Hydrospatial Analysis
Homepage: www.gathacognition.com/journal/gcj3
http://dx.doi.org/10.21523/gcj3

Original Research Paper

Spatial Analysis of Groundwater Qualities in Vempalle Mandal of YSR District, Andhra Pradesh, India using Geospatial Techniques

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Abstract

The present study analyses the spatial variations of groundwater qualities in the Mogamureru basin of the Vempalle Mandal, YSR district of Andhra Pradesh, South India. Twenty-two groundwater samples from the post-monsoon season collected in January 2020 and tested in the laboratory for chemical analysis including Carbonate (CO_3^-), Bicarbonate (HCO_3^-), Magnesium (Mg^{2+}), Chloride (Cl^-), Calcium (Ca^{2+}), Sodium (Na^+) and Potassium (K^+). The spatial variations in quality parameters mapped using interpolation technique in ArcGIS software. Water Quality Index (WQI) calculated for quality analysis and four groundwater samples classified into very poor category and eighteen samples are unsuitable for drinking purpose. The usage of groundwater for drinking purpose needs a proper water quality treatment for better health implications. The methodology adopted in this study has been found to be effective and can be used to establish strong water quality monitoring network in similar areas.

Article History

Received: 22 January 2022
Revised: 01 April 2022
Accepted: 02 April 2022

Keywords

Components;
GIS;
Groundwater;
Spatial Distribution;
Water Quality;
WQI.

Editor(s)

P. Hire

1 INTRODUCTION

In many countries, groundwater is a major source of water for domestic, industrial and irrigation purposes worldwide (Lapworth *et al.*, 2020). Significant population growth and accelerated modernization have resulted in a massive increase in the demand for fresh water over the last few decades. According to Siebert *et al.* (2010), groundwater accounts for 43% of global irrigation water consumption (1277 km3) per year. One of the most pressing challenges of the twenty-first century appears to be ensuring adequate supplies of usable water to meet the needs of people and the environment (Gowd, 2005; Oki and Akana, 2016). Waterborne diseases account for nearly 80% of all human diseases, according to the WHO (2017) (Srinivasamoorthy *et al.*, 2014; Wu *et al.*, 2017; Li *et al.*, 2019; Adimalla *et al.*, 2021; Panneerselvam *et al.*, 2021). Therefore, water quality testing is essential for determining its suitability for various applications. The water quality index is one of the most effective methods for disseminating water quality information to concerned individuals and policymakers. As a result, it has become an important indicator for assessing and managing groundwater. As a result, it has become an important indicator for assessing and managing groundwater. In order to properly create new groundwater schemes and manage groundwater resources, it is necessary to analyze a groundwater flow system and map spatial variation of groundwater parameters (Manoj *et al.*, 2017). Over the last few decades, a water quality index (WQI) has been used all over the world to assess both surface and groundwater quality in order to better understand the overall

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https://doi.org/10.21523/gcj3.2022060101

water quality of a water source (Tyagi *et al.*, 2014; Yadav *et al.*, 2015; Seth *et al.*, 2016; Bora *et al.*, 2017;Vishnu Radhan *et al.*, 2017; Bhutiani *et al.*, 2018; Dash *et al.*, 2021). In recent years, groundwater quality has been assessed and monitored on a regular basis using GIS technology combined with the IDW interpolation techniques, which has proven to be a powerful tool for evaluating and analyzing spatial data of water resources (Balamurugan *et al.*, 2020; Soujanya Kamble *et al.*, 2020; Ram *et al.*, 2021). It's a quick and low-cost way to transform massive data sets into diverse spatial distribution maps and projections that show trends, associations, and sources of toxins and pollutants. A Geographic Information System (GIS) was used in this study to assess the spatial distribution of various groundwater quality parameters (Ram *et al.*, 2021). Groundwater samples have been collected during pre-monsoon (2020) and these samples analyzed using laboratory methods. The spatial variations of groundwater qualities estimated using interpolation technique in ArcGIS environment to study the groundwater suitability for drinking purposes using WQI

2 STUDY AREA

The study region lies between 78º 24′ 32" to 78º 05′ 0" E and 14º 32′ 0" to 14º 35′ 30" N (SOI toposheets: 57J/06 and 57J/11) with an area of 168.21 km^2 of the Vempalle Mandal, YSR district, Andhra Pradesh (Figure 1). A tropical climate observed with an average annual temperature of 34ºC and precipitation of 753mm per year. Brown and red soils as well as loam and shallow and deep clay loam soils are observed in the region. Groundnut, sunflower, red gram, Bengal gram, paddy, cotton, and Sesamum are among the crops produced.

According to Zachariah (1999), the Tadipatri and Vempalle formations are 1779 Ma and 1752 Ma, respectively, and the Pulivendula formation is 1817 Ma, according to Bhaskar Rao *et al.*, (1995). The Papaghni Group's Vempalle Formation in the Cuddapah Supergroup is mostly composed of basic

