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Groundwater quality assessment by WQI and GIS tools in the villages of Bukkapatnam Mandal, Anantapur district, Andhra Pradesh (India)

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Abstract-*Groundwater is the main source for drinking water all over the world. With the ever rising demand caused by agriculture and industry, the quality and quantity of groundwater has fallen down to a critical level. Regular water quality monitoring and management of water supply is emerging as a major engineering application today .Water quality index(WQI) is a special tool that represents the combined influence of individual water quality parameters on the overall quality of water, determining its suitability for human consumption. The Geographical Information System (GIS) also provides a unique platform forwater quality assessment as it stores, analyzes and displays spatial data which aids in quick and effective decision making for the environmentalists and policy makers.The main purpose of this study was to monitor, evaluate and classify the water type based on WQI and GIS mapping to assess the drinking water quality in Bukkapatnam Mandal, Anantapur District, Andhra Pradesh which belongs to the rain-shadow region of Rayalseema belt. The water samples were collected from the bore-well and the results of the physico-chemical analysis were compared with the drinking water standards set by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS). The range of physiochemical parameters observed for groundwater were pH (7.44 to 8.27), Total Dissolved Solids (185 to 1570 mg/l), Total Alkalinity(100.58 to 684.80 mg/l), Total hardness(145 to 990 mg/l), Electrical conductivity(288.6 to2949.2µS), fluoride (1.45 to 7.21 mg/l), nitrate (0.72 to190.79 mg/l),sulphate (11.30 to 438.39mg/l), chloride(9.02 to 723.93 mg/l), phosphate(0 to 7.88 mg/l), sodium(19.93 to 318.79 mg/l), potassium (0.39 to 11.49 mg/l), calcium(4 to 240.03mg/l), magnesium(11.86 to 61.12 mg/l), iron(0.023 to 0.125 ppm) during this study. The latitude and longitude of the sampling location were taken to develop geospatial maps on GIS plat form. Water quality index was calculated and the result revealed that 92% of the groundwater in the region was unfit for drinking purpose without appropriate pre-treatment.*

Keywords- *fluoride, nitrate, TDS,GIS,WQI,Bukkapatnammandal*

I. INTRODUCTION

There is a direct and strong inter-relationship between the social, economic, environmental and technological development of a society and the availability of the water resources in that region [1]. This development also places a considerable pressure on water resources, especially the agriculture, energy and industrial sectors, which have a major impact on the use and governance of water [2]. Majority of the world population, especially the developing countries depend on agriculture for their sustenance and survival. Despite the focus on industrialization, agriculture remains the mainstay of Indian economy, with 70% of Indian household in rural area depending on agriculture as their principle means of livelihood [3]. In India, groundwater supports 65% of irrigation water requirement and 85% of drinking water requirement [4]. Supply of safe drinking water by regular water quality monitoring and management of water supply to meet the ever increasing demands of the rising population is emerging as an important engineering application [5]. The community health and wellbeing are intrinsically linked to water quality and quantity management [6].
Groundwater is vulnerable to pollution in rural area due to improper agriculture practices [7] and indiscriminate animal waste and sewage disposal [8].Unlike the urban sector, where environmental services play the role of maintaining high water quality through water treatment facilities [9], the rural sector lacks a mechanism of ensuring a wide ranging assessment of water quality. Water quality assessment provides the base line information on water safety [10], with World Health Organization (WHO) [11] or Bureau of Indian Standards (BIS) [12] guideline values for drinking water as the standard reference. To add to the anthropogenic pollution, the geo-genic mineralswith toxicological impact on human health in certain belts of the aquifer network, leaches down to groundwater with the infiltrating rain water. One of the primary geo-genic pollutants is fluoride which causes dental and skeletal fluorosis [13]. Numerous factors influence the overall ground water quality with their varied degree of impact on human health. It becomes essential to identify the primary contaminants and

demarcate areas where relatively safer sources of drinking water supply can be tapped, even as we design a parallel and effective means of waste disposal to check the groundwater pollution [14].

