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Research Article

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Spatial Distribution Analysis of Groundwater Quality Index Using GIS: A Case Study of Ranchi Municipal Corporation (RMC) Area

A K Gorai[1]* and Subhash Kumar[1]

Abstract

The exploration, exploitation, and unscientific management of groundwater resources in the capital of Jharkhand (Ranchi) have posed a serious threat of reduction not only in quantity but also deterioration in quality. The aim of the present study is to provide an overview of current status of groundwater quality and to analyse spatial distribution of groundwater quality in Ranchi Municipal Corporation (RMC) area for the risk assessment. The groundwater quality parameters were analysed for 65 samples collected from the existing wells in Ranchi. The thematic maps of each water quality parameters were generated using geostatistical (Kriging) approach. Experimental semivariogram values are tested for different ordinary Kriging models to identify the best fitted for the twelve water quality parameters (calcium, magnesium, iron, nitrate, manganese, sodium, potassium, pH, TDS, total hardness, alkalinity, and turbidity) and the best models are selected on the basis of mean square error (MSE), root mean square error (RMSE), average standard error (ASE), and root mean square standardised error (RMSSE). The thematic maps of 12 groundwater quality parameters were used for ground water quality index (GWQI) map generation using overlay & index method. The results will be beneficial for the planners and decision makers to devise policy guidelines for efficient management of the groundwater resources.

Keywords

Groundwater quality index; Geostatistics; GIS

Introduction

Water is essential for sustenance of life. Most of the cities in India is rapidly growing and as results facing both groundwater quality and quantity problems as the significant amount of water demand fulfilled from groundwater. Growing urbanization, exploding population, and intensive agriculture are just some of the contributing factors for groundwater quality deterioration. The knowledge of the occurrence, replenishment and recovery of potable groundwater assumes special significance in quality-deteriorated regions, because of scarce presence of surface water. In addition to this, unfavorable climatic condition i.e. low rainfall with frequent occurrence of dry spells, high evaporation and etc. on one hand and an unsuitable geological set up on the other, a definite limit on the effectiveness of surface and subsurface reservoirs [1]. The over dependency on groundwater has led to 66 million people in 22 states at risk due to excessive fluoride and around 10 million at risk due to arsenic in six states [2] in India.

Geostatistical approach was widely used by many researchers for the analysis of spatial variations of groundwater characteristics. The spatial distribution of polluted groundwater show some heterogeneity and the pollutant concentration values are rarely available for every possible location of an area. The measurement of pollutant concentration at every location is not always feasible in view of the time and the cost involved in data collection. Therefore, prediction of values at other locations based upon selectively measured values could be one of the alternatives. In this context, to predict the concentration of pollutants at unmeasured locations, the geostatistical techniques can be used. The basic assumption in using geostatistics is that the properties in the earth have some spatial continuity up to a certain lag distance. The geostatistical concepts and its applications are reported by different researchers around the world [3-7]. Kriging method considers the spatial correlation between the sample points and is mostly used for mapping spatial variability [8,9]. Kriging is distinguished from IDW and other interpolation methods by taking into consideration the variance of estimated parameters [10].

It is recognized that the statistical approach (geostatistical methods or Kriging), has several advantages over the deterministic techniques [4,5]. The fact of giving unbiased predictions with minimum variance and taking into account the spatial correlation between the data recorded at different locations is an important advantage of Kriging. Moreover, besides interpolation, Kriging provides information on interpolation errors. Such values can be mapped to generate error surfaces which inform about the reliability of estimates.

In India several ground water related studies have been conducted to determine potential sites for groundwater evaluation [11,12] and groundwater quality mapping [13,14] using GIS. Previous studies [15,16] indicated that the groundwater recharge zones are distributed in small patches and used as sources of contaminant migration to groundwater. Open unlined drains and the pollution dumping sites in the recharge areas act as source of pollution to the groundwater [17]. Groundwater quality maps are effective for identifying locations that involve the threat of contamination.

The main aims of this investigation are to provide an overview of present groundwater quality for parameters such as calcium, magnesium, iron, nitrate, manganese, sodium, potassium, pH, TDS, total hardness, alkalinity, and turbidity levels. Geostatistics (Kriging) was used to determine the spatial distribution of groundwater quality parameters in the study area using GIS and geostatistical techniques. The ground water quality index map was also derived using overlay & Index method from the spatial distribution maps in GIS.

Materials and Methods

Study area

Ranchi, capital of Jharkhand is divided into Ranchi and Bundu subdivisions and each subdivision is further divided into blocks. It

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***Corresponding author:** A K Gorai, Environmental Science and Engineering Group, Birla Institute of Technology, Mesra, Ranchi 835215, India; Tel: +91-0651-2276587; Fax: 0651-2275401; E-mail: akgorai@bitmesra.ac.in

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consists of 18 blocks and 303 panchayats. Under Ranchi sub division, there are 14 blocks and Bundu sub division consists of 4 blocks. As per 2011 population census, the total population of Ranchi was 2,912,022. The share of the rural population was 1,654,682 (56.82% of the total population). The population growth rate in Ranchi was high (23.9%) as compared to national growth rate (21.15%) in the last decade (2001 to 2011). Due to the rising population and growing economy in agriculture, industry, and other sectors, the demand for freshwater is increasing rapidly in Ranchi and the domestic water demand is estimated to be 58.81 million cubic meter (mcm) at the rate of 135 litre per capita per day (lpcd) in 2011 (CGWB, 2011). It has also been worked out that about 30 % of the total water demand is met from ground water. The present water supply covers 65% of the population (RMC). On an average, it is stated that water is supplied to households at 100 lpcd per household. The expected water demand will increase to about 83 mcm by 2020 and 232 mcm by the year 2051 and ground water demand will increase from 17.64 mcm at present to 69.73 mcm by 2050 taking 30% dependency on ground water in Ranchi Urban Area (CGWB, 2011). Beside this, huge amount of water is needed for domestic and other industrial uses. To meet this huge demand of freshwater, groundwater plays a crucial role as a decentralized source of drinking water for millions of rural and urban families. Because of insidious nature of groundwater pollution, it is necessary to know the spatial distribution of polluted groundwater as it takes many years to show its full effect in the quality of water pumped from wells.

The present study covers only the Ranchi Municipal Corporation (RMC) area. The total area covered under the RMC is approximately 175.12 square kilometers and the average elevation of the city is 629 m above sea level. It is located on the southern part of the Chotanagpur plateau which forms the eastern edge of the Deccan plateau. The annual rainfall is about 1430 mm (56.34 inches). Ranchi urban area is underlain by Chotanagpur Gneiss Granulite Complex of Precambrian age and exhibits a gently rolling to undulating topography. Figure 1a shows the study area map and Figure 1b shows the sampling points in Ranchi Municipal Corporation Area.

Groundwater sampling and analysis

Water samples were collected directly from 65 wells in February 2012 from different parts of the RMC as shown in Figure 1b. Plastics containers were used for the collection of water samples and analyses were carried for water quality parameters viz. Calcium, Magnesium, Iron, Manganese, pH, Turbidity, Alkalinity, Total Hardness, Sodium, Potassium, Nitrate, and Total dissolve solids in the laboratory. The sampling locations were obtained using a global positioning system (GPS) receiver. Collected samples were analyzed in the laboratory to measure the concentration of the quality parameters. The specific methods of estimation of different parameters are given in Table 1.

