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Analysis of Water Quality Index for Groundwater in Gudur Mandal, SPSR Nellore District - Integrated With RS And GIS

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ABSTRACT
Groundwater has become a necessary resource over the past decades due to the increase in its usage for drinking, water supply, irrigation and industrial uses etc. Groundwater resources are now facing threats due to anthropogenic activities. The groundwater quality is equally important as that of quantity. Mapping of spatial variability of groundwater quality is of vital importance and it is particularly significant where groundwater is primary source of potable water. The present study has been undertaken to analyze the spatial variability of groundwater quality for Gudur Mandal, SPSR Nellore District located in the Andhra Pradesh State. MS Excel-Analysis ToolPak is used for mathematical analysis of the parameters and ArcGIS Version 10.1 is used for the spatial analysis and it is a powerful tool for representation and analysis of spatial information related to water resources. A total of 280 bore well water samples are collected. The major water quality parameters such as pH, Total dissolved solids, Total alkalinity as calcium carbonate, Total hardness, Chloride, Sulphate, Nitrate, Fluoride, Iron have been analysed as per BIS 10500-2012. The spatial variation maps of these groundwater quality parameters were derived and integrated through GIS. The final integrated map shows five priority classes such as Excellent, Good, Poor, Very poor, Unsuitable for zones of the study area and provides a guideline for the suitability of groundwater for domestic purposes.
Keywords - GIS, Groundwater, Spatial variation, Regression models, Water Quality Index.

I. INTRODUCTION

Groundwater is a valuable natural resource that is essential for human health, socio-economic development, and functioning of ecosystems (Steube et al, 2009). In India severe water scarcity is becoming common in several parts of the country, especially in arid and semi-arid regions. Due to rapid growth of population and anthropogenic activities, the quality of groundwater is deteriorating day by day.

The possibility of groundwater contamination is due to the prevailing drought-prone conditions, the improperly treated and unplanned release of effluents of industry, municipal and domestic into the nearby streams and ponds and the majority usage of groundwater for irrigation are increasing the ionic concentration of the groundwater and making it more saline. Temporal changes in the origin and constitution of the recharged water, hydrological and human factors, may cause periodic changes in groundwater quality. Ascertaining the quality is crucial before its use for various purposes such as drinking, agricultural, recreational and industrial use. According to WHO organization, about 80% of all the diseases in human beings are caused by water. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it. Water quality index is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of groundwater. WQI is defined as a rating. reflecting the composite influence of different water quality parameters. WQI is calculated from the point of view of the suitability of groundwater for human consumption. The objective of the present work is to discuss the suitability of groundwater for human consumption based on computed water quality index values and attempts to map the spatial variation of groundwater quality parameters for Gudur Mandal, SPSR Nellore District.

GIS is an effective tool for groundwater quality mapping and essential for monitoring the environmental change detection. GIS has been used in the map classification of groundwater quality, based on correlating total dissolved solids (TDS) values with some aquifer characteristics or land use and land cover (Asadi, 2007). Other studies have used GIS as a database system in order to prepare maps of water quality according to concentration values of different chemical constituents. In such studies, GIS is utilized to locate groundwater quality zones suitable for different usages such as irrigation and domestic (Yammani, 2007). Babiker et al. (2007) proposed a GIS-based groundwater quality index method which synthesizes different available water quality data by indexing them numerically relative to the WHO standards.

II. Study Area

It is located 79°43'11"E to 79°54'20"E and 14°1'09"N to 14°17'24"N coordinates and covering an area of 258.243 sq.km Fig.1. It is included in the Survey of India Topographical sheets of 57N6 and 57N7 on a scale of 1:50,000. As of 2011 census of India, the town had a population of 60,625. The total population constitute, 29,786 males, 30,839 females and 5,672 children, in the age group of 0–6 years. The average literacy rate stands at 74.06% with 44,901 literates, slightly lower than the national average of 73.00%. Gudur is very hot in summer. The town is quite frequently affected by cyclones and has an almost nonexistent winter. The best season to visit is from October to March. The eastern part of town is flooded often during the rainy season, with people facing hardships.

