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RESEARCH ARTICLE

DETERMINATION OF WATER QUALITY INDEX OF THE GROUND WATER IN THE VILLAGES OF THE KOTHACHERUVU MANDAL, ANANTAPUR DISTRICT, ANDHRA PRADESH, INDIA ON A GIS PLATFORM

[1]Ganesh, K. M., [2]Suryanarayana, G. and [*,1]Chelli Janardhana

[1]Department of Chemistry, Sri Sathya Sai Institute of Higher Learning, Prashanti Nilayam, Puttaparthi, Anantapur District, Andhra Pradesh, India
[2]Environmental Protection Training and Research Institute, Hyderabad, Telangana State, India

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ABSTRACT

There has been an unprecedented increase in groundwater withdrawal around the world on account of tremendous agricultural and industrial expansion leading to severe degradation of groundwater quality and quantity. There is an imminent need to implement efficient water management systems aided by effective water quality monitoring programs. Tools like Water Quality Index (WQI) which represents the combined influence of individual water quality parameters supported by the Geographical Information System (GIS) helps the environmentalists and policy makers to make effective predictions and decisions. The objective of the current study was to monitor, evaluate and classify the water types based on WQI and GIS mapping to assess the drinking water quality in Kothacheruvu mandal of Anantapur District, Andhra Pradesh. The physico-chemical analysis of bore-well water samples were done and compared with the drinking water standards set by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS). The latitude and longitude of the sampling location were taken to develop geospatial maps on the GIS platform. Fluoride and Nitrate were found to be the main contaminants in the region. WQI calculations revealed that 83.3% of the groundwater in the study area was unfit for drinking purpose without appropriate water pre-treatment.

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INTRODUCTION

Groundwater is by far the largest unfrozen volume of fresh water in the world. The rapid growth in population, indiscriminate industrial and agricultural expansion has led to severe exploitation of this natural resource. On a global level, the key issue that needs to be addressed is the sustainability of groundwater by putting a check on the rate of its depletion and pollution from anthropogenic cause (Jac van der gun, 2012). The unprecedented climate change has resulted in major alterations to the hydrological cycle which has resulted in random, untimely and scanty rainfalls in several regions of the world leading to an alarming decline of groundwater level in the sub surface region (UNDESA, 2013). In a country like India where nearly 17.5% of the world population is residing (Worldometers, 2015), groundwater caters to 65% irrigation water and 85% of drinking water requirements of the country (Paul Wyrwoll, 2012).

***Corresponding author: Chelli Janardhana,**
Department of Chemistry, Sri Sathya Sai Institute of Higher Learning, Prashanti Nilayam, Puttaparthi, Anantapur District, Andhra Pradesh, India.

Historically, the drinking water supply in rural India was never under the government's sphere of direct influence. The local community used to manage the open wells, private wells, ponds and small-scale irrigation reservoirs as the main source of drinking water. The Government of India's involvement in the rural drinking water supply sector started only in 1972-73 with the launch of Accelerated Rural Water Supply Program (ARWSP) (Rajwanth Sandu, 2010). In 2010, National Rural Drinking Water Program came into existence with the objective of providing sustainability of water supply, portability, adequacy, convenience and affordability with equity(Joydeep, 2013). With both the quality and quantity of groundwater spiraling down to a critical condition, it is imminent that we invoke and implement effective water quality monitoring and management strategies.

Water quality analysis is one of the most important issues in groundwater studies. With the aid of ground water chemistry and guideline values set for each water quality parameter by the international agencies like W.H.O as the standard reference, WQI can be calculated to decide if the given water sample is fit for human consumption (Ganeshkumar and Jaideep, 2011). WQI reflects the composite influence of individual parameters on the overall quality of the water (Mitra, 1998). Once the chemical constituents are determined by various analytical instruments and the WQI is calculated, we need a database that is capable of managing this huge set of information efficiently. GIS is one such information management system which provides a spatial projection of these chemical parameters, guiding us to identify critical patterns and co-relations to diagnose the source of pollution, be it geo-genic or anthropogenic (Selvam *et al*., 2014). The representation of the concentration gradients of the chemical constituents in the water quality map is one of the main applications of GIS (Skubon, 2005).