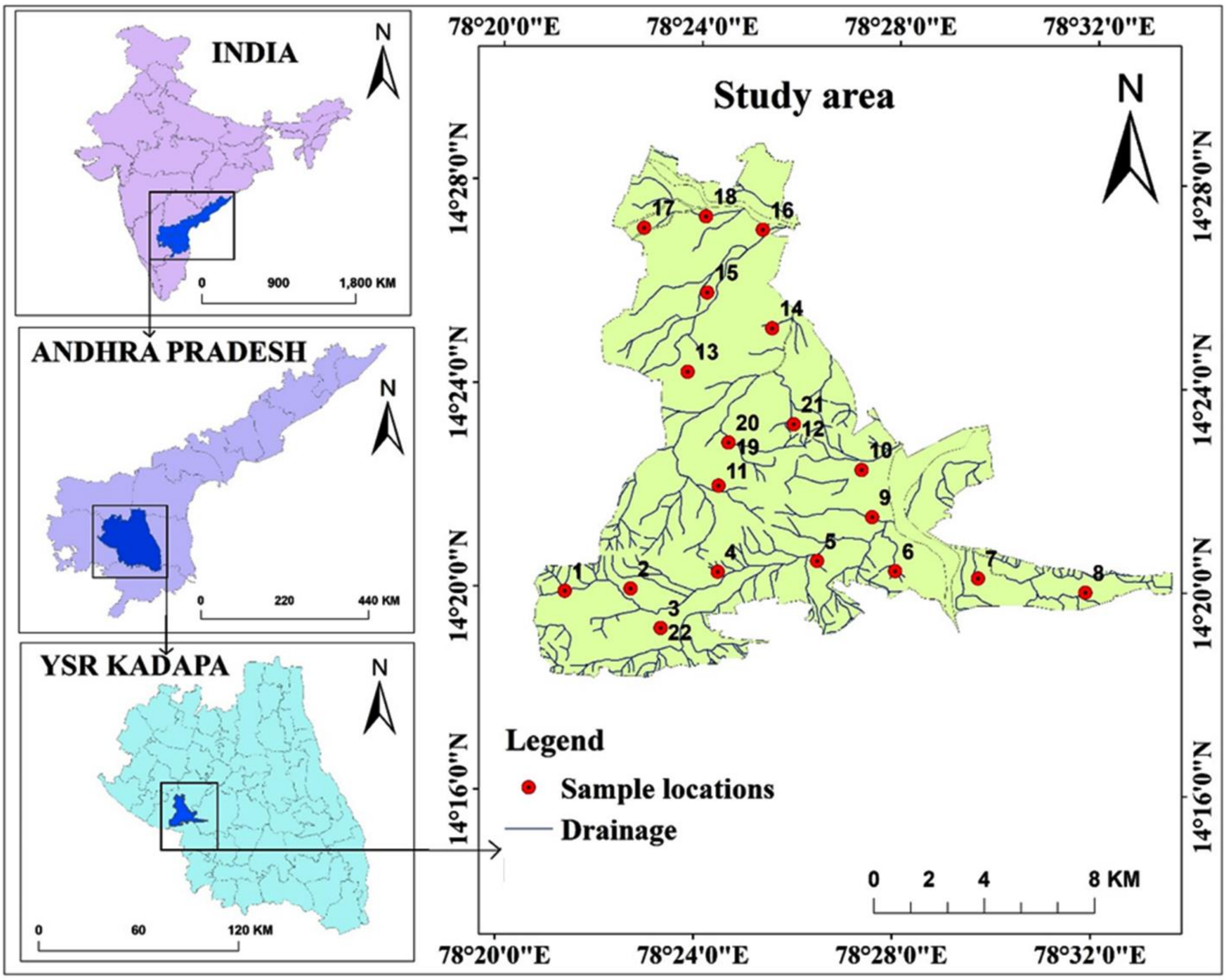

Figure 1. Study area

flows, dolomite, quartzite, conglomerate, and shale (Figure 2). Residual hills, Pediment, Pediplain, Structural hills and valleys are examples of geomorphological terrain generated by denudational, fluvial, and structural sources (Figure 3). The depth of the water fluctuates between 10 and 50m (CGWB, 2014). The Mogamureru River, a tributary of the Papaghni River, rises from west to east and joins the Papaghni River in Animela village in Veerapunayunipalle Mandal, with a primarily dendritic drainage pattern (Figure 4).

3 METHODOLOGY

Twenty-two samples collected from villages in the Vempalle Mandal of the YSR district. One liter storage cans were cleaned and disinfected before being preserved with nitric acid. The samples were analyzed to determine ex-site and in-site characteristics such as alkalinity (carbonates and bicarbonates), chlorides, magnesium, calcium, electrical conductivity, pH, total dissolved solids, and total hardness (Table 1). In the laboratory, alkalinity,