III. Methodology

Groundwater samples were collected from 280 locations during January 2013. Each of the groundwater samples was analyzed for 9 parameters such as pH, Total dissolved solids (TDS), Total alkalinity as calcium carbonate, Total hardness (as $CaCO_3$), Chloride (as Cl), Sulphate (as SO_4), Nitrate (as NO_3), Fluoride (as F), Iron (as Fe) using standard procedures recommended by BIS. The WQI is developed by using MS Excel. The base map of the Gudur Mandal is derived from the NRCS-BHUVAN 2D. Spatial interpolation technique through Inverse Distance Weighted (IDW) approach has been used in the present study to delineate the distribution of water quality parameters. The Inverse Distance Weighted (IDW) referred to as deterministic interpolation methods because they assign values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface. Determines the cell values using a linearly weighted combination of a set of sample points and controls the significance of known points upon the interpolated values. This method uses a defined or selected set of sample points for estimating the output grid cell value.

The chemical parameters obtained were used for regression analysis. The regression analysis is carried out using MS-Excel ToolPak by taking TDS as dependent variable and rest of the parameters as independent variables. Trend analysis represents the process of using the analysed data for predictions. This may be used to predict or forecast values of the dependent variable. The regression models can be used to find out the ionic concentration of the groundwater samples, if the dependent variable TDS is measured for different locations, by inverse calculations. Water quality index is calculated from the point of view of suitability of groundwater for human consumption (drinking).

Since the mandal is mostly depended on the ground water for the domestic consumption therefore, the values of the parameters are checked with the Indian Standards Permissible Limit in the Absence of Alternate Source of BIS: 10500-2012.

IV. Results And Discussions

The chemical analyses of the groundwater and the percent compliance with the Indian Standards are summarized in Table 1. Normal statistics of water quality parameters of 280 groundwater samples are presented in Table 2. The following regression models have been obtained from the results of analysis of water samples. Considering a known value of TDS, the percentage contribution of each ion can be obtained by substituting an average ionic value for the entire study area for premonsoon season. Groundwater quality maps are useful in assessing the usability of the water for different purposes. The spatial and the attribute database generated are integrated for the generation of spatial variation maps of major water quality parameters. Based on these spatial variation maps of major water quality parameters, an Integrated Groundwater quality map of the study area was prepared using GIS. This integrated groundwater quality map helps us to know the existing groundwater condition of the study area.

For computing WQI three steps are followed. In the first step, each of the 19 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes (Table 3). The maximum weight of 5 has been assigned to the parameter nitrate due to its major importance in water quality assessment. Minimum weight of 1 as total hardness by itself may not be harmful.

In the second step, the relative weight (Wi) is computed from the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. Calculated relative weight (W_i) values of each parameter are also given in Table 3.

In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS and the result multiplied by 100:

$$q_i = (C_i / S_i) \times 100 \quad (2)$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter in sample in mg/L, and S_i is the Indian drinking water standard for each chemical parameter in mg/L according to the guidelines of the BIS[7]: 10500-2012.

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$SI_i = W_i q_i \quad (3)$$
$$WQI = \sum SI_i \quad (4)$$

Regression models are used to predict one variable from one or more other variables. Regression models provide the scientist with a powerful tool, allowing predictions about past, present, or future events to be made with information about past or present events. The scientist employs these models either because it is less expensive in terms of time and/or money to collect the information to make the predictions than to collect the information about the event itself or more likely because event to be predicted will occur in some future time.

Regression relations are developed by keeping the TDS as dependent variable and remaining variables as independent variables. The linear trendline fitting shown high R^2 (0.92) between TDC and Chloride.(Fig:3). Correlation Coefficient (r) matrix of water quality parameters is developed Table 4

pH

pH is one of the important parameters of water and determines the acidic and alkaline nature of water. The pH value of water ranged between 7 and 8. The Total Dissolved Solids (TDS) was classified to five ranges as Excellent (6.5-8.5), Good (6.0-6.4 and 8.0-8.4), Poor (5.5-5.9 and 9.1-9.5), Very Poor (<5.5 and >9.5), Unsuitable (<5.5 and >9.5). The pH of the samples was well within the prescribed standards for drinking water. The spatial variation map for pH was prepared and presented in Fig 4.