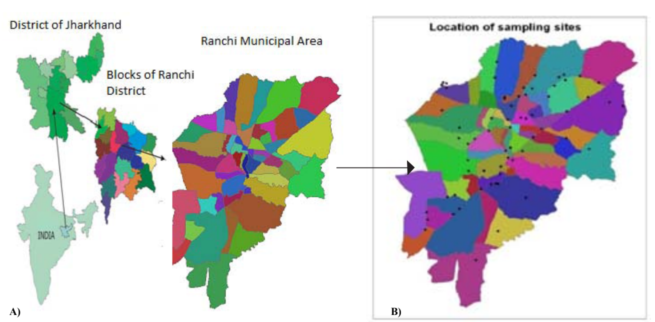


Figure 1: a) Location map of the study area. **b)** Location of sampling points.

Table 1: Specific methods of estimation of different physico-chemical parameters of groundwater in the study area.

Sl. No.	Parameters	Methods
1	Calcium	ICP Mass Spectrometry
2	Magnesium	ICP Mass Spectrometry
3	Iron	ICP Mass Spectrometry
4	Manganese	ICP Mass Spectrometry
5	Nitrate	PDA Spectrophotometric method
6	Turbidity	Nephelometer
7	pH	Digital pH meter
8	Na	Flame Photometric method
9	K	Flame Photometric method
10	Alkalinity	Titrimetry
11	Total Hardness	EDTA titration method
12	TDS	Gravimetric method

The concentrations of various physical and chemical parameters of water quality are reported in Table 2. To gain an understanding on the population parameters of various geochemical constituents of groundwater, the geochemical constituents have been treated for univariate statistical analyses, the results of which are provided in Table 3. Statistical analyses were carried out using SYSTAT. The concentration of Ca in groundwater ranged from 11.63 mg/L to 147.2 mg/l with a mean and standard deviation as 66.2 and 36.6 respectively. Out of 65 groundwater samples analysed, the concentration levels of 43 samples were found to be within the desirable limit (75 mg/L) whereas the concentration levels in rest of the samples are within the permissible limit (200 mg/l).

Mg concentration in groundwater ranged from 1.542 mg/L to 28.86 mg/l with a mean and standard deviation as 11.63 and 6.976 respectively. The concentrations of all the groundwater samples analysed were found to be within the desirable limit (30 mg/L).

Fe concentration in groundwater ranged from below detectable limit (BDL) to 1.062 mg/l with a mean and standard deviation as 0.09 and 0.2 respectively. Out of 65 groundwater samples analysed, the concentration levels in 59 samples were found to be within the desirable limit (0.3 mg/L). Iron concentration in 5 samples was within the permissible limit (1 mg/L) and the level in remaining 1 sample exceeded the permissible limit.

The nitrate levels in groundwater ranged from 0.076 mg/L to 82 mg/l with a mean and standard deviation as 16.2 and 24.4 respectively. Out of 65 groundwater samples analysed, the concentration levels in 54 samples were found to be within the desirable limit (45 mg/L) whereas the concentration levels in 11 samples exceeded the desirable limit.

Mn concentrations level in groundwater ranged from BDL to 0.644 mg/l with a mean and standard deviation as 0.135 and 0.143 respectively. Out of 65 groundwater samples analysed, the concentration levels of 34 samples were found to be within the desirable limit (0.1 mg/L). The concentration levels of 25 samples were within the permissible limit (0.3 mg/L) and the levels in remaining 6 samples exceeded the permissible limit.

The pH levels in groundwater ranged from 6.63 to 8.3 with a mean and standard deviation as 7.527 and 0.434 respectively. pH levels in

Table 2: Concentrations of groundwater quality parameters.

Sample ID	Concentrations Levels of Water Quality Parameters											
	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Nitrate (mg/l)	Mn (mg/l)	pH	Turbidity (NTU)	Na (mg/l)	K (mg/l)	Alkalinity (mg/l)	TH (mg/l)	TDS (mg/l)
S-0	36.0	9.632	0.044	3.205	0.113	7.51	1.3	20.1	6.5	250	61.5	228
S-1	19.85	3.113	0.565	1.3076	0.046	7.38	3.2	10.9	3.5	120	24.91	265
S-2	41.71	5.477	0.002	2.64	0.001	8.2	0.3	60.5	5.4	210	61.75	127
S-3	64.32	7.635	0.09	0.589	0.026	7.53	0.7	45.4	1.7	160	51.9	258
S-4	33.69	3.178	0.188	0.461	0.06	8.07	4.8	20.9	1.4	280	27.9	236
S-5	22.87	2.161	0.005	0.153	0.018	7.17	0.6	37.3	2.1	150	18.4	245
S-6	15.6	20.23	1.062	1.2564	0.148	7.57	10.1	22.5	1	170	118.3	258
S-7	57.52	19.47	0.021	46.3	0.184	7.48	0.1	52.3	19.8	180	98.7	175
S-8	30.49	5.292	0.011	5.589	0.01	7.84	0.6	14.5	7.7	160	53.7	150
S-9	57.52	19.9	0.05	2.256	0.028	7.59	1.3	52.8	21.2	180	100.5	165
S-10	55.16	7.323	BDL	5.205	0.221	7.8	8.9	72.1	3.8	170	62.4	122
S-11	56.46	7.619	0.151	0.333	0.011	7.71	2.4	34.5	2.6	230	64.9	135
S-12	49.87	8.609	0.529	6.87	0.232	7.92	5.5	51.8	8.3	160	69.8	179
S-13	82.65	13.95	BDL	11.89	0.008	7.67	2.4	22.2	3.5	230	87.8	146
S-14	29.13	7.036	0.01	6.4619	0.005	7.57	4.5	18.7	10.3	120	79.33	132
S-15	119.5	18.67	BDL	40.615	0.196	8.02	0.2	63.9	10.8	140	94.60	456
S-16	133.8	18.85	BDL	40.1025	0.213	8.03	1.3	66.1	10.3	270	150.4	648
S-17	37.06	5.526	0.008	12.666	0.11	7.94	1.4	70.1	8.4	250	104.29	220
S-18	139.1	24.39	BDL	0.1794	0.093	8.09	0.5	77.2	9.4	200	122.9	434
S-19	147.2	26.38	0.337	1.5897	0.211	8.06	0.4	72.1	12.5	210	193.3	336
S-20	144.1	24.1	BDL	2.025	0.178	8.18	0.1	74.1	13.4	180	188.9	532
S-21	99.52	16.9	BDL	78.05	0.061	7.82	0.9	100.4	11.3	190	157.3	259
S-22	19.64	2.549	0.986	1.8974	0.109	8.1	1.8	19.1	1.3	130	71.15	356
S-23	31.89	4.453	0.001	0.743	0.047	6.82	0.2	28.2	2.7	100	30.3	210
S-24	80.18	9.03	0.051	0.769	0.192	8.08	11.5	52.8	2.9	120	56.6	218
S-25	79.96	8.921	0.011	0.538	0.206	7.21	0.1	50.1	3.1	260	41.7	186
S-26	87.12	20.64	BDL	6.158	0.047	7.18	0.3	59.1	12.2	260	133.7	372
S-27	94.1	23.08	BDL	59.53	0.031	7.01	0.4	58.2	7	230	135.7	958
S-28	46.6	7.319	BDL	45.8	0.043	7.56	0.1	32.9	16.4	240	87.5	176
S-29	45.47	10.27	0.009	24.66	0.179	7.97	0.2	51.8	12.5	100	70.6	268
S-30	57.83	10.61	0.01	3	0.051	7.83	0.4	32.5	5.01	170	71.4	234
S-31	45.52	5.965	BDL	6.974	0.053	7.66	10.5	49.6	10.7	150	59.8	240
S-32	114.4	19.75	0.023	53.48	0.397	7.69	12.5	54.3	14.8	150	109.03	490
S-33	95.32	19.35	0.028	54.41	0.245	7.78	8.9	56.7	14.9	80	149.4	321
S-34	64.78	11.98	0.042	3.179	0.034	7.06	3.4	64.1	9.01	330	107.4	294
S-35	45.47	8.74	BDL	3.205	0.058	6.7	3.1	28.6	4.1	230	75.5	188
S-36	40.59	10.99	0.148	67.23	0.126	7.08	3.4	25.5	4.01	100	72.9	276
S-37	44.7	5.73	0.15	7.23	0.11	7.53	15.5	36.5	2.7	190	48.3	740
S-38	40.8	7.657	0.285	0.4358	0.178	7.48	6.5	40.1	3.7	215	58.7	266
S-39	33.01	7.627	BDL	0.9487	0.097	6.63	4.8	44.2	2.01	260	56.2	305
S-40	48.3	5.012	BDL	77.17	0.094	6.8	2.5	57.3	3.1	130	40.75	396
S-41	49.97	5.139	BDL	73.07	0.072	7.41	2.5	57.2	3.3	150	50.6	366
S-42	134.8	7.974	BDL	82.05	0.644	6.82	3.8	60.9	4.4	110	63.2	490
S-43	49.28	5.314	BDL	8.205	0.073	6.68	0.3	60.1	4.8	160	104.03	314
S-44	133.4	8.025	BDL	82.05	0.624	6.93	0.5	60.9	4.6	185	63.06	628
S-45	45.68	7.289	0.019	3.358	0.087	6.92	0.1	31.4	16.01	130	111.3	555
S-46	28.68	4.201	0.021	5.358	0.06	7.25	0.3	40.3	2.1	120	45.1	148
S-47	35.54	4.763	0.039	15.43	0.197	7.25	0.1	39.8	2.4	140	37.08	246
S-48	87.76	13.17	0.039	3.2	0.116	7.8	0.5	40.2	3.9	180	75.86	310
S-49	87.96	13.07	0.047	0.076	0.111	7.28	0.2	42.1	3.3	230	107.3	430
S-50	64.81	10.12	BDL	1.641	0.118	7.14	0.6	50.9	3.6	190	81.15	230
S-51	141.4	28.86	BDL	6.641	0.124	7.93	1.1	83.6	11.6	175	204.9	560
S-52	131.6	26.38	0.144	6.179	0.017	7.15	1.4	85.7	12.3	130	188.79	688
S-53	72.38	18.01	BDL	8.23	0.233	7.4	1.2	70.4	10.5	160	118.24	422
S-54	74.73	13.97	BDL	7	0.092	7.37	5.6	56.1	7.01	170	103.04	235
S-55	109.4	14.1	0.079	0.343	0.005	7.11	3.4	47.1	8.01	110	124.7	259
S-56	62.88	16.85	0.016	5.43	0.527	7.43	2.8	49.1	8.2	230	107.7	315