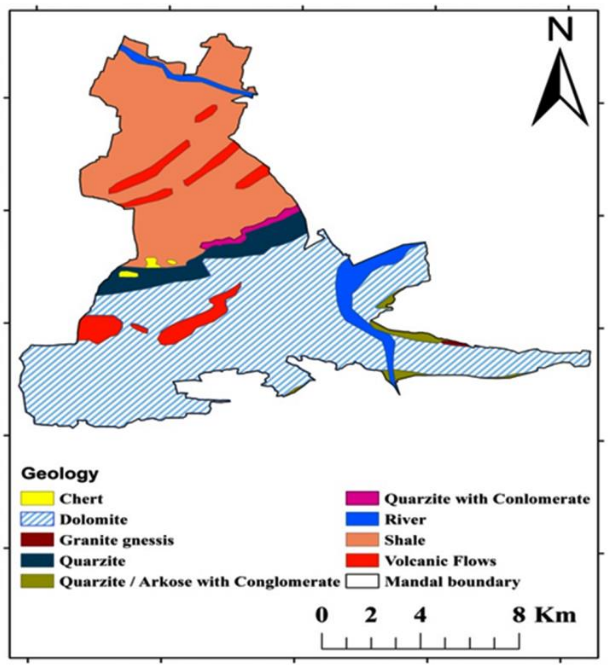

Figure 2. Geology

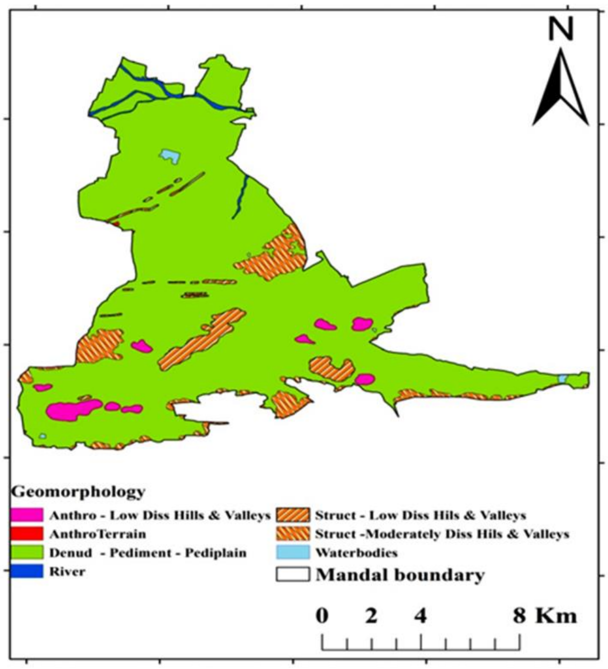

Figure 3. Geomorphology

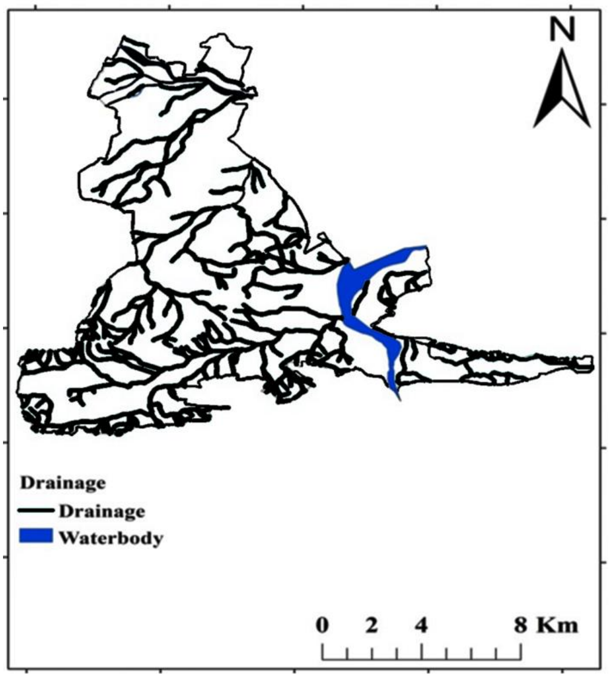

Figure 4. Drainage network

Cl^-, and Mg^{2+} parameters are measured using the titration method, Ca^{2+} is measured using a flame photometer, pH is determined using a pH meter, and EC and TDS are assessed using conductivity meter. Parameters that are compared to the ranges of the Bureau of Indian Standards are also shown in the graphs. The weighted arithmetic technique was used to calculate the Water Quality Index. The parameters and WQI values showed on the maps using the IDW tool of Arc-GIS software.

3.1 Water Quality Index (WQI)

The Water Quality Index is unique measurement that identifies the root causes of contradictory water qualities. The suitability components of water for people used to calculate the WQI. pH, electrical conductivity, chloride, dissolved solids, hardness, sulphate, sodium, manganese, calcium, potassium, and magnesium were taken into account while computing WQI. The weighted computation by the WQI used in many kinds of research this type of estimates (Bouslah *et al*., 2017; Jamshidzadeh *et al*., 2018; Ekere *et al*., 2019; Chowdhury *et al*., 2021).

3.2 Weighted Arithmetic Water Quality Index

The weighted arithmetic water quality index clarifies the water quality according to the standard of quality by using the most commonly measured water quality factors. Numerous scientists have used this technique (Chauhan *et al*., 2010; Balan *et al*, 2012; Chowdhury *et al*., 2021) to calculate WQI (Rown *et al*., 1972; Xiao *et al*., 2019; Gao *et al*., 2020; Ram *et al*., 2021):

$$K = \frac{1}{\sum(\frac{1}{Si})}$$

where, k denotes steady-state proportionality, Si is standards of parameter.

The sub-index (Wi) was calculated by taking the parameter's optimal (ideal) value:

$$Wi = \frac{K}{Si}$$

The following formula used to calculate the sub-index (Qi).

$$Qi = 100[\frac{Vi - V0}{Si - V0}]$$

where, Vi is concentrate of the parameter in analyzing water, Si is standard desirable value of parameter, Vo is the parameter's actual value in pure water (for natural water and Vo is 0 for hardness.

$$WQI = \frac{\sum Wi\ Qi}{\sum Wi}$$

where, WQI is a number between 0 and 100 that indicates the quality of the water; Qi is a relative value of water specific to each parameter; i is represent the range of parameters.