Total Dissolved Solids (TDS)

In the absence of potable water source the permissible limit of TDS is upto 2000 mg/L. The range of TDS levels in the study area is 162 - 6253 mg/L. Total 62 samples show TDS value beyond the desirable limit of 2000 mg/L. The Total Dissolved Solids (TDS) was classified to five ranges as Excellent (500), Good (1000), Poor (1500), Very Poor (3000), Unsuitable (>3000). The spatial variation map for TDS was prepared based on these ranges and presented in Fig 5. High values of TDS in groundwater are generally not harmful to human beings but high concentration of these may affect persons, who are suffering from kidney and heart diseases. Water containing high solids may cause laxative or constipation effects.

Total Hardness

Hardness in water is caused primarily by the presence of carbonates and bicarbonates of calcium and magnesium, sulphates, chlorides and nitrates. The Total hardness was classified in to five ranges as Excellent (<300), Good (400), Poor (500), Very Poor (600), Unsuitable (>600). Based on the comparisons of chemical constituents with BIS, it is found that, for 280 water samples, 62 samples have total hardness value above maximum permissible limit of 600 mg/L. Total hardness varies from 120 to 1312 mg/L. The spatial variation map for total hardness has been obtained and presented in Fig 6.

Chloride

Chloride is a widely distributed element in all types of rocks in one or the other form. Its affinity towards sodium is high. Therefore, its concentration is high in ground waters, where the temperature is high and rainfall is less. Soil porosity and permeability also has a key role in building up the chlorides concentration. The chloride was classified in to five ranges as Excellent (200), Good (250), Poor (600), Very Poor (800), Unsuitable (>800). Based on the comparisons of chemical constituents with BIS, it is found that, for 280 water samples, 39 samples have chloride value above maximum permissible limit of 1000 mg/L. Chloride value varies from 179 to 3010 mg/L. The spatial variation map for chloridex has been obtained and presented in Fig 7.

Sulphates

Sulphates occur in natural waters at concentration up 50mg/l and concentration of 1000 mg/l can found in water having contact with certain geological formations such as pyrite, lignite and coal. Sulphates was classified in to five ranges as Excellent (25), Good (150), Poor (250), Very Poor (400), Unsuitable (1000) and based on these ranges the spatial variation map for Sulphates has been obtained and presented in Fig 8. On the comparisons of with BIS, it is found that, for 280 water samples, all the samples have sulphates value less then permissible limit of 400 mg/L. Sulphate value varies from 20 to 310 mg/L.

Nitrate

In study area, the nitrate value varies from 4 to 45 ppm. The nitrate value for the study area is found to be within the 45 ppm as per BIS: 10500-2012 in 280 locations. Nitrate was classified in to five ranges as Excellent (10), Good (20), Poor (50), Very Poor (100), Unsuitable (>100) and based on these ranges the spatial variation map for Nitrate has been obtained and presented in Fig 9.

Fluoride

Groundwater usually contains fluoride dissolved by geological formation. The desirable limit of Fluorides is 1-1.5 mg/l, beyond this limit the water is considered as poor quality. Based on these range the spatial variation map for Fluorides has been obtained and presented in Fig. 10. On the comparisons of with BIS, it is found that, for 280 water samples, 3 of the samples have fluoride value greater then permissible limit of 1.5 mg/L.

Iron

Iron in is a common problem, in the present study area its concentration level ranges from 0.1 to 1 mg/l, while BIS recommended level is < 0.3 mg/l. based on these ranges the spatial variation map for Iron has been obtained and presented in Fig 11. The iron occurs naturally in the aquifer but levels in groundwater can be increased by dissolution of ferrous borehole and hand pump components. Iron-bearing groundwater is often noticeably orange in colour, causing discoloration of laundry, and has an unpleasant taste, which is apparent in drinking and food preparation.