S-57	54.49	15.75	0.023	8.02	0.511	7.64	0.1	50.6	4.1	230	98.03	345
S-58	77.56	20.27	0.318	10.589	0.312	7.99	0.1	35.1	3.2	200	130.7	245
S-59	27.18	7.705	BDL	2.7179	0.144	8.01	0.1	29.9	5.4	110	48.2	155
S-60	11.63	1.542	0.008	3.201	0.001	7.91	5.4	30.4	5.8	170	13.4	140
S-61	56.07	8.864	0.221	5.03	0.025	7.06	0.1	30.1	8.1	120	70.65	180
S-62	35.2	4.574	0.017	6.0145	0.034	8.3	0.4	32.9	1.3	170	40.28	201
S-63	71.71	13.11	0.02	6.321	0.027	7.64	0.1	47.2	2.9	130	97.668	129
S-64	78.38	18.51	0.02	4.025	0.03	8.3	0.3	42.1	3.4	140	123.96	164

Table 3: Descriptive Statistics of Groundwater Quality Parameters.

Parameter	N	Min	Max	Mean	Median	S.D.	Skewness	Kurtosis	Desirable Limit (DL)	Permissible Limit (PL)	< DL	DL<C< PL	> PL
Ca	65	11.63	147.2	66.32	56.46	36.3	0.786	-0.32	75	200	43	22	0
Mg	65	1.542	28.86	11.73	9.03	6.97	0.654	-0.59	30	NA	65	0	0
Fe	65	0	1.062	0.09	0.011	0.2	3.45	12.95	0.3	1.0	59	5	1
Nitrate	65	0.076	82	16.02	5.43	24.3	1.72	1.58	45	NA	54	11	0
Mn	65	0	0.644	0.133	0.094	0.142	2.05	4.48	0.1	0.3	34	24	6
pH	65	6.63	8.3	7.54	7.57	0.44	-0.256	-0.87	6.5-8.5	NA	65	0	0
Turbidity	65	0.1	15.5	2.59	1.1	3.50	1.89	3.22	5	10	54	6	5
Na	65	10.9	100.4	47.32	49.1	18.71	0.31	-0.07	200	NA	65	0	0
K	65	1	21.2	6.88	5.01	4.8	0.99	0.387	12	NA	54	11	0
Alkalinity	65	80	330	176.85	170	52.97	0.50	-0.198	200	NA	48	17	0
TH	65	13.4	204.9	87.3	75.86	43.64	0.76	0.333	300	NA	65	0	0
TDS	65	122	958	307	258	168.8	1.598	2.88	500	NA	57	8	0

all the analysed samples were found to be within the desirable range (6.5-8.5).

The turbidity levels in groundwater ranged from 0.1 NTU to 15.5 NTU with a mean and standard deviation as 2.63 and 3.51 respectively. Out of 65 groundwater samples analysed, the turbidity levels in 54 samples were found to be within the desirable limit (5 NTU), 6 sample's levels were within the permissible limit (10 NTU) and in remaining 5 sample's levels exceeded the permissible limit.

Na concentrations level in groundwater ranged from 10.9 mg/L to 100.4 mg/l with a mean and standard deviation as 47.4 and 18.85 respectively. Na concentrations in all the analysed samples were found to be within the desirable limit (200 mg/l).

Potassium levels in groundwater ranged from 1 mg/L to 21.2 mg/l with a mean and standard deviation as 6.935 and 4.833 respectively. Out of 65 groundwater samples analysed, the concentration levels in 54 samples were found to be within the desirable limit (12 mg/L) whereas the levels in 11 samples exceeded the desirable limit.

Alkalinity levels ranged from 80 mg/L to 330 mg/l with a mean and standard deviation as 177.4 and 53.2 respectively. Out of 65 groundwater samples analysed, the concentration levels of 48 samples were found to be within the desirable limit (200 mg/L) whereas the levels in remaining 17 samples exceeded the desirable limit.

Total Hardness (TH) levels ranged from 13.4 mg/L to 204.9 mg/l with a mean and standard deviation as 86.8 and 43.7 respectively. Total Hardness (TH) levels in all the analysed samples were found to be within the desirable range (300 mg/L).

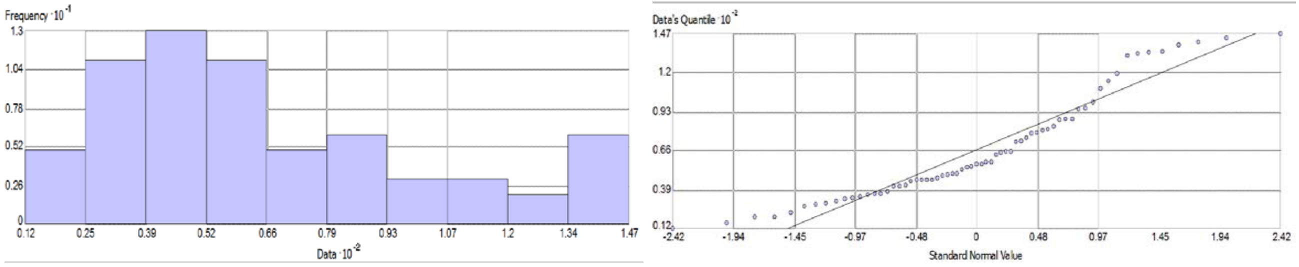
Total dissolved solids (TDS) level in groundwater ranged from 122 mg/L to 958 mg/l with a mean and standard deviation as 309.23 and 169.1 respectively. Out of 65 groundwater samples analysed, the concentration levels of 57 samples were found to be within the desirable limit (500 mg/L) whereas the levels in remaining 8 samples exceeded the desirable limit.