Groundwater chemistry is used here to quantify the quality of the groundwater with reference to the standards set by WHO and BIS for drinking water. Water Quality Index (WQI) is an important tool to classify groundwater quality based on the normalization method using the weighted average in a given set of samples. It represents the combined influence of individual water quality parameters on the overall quality of water, determining its suitability for human consumption [15].Geographic information system (GIS) is yet another powerful tool for water quality assessment as it stores, analyzes and displays spatial data which aids in quick and effective decision making for the environmentalists and policy makers [16].

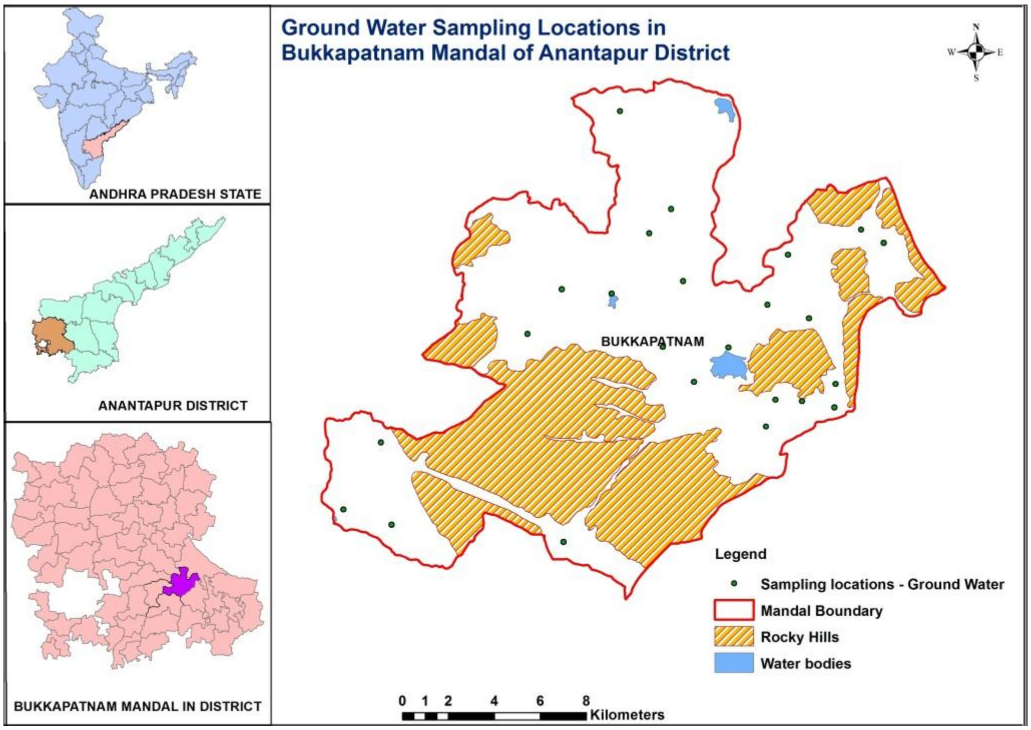

Figure 1. The base map of the Study Area

In the present study the water samples were collected from the bore-wellas per the American Public Health Association (APHA)guidelines [17] and were assessed for drinking water quality in the Bukkapatnam mandal of the Anantapur District. The geospatial maps showing the concentration gradients of fluoride, nitrate, TDS and WQI were developed by ArcGIS 9.2 software. It gave us a geo-spatial distributionof the high contaminant zone, both attributed to geogenic (fluoride) and anthropogenic (nitrate) reasons. 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 groundwater. GIS maps also show a trend in nitrate pollution which can be attributed to excessive fertilizer usage and improper sewage disposal or leakage in septic tanks in certain villages.

II. MATERIAL AND METHODS

The sampling area is located in the southernmost district of the drought prone Rayalseema region of Andhra Pradesh state (Fig.1). The Bukkapatnam mandalextends from 14° 11.15' N to 14° 20.84' N latitude and stretches across 77°49.00'E to 77°59.78' E longitude, covering an area of about 299.67 sq. kms. The fresh groundwater samples were collected during the pre-monsoon periodfrom the bore-wellsof 25 villages of the Bukkapatnam Mandal as per the APHA guidelines.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).