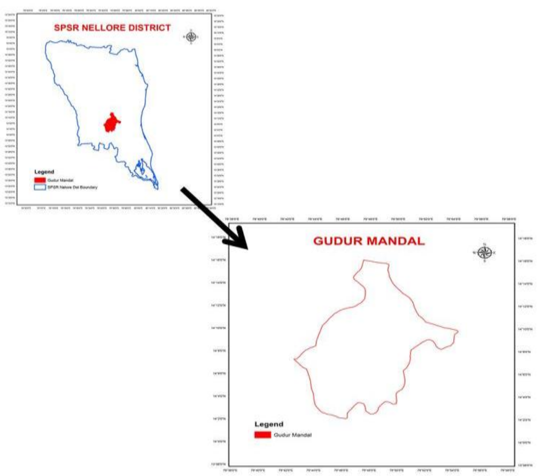

Fig: 1. Study area

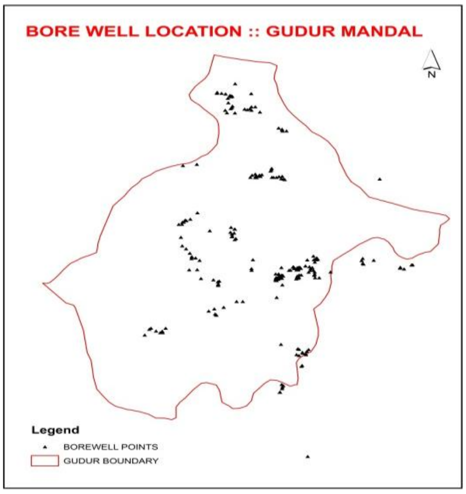

Fig 2: Location of Bore wells

Table 1. Comparison of groundwater quality with drinking water standards of Indian Standards

Parameters	Indian Standards Permissible Limit in the Absence of Alternate Source (BIS: 10500-2012)	Percent compliance
pH	6.5-8.5	100
Total dissolved solids (TDS)	2000	78
Total alkalinity as calcium carbonate	600	82
Total hardness TH (as CaCO3)	600	78
Chloride (as Cl)	1000	86
Sulphate (as SO4)	400	100
Nitrate (as NO3)	45	100
Fluoride (as F)	1.5	99
Iron (as Fe)	0.3	74

Table 2. Normal statistics of water quality parameters of groundwater samples.

STATISTICS	WATER QUALITY PARAMTERS								
	pH	TDS	ALKALINITY	TH	CL	SULPHATE	NO_3	F	Fe
Minimum	7.0	162.0	124.0	120.0	179.0	20.0	4.0	0.0	0.1
Maximum	8	6253	1000	1312	3010	310	332	2	1
Avrg.	7.5	1468.7	374.8	437.7	519.3	113.6	22.8	0.9	0.3
Stnd. Deviation	0.3	764.5	176.8	208.7	367.2	68.9	21.0	0.3	0.1
Coeff. Of Variation (CV)	0.0	0.5	0.5	0.5	0.7	0.6	0.9	0.3	0.5
Median	7.5	1245.5	332.0	364.0	400.0	72.5	20.0	0.9	0.3

All units except pH and Electrical conductivity are in mg/l, Min-Minimum, Max-Maximum, AMArithmetic mean, SD-Standard deviation, CV-Coefficient variation, Med-Median.

Table 3. Relative weight of chemical parameters.

Parameters	Indian Standards Permissible Limit in the Absence of Alternate Source	Weight (w_i)	Relative weight (W_i)
pH	6.5-8.5	4	0.12121
Total dissolved solids (TDS)	2000	4	0.12121
Total alkalinity as calcium carbonate	600	3	0.09091
Total hardness (as CaCO3)	600	2	0.06061
Chloride (as Cl)	1000	3	0.09091
Sulphate (as SO4)	400	4	0.12121
Nitrate (as NO3)	45	5	0.15152
Fluoride (as F)	1.5	4	0.12121
Iron (as Fe)	0.3	4	0.12121
	$\sum w_i$	**33**	**1**

SI_i is the subindex of i^{th} parameter; q_i is the rating based on concentration of i^{th} parameter and n is the number of parameters. The computed WQI values are classified into five types, "Excellent, Pristine Quality" to "Unsuitable for drinking".

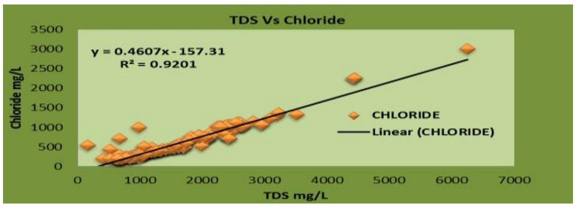

Fig 3: Liner Fitting between TDS and Chloride

Table 4 : Correlation Coefficient (r) Matrix of Water Quality Parameters of Gudur Mandal (January 2013)