Geostatistical approach in development of spatial variability models

Though, there are many interpolation techniques available but Kriging is most suitable and having many advantages over others as mentioned in the literature. Thus, in this study also Kriging was used for spatial variation analysis. Kriging method involves three steps as

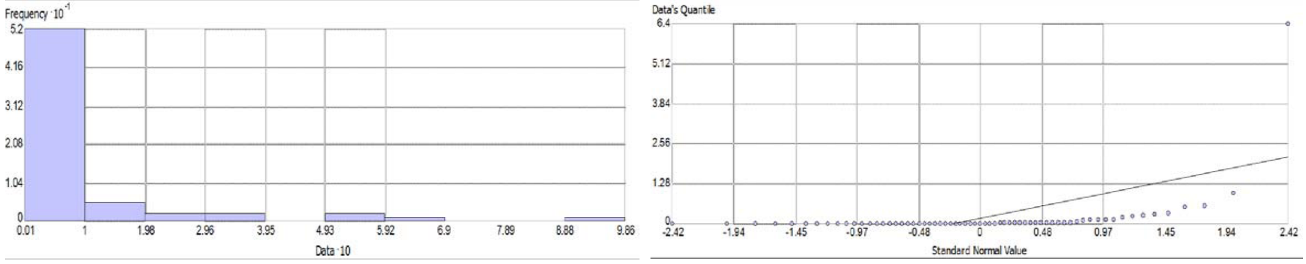
Exploratory data analysis: Exploratory data analysis has been performed to explore your data was check data consistency, removing outliers and identifying statistical distribution where data came from. Kriging methods work best for normal distribution data [5]. The histograms and normal QQplots were plotted as shown in Figure 2 to check the normality of the observed data. Histogram and QQPlot analyses were carried out for each water quality parameter and it was found that all the analysed parameters Fe, Mn, Nitrate, Ca, Mg, pH Turbidity, Na, K, TDS, Alkalinity (total), and Total Hardness (TH) showed more or less a normal distribution. For each sampling campaign, the mean and median are very similar (Table 3) which is, indicative of data coming from a normal distribution is somewhat nearer. High skewness values can indicate the existence of outliers. Outlier is a measured sample point that has a very high or low value relative to the values in the dataset. It is important to detect outliers because they may be values that were measured or recorded incorrectly and, in this case, their effects on subsequent stages of the geostatistical study are very negative. Transformations can be used to make the data normally distributed and satisfy the assumption of equal variability for the data. In present study, no transformation of data was done before geostatistical analysis.

Structural analysis of data: Spatial correlation or dependence can be quantified with semivariograms (or variograms). Kriging relates the semivariogram, half the expected squared difference



