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Groundwater Quality Assessment for Drinking Purpose in Raipur City, Chhattisgarh Using Water Quality Index and Geographic Information System

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ABSTRACT

An effort has been made to comprehend the groundwater quality of Raipur city for drinking purpose utilizing Water Quality Index (WQI) and Geographic Information System (GIS) techniques. In this study thirty four groundwater samples were collected during May, 2015. Standard methods has been adopted in groundwater sampling which are prescribed by the American Public Health Association (APHA, 1995). Eight water quality parameters have been considered to ascertained water quality index viz. pH, chloride, fluoride, calcium, magnesium, alkalinity, hardness and nitrate. The Bureau of Indian Standard (BIS, 2009) has been considered to assess the suitability of groundwater for drinking purposes and for the calculation of WQI. This study reveals that 76% area is falling under excellent, very good and good category and 24% area is falling under poor, very poor and unfit category as per the WQI classification. The predicted accuracy of the obtained result is around 97.05% reflecting capability of adopted techniques. Anthropogenic activities are influencing the groundwater quality of the study area. The present study is helpful in proper planning and management of available water resource for drinking purpose.

INTRODUCTION

Ground water is a very valuable natural resource for the economic development and secure provision of potable water supply in both urban and rural environments (Foster et al. 2002; Ghezelsofloo and Ardalan, 2012; Wakode et al. 2014). Nowadays groundwater pollution has become one of the most serious problems throughout the world. Urbanization, industrialization and agricultural activity affecting groundwater quantity and quality (Jat et al. 2009; Tiwari et al. 2015; Rubia and Jhariya, 2015; Khan and Jhariya, 2016). Water pollution threats human health, economic development and social success (Milovanovic 2007; Wakode et al. 2014; Tiwari et al. 2015). In recent years it has been recognized that the quality of groundwater is of nearly equal importance as the quantity (Todd 1976; Jhariya et al. 2012). The present realization is clear about the limited resources and competing demands. This indeed has placed urgency on the observation and the protection of quality of groundwater using advanced techniques.

GIS is being recognized as a powerful tool in addressing issues and managing geographical information in holistic manner without losing the spatio-temporal variability which are often critical in assessment and decision making (Mtetwa et al. 2003; ESRI 2005). The GIS technology integrates common database operations such as query and statistical analyses with the unique visualization and geographic analysis benefits offered by maps and spatial databases. It also provides capabilities to analyze and simulate this complex phenomenon, thus, it has become a support tool for researchers and natural resources managers (Xingmei et al. 2006; Oke et al. 2013).

The main objective of the present study is to assess the groundwater quality for drinking purpose using Water quality index (WQI) and Geographic Information System (GIS).

Present study has been carried-out in Raipur city, which is situated in the western part of Raipur district, Chhattisgarh state in India. Study area falls under longitude 81°35' to 81°40' and latitudes 21°10' to 21°20' under Survey of India (SOI) toposheet no. 64G/11 and 64G/12 (Fig. 1). The temperature in April to May sometimes rises above 45 °C. The annual rainfall of the city is about 1100 mm. Major rock unit of study area are stromatolitic limestone, sandstone and shale belongs to Chhattisgarh Supergroup of Proterozoic age (Sinha et al. 2002; GSI 2005).

MATERIAL AND METHODOLOGY

Systematic methodology has been adopted to carried-out present study, involving detailed laboratory and field study as shown in Fig. 2.

Sample Collection and Analysis

A total of 34 numbers groundwater samples were collected from various locations of the study area as per the standard protocol prescribed by APHA (1995). The groundwater sample location point were delineated using Global Positioning System (GPS) and simultaneously water level depth was also measured and groundwater level depth map was prepared as shown in Fig.3. The groundwater level in study area vary from 3.06 m. bgl. to >16. 02 m. bgl during pre-monsoon period (May, 2015).

Groundwater sample location points are shown in Fig. 1. In this study eight groundwater quality parameters viz. pH, alkalinity, calcium, magnesium, chloride, hardness, nitrate and fluoride were analyzed using standard method prescribed by APHA (1995). The statistical analysis of the analyzed groundwater quality is given in Table 1, Correlation matrix between groundwater quality parameters is given in Table 2 and status of groundwater quality parameters as

Table 1 Statistical analysis of physico - chemical groundwater quality parameter

Parameter	Maximum	Minimum	Mean	Standard deviation
pH	8.5	7.1	7.52122	0.37578
Alkalinity	390	20	202.1957	72.12878
Hardness	550	80	263.1707	96.68089
Chloride	270	0	102.8049	51.45446
Nitrate	75	20	34.70588	53.24162
Fluoride	0.896	32	0.262349	0.207456
Calcium	260.603	36	125.223	49.05816
Magnesium	62.62	4.397	23.38424	14.93739