Paramters	TDS	pH	ALKALINITY	TH	Cl	SULPHATE	NO_3	F
TDS	**1.000**							
PH	0.742	**1.000**						
ALKALINITY	0.873	0.744	**1.000**					
HARDNESS	0.891	0.737	0.864	**1.000**				
CHLORIDE	**0.959**	0.721	0.851	**0.882**	**1.000**			
SULPHATE	0.812	0.714	0.785	0.777	0.787	**1.000**		
NITRATE	0.446	0.436	0.486	0.463	0.399	0.453	**1.000**	
FLOURIDE	0.269	0.279	0.226	0.282	0.277	0.254	0.264	**1.000**
IRON	0.398	0.352	0.313	0.374	0.413	0.395	0.242	**0.093**

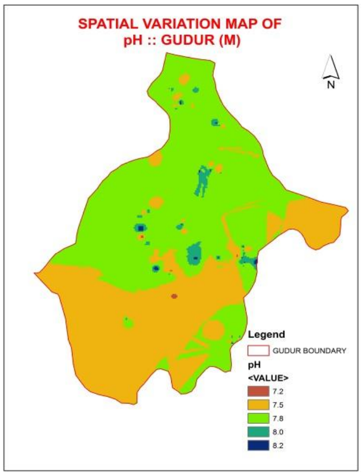

Fig 4: Spatial variation of pH

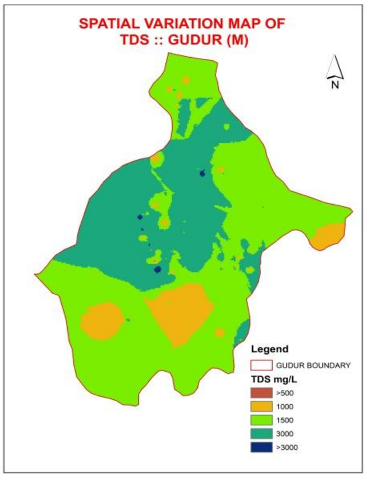

Fig 5: Spatial Variation of TDS

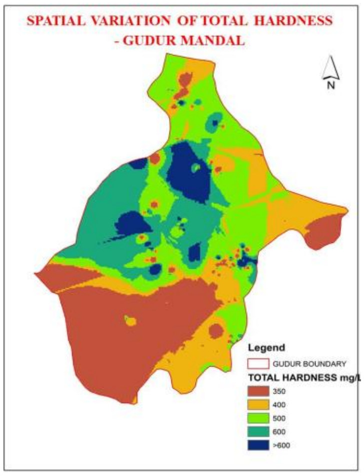