Table 1. Physico-chemical parameters

S. No	Village Name	Longitude	Latitude	pH	EC	TDS	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	TH
1	Vempalle	78.355721°	14.331964°	7.9	1020	600	50	65	15	85	350	68
2	Edupulapaya	78.377839°	14.332943°	8.5	968	575	125	82	47	69	110	87
3	A. Cherlopalli	78.388129°	14.320102°	7.5	1151	690	84	39	24	42	454	25
4	Ramireddypalle	78.407050°	14.338755°	8.5	1590	954	135	58	58	0	647	658
5	Ammaigaripalli	78.440434°	14.342626°	7.7	634	390	65	112	12	36	100	125
6	pamuluru	78.466688°	14.339588°	7.2	875	520	190	96	37	94	78	98
7	Alavalapadu	78.494623°	14.337503°	8	1350	800	150	35	45	54	441	358
8	Borlagondicheruvu	78.530698°	14.333185°	7.2	942	570	84	99	0	0	332	574
9	Naguru	78.458748°	14.357179°	8.8	1110	675	73	112	24	65	376	45
10	Musulreddypalli	78.455109°	14.372630°	7	954	590	100	58	29	38	320	39
11	T. Velamavaripalli	78.407051°	14.366983°	7.4	798	490	95	43	0	0	232	187
12	Alireddypalli	78.432104°	14.387316°	8.5	1105	670	120	120	0	0	410	354
13	Chinthalamadugupalli	78.396207°	14.404166°	7.5	1288	780	50	45	19	90	500	456
14	kattuluru	78.424502°	14.418699°	8	1006	612	174	65	46	68	195	291
15	kuppalapalli	78.402485°	14.430193°	7.6	748	460	32	54	35	85	230	257
16	pamuluru	78.420971°	14.450894°	8.5	967	590	71	100	21	36	290	457
17	Vempalli	78.381039°	14.451130°	7.7	1120	670	89	87	27	65	364	354
18	Tallapalli	78.401835°	14.455093°	7.7	990	600	150	30	38	102	270	254
19	Eguvathuvvapalli	78.410204°	14.381103°	7	600	500	55	60	17	0	200	74
20	Mallepalli	78.371232°	14.390213°	8	1000	650	90	118	25	70	420	550
21	mopurigaripalli	78.501485°	14.420752°	8.3	700	590	86	85	44	80	300	130
22	Nandipalli	78.512934°	14.440371°	8	620	750	35	125	35	100	445	200

4 RESULTS AND DISCUSSION

4.1 pH

The quality and penetration rate of groundwater recharge, the rate of refilling water, and the interaction between water and rock in the aquifer all influence pH fluctuations in space and time. The recommended BIS limit for drinking purposes is 6.5 to 8.5 pH, and in the study area ranges from 7.0 to 8.8 (Figures 5 and 6).

4.2 Electrical Conductivity

Electrical conductivity defined as its ability to conduct an electric current. When salts or other chemical substances dissolve which divided into positive and negative ions. Electrical conductivity can be classed into four categories: excellent, good, permitted, and dubious (Tlili-Zrelli *et al.*, 2018). The study region ranges from 600 to 1590 µS/Cm, with samples falling into the good and permissible categories (Table 2; Figure 7).