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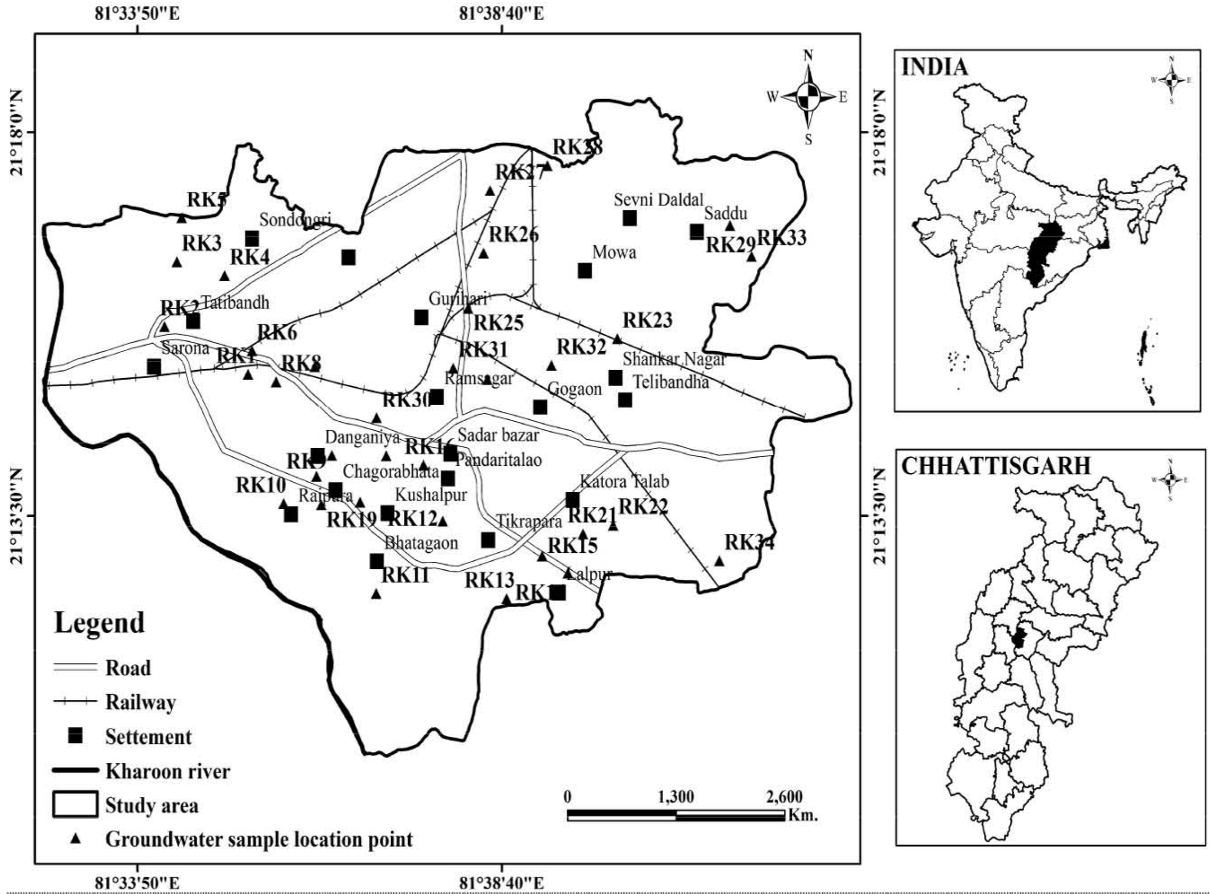


Fig. 1 Location map of study area and groundwater sampling points.