In the present study the water samples were collected from the bore-well as per the American Public Health Association (APHA) guidelines and were assessed for drinking water quality in 24 villages of Kothacheruvu mandal of the Anantapur District. Water quality index was calculated by selecting suitable water quality parameters which play a dominant role in determining water quality as per the weighted arithmetic mean method after giving appropriate weight age to the selected parameters. The concentration gradients of fluoride, nitrate, TDS and WQI can be seen in the geospatial maps developed by ArcGIS 9.2 software. The source of nitrate pollution can be attributed to excessive fertilizer usage and improper sewage disposal or leakage in septic tanks of certain villages. The concentration gradient of fluoride ion in the study area shows prospective areas to tap new groundwater sources where there is relatively less activity of fluoride leaching into the groundwater.

MATERIALS AND METHODS

The study area is located in the drought prone area of Anantapur District in the Rayalseema belt of Andhra Pradesh (Fig. 1). The Kothacheruvu mandal spans from 14°6.746' N to 14°15.892' N latitude and stretches across 77°40.471' E to 77°47.140' E longitude, covering an area of about 214.81 sq. kms. The fresh groundwater samples were collected in the pre-monsoon period from the bore-wells of 24 villages of Kothacheruvu mandal as described in APHA (2001). The pH was measured with microprocessor based pH meter (Labmate model), the TDS and EC with digital TDS meter, Systronics 308 model. The fluoride, nitrate, sulphate, chloride, phosphate, calcium, magnesium, sodium, potassium were measured with Ion Chromatography System of Metrohm Basic IC plus 883 Model and iron with Atomic Absorption Spectrometer (Varian model). The latitude and longitude was recorded in Terra Sync software supported Trimble handheld set. Arc GIS 9.2 software was used to map the geospatial profile of the groundwater parameters. The Inverse Distance Weight (IDW) interpolation method was applied to show the concentration gradients of various chemical parameters in the study area.

Calculating the Water Quality Index

The computation of WQI reduces the large amount of water quality data into a single numerical value. The BIS (2009) and WHO (2011) guideline values have been taken as the standard reference. The WQI of the groundwater samples of Kothacheruvu mandal has been calculated here using the relative weight of 8 water quality parameters as shown in Table 1.