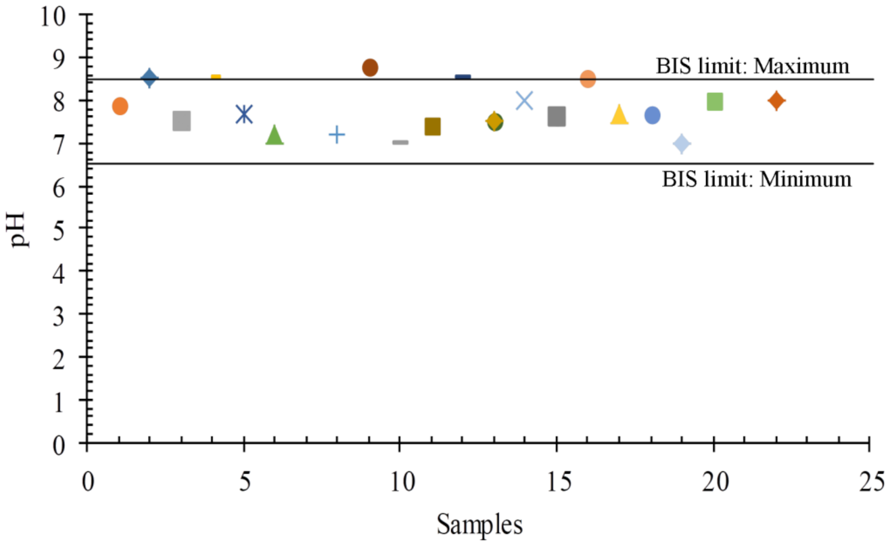

Figure 5. pH with BIS limits

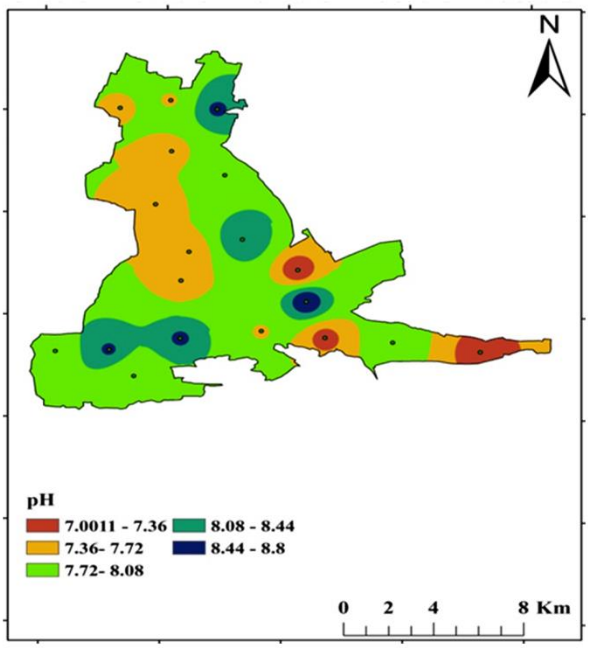

Figure 6. pH

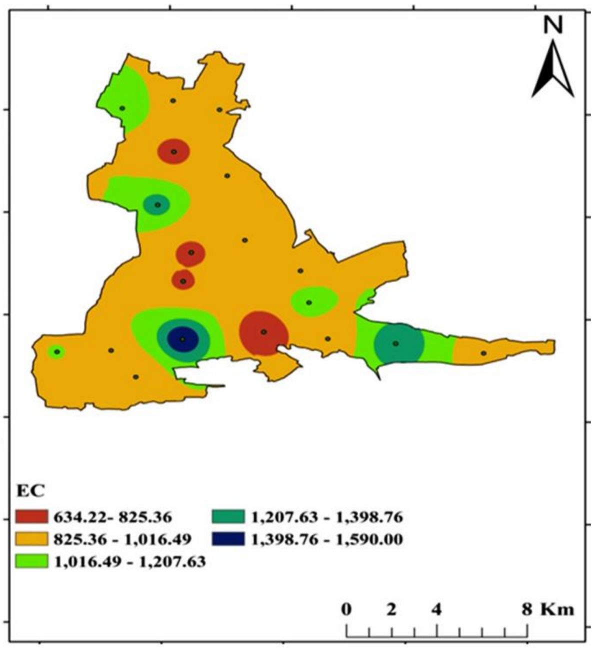

Figure 7. Electrical Conductivity

4.3 Total Dissolved Solids (TDS)

TDS is an abbreviation for total dissolved solids, which are inorganic and small amounts of organic components that are present in water as a solution. For drinking purposes, the BIS (2012) permissible limit is 500 mg/L to 2000 mg/L, with a range of 390-954 mg/L in the study region (Figure 10 and 8). Fresh water, slightly brackish water, slightly brackish water, brackish water, saline water, and braine water are the six forms of TDS (Ramaraju and Giridhar 2017). All samples were fallen into freshwater category and the TDS (Table 3).

4.4 Hardness

Dissolved polyvalent metallic ions from sedimentary rocks such as limestone and dolomite are the most common causes of hardness in water, and the two main ions are Ca^{2+} and Mg^{2+}. Carbonate (temporary) and non-carbonate (permanent) hardness are two types of total hardness. For drinking purposes, the BSI (2012) permissible range is 200 mg/L to 600 mg/L TH, with a range of 25mg/L-658 mg/L in the study region (Figure 9 and 11).

Total hardness (mg/l as CaCO3) = Carbonate hardness + Non-carbonate hardness

$$\text{Calcium Hardness} = 20\frac{\text{mg}}{\text{L}} \times \frac{100\ \text{Caco3}/\text{Mm}}{400\ \text{mg Calcium}/\text{Mm}}\ \text{mg/L}$$

$$\text{Magnesium Hardness} = 10\frac{\text{mg}}{\text{L}} \times \frac{100\ \text{Caco3}/\text{Mm}}{24.31\ \text{mg Magnesium}/\text{Mm}}\ \text{mg/L}$$

4.5 Calcium

Calcium (Ca^{2+}) may dissolve from rocks such as limestone and dolomite in the study area. For drinking purposes, the BIS (2012) permissible limit is Ca^{2+} 75 mg/L to 200 mg/L, whereas in the study area ranges between 32 mg/Land 190 mg/L (Figures 12 and 14).

4.6 Magnesium

Magnesium (Mg^{2+}) is the most abundant element in the earth's crust and is formed by the weathering of specific minerals such as dolomite. Magnesium, together with calcium, is necessary for water hardness. For drinking purposes, the BIS (2012) permissible limit is Mg^{2+} from 30 mg/L to 100 mg/L, and concentrations ranging from 30 mg/L-125 mg/L in the study area (Figure 13 and 15).

Table 2. Electrical conductivity

Water classes	EC	Samples No.	Sample %
Excellent	<250	-	-
Good	250-750	4	18
Permissible	750-2250	18	82
Doubtful	>2250	-	-

Table 3. Total Dissolved Solids

Water Class	Concentration of TDS (Todd 2005) mg/l	No. of Samples
Fresh water	10-1000	All
Slightly water	-------	-
Slightly-brackish water	1000-10,000	-
Brackish water	10,000-10,0000	-
Saline water	-----	-
Braine water	>10,0000	-

