0.44	1.00

Fig. 6 Seasonal variation of TH in selected sample locations in Palakonda mandal

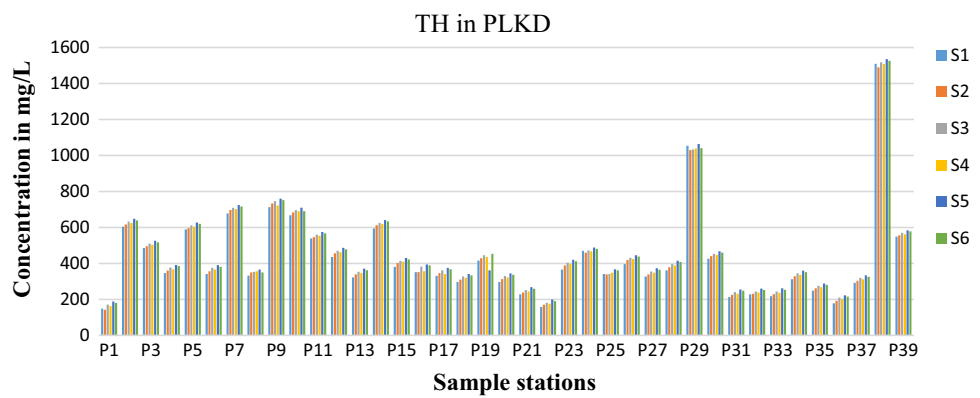


Table 5 Correlation of physicochemical parameters in Palakonda mandal in June 2014

	EC	pH	Turbidity	TDS	TH	Ca	Mg	F ⁻	Cl ⁻	DO	Total alkalinity	Nitrite
EC	1.00											
pH	0.13	1.00										
Turbidity	0.11	0.04	1.00									
TDS	0.89	-0.03	0.05	1.00								
TH	0.80	-0.07	-0.01	0.66	1.00							
Ca	0.07	-0.23	0.17	0.16	0.34	1.00						
Mg	0.79	0.00	-0.01	0.63	0.95	0.17	1.00					
F ⁻	0.25	0.14	0.19	0.17	0.05	-0.28	0.10	1.00				
Cl ⁻	0.97	0.04	0.07	0.89	0.81	0.17	0.78	0.19	1.00			
DO	0.22	0.12	-0.06	0.35	0.05	0.20	0.08	0.08	0.29	1.00		
Total alkalinity	0.70	0.45	0.18	0.48	0.41	-0.31	0.46	0.42	0.54	-0.05	1.00	
Nitrite	0.74	0.09	0.10	0.71	0.60	0.10	0.65	0.18	0.70	0.30	0.43	1.00

CaCO₃) and from 142 to 1526 mg/L with a mean value of 449.60 mg/L (as CaCO₃) during the pre-monsoon and post-monsoon seasons, respectively. The mean value of hardness was found above the acceptable limit (300 mg/L) of BIS (2012). Accordingly only 8 (20.5%) pre- and post-monsoon samples have values lower than 300 mg/L. The high TH leads to heart disease and kidney stone (Lalitha et al. 2004) formation of sludge and scales and decays pipes. It inhibits the cleansing action of soaps and detergents. Variation of total hardness is shown in Fig. 6.

Calcium

The presence of calcium in groundwater is due to natural leaching of minerals like limestone, dolomite, gypsum, and anhydrides. Ca²⁺ is a foremost cation present in water that affects water hard. Calcium is found in human body, in bones and teeth, and is an essential element in the body. Due to the inadequate amounts of calcium the risk of osteoporosis, nephrolithiasis (kidney stones), colon cancer, high blood

pressure and stroke, coronary artery disease, insulin resistance and obesity also increase (Howladar et al. 2018)

Concentration of calcium ions in the study area is observed from 13.46 to 114.87 mg/L with mean value of 61.66 mg/L in pre-monsoon and 20.2–109.31 mg/L with an average of 59.05 mg/L during post-monsoon season. As per WHO (2012), and BIS (2012) standards, the limit of calcium content in drinking water is acceptable as 75 mg/L. In the pre-monsoon 17 (43.5%) and in post-monsoon 11 (28.2%) samples are above the standard prescribed. The variation of calcium in the groundwater of Palakonda mandal is shown in Fig. 7.