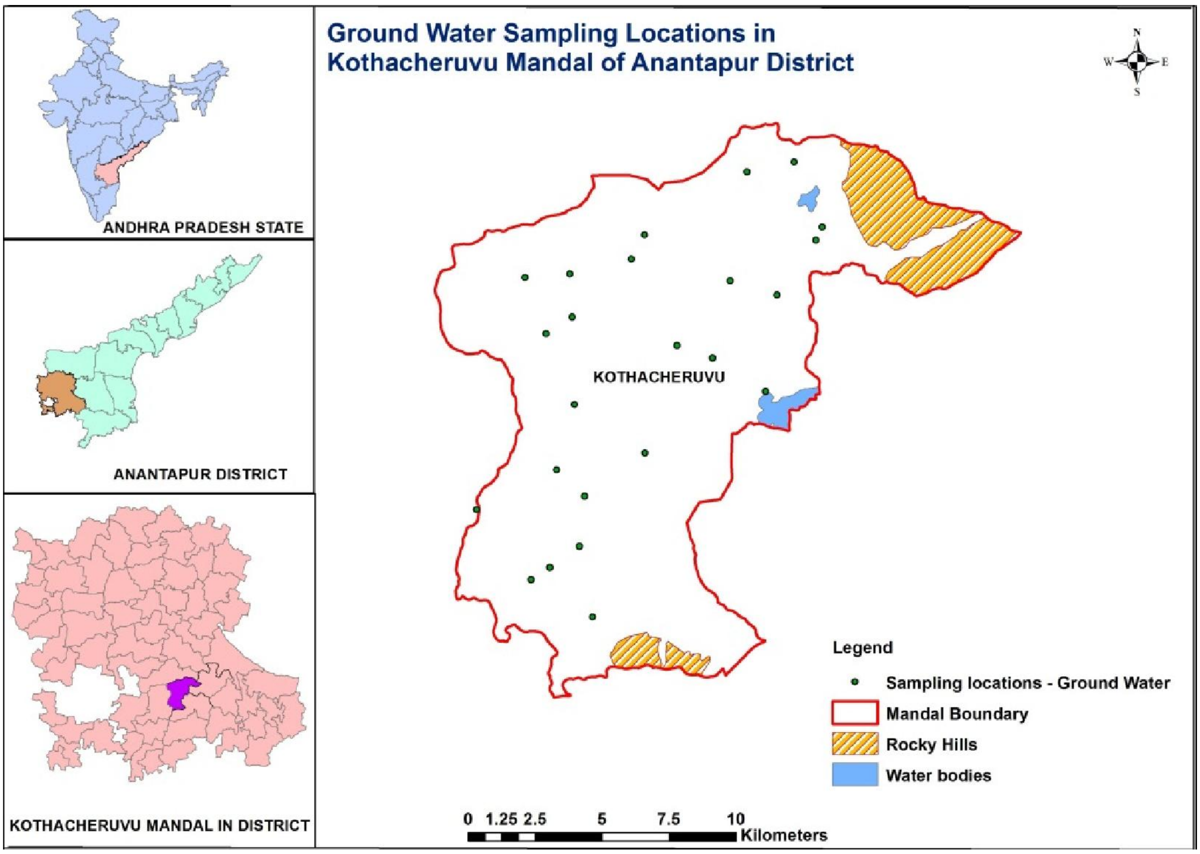

Fig. 1. The base map of the study area showing sampling locations

Table 1. BIS and WHO standards and relative weights of chemical parameters used to determine WQI

Chemical parameters	BIS (ppm)	WHO (ppm)	weight (w_i)	Relative weight $W_i= w_i/(\sum_{i=0}^{n} \mathbf{wi})$
Total Dissolved salts	500	500	5	0.20
Total Alkalinity	600	-	1	0.04
Total Hardness	300	300	2	0.08
Fluoride	1.2	1.5	5	0.20
Nitrate	45	50	5	0.20
Chloride	250	250	2	0.08
Sulphate	150	250	3	0.12
Sodium	200	200	2	0.08
			$\sum_{i=0}^{n} \text{wi} = 25$	$\sum_{i=0}^{n} \text{Wi} = 1$

Relative weight is calculated by the formulae: $W_i = w_i / (\sum_{i=0}^{n} \text{wi})$, where W_i is relative weight, w_i is the weight age of each parameter and n is the number of parameters used to calculate WQI. The selection of parameters for the determination of WQI should be done discreetly so that the parameters that play a significant role in influencing the hydo-chemistry of the water get appropriately accentuated. Involving too many parameters leads to the reduction of orthogonality between certain parameters, leading to redundancy. This also results in the undesirable masking of the weight age of important parameters which deserve higher relative weights. In the next step we determine the quality rating of each parameter by the formula: $q_i = (C_i /S_i)*100$, where q_i is the quality rating, C_i is the concentration of the parameter and S_i is the guideline value as prescribed by WHO or BIS. For the calculation WQI, the sub-index (SI_i) has to be determined which is derived by the formulae: $SI_i = W_i \times q_i$. The WQI is derived by the summation of all the SI_i, as shown by the formulae: $WQI = \Sigma SI_i$. WQI is used to classify the water quality type for domestic consumption. Table 2 shows the concentration of parameters (nitrate ion, fluoride ion and TDS) which were given the maximum weight age of 5 (In the scale of 1 to 5) to determine the WQI.

1993). Transforming huge sets of hydro-chemical data into spatial projections gives an immediate advantage of identifying the patterns and connection of pollutants and their potential point and non-point sources.

In the current study, the fluoride, nitrate, TDS concentrations and the WQI values for each location were selected as the input parameters and their values were interpolated, with the sampling locations as the geo-reference.

Inverse distance weight (IDW) method has been used for creating a surface grid in ArcGIS.

RESULTS AND DISCUSSION

The concentration range of physiochemical parameters observed for groundwater samples were pH (7.35 to 8.43), Total Dissolved Solids (285 to 1330 mg/l), Total Alkalinity (113.42 to 445.12 mg/l), Total hardness (80 to 680 mg/l), Electrical conductivity(444.6 to 2674.8µS), fluoride (1.04 to 3.40 mg/l), nitrate (3.06 to300.64 mg/l), sulphate (7.59 to 226.8 mg/l), chloride (6.22 to 543.01 mg/l), phosphate (0 to 4.13 mg/l), sodium (48 to 368.29 mg/l), potassium (0.31 to 13.84 mg/l), calcium (9.93 to 112.66 mg/l), magnesium (7.90 to 95.36 mg/l), iron (0.019 to 0.187 ppm) during this study. Out of the above physico-chemical parameters, we have selected eight parameters with significant influence in determining the WQI. The WQI values of the 24 villages in the Kothacheruvu mandal ranges from 45.02 to 254.41. The WQI range, type of water and the percentage of villages in the study area that fall in different categories is shown in Table 3.