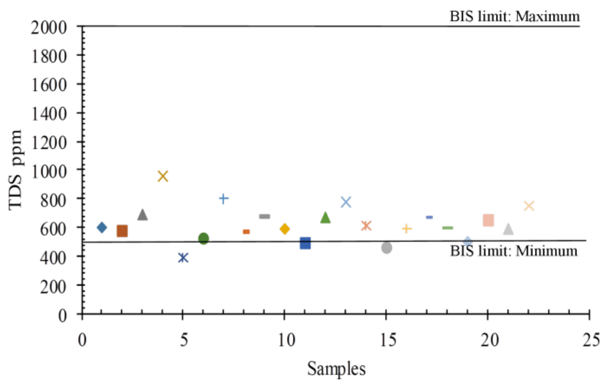

Figure 8. TDS with BIS limits

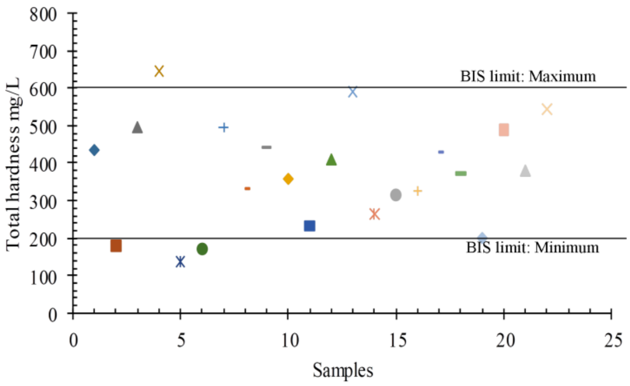

Figure 9. Total hardness with BIS limits

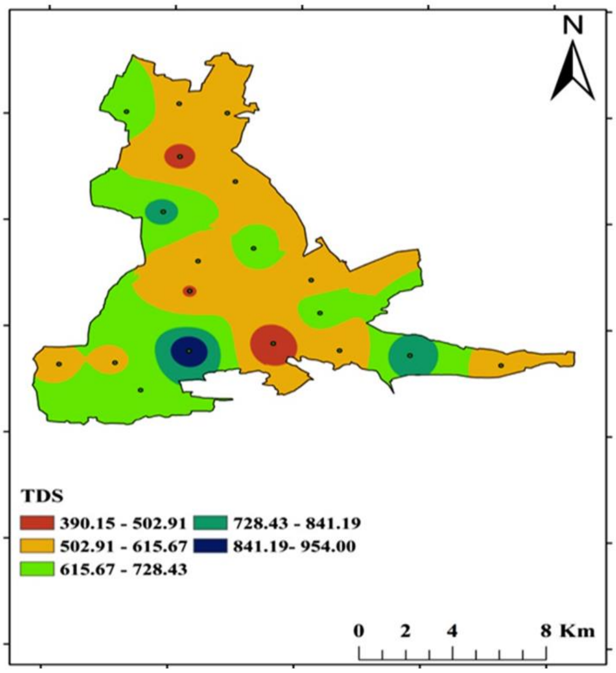

Figure 10. Total Dissolved Solids

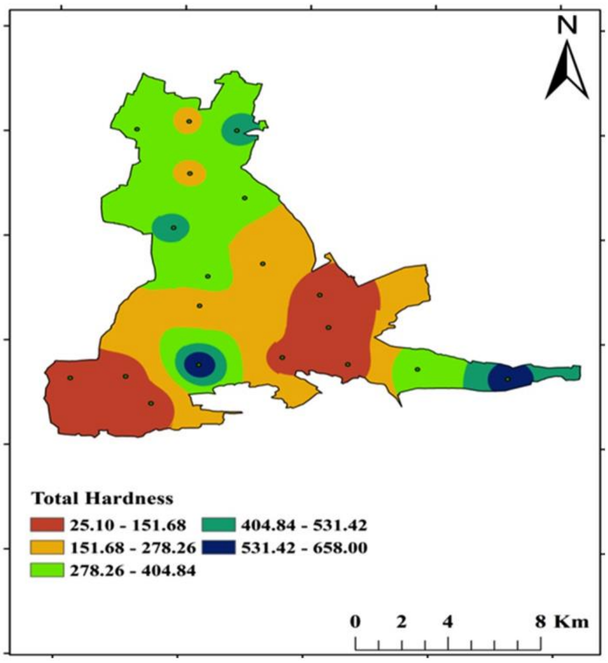

Figure 11. Total hardness

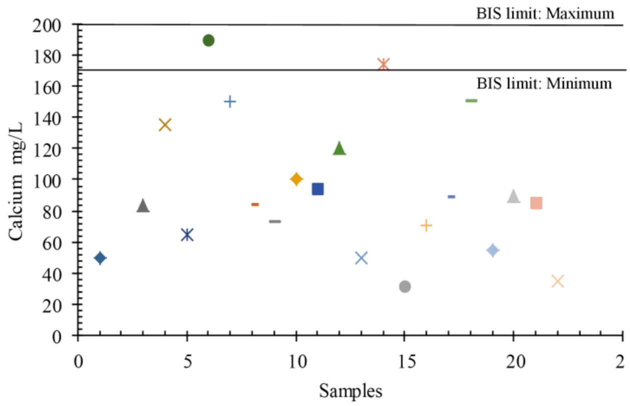

Figure 12. Calcium with BIS limits

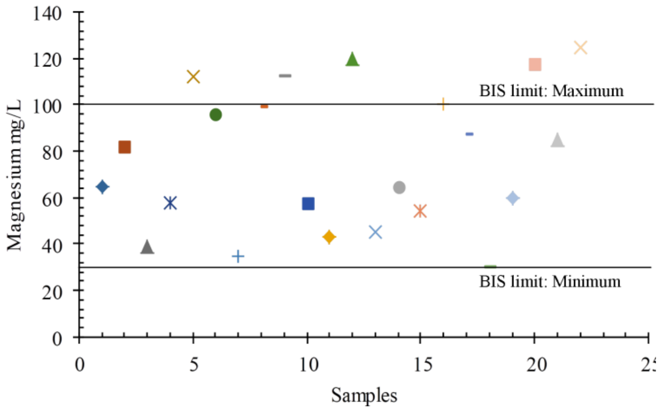

Figure 13. Magnesium with BIS limits

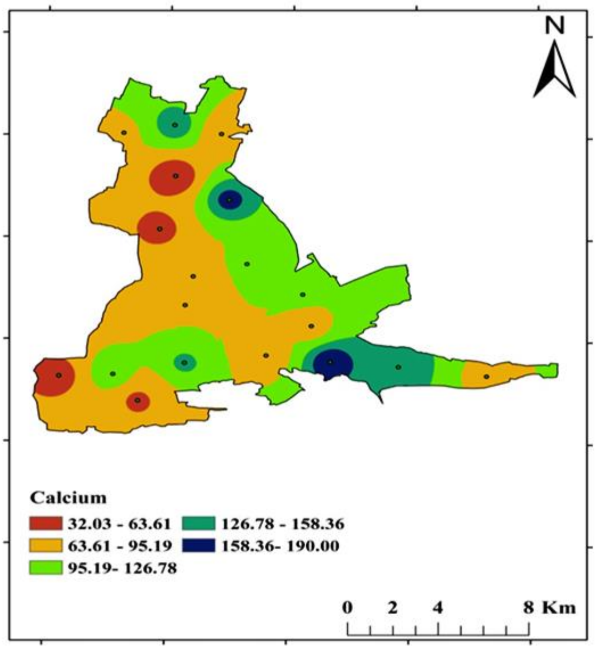

Figure 14. Calcium

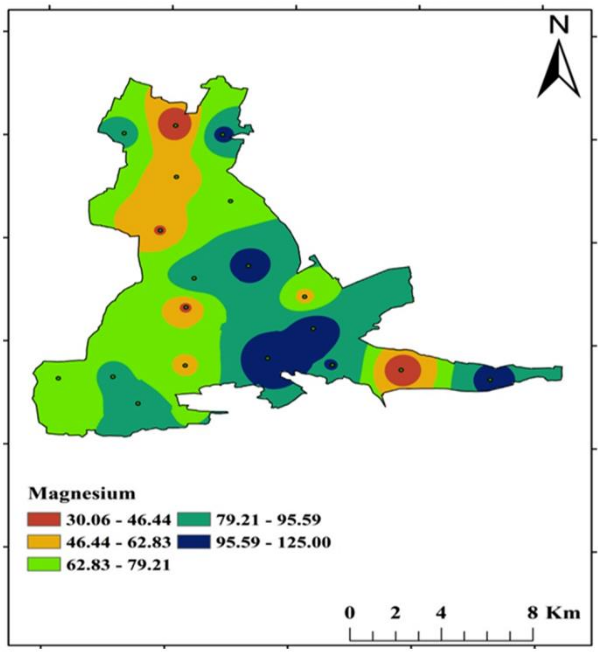

Figure 15. Magnesium

4.7 Carbonates (CO_3^-) and Bicarbonates (HCO_3^-)

Carbonates (CO_3^{2-}), Bicarbonates (HCO_3^-), and hydroxide compounds, as well as Phosphates, Silicates, and Borates, make up the alkaline character of water. Carbonates are typically found in carbonaceous rocks such as limestone, and this sort of environment has a high alkalinity and hardness. CO_3^- and HCO_3^- concentrations in the research area range from 0-58 mg/L and 0-102 mg/L, respectively. Soft water has low alkalinity, while hard water has significant alkalinity Figure 16 and 17 shows a spatial distribution map of CO_3^- and HCO_3^- concentrations.