A.Calculating the Water Quality Index (WQI):

The computation of WQI involves three main steps:In the first step,parameters which have a major role in defining the water quality are carefully selected. To avoid redundancy, it is ensured that these parameters are relatively exclusive to each other in their role of influencing water quality. In the current study we have taken TDS (which covers Electrical Conductivity), Total Hardness(which covers Ca^{2+} and Mg^{2+}), Total Alkalinity, F^-,NO_3^-, Cl^-, SO_4^-,and Na^+ to determine the WQI. The second step is to assign weights to each of the parameters based on their role in influencing water quality.This is directly determined by its degree of impact over the human health and palatability. The highest weightage of 5 has been given to parameters like nitrate, fluoride and TDS as they are the primary pollution indicators of this region. Once the weightage for each parameter is given, we calculate the relative weight of each of the parameters by the following equation:

Equation 1: $W_i = w_i/(\sum_{i=0}^{n} wi)$

Where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. The discretion in choosing the number of parameters is also important to keep the relative weight of a more influencing parameter higher thanthe other less influencing parameters. Table [1] shows the relative weight of each parameter.

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

Chemical parameters	BIS (ppm)	WHO (ppm)	Weight (w_i)	Relative Weight $W_i = w_i/(\sum_{i=0}^{n} wi)$
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
			$\sum_{i=0}^{n} wi = 25$	$\sum_{i=0}^{n} Wi = 1$

In the third step, apercentage rating scale is assigned for the quality of each parameters by dividing its measured concentration in each water sample by its respective standards as prescribed by BIS(since it is an Indian scenario in the current study) and the result is multiplied by 100:

Equation 2: $q_i = (C_i/S_i) * 100$,

whereq_i is quality rating, C_i is concentration of each parameter in each samples in ppm and S_i is the drinking water standard as prescribed by the guidelines set by BIS. For computing the WQI, the sub-index (SI_i) is first determined for each chemical parameter by the following formulae:

Equation 3: $SI_i = W_i \times q_i$.

It is then used to determine the WQI as per the following equation:

Equation 4:$WQI = \Sigma SI_i$.

Here SI_i is the sub-index of i^{th} parameter, q_i is the rating based on concentration of i^{th}parameter.The water quality types were determined on the basis of WQI.

B.Geospatial Mapping for water quality assessment on the GIS platform:

GIS is widely used in water quality modeling, monitoring, forecasting, planning and management [18]. It provides a very effective means of graphically conveying complex information patterns with mapped data. Total water quality management has become an important area in engineering applicationswhich is efficiently supportedon a GIS platform.In this study, the coordinates of sampling points were recorded in Terra Sync supported Trimble handheld set. The sampling points are shown in Fig. 1 and sampling location with their respective latitude , longitude along with the chemical parameters which had a major influence in the determination of WQI are listed in table 2.Geospatial mapping of these water parameters were done by using Arc GIS 9.2 software.

Table 2. Name of villages with their Latitude, Longitude and concentrations of NO_3^-, F^-, TDS and WQI value