Table 3. Classification of water types based on WQI

Range	Type of water	Villages in this category (%)
< 50	Good	4.2
50 to 75	Acceptable in the absence of alternative	12.5
75 to 100	Poor	33.3
100 to 125	Very poor	16.7
125 to 150	Water is unsuitable for drinking	20.8
150<	Harmful for health	12.5

Table 2. Concentration of NO_3^-, F^-, TDS and WQI value of the groundwater samples

Villages	NO_3^-	F^-	TDS	WQI	Villages	NO_3^-	F^-	TDS	WQI
Kothacheruvu	4.326	1.64	513	64.52	Kothadevarapalli	82.054	2.42	347	94.25
Lingareddipalli	111.01	1.04	445	98.31	Meerjapuram	101.5	2.96	649	137.41
Mylepalli	11.279	2.16	480	72.28	Bangaruchinnapalli	38.5	2.07	454	78.34
K.Nagareddipalli	229.95	1.29	1110	213.73	Indlavenkatammapalli	90.184	2.16	744	141.67
Eragampalli	85.811	1.32	879	133.39	Dantulapalli	22.055	2.13	570	90.97
Locherla	126.61	2.19	734	146.27	Kesapuram	3.057	1.42	327	45.02
Sainagar	52.981	1.98	382	80.64	K.Venkatapuram	98.693	1.36	644	116.24
Byrapuram	28.051	1.88	1330	161.24	Narepalli	38.148	2.48	858	124.32
Yerrapalli	113.76	1.44	534	114.22	Bandamidapalli	106.21	2.38	686	132.73
Pothulakuntla	8.309	2.57	555	83.49	Statistical data for the water samples from 24 villages				
Narayanapuram	300.64	1.48	1150	254.41		NO_3^-	F^-	TDS	WQI
Honnurapalli	34.654	3.40	335	84.95	Maximum	300.64	3.40	1330	254.41
Virupapuram	27.843	1.98	285	59.41	Minimum	3.057	1.04	285	45.02
Marakuntapalli	25.114	2.15	541	82.33	Average	75.587	2.02	634.3	113.847
Talamarla	73.353	2.66	671	122.2	Std. Dev.	±71.08	±0.58	±271.9	±48.19

GIS aided water quality assessment

Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields (Goodchild,

The WQI computation shows that 83.3% of water samples in the study area are not fit for domestic consumption with 12.5% of water samples posing direct health threat.

The GIS map in Fig. 2 shows the concentration gradient for the TDS. The western strip of Kothacheruvu mandal and a northern segment shows the TDS in the range from 300 ppm to 600 ppm which is acceptable in the absence of other alternative source for domestic consumption. The TDS of majority of the region falls in the range of 600 ppm to 1000 ppm, with two regions exceeding 1000 ppm. One region is in the middle of Kothacheruvu mandal which is around the village K. Nagareddipalli where the TDS of 1110 ppm was recorded and one in southern part, around the villages of Narayanapuram and Byrapuram where the TDS recorded was 1150 ppm and 1330 ppm respectively. In these two regions as seen in Fig. 2, the groundwater needs a water softening treatment as a pre-treatment prior to any water purification methodology like reverse-osmosis.

The fluoride ion concentration profile as seen in Fig. 3 shows a clear streak of green color which is the region of ground water with fluoride ion concentration within the permissible level of 1.5 ppm as per the WHO guidelines. Large part of the study area falls under the range of 1.5 to 2.5 ppm with few places ranging from 2.5 to 4 ppm.