4.8 Water Quality Index (WQI)

The value generated for the Weighted Arithmetic WQI technique can be used to calculate the water ecological popularity. Table 4 shows the water quality criteria for drinking purposes and the unit-weights allocated to each parameter used in calculating the WQI. Brown (1972) categorizes the WQI into five classes (Table 5). Four samples from villages namely Cherlopalli, T. Velamavaripalli, Kuppapalapalli, Tallapalli, and Eguvathuvvapalli classified into poor category and others falling into the unsuitable category (Table 6, Figure 18).

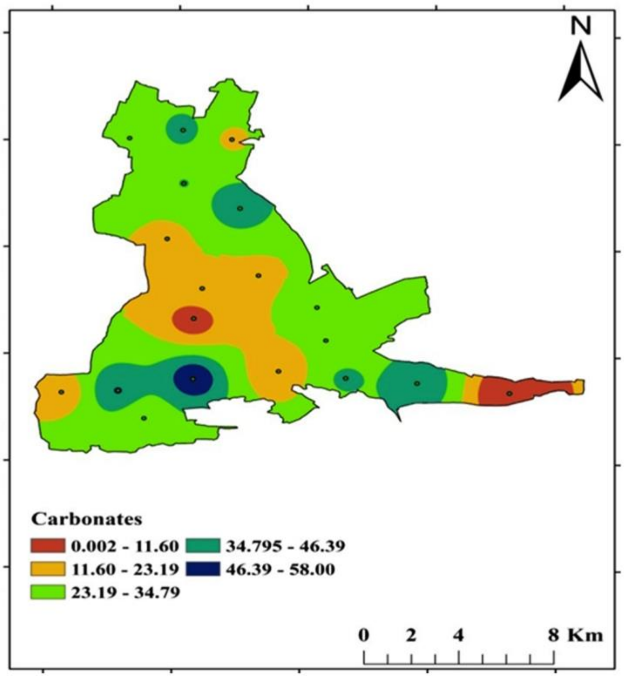

Figure 16. Carbonates

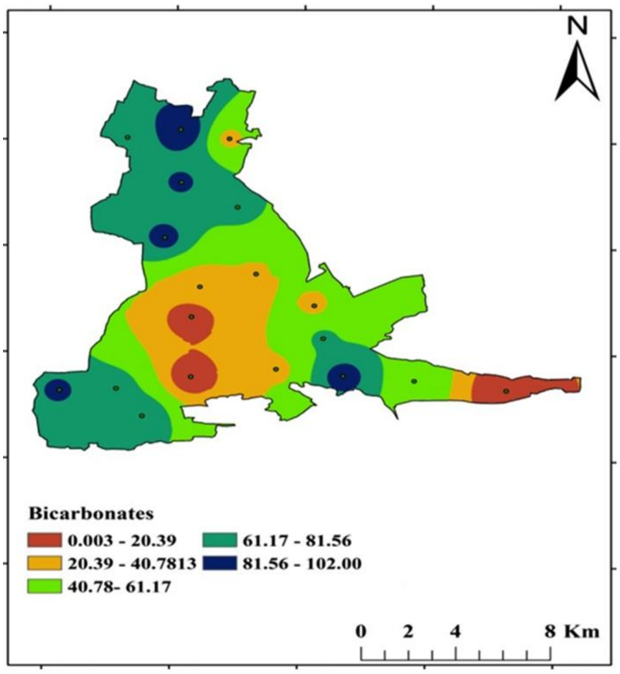

Figure 17. Bicarbonates

Table 4. Relative weights (Wn) used to calculate the WQI

Parameters	BIS standard (Vs)	Ranges	Unit weight (Wn)
pH	8.5	7.0-8.8	0.60
EC	300	634-1590	0.02
TDS	500	390-954	0.010
TH	300	25-658	0.02
Ca2+	75	32-190	0.10
Mg2+	30	30-120	0.20
TA	200	58- 102	0.03
Cl-	250	78-647	0.02
Σ Wn			1