No	Village	Latitude	Longitude	NO_3^- ppm	F^- ppm	TDS ppm	WQI

1	Janakampalli	14°11'9.13"	77°49'0.51"	52.30	2.33	414	93.96
2	Buchaigaripalli	14°13'5.52"	77°48'46.71"	68.64	1.45	704	116.56
3	Kotlapalli	14°15'36.58"	77°52'21.28"	34.49	4.53	810	148.76
4	Sidharampuram	14°16'39.36"	77°53'11.75"	78.82	2.69	567	125.21
5	Gonipalli	14°16'32.27"	77°54'23.85"	2.04	2.46	399	72.44
6	Rasimpalli Tanda	14°16'48.89"	77°56'7.23"	47.54	3.79	478	122.46
7	Bitruguntapalli	14°15'15.66"	77°55'36.99"	15.45	7.21	683	180.93
8	Kothakota	14°14'25.61"	77°56'21.67"	64.16	3.82	338	118.71
9	Reddivaripalli Tanda	14°13'21.47"	77°58'5.58"	73.73	2.16	185	82.73
10	Madirebailu	14°13'59.21"	77°58'19.23"	70.96	2.71	330	103.14
11	Nyanavaripalli	14°13'47.56"	77°59'44.98"	127.32	2.78	400	135.52
12	Chilakalgeddapalli	14°13'56.68"	77°58'57.71"	55.10	2.63	395	104.13
13	Guruvureddipalli	14°14'20.32"	77°59'46.71"	9.12	4.70	565	130.37
14	Venkatapuram	14°15'53.80"	77°59'9.49"	29.08	5.24	680	157.05
15	Pamdhurthi	14°16'13.95"	77°58'9.49"	0.72	3.05	610	100.43
16	Agraharam	14°15'13.68"	77°57'11.98"	10.77	1.81	447	67.65
17	Gasikavaripalli	14°17'24.25"	77°58'40.08"	6.18	1.99	1570	197.2
18	P Kondapalli	14°17'58.46"	77°0'26.65"	90.35	1.92	704	135.99
19	Chintalyagaripalli	14°17'39.62"	77°0'59.06"	129.07	2.69	579	147.32
20	Marla	14°18'31.10"	77°55'51.57"	190.79	4.29	918	235.01
21	Chinnacheruvu Tanda	14°17'57.26"	77°55'19.59"	54.76	4.02	766	155.97
22	Krishnapuram	14°20'50.25"	77°54'39.39"	136.47	2.77	994	189.11
23	Bukkapatnam	14°11'31.46"	77°47'51.10"	70.80	1.76	731	123.36
24	Gorantlapalli	14°12'26.60"	77°47'21.56"	107.61	2.19	779	152.06
25	Narasimpalli Tanda	14°10'41.81"	77°53'9.53"	20.86	4.21	403	109.75
			Maximum	190.79	7.21	1570	235.01
			Minimum	0.72	1.45	185	67.65
			Average	61.88	3.17	617.96	132.23
			Std. Deviation	±48.48	±1.37	±281.05	±39.77

The study area map was imported and the geo-reference was marked by using the coordinate system. With sampling locations as the geo-reference, the fluoride, nitrate, TDS concentrations along with the calculated WQI values for each location were selected as the input parameters and their values were interpolated.Inverse distance weight (IDW) method has been used for creating a surface grid in ArcGIS. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weighs the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted method[19].The results of chemical analysis were transformed into digital GIS maps which provide a highly informative view of the study region, helping in quick policy decisions for effective environmental check by environmental and government agencies[20].
The interpolated values have been calculated from the values recorded at the neighboring place according to the following equation:
Equation 5: $Z(S_0) = \Sigma\ (Z(S_i)/h_i^{\beta})/\ \Sigma(1/\ h_i^{\beta})$
where $Z(S_0)$ is the interpolated grid value, $Z(S_i)$ is the neighboring data point, h_i is the distance between the grid node and data point and power β is taken as 3 in this study, n is the number of measuring points. By defining a higher weighting power (β), more emphasis is placed on the nearest points, and the resulting surface will have a finer detail [5].

III. RESULTS AND DISCUSSION

The computed WQI values ranges from 67.65 to 235.01 in the study area. 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	0
50 to 75	Acceptable in the absence of alternative	8
75 to 100	Poor	8
100 to 125	Very poor	32
125 to 150	Water is unsuitable for drinking	24
150<	Harmful for health	28

The WQI computation shows that 92% of water samples in the study area are not good for domestic consumption with 28% of water samples posing direct health threat.
The GIS map in fig. 2 shows the concentration gradient for the TDS with a clear geo-spatial demarcation of lower to higher TDS concentration levels as we move north. The middle segment of Bukkapatnam has relatively an acceptable range of TDS which is below 600 ppm. The zone marked red shows a TDS of more than 1000 ppm. In this region the groundwater needs a water softening treatment as a pre-treatment prior to any commercial water purification methodology like reverse-osmosis.