Magnesium

Magnesium is another most abundant inorganic ion present in water (Howladar et al. 2018). Ca²⁺ and Mg²⁺ ions are generally derived from the carbonate minerals, for example, calcite and dolomite. Magnesium ion concentration in the groundwater samples is in the range 19.01–350.12 mg/L with mean value of 93.05 mg/L in pre-monsoon and

Table 6 Correlation of physicochemical parameters in Palakonda Mandal in December 2014

	EC	pH	Turbidity	TDS	TH	Ca	Mg	F ⁻	Cl ⁻	DO	Total alkalinity	Nitrite
EC	1.00											
pH	0.13	1.00										
Turbidity	0.11	0.04	1.00									
TDS	0.89	-0.03	0.05	1.00								
TH	0.80	-0.07	-0.01	0.66	1.00							
Ca	0.07	-0.23	0.17	0.16	0.34	1.00						
Mg	0.79	0.00	-0.01	0.63	0.95	0.17	1.00					
F ⁻	0.25	0.14	0.19	0.17	0.05	-0.28	0.10	1.00				
Cl ⁻	0.97	0.04	0.07	0.89	0.81	0.17	0.78	0.19	1.00			
DO	0.22	0.12	-0.06	0.35	0.05	0.20	0.08	0.08	0.29	1.00		
Total alkalinity	0.70	0.45	0.18	0.48	0.41	-0.31	0.46	0.42	0.54	-0.05	1.00	
Nitrite	0.74	0.09	0.10	0.71	0.60	0.10	0.65	0.18	0.70	0.30	0.43	1.00

Fig. 7 Seasonal variation of Ca in selected sample locations in Palakonda mandal

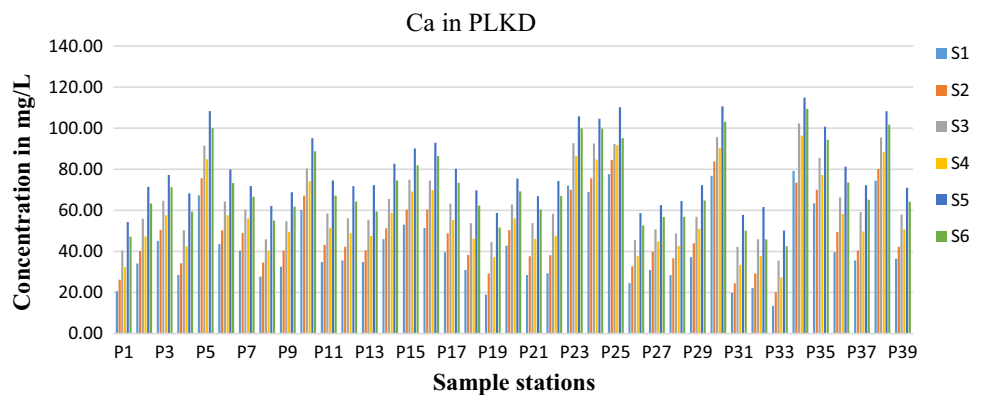


Table 7 Correlation of physicochemical parameters in Palakonda mandal in June 2015