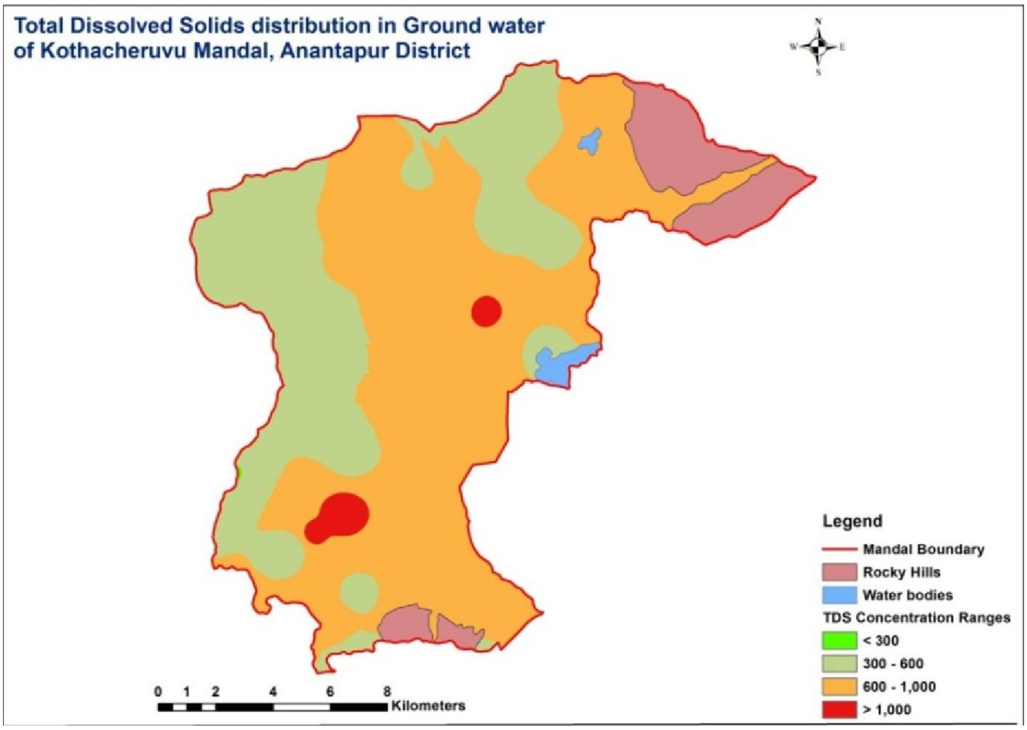

Fig. 2. Geospatial map showing concentration gradient of TDS in the study area

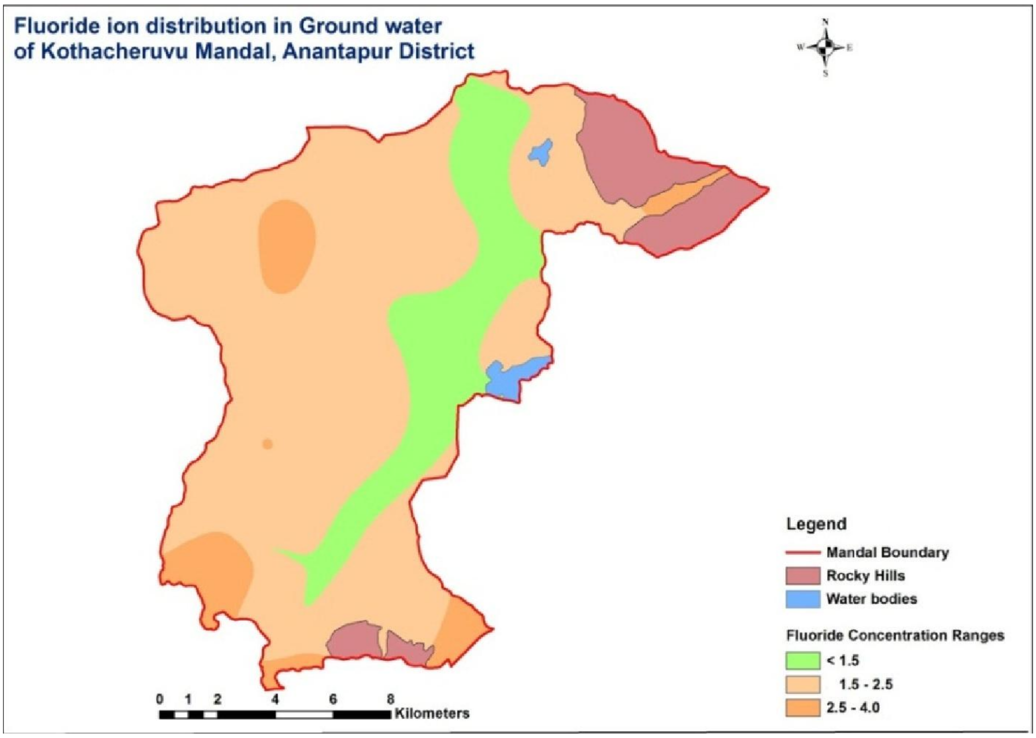

Fig. 3. Geospatial map showing concentration gradient of Fluoride ion in the study area