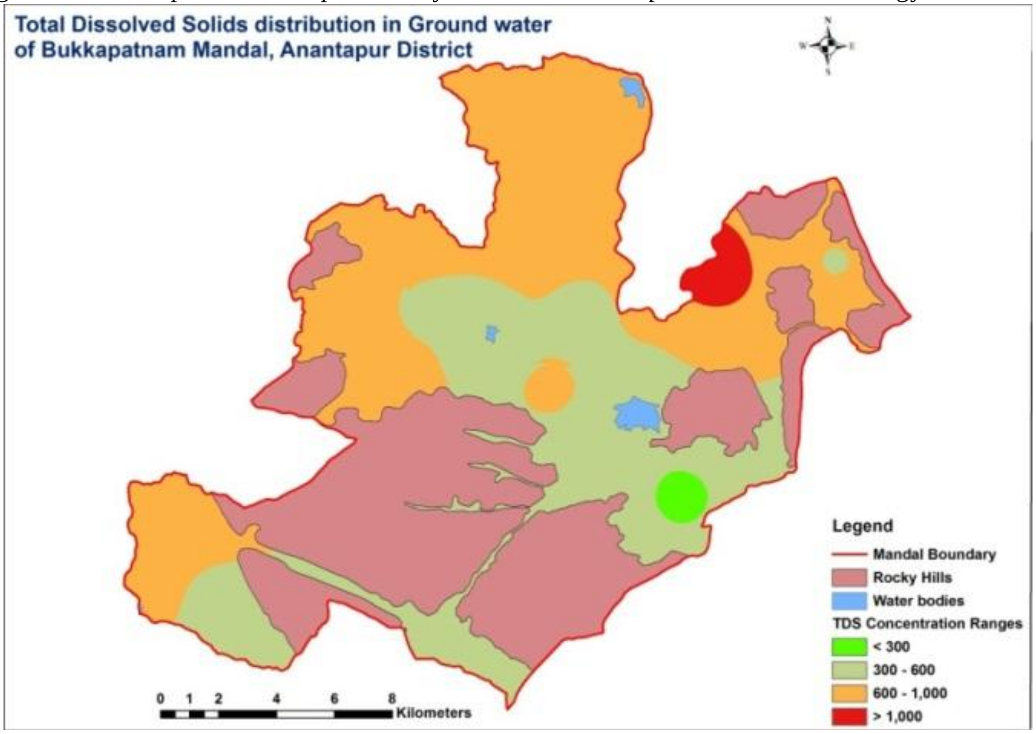

Figure 2. Geospatial map showing concentration gradient of TDS in the study area

The fluoride ion concentration profile as seen in fig. 3 show four major high fluoride zonesdispersed in four direction of the Bukkapatnam map. The highest intensity of fluoride concentration can be seen in the western part of Bukkapatnam. The south east region of Bukkapatnam shows an acceptable range of permissible fluoride ion concentration in groundwater.