	EC	pH	Turbidity	TDS	TH	Ca	Mg	F ⁻	Cl ⁻	DO	Total alkalinity	Nitrite
EC	1.00											
pH	0.15	1.00										
Turbidity	0.10	0.03	1.00									
TDS	0.89	-0.01	0.05	1.00								
TH	0.80	-0.06	-0.02	0.66	1.00							
Ca	0.04	-0.29	0.14	0.18	0.31	1.00						
Mg	0.79	0.02	-0.01	0.64	0.95	0.16	1.00					
F ⁻	0.29	0.18	0.18	0.18	0.09	-0.32	0.13	1.00				
Cl ⁻	0.97	0.05	0.07	0.89	0.81	0.14	0.78	0.22	1.00			
DO	0.22	0.15	-0.06	0.35	0.05	0.22	0.11	0.08	0.29	1.00		
Total alkalinity	0.69	0.44	0.18	0.48	0.41	-0.36	0.44	0.47	0.54	-0.05	1.00	
Nitrite	0.75	0.12	0.21	0.71	0.56	0.05	0.62	0.28	0.68	0.29	0.48	1.00

25.22–341.21 mg/L with mean value of 88.78 mg/L during post-monsoon in the study area. According to the standards of BIS (2012), the acceptable limit of Mg²⁺ concentration

is 30 mg/L for drinking water. According to BIS standard limits, all the samples in the study area during two seasons

Fig. 8 Seasonal variation of Mg in selected sample locations in Palakonda mandal

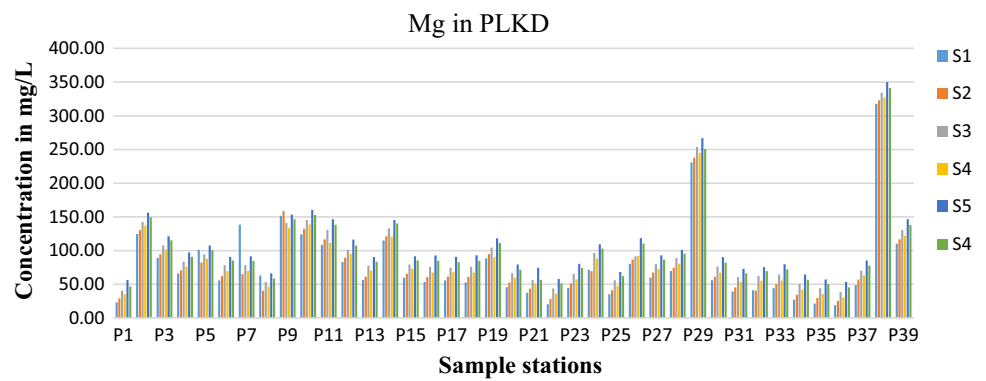
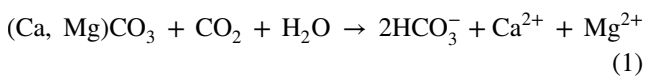


Table 8 Correlation of physicochemical parameters in Palakonda Mandal in December 2015

	EC	pH	Turbidity	TDS	TH	Ca	Mg	F ⁻	Cl ⁻	DO	Total alkalinity	Nitrite
EC	1.00											
pH	0.24	1.00										
Turbidity	0.10	0.00	1.00									
TDS	0.89	0.08	0.05	1.00								
TH	0.80	0.00	-0.01	0.66	1.00							
Ca	-0.01	-0.29	0.11	0.13	0.30	1.00						
Mg	0.79	0.10	-0.02	0.64	0.95	0.14	1.00					
F ⁻	0.28	0.28	0.17	0.18	0.09	-0.35	0.12	1.00				
Cl ⁻	0.97	0.15	0.07	0.89	0.82	0.09	0.78	0.21	1.00			
DO	0.22	0.31	-0.06	0.35	0.06	0.20	0.11	0.07	0.29	1.00		
Total alkalinity	0.69	0.51	0.18	0.48	0.41	-0.39	0.44	0.47	0.54	-0.05	1.00	
Nitrite	0.73	0.19	0.26	0.69	0.53	0.00	0.58	0.31	0.67	0.29	0.50	1.00

are above the acceptable limit. Variation of magnesium is shown in Fig. 8.

Concentration of Mg²⁺ ion in groundwater samples in the research area is quite excessive as relative to Ca²⁺ ion concentration; Mg²⁺ concentration is mainly because of weathering and leaching of magnesium minerals (Kumar et al. 2009).