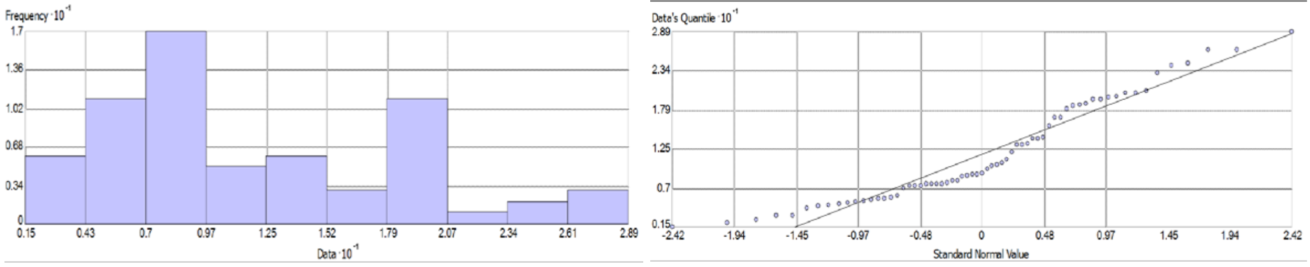
Histogram plot of Ca

QQ plot of Ca



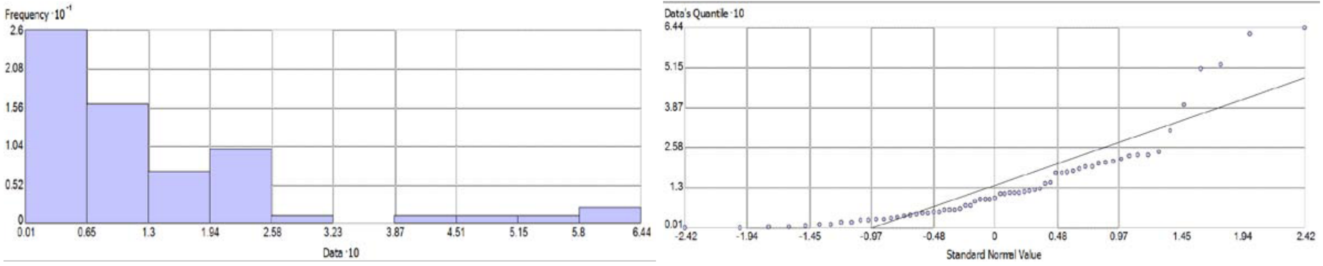
Histogram plot of Fe

QQ plot of Fe



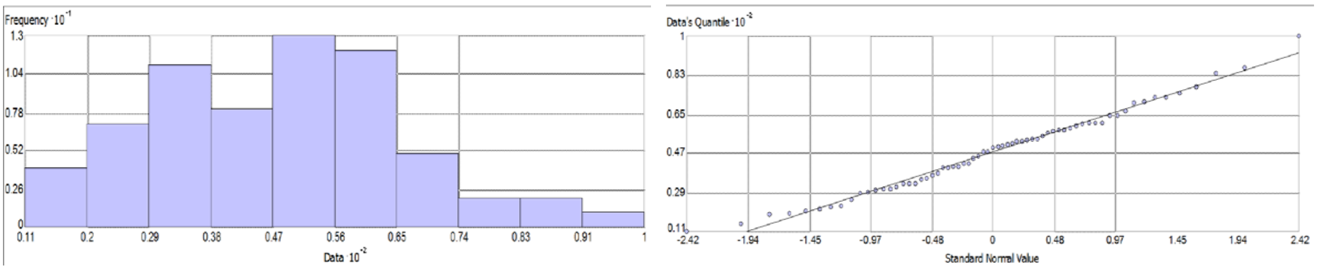
Histogram plot of Mg

QQ plot of Mg



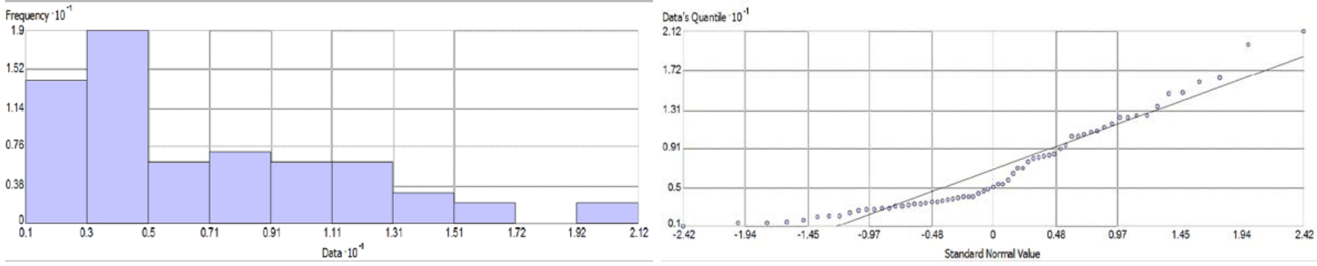
Histogram plot of Mn

QQ plot of Mn



Histogram plot of Na

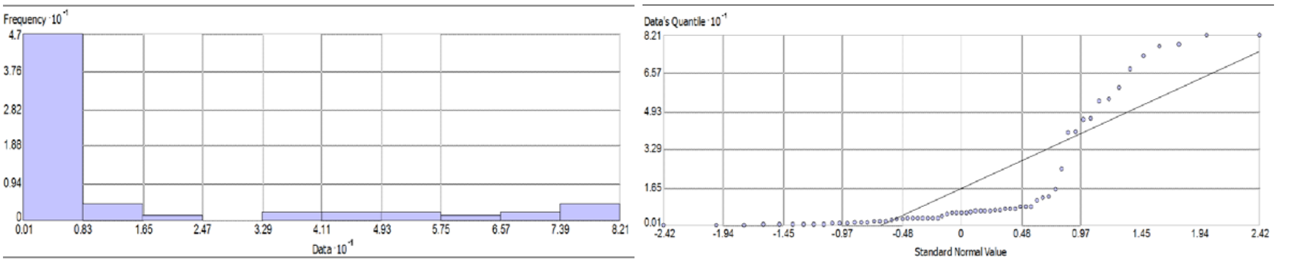
QQ plot of Na



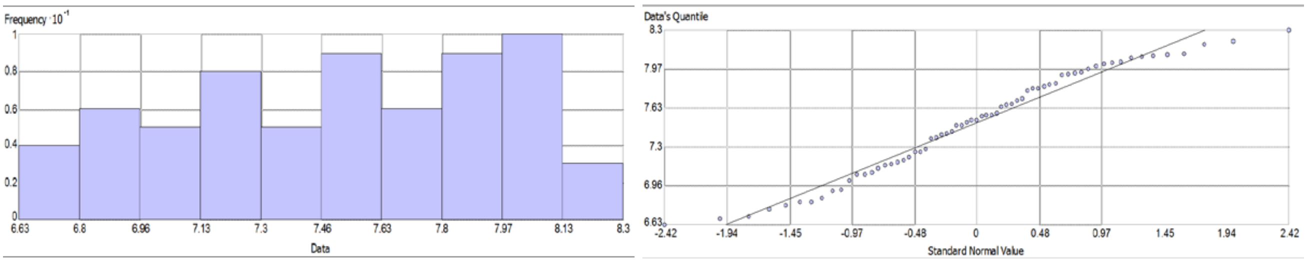
Histogram plot of K

QQ plot of K

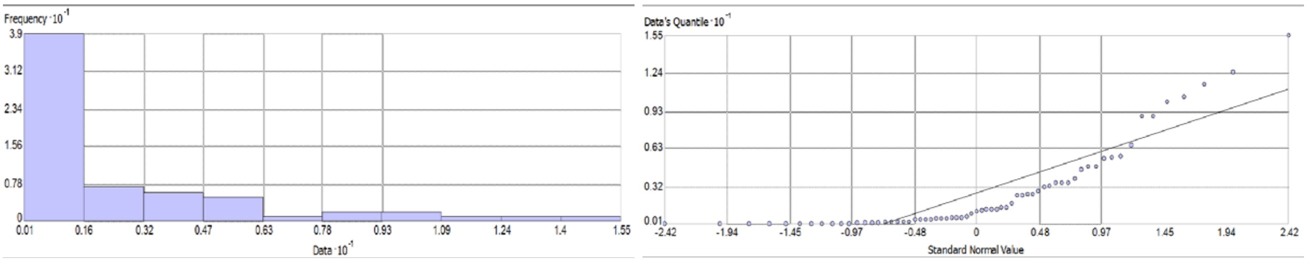
Figure 2 to Continued...



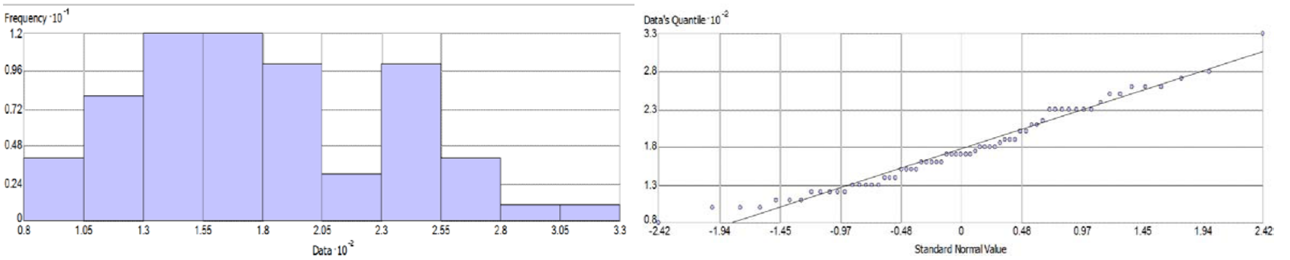
Histogram plot of Nitrate **QQ plot of Nitrate**



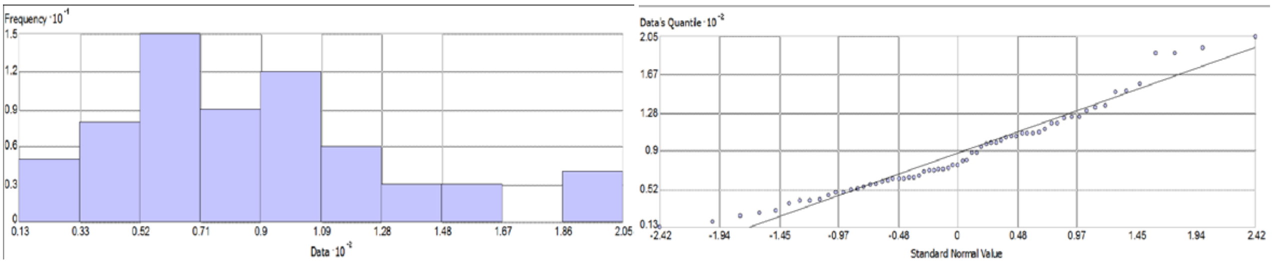
Histogram plot of pH **QQ plot of pH**



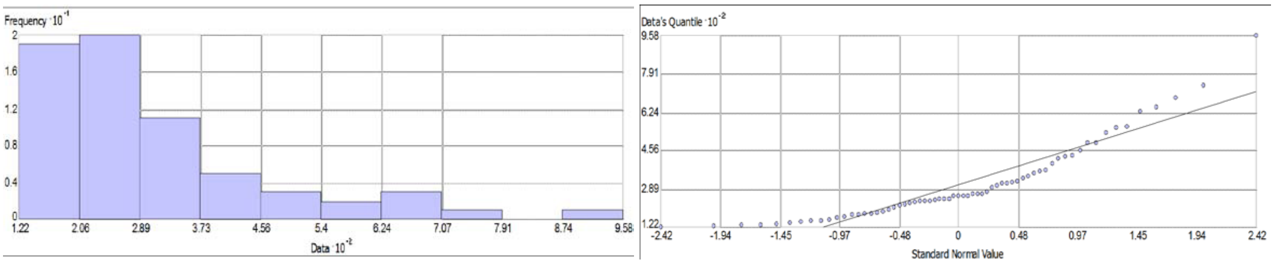
Histogram plot of Turbidity **QQ plot of Turbidity**