Fig 6: Spatial Variation of TH

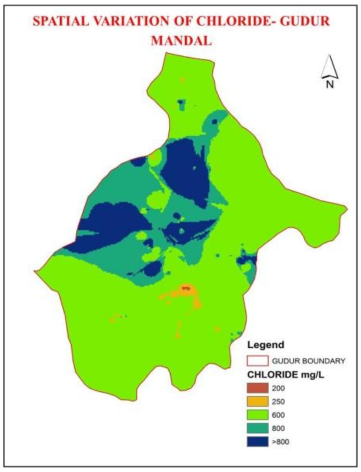

Fig 7: Spatial variation of Cl

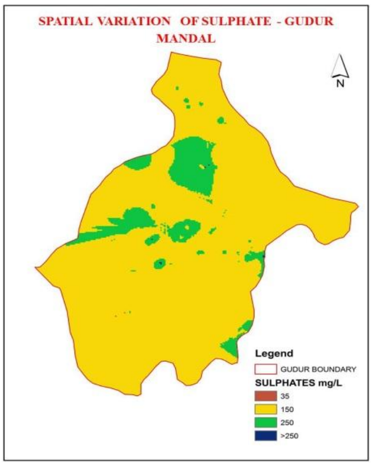

Fig 8: Spatial Variation of SO_4

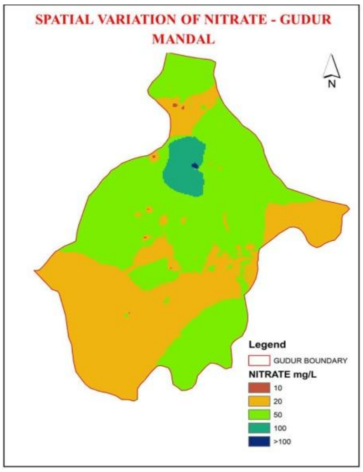

Fig 9: Spatial Variation of NO_3

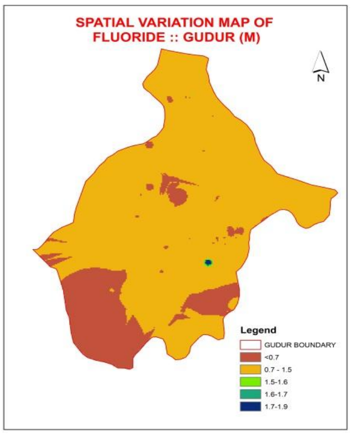

Fig 10: Spatial variation of F

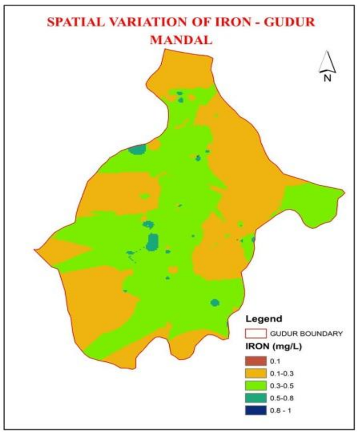

Fig 11: Spatial Variation of Fe

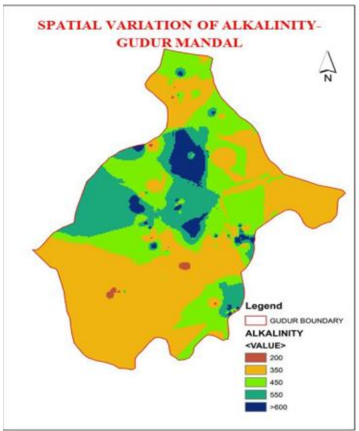

Fig 12: Spatial Variation of Alkalinity

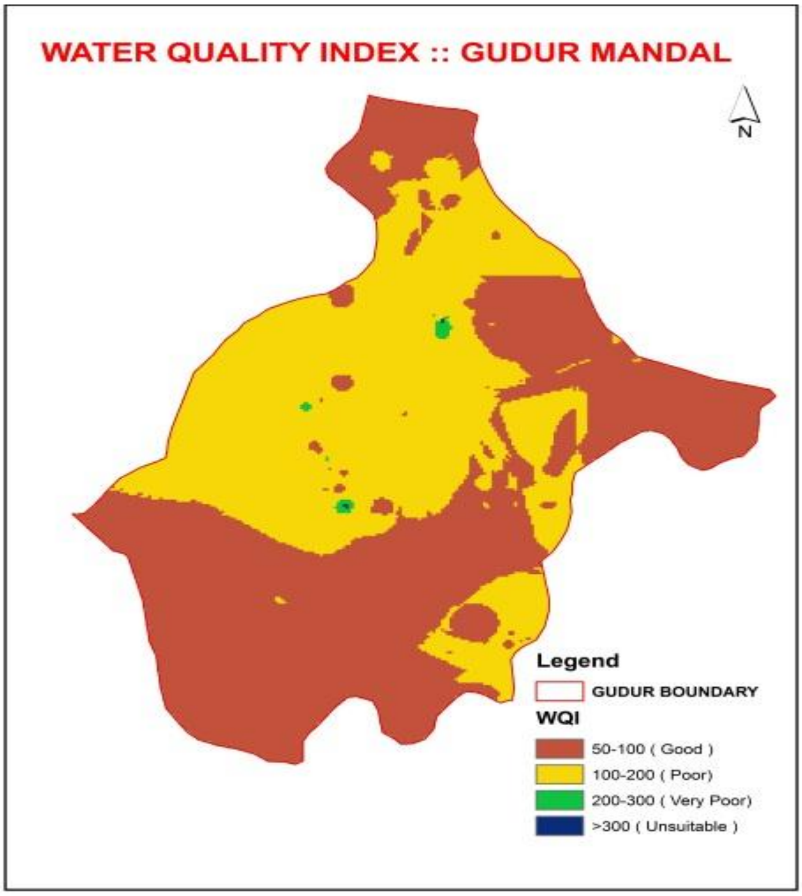

Fig 13: Integrated WQI map of Gudur Mandal

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