Fluoride

Fluoride is present in all types of natural water at various concentrations. The concentration of fluoride in drinking water is limited by solvency of the fluorite, so that it should be limited to 3.1 mg/l in the presence of 40 mg/l calcium. In the absence of calcium in solution that allows higher fixations to be stable (Singh and Hussian 2016). Excess of fluoride intake causes different sorts of fluorosis, essentially dental and skeletal fluorosis. As per the BIS (2012)

recommendations, 1 mg/L is acceptable limit and 1.5 mg/L is permissible limit for fluoride in drinking water. Groundwater samples collected in the study area showed a high concentration of fluoride in the post-monsoon period (Narsimha and Rajitha 2018), highest value of fluoride in post-monsoon is 1.77 mg/L, whereas in the pre-monsoon it was 1.65 mg/L.

Fluoride concentration of all groundwater samples in Palakonda mandal varied from 0.01 to 1.65 mg/L with an arithmetic mean value of 0.47 mg/L during pre-monsoon and 0.05–1.77 mg/L with a mean value of 0.58 mg/L during post-monsoon season. According to BIS (2012) and WHO (2012), samples P27 and P33 have more fluoride concentration than the acceptable limit (Kumar et al. 2015a, b). The remaining samples were well within the acceptable limit. The variation of fluoride in the research area is shown in Fig. 9.

Chloride

Due to weathering and leaching of sedimentary rocks and soils, the dissolved salts get deposited; hence, chloride is observed in groundwater (Kumar et al. 2015a, b). Chloride

Table 9 Correlation of physicochemical parameters in Palakonda mandal in June 2016

	EC	pH	Turbidity	TDS	TH	Ca	Mg	F ⁻	Cl ⁻	DO	Total alkalinity	Nitrite
EC	1.00											
pH	0.04	1.00										
Turbidity	0.11	0.04	1.00									
TDS	0.89	-0.10	0.05	1.00								
TH	0.79	-0.08	-0.01	0.65	1.00							
Ca	0.02	-0.12	0.10	0.15	0.30	1.00						
Mg	0.79	-0.07	-0.02	0.63	0.95	0.16	1.00					
F ⁻	0.28	0.11	0.18	0.20	0.09	-0.33	0.14	1.00				
Cl ⁻	0.97	-0.04	0.07	0.89	0.81	0.12	0.78	0.22	1.00			
DO	0.21	0.02	-0.06	0.35	0.05	0.20	0.10	0.08	0.29	1.00		
Total alkalinity	0.69	0.37	0.18	0.47	0.41	-0.38	0.45	0.47	0.54	-0.05	1.00	
Nitrite	0.73	-0.02	0.30	0.68	0.52	0.00	0.56	0.33	0.66	0.26	0.51	1.00