Table 5. Classification of the Water Quality Index (Brown 1972)

Water Quality Class	Range	Grade	Possible Usage	No. of Samples
Excellent	0-25	A	Drinking, irrigation and industrial	-
Good	26-50	B	Drinking, irrigation and industrial	-
Poor	51-75	C	Irrigation and industrial	-
Very Poor	76-100	D	Irrigation	5
Unsuitable	>100	E	Proper treatment required before use	17

Table 6. WQI categories

Sample Id	Longitude	Latitude	WQI Values	WQI Category
V1	78.355721°	14.331964°	111.6	Unsuitable
V2	78.377839°	14.332943°	128.5	Unsuitable
V3	78.388129°	14.320102°	98.6	Very Poor
V4	78.407050°	14.338755°	126.2	Unsuitable
V5	78.440434°	14.342626°	131.4	Unsuitable
V6	78.466688°	14.339588°	132.5	Unsuitable
V7	78.494623°	14.337503°	107.3	Unsuitable
V8	78.530698°	14.333185°	126.8	Unsuitable
V9	78.458748°	14.357179°	147.7	Unsuitable
V10	78.455109°	14.372630°	104.1	Unsuitable
V11	78.407051°	14.366983°	94.8	Very Poor
V12	78.432104°	14.387316°	153.6	Unsuitable
V13	78.396207°	14.404166°	101.4	Unsuitable
V14	78.424502°	14.418699°	121.1	Unsuitable
V15	78.402485°	14.430193°	98.01	Very Poor
V16	78.420971°	14.450894°	135.8	Unsuitable
V17	78.381039°	14.451130°	126.9	Unsuitable
V18	78.401835°	14.455093°	98.3	Very Poor
V19	78.410204°	14.381103°	96.5	Very Poor
V20	78.371232°	14.390213°	146.9	Unsuitable
V21	78.501485°	14.420752°	109.7	Unsuitable
V22	78.512934°	14.440371°	126.1	Unsuitable

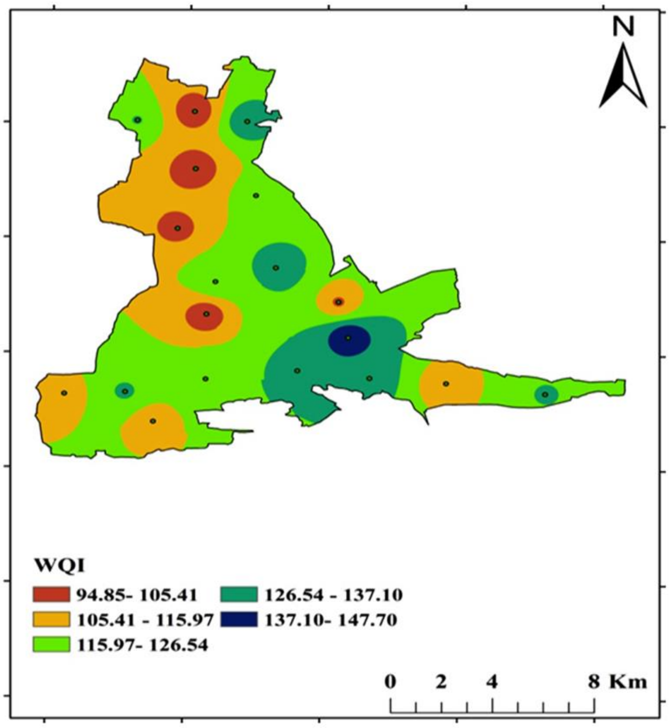

Figure 18. Water qualities

5 CONCLUSION

The BIS (2012) establishes the study for the evaluation of groundwater samples for drinking and irrigation purposes. The collected samples analyzed to determine ex-site and in-site characteristics such as alkalinity (carbonates and bicarbonates), chlorides, magnesium, calcium, electrical conductivity, pH, total dissolved solids, and total hardness. The weighted arithmetic technique used to calculate the Water Quality Index. The parameters and WQI values plotted to show spatial distribution using the IDW tool of Arc-GIS software.

The EC of groundwater is good in 18% of the samples and permissible in 82% of the samples. Most of the samples are permissible resulting in high EC values. Absolute TDS, hardness, calcium, magnesium bicarbonates, and carbonates classified into permissible limits. WQI estimated for 22.8% samples classified as very poor and 77.2% are unsuitable. Water collected from these samples contaminated due to mining in the region. Very poor quality groundwater is useful only for irrigation purposes.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

The first author C. Krupavathi greatly thankful to Department of Science and Technology (DST), Government of India for financial support through INSPIRE program (Sanction order No. DST/INSPIRE Fellowship/2018/IF170787). We are also thankful to USGS for remote sensing data and Department of Geology, Yogi Vemana University, for necessary facilities for carrying out the research work.

ABBREVIATIONS

BIS: Bureau of Indian Standards; **CGWB**: Central Groundwater Board; **EC**: Electrical Conductivity; **GIS**: Geographic information system; **RS**: Remote Sensing; **TDS**: Total Dissolved Solids; **TH**: Total Hardness; **WHO**: World Health Organization; **WQI**: Water Quality Index.

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