Histogram plot of Alkalinity **QQ plot of Alkalinity**



Histogram plot of Hardness **QQ plot of Hardness**



Histogram plot of TDS **QQ plot of TDS**

Figure 2: Histogram & QQ plot of Water Quality Parameters.

between paired data values z(x) and z(x + h) to the distance lag h, by which locations are separated.

$$\mathbf{y}\left(\mathbf{h}\right) = \frac{1}{2}\,\mathrm{E}\left[\mathrm{z}\left(\mathrm{x}\right) - \mathrm{z}\left(\mathrm{x}+\mathrm{h}\right)\right]^2 \tag{1}$$

For discrete sampling sites the function is written in the form:

$$\gamma(\mathbf{h}) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[\mathbf{z}\left(\mathbf{x_i}\right) - \mathbf{z}(\mathbf{x_i} + \mathbf{h})\right]^2 \tag{2}$$

Where z (x_i) is the value of the variable Z at location of x_i, h is the lag, and N (h) is the number of pairs of sample points separated by h. For irregular sampling, it is rare for the distance between the sample pairs to be exactly equal to h. A semivariogram plot is obtained by calculating values of the semivariogram at different lags. These values were then usually fitted with a theoretical model: circular, spherical, exponential, or Gaussian. The models provide information about the spatial structure as well as the input parameters for the Kriging interpolation. Out of different Kriging techniques, the ordinary Kriging (OK) method was used in the present study because of its simplicity and prediction accuracy in comparison to other Kriging methods.

Prediction: Four types of semivariogram models (Circular, Spherical, Exponential, and Gaussian,) were tested for each water quality parameters (Ca, Mg, pH, Mn, Fe, Nitrate, Turbidity, Na, K, TDS, Alkalinity and Total Hardness (TH)) for the selection of the best one. Predictive performances of the fitted models were checked on the basis of cross validation tests. The values of mean error (ME), mean square error (MSE), root mean error (RMSE), average standard error (ASR) and root mean square standardized error (RMSSE) were estimated to ascertain the performance of the developed models. If the predictions are unbiased, the ME should be near zero. However, this statistic has some important drawbacks: it depends on the scale of the data and is insensitive to inaccuracies in the variogram. So, usually the MSE is used to standardize the ME, being ideally zero, i.e., an accurate model would have a MSE close to zero. Besides making predictions, each of the Kriging techniques gives the Kriging variances which estimate the variability of the predictions from the known values. The Kriging variances must be accurately calculated because they have an important influence on some applications of Kriging, e.g., the probability Kriging. If the RMSE is close to the ASE, the prediction errors were correctly assessed. If the RMSE is smaller than the ASE, then the variability of the predictions is overestimated; conversely, if the RMSE is greater than the ASE, then the variability of the predictions is underestimated. The same could be deduced from the RMSSE statistic. It should be close to one. If the RMSSE is greater than one, the variability of the predictions is underestimated; likewise if it is less than one, the variability is overestimated. After conducting the cross validation process, maps of kriged estimates were generated which provided a visual representation of the distribution of the groundwater quality parameters. Various errors are defined by the equation (3)-(7) given below.

The corresponding sill, nugget, and range values of the best fitted theoretical models were observed and reported in Table 4. The best fitted variogram models are shown in Figure 3. Subsequently, thematic maps for groundwater quality parameters were generated using ordinary Kriging.

$$ME = \frac{1}{N}\sum_{i=1}^{n}\left[\hat{Z}\left(X_i\right) - Z(X_i)\right] \tag{3}$$

$$MSE = 1/N\sum_{(i=1)}^{n}[\tilde{Z}(X_i) - Z(X_i)]/\tilde{\sigma}(X_i) \tag{4}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\hat{Z}\left(X_i\right) - ZX_i\right]^2} \tag{5}$$

$$ASE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\tilde{\sigma}^2(X_i)} \tag{6}$$

$$\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\left(\hat{Z}\left(X_i\right) - Z\left(X_i\right)/\tilde{\sigma}\right)\left(X_i\right)\right]^2} \tag{7}$$

Where $\tilde{\sigma}^2$ (x_i) is the Kriging variance for location x_i [5,18]. After conducting the cross validation process, maps of kriged estimates were generated which provided a visual representation of the distribution of the water quality parameters in Ranchi Municipal Corporation Area. These maps were produced with the ArcMap module of the Arc GIS.

Table 4: Characteristics parameters of variogram models.

Groundwater parameters	Best fitted model	Nugget (C_0)	Sill (C0+C)	Lag size (Km)	Range (Km)	[C0/ (C0+C)]%	ME	RMSE	ASE	MSE	RMSSE
Ca	Spherical	0	1396	387.87	1351.62	0	-3.35	33.76	34.49	-0.06	0.99
Mg	Exponential	0	50.84	296.85	845.772	0	0.033	6.428	7.290	0.017	0.90
Fe	Spherical	0.51998	0.741	1244.6	14752.6	70.15	0.006	0.8334	0.7718	0.006	1.089
Nitrate	Exponential	386.4	688.8	1244.6	14752.6	56.10	-0.02	23.09	22.31	-0.003	1.039
Mn	Gaussian	0.016521	0.025	1244.6	14752.6	65.10	0.0004	0.1479	0.1343	0.002	1.099
pH	Spherical	0.1576	0.238	1244.6	14752.6	66.27	0.0006	0.4288	0.4274	0.0045	1.004
Turbidity	Circular	0	15.38	69.554	436.822	0	-0.182	3.541	4.114	-0.042	0.86
Na	Circular	5.0745	371.6	386.6	2283.04	1.36	-0.40	15.54	16.20	-0.013	1.002
K	Circular	17.636	404.7	6.8771	3073.00	4.35	0.13	4.299	4.846	0.027	0.90
TDS	Spherical	0	35197	74.989	517.058	0	-2.22	168.1	196.4	-0.005	0.86
Alkalinity	Gaussian	97.251	3247	121.29	669.828	2.99	0.95	57.08	56.81	0.020	1.013
Total Hardness	Gaussian	1261.8	2148	546.16	3538.46	58.73	0.97	37.1	41.34	0.024	0.91