Fig. 9 Seasonal variation of F⁻ in selected sample locations in Palakonda mandal

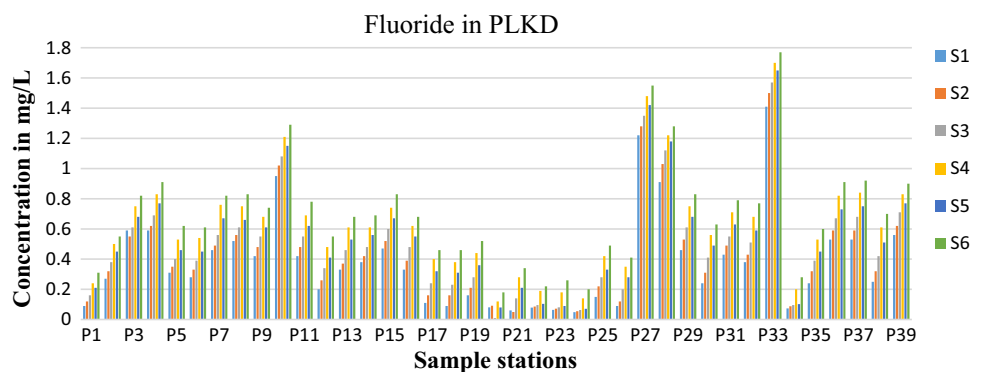
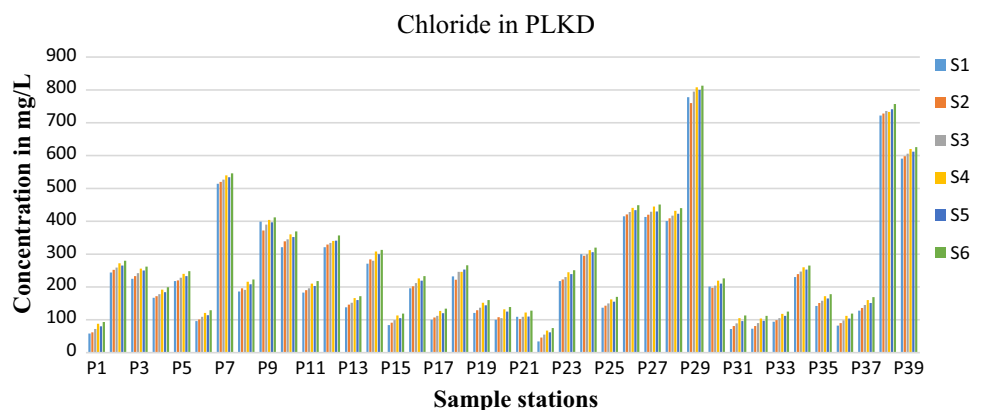


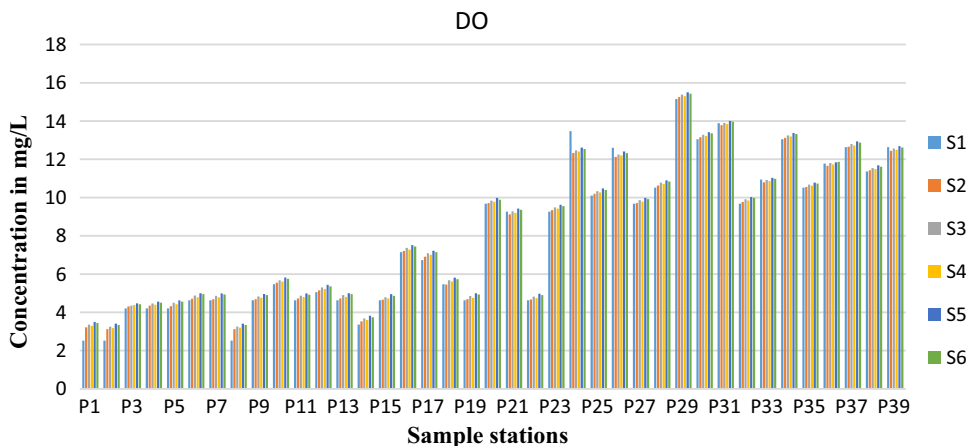
Fig. 10 Seasonal variation of Cl⁻ in selected sample locations in Palakonda mandal



is frequently appended to sodium, as sodium chloride. NaCl adds a salty flavor to the water. The concentration of Cl⁻ in the groundwater samples of Palakonda mandal varied in the range 34–800 mg/L with an average of 249.62 mg/L and from 46 to 813 mg/L with an average value of 260.68 mg/L during before monsoon and post-monsoon, respectively. When compared to pre-monsoon, in post-monsoon the chloride content increased. According to BIS (2012), the chloride limit in potable water has

been acceptable as 250 mg/L. In pre-monsoon 14 samples (35.8%) and 17 samples (43.5%) in post-monsoon were exceeded and remaining samples were within the standard limits of BIS. Increased level of chloride in groundwater may be harmful to persons suffering from kidney and heart problems. (WHO 2012; Kuppuraj et al. 2012). Variation of chloride in research area is shown in Fig. 10.