The nitrate ion concentration as shown in Fig. 4 is high in the middle and southern region of Kothacheruv mandal and to some extent on the northern part next to the hills. The agriculture practise and the animal waste disposal practices of these villages needs to be monitored. The topographical factors also come into play where the general drift of irrigated water that seeps beneath the aquifer may graually move in the regions that is showing high nitrate concentration on account of slope of the ground level.

The geospatial map of the water qaulity index in Fig. 5 clearly show that the groundwater in the two regions, one in the middle and one in the southern segment of the Kothacheruvu mandal is unfit for drinking purpose which can be directly attributed to high nitrate, fluoride and TDS concentration.The WQI of the western strip of Kothacheruv mandal, a few segment in the northern and southern most region along with few regions next to the water body of Kothacheruvu lake are relatively falling in the acceptable category.

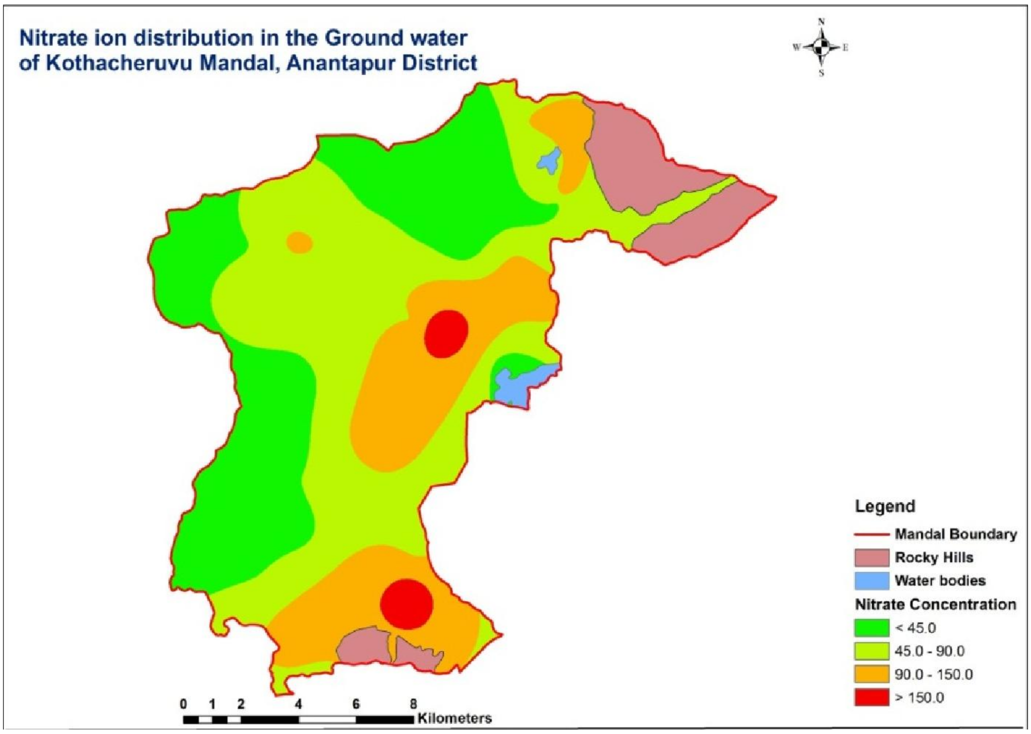

Fig. 4. Geospatial map showing concentration gradient of Nitrate ion in the study area