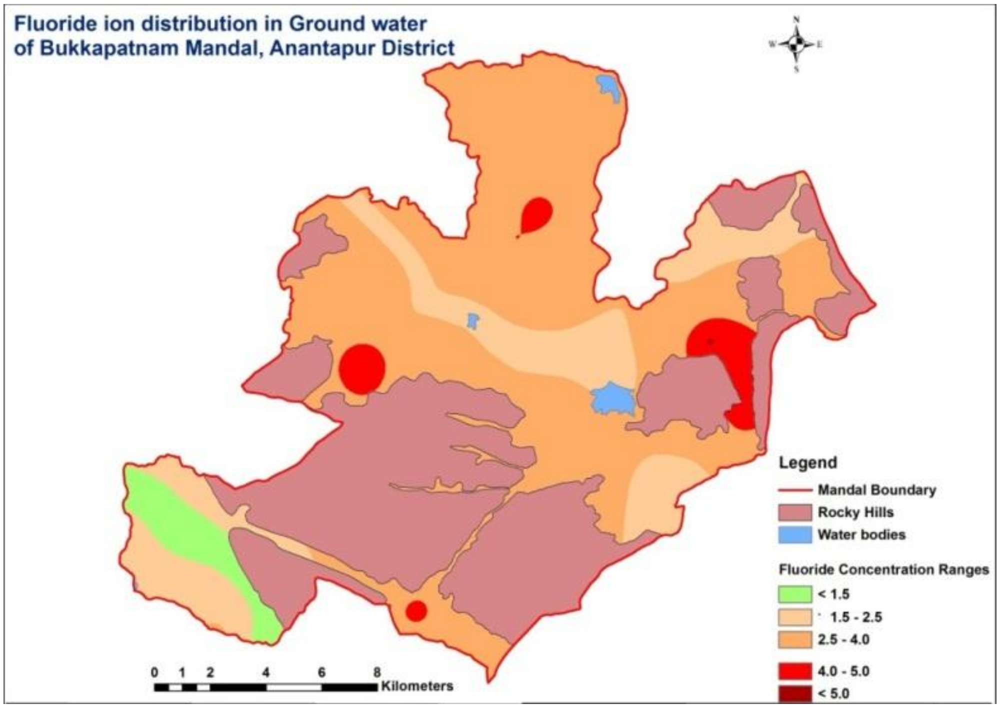

Figure 3. Geospatial map showing concentration gradient of Fluoride ion in the study area

The nitrate ion concentration as shown in fig. 4 is high in the northern region of Bukkapatnam and to some extent on the northwest region between the hills. The agriculture practise and the animal waste disposal practices of these villages needs to be monitored. The topographical factor s also come into play where general drift of irrigated water that seeps beneath the aquifer may graually move in the north directionon account of slope of the ground level.

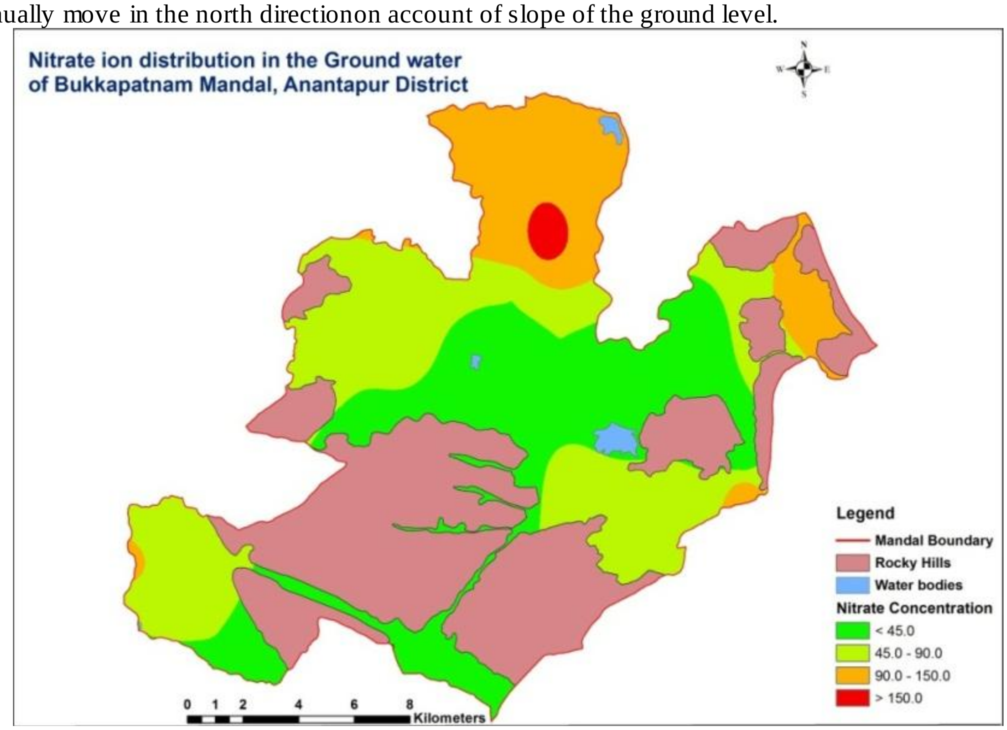

Figure 4. Geospatial map showing concentration gradient of Nitrate ion in the study area

The geospatial map of the water qaulity index in fig. 5 clearly show that the groundwater in the northern part of Bukkapatnam is unfit for drinking purpose which can be directly attributed to high nitrate, fluoride and TDS concentration. There are two areas where the groundwater falls in the relatively acceptable category which is also situated next to the surface water bodies in Bukkapatnam.. 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 several factors, primarily being 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 diract impact on the quality of groundwater.