Fig. 11 Seasonal variation of DO in selected sample locations in Palakonda mandal



Dissolved oxygen

The dissolved oxygen is a vital parameter which is essential to the metabolism of all aquatic organisms. In the present analysis, according to the WHO (2012), BIS (2012) guidelines, 53.8% of samples found to have a DO concentration more than 6 mg/L that indicates the groundwater in the study area is free of the organic matter and pollution. Therefore, it is obvious that the groundwater was suitable for drinking in such locations in Palakonda mandal, as the people of Palakonda mandal depend on groundwater sources mainly for drinking; further, it can also be used for irrigation purposes. Variation of DO in research area is shown in Fig. 11.

Total alkalinity (TA)

Total Alkalinity (TA) of groundwater provides an indication of natural salts present in the groundwater. The alkalinity of water is its ability to neutralize the acid and usually it is due to the presence of bicarbonates, carbonates and hydroxide compounds of calcium, sodium, and potassium (Kundu and

Nag 2018). TA varied in the groundwater samples of the present study area from 118 to 897 mg/L (as CaCO₃) with an average of 457.29 mg/L (as CaCO₃) in pre-monsoon; during post-monsoon the values are varied from 123 to 903 mg/L (as CaCO₃) with an average of 463.94 mg/L (as CaCO₃). As per the BIS (2012), the permissible limit of TA in the groundwater is 200 mg/L. The TA values for all the investigated samples in research area were observed to be more in alkalinity in both the seasons except P1, P23, and P34 samples are within the prescribed range. Water with minimal alkalinity can cause corrosiveness and causes irritation to the eyes. High alkalinity water has a soft drink like taste, can dry out the skin and cause flaking on appliances, fittings and the entire water distribution system (Howladar et al. 2018). Variation of alkalinity in the research area is shown in Fig. 12.

Nitrite

Nitrite concentrations are found to be in the range of 0.011–0.45 mg/L in pre-monsoon and from 0.011 to 0.48 mg/L during post-monsoon. The desirable limit for

Fig. 12 Seasonal variation of TA in selected sample locations in Palakonda mandal

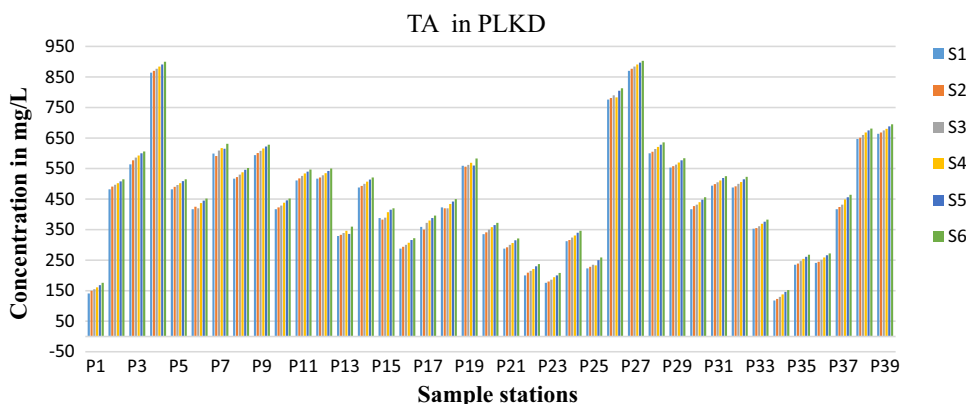
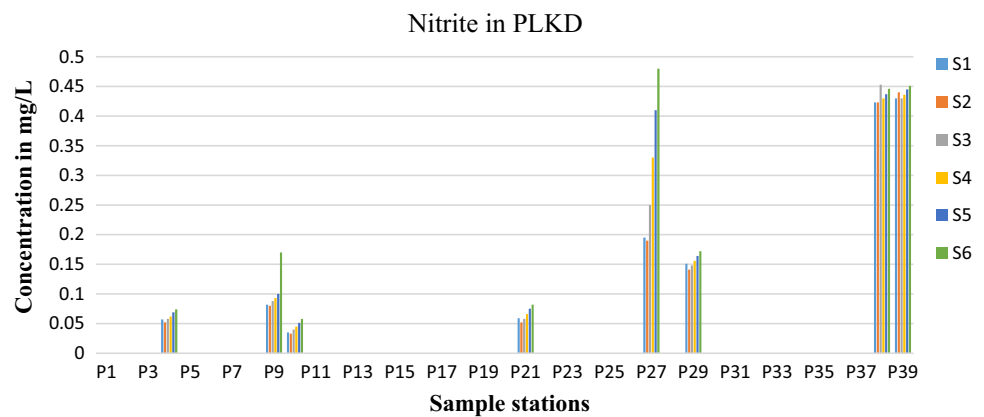