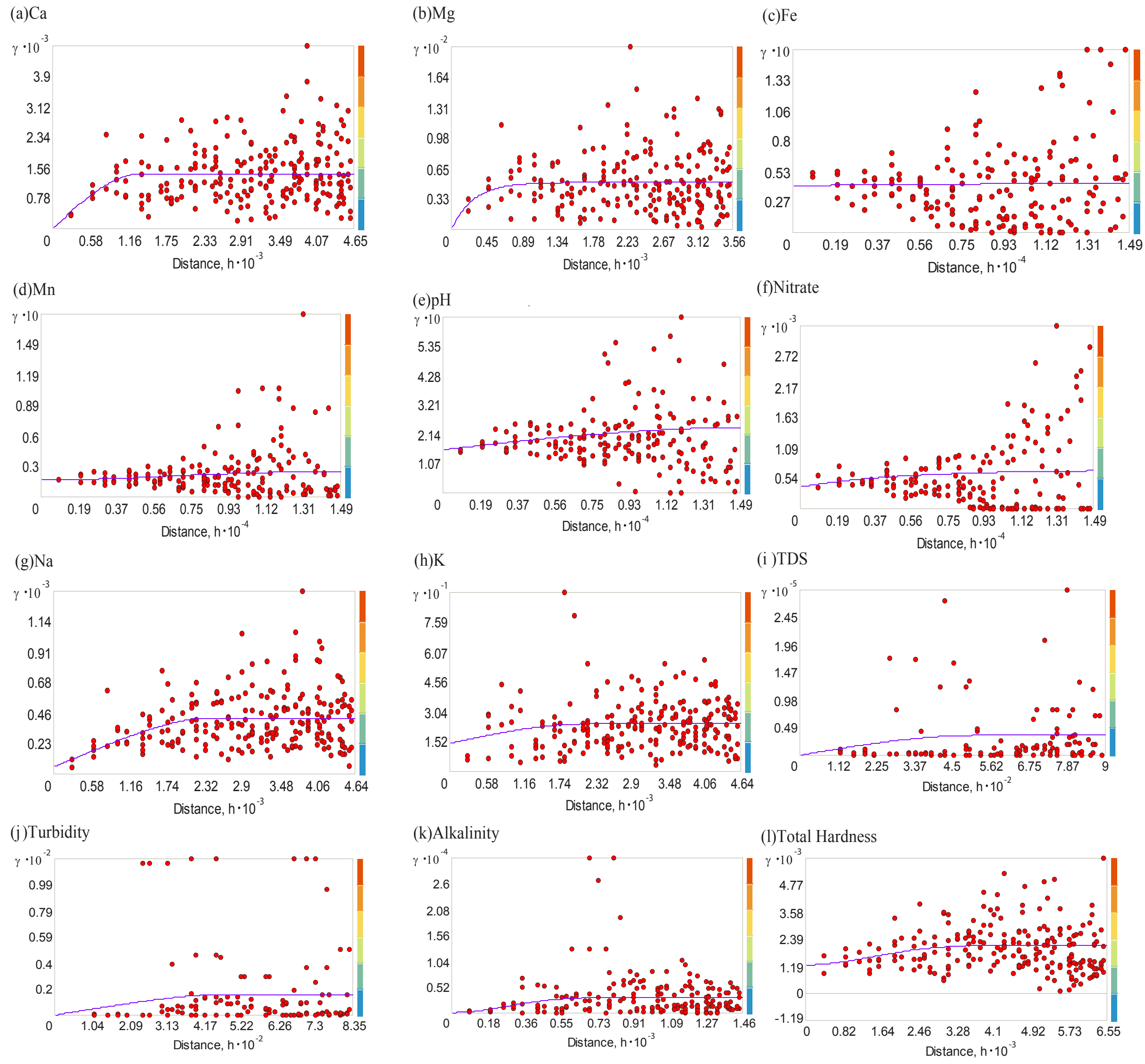


Figure 3: Best-fitted semivariograms models for water quality parameters.

Table 4 represents characteristics parameters of best fitted semi-variogram models of groundwater quality parameters in the study area region. The results shows that the best fit model for the prediction of Ca, Mg, pH, Mn, Fe, Nitrate, Turbidity, Na, K, TDS, Alkalinity (total) Total Hardness(TH) were spherical, exponential, spherical, gaussian, spherical, exponential, circular, circular, circular, spherical, gaussian, and gaussian respectively. The ratio of nugget variance to sill expressed in percentages can be regarded as a criterion for classifying the spatial dependence of ground water quality parameters. If this ratio is less than 25%, then the variable has strong spatial dependence; if the ratio is between 25 and 75%, the variable has moderate spatial dependence and greater than 75%, the variables shows only weak spatial dependence. All parameters of ground water quality have strong spatial structure except TH, Fe, pH, Mn, & Nitrate which have moderate spatial dependence.

The mean standardised error for Ca, Mg, pH, Mn, Fe, Nitrate, Turbidity, Na, K, TDS, Alkalinity (total), and Total Hardness (TH) were -0.06, 0.017, 0.006, -0.003, 0.002, 0.0045, -0.042, -0.013, 0.027, -0.005, 0.020, 0.024 respectively. The respective values of RMSSE were 0.99, 0.90, 1.089, 1.039, 1.099, 1.004, 0.86, 1.002, 0.90, 0.86, 1.013, and 0.91. The MSE values were close to zero and their corresponding RMSSE values close to one represent a good prediction model. Close values of RMSE and ASE for all the twelve water quality parameters also shows good agreement of the model.

Spatial variation of groundwater quality parameters: Spatial distribution of groundwater quality parameters such as Ca, Mg, pH, Mn, Fe, Nitrate, Turbidity, Na, K, TDS, Alkalinity (total) Total Hardness (TH) concentrations were carried out through GIS and Geostatistical techniques. Ordinary Kriging was used to obtain the spatial distribution of groundwater quality parameters over the area. The distribution map clearly reveals that the water quality levels at some places are poor with respect to the measured quality parameter.

Figure 4a shows that Ca concentration in major portion of the study area is within the permissible limit of 200 mg/L (as per the guideline of BIS for drinking water). The thematic map of Ca concentration reveals that the range of Ca concentrations in groundwater was varying from 11.6 mg/l to147.2 mg/l. Similarly, the thematic maps of Mg, pH, Mn, Fe, Nitrate, Turbidity, Na, K, TDS, Alkalinity, Total Hardness(TH) were generated using the corresponding best-fitted model and semivariogram parameters as shown in Figure 4.

Estimation of ground water quality index (GWQI)

WQI is computed to reduce the large amount of water quality data to a single numerical value. It reflects the composite influence of different water quality parameters on the overall quality of water. It is a very useful tool for communicating the information on the overall quality of water. The standards for purposes of drinking have been considered for the calculation of WQI as recommended by Bureau of Indian Standard (BIS) 10050 and World Health Organization (WHO) [19].

The weighted arithmetic mean function has been used or proposed by many researchers [20-27] to determine the groundwater quality index (WQI). The weighted arithmetic mean function is ambiguity free function, shows small eclipsing with large number of variables and is widely used aggregation function. The formula used to determine the aggregated water quality index is given below in eqn. 8.

$$WQI = \sum_{i=1}^{n} W_i I_i \tag{8}$$

Where,

I_i is the sub-index of ith water quality parameter

WQI is water quality index and 'n' is the number of water quality parameters considered.

W_i is the weightage of the ith water quality parameter

The sub-index of ith quality parameter can be determined by eqn. 9 as given below:

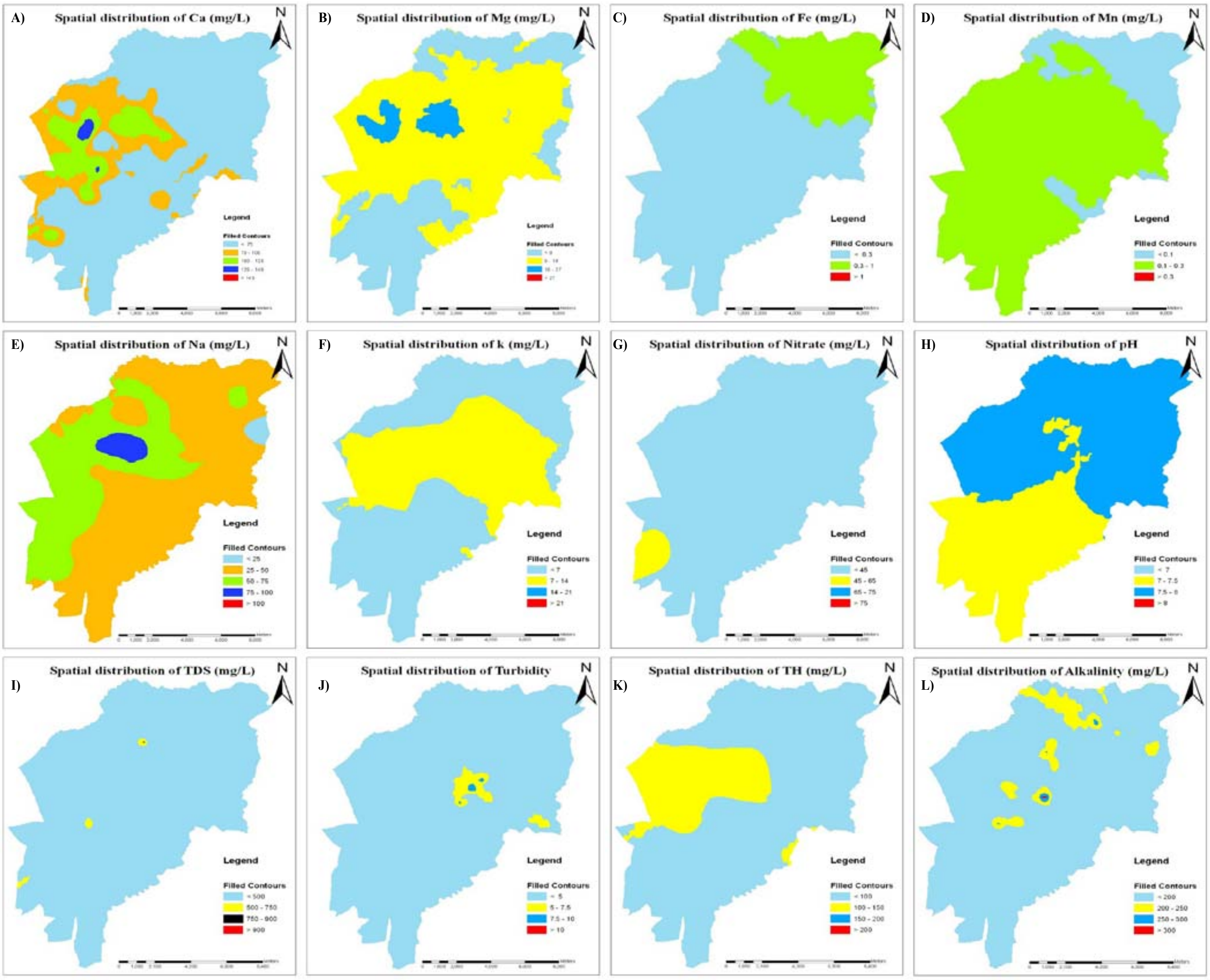


Figure 4: Spatial distribution map of groundwater quality parameters.

$$I_i = \left(\frac{C_i - C_{\min}}{C_s - C_{\min}}\right) * 100 \qquad (9)$$

Where,

C_i = the observed concentration of the i^{th} water quality parameter

C_s = the concentration limit value (desirable limit) of the i^{th} water quality parameter as mentioned in Table 5.

C_{min} = the minimum concentration of the parameter reflecting best water quality

The minimum value for all the parameters considered in the model were 0 except pH (for pH = 7, represent best water quality)

The weightage of individual pollutants can be found out using eqn. 10 as below:

$$w_i = k/s_n \qquad (10)$$

$$\text{where} \quad k = \left[1 \Big/ \left(\frac{1}{S_1} + \frac{1}{S_2} \ldots\ldots. \frac{1}{S_n} \right) \right] = \text{Constant}$$

Sn = desirable limit of the nth water quality parameters as listed in Table 5.

The weightage thus calculated is listed below in Table 5.

Groundwater quality index map is derived from twelve thematic layers (Figure 5) of water quality parameters. These maps were processed in GIS environment to get the output map (water quality index map) as shown in Figure 6. The water quality index was reclassified into three classes that describe the quality of groundwater in the studied region. These three classes are: good, moderate, and poor. The ranges and class of the groundwater quality index of WQI map is given below in Table 6.

The result of groundwater vulnerability to pollution assessment shows index values which vary from 56 to 191. According to the results of the groundwater vulnerability assessment, the study area has been divided into three types of zones: Poor water quality (56-100), Moderate water quality (100.1-136), and Good water quality (136.1-191).

Table 5: Relative weightage of water quality parameters.

Groundwater parameters	Desirable Limits	Weightage
Ca	75	0.00096
Mg	30	0.0024
Fe	0.3	0.2406
Mn	0.1	0.7218
Nitrate	45	0.0016
pH	6.5-8.5	0.0144
Turbidity	5	0.0111
Na	200 (WHO)*	0.0004
K	12 (WHO)*	0.006
TDS	500	0.0004
Alkalinity	200	0.0002
Hardness	300	0.0001
Total Weightage		1

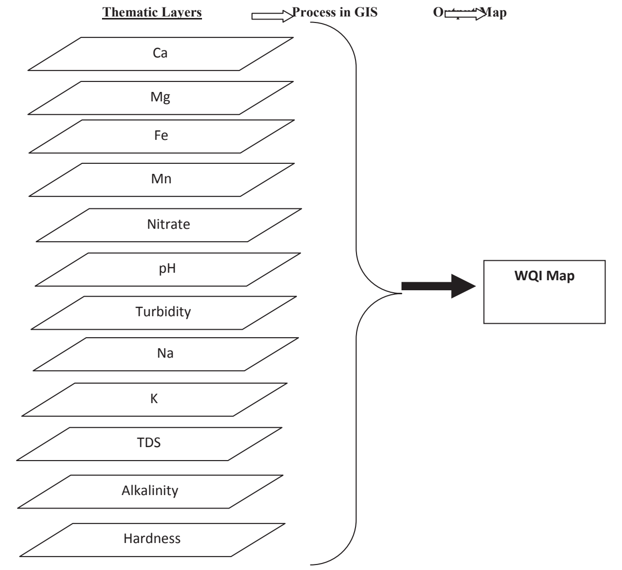


Figure 5: Thematic Layers processed in GIS to derive water quality index (map).

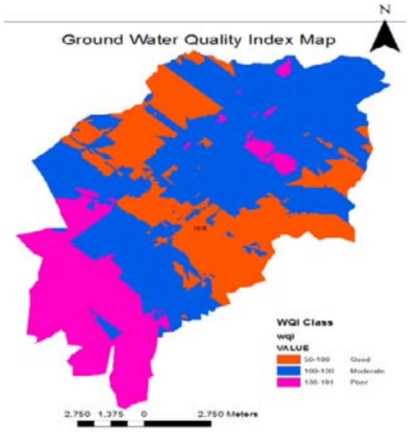


Figure 6: Groundwater quality index map.

It is very difficult to say the role of particular parameter on the spatial changes in the groundwater quality index. The total area under different groundwater quality index and their corresponding percentage are reported in Table 6. The results revels that the percentage of area (total area) under different groundwater quality indices class are 26.23% (45.99 km^2), 52.02% (91.19 km^2), 21.75 % (38.12 km^2) for Good, Moderate, and Poor respectively.

Conclusions

The groundwater quality analyses were done in Ranchi Municipal Corporation, Jharkhand, India using geostatistical tool. Geostatistical analyses (Ordinary Kriging) were carried out for distribution analysis of various water quality parameters. Results showed that deterioration of ground water quality in RMC is not very serious problem except few areas. For a better groundwater quality management, spatial distribution analyses of groundwater quality parameters in the regions were carried out. The conventional method of water quality index (WQI) determination has some drawbacks. This is generally unable to represent the water quality status of specific locations. Thus

Table 6: Groundwater quality classes of the final output.

Water Quality Class	Water Quality Index	Area in km^2	Percentage of area
Good	56-100	45.99	26.23
Moderate	100.1-136	91.19	52.02
Poor	136.1-191	38.12	21.75

WQI was developed from the thematic maps of generated for water quality parameters using overlay and index method. The WQI map clearly reveals the suitability of groundwater quality for drinking purposes.

Thus, the study illustrates the of geostatistical techniques for water quality assessment and investigating spatial variations of water quality as an effort toward a more effective groundwater quality management.

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Author Affiliation

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[1]Environmental Science and Engineering Group, Birla Institute of Technology, Mesra, Ranchi 835215, India