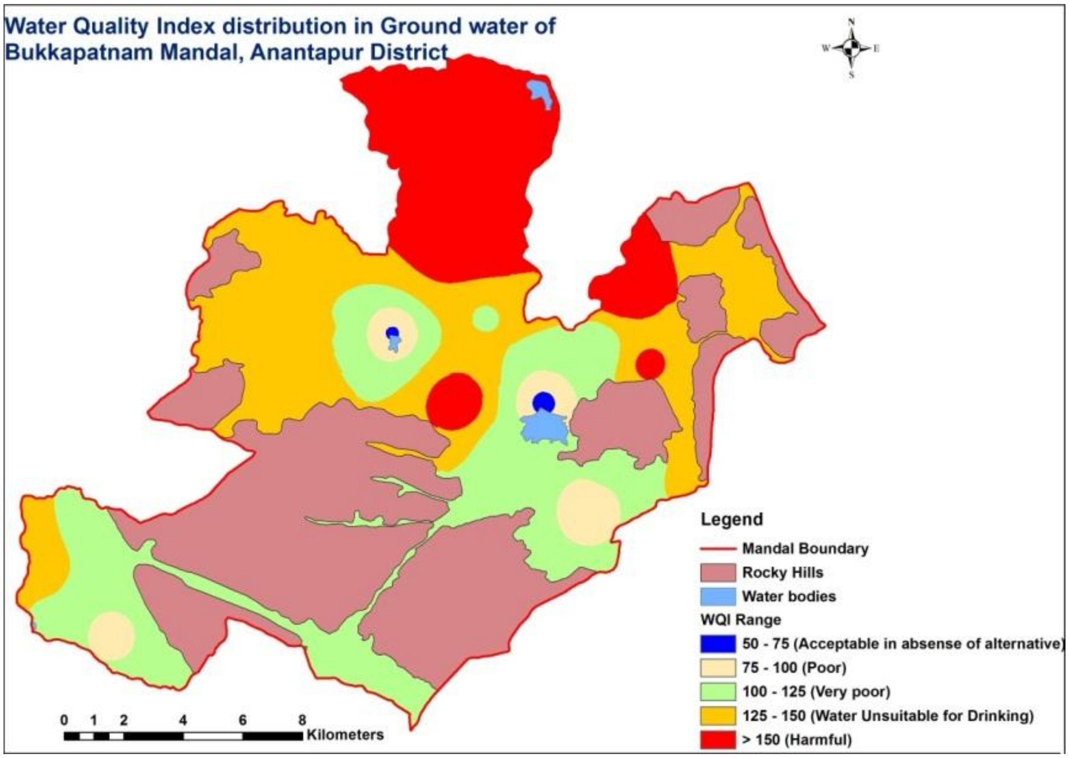

Figure 5. Geospatial map showing concentration gradient of Nitrate ion in the study area

IV. CONCLUSION:

The poor water quality index in the study region can be attributed to high fluoride ion, nitrate ion and TDS concentrations. With 92% 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. 96 % of groundwater samples in the study area exceed the WHO guideline value of 1.5 ppm for fluoride, with the highest value of 7.213 ppm recorded in Bitraguntapalli village. Fluoride ion is attributed to 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 predicted by IDW method of GIS to tap new source of drinking water. 64% of water samples in Bukkapatnam have nitrate ion levels which exceed the BIS guideline value of 45 ppm. The agriculture practice and sewage disposal methods in the northern part of Bukkapatnam needs to be reviewed as they show very high nitrate concentration which ranges from 90 ppm to 150 ppm. The highest recorded nitrate ion concentration is 190.79 ppm in Marla village situated in the North Bukkapatnam. Based on WQI and GIS map analysis, in the overall groundwater quality assessment of Bukkapatnam mandal, the water quality deteriorates as we go from southern to northern parts of Bukkapatnam. Hence, the order of priority for immediate intervention in groundwater treatment and remediationshould be given to villages situated in the northern part of Bukkapatnam followed by central and southern regions of the mandal. In the absence of alternate source, the ground water must be pre-treated before used for drinking purpose.

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