Fig. 13 Seasonal variation of Nitrite in selected sample locations in Palakonda mandal



nitrite is 0.02 mg/L. Nitrite concentrations over 1 mg/L should not be used for infant feeding (Ahamad et al. 2018). In the present analysis, all the samples are within the acceptable limit. Variation of nitrite in PLKD mandal is shown in Fig. 13.

Phenol

Phenol in the groundwater of the present study area is found to be below the detection limits, and it is inferred that the water is free from phenol contamination (Kumar et al. 2015a, b).

Water quality index

WQI was computed using weighted arithmetic mean method as mentioned earlier. The variations of WQI of the groundwater are in the range 20.20–34.20 in selected locations in Palakonda mandal. The calculated value of WQI shows that the groundwater is grouped into the category of water quality, which is good for drinking as suggested by Brown et al. (1972) which indicates that it is fit for domestic as well as irrigation and industrial purpose.

Correlation

The degree of linear correlation between any two parameters of water quality is measured by a simple correlation coefficient (R^2). In the present analysis, the following classifications were used: perfectly correlated ($R^2 = 1$), very strongly correlated ($\pm 0.9 \leq R^2 \leq 1$), strongly correlated ($\pm 0.7 \leq R^2 < \pm 0.9$), moderately correlated ($\pm 0.5 \leq R^2 < \pm 0.7$), and ($R^2 < \pm 0.5$) as poorly correlated (Sajobi 2016).

In Palakonda mandal, the correlation between the physico-chemical parameters (Tables 4, 5, 6, 7, 8, 9) are calculated, calcium, DO, and NO_2^- are did not strongly correlated with

any of the parameters. pH is poorly correlated with TA. EC is very strongly correlated with Cl^- , strongly correlated with TDS, TH, Mg, NO_2^- and moderately correlated with TA. TDS is strongly correlated with Cl^- , NO_2^- , and moderately with TH, and Mg. However, TDS is high due to the presence of mostly dissolved salts of Mg. Total hardness is very strongly correlated with Mg, and strongly correlated with Cl^- and moderately with NO_2^- . It means that hardness was mainly attributed to the dissolved Mg salts. Mg had a strong correlation with chloride, moderately with NO_2^- which also implies that the groundwater hardness is permanent in nature.

Conclusion

During the period of the study, the computed WQI values range from 20.20 to 34.20 in Palakonda mandal. During this period of the study, the quality of water availability is decreasing due to lack of sanitation facilities and domestic sewage and seepage runoffs. The value of WQI in the study area is affected due to increasing the concentrations of TDS, TH, Mg and fluoride in the groundwater. The outcome of the correlation study clearly showed that a strong positive correlation between magnesium and chloride is vastly related to each other and that the water hardness is permanent; moreover, the amount of fluoride in P27 and P33 samples has exceeded the fluoride concentration than the acceptable limit. The analysis of the results exhibits that the WQI for the groundwater of the selected locations requires some pre-treatment prior to utilization and must be protected against the contamination hazards.

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