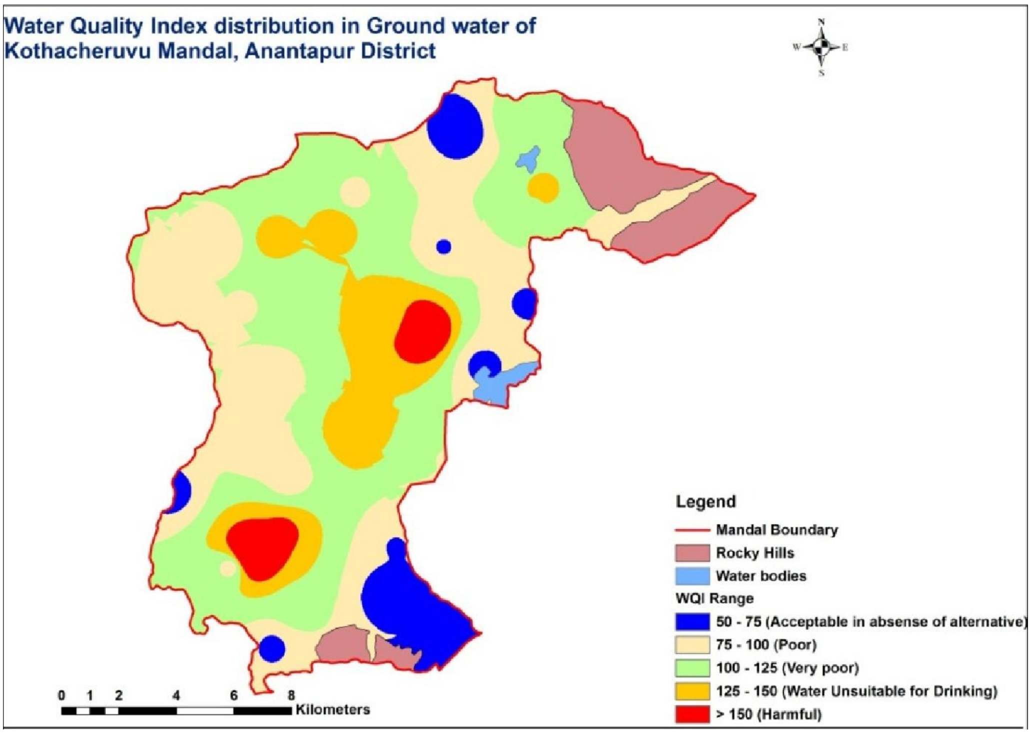

Fig. 5. Geospatial map showing the gradient of WQI value in the study area

The lake water is likely to have an influence in diluting the impact of fluoride and nitrate concentration in the region. These areas of water bodies which are generally dry throughout the year are the potential water catchment areas during the rainy season. Water catchment area is planned based on several factors, primarily the topography of the area. The knowledge of WQI of the region can help the policy makers to prioritize the zones with better WQI as potential sight for water catchment and rainwater harvesting since they have a direct impact on the quality of groundwater.

Conclusion

The poor water quality in the study region can be attributed to high fluoride ion, nitrate ion and TDS concentrations. With 83.3% of water samples in the study area exceeding the acceptable drinking water standards as derived by WQI computation, it is imperative to tap alternate source of drinking water. 71 % of groundwater samples in the study area exceed the WHO guideline value of 1.5 ppm for fluoride, with the highest value of 3.4 ppm recorded in Honnurapalli village. Fluoride ion leaches from geogenic source and based on the concentration gradient drift in the GIS maps, fresh borewell should be dug in regions of less fluoride ion concentration as derived by the IDW method of GIS to tap new source of drinking water. 54% of water samples in Kothacheruvu mandal have nitrate ion levels which exceed the BIS guideline value of 45 ppm. The agriculture practice and sewage disposal methods in the middle and southern part of Kothacheruvu mandal needs to be reviewed as they show very high nitrate concentration which ranges from 150 ppm to 300 ppm. The highest recorded nitrate ion concentration is 300.64 ppm in the Narayanapuram village situated in the southern part of the Kothacheruvu mandal. Based on WQI and GIS map analysis, in the overall groundwater quality assessment of Kothacheruvu mandal, the water quality is very bad in two regions, one in the middle of Kothacheruvu mandal and one in the southern region as shown in the Fig.5. Hence, the order of priority for immediate intervention in groundwater treatment and remediation should be given to villages situated in these regions. In the absence of alternate source, the ground water must be pre-treated before being used for the drinking and other domestic purpose.

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