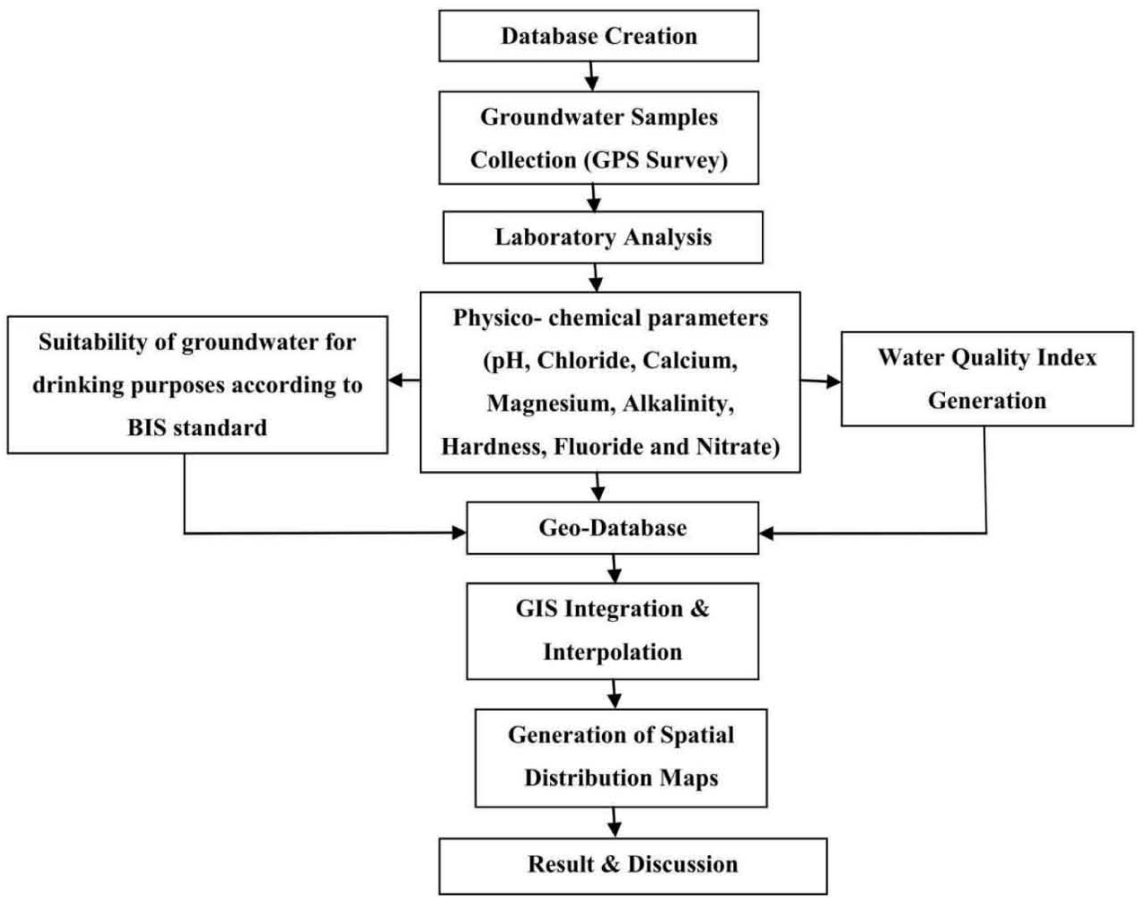


Fig. 2 Adopted methodology Flow chart for present study.

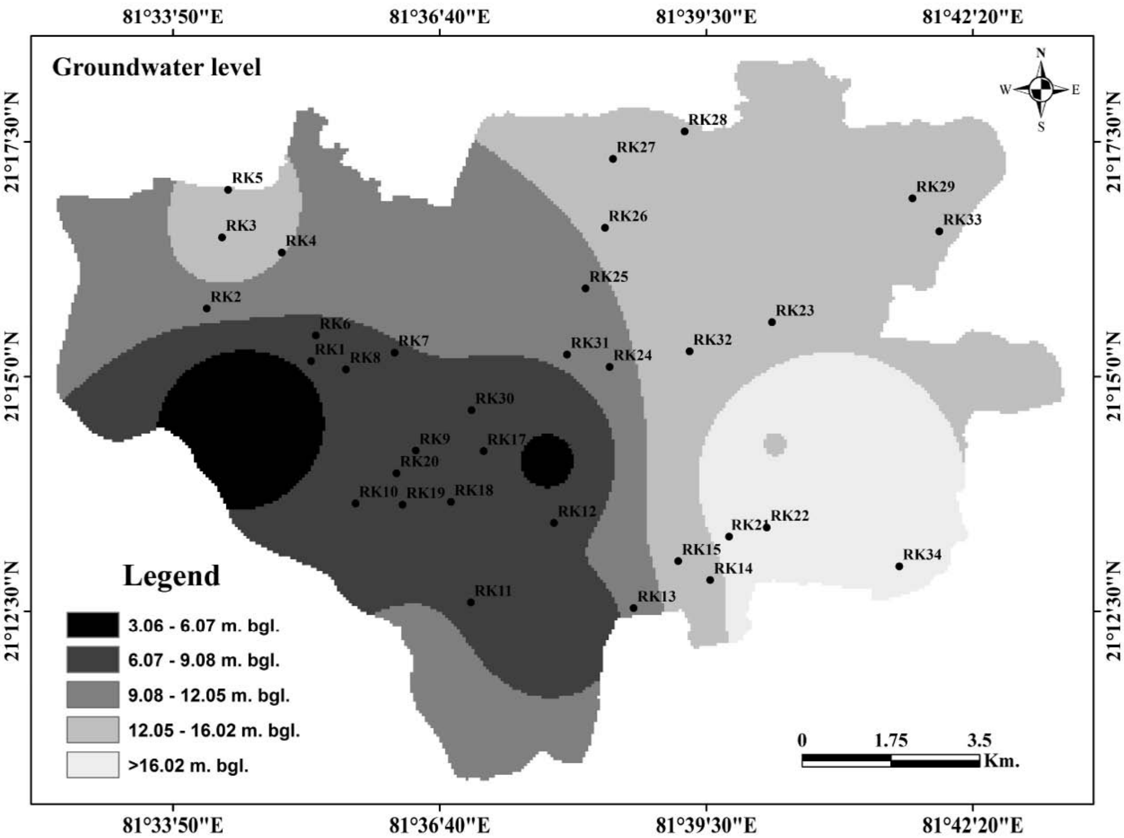


Fig.3. Groundwater level depth map.

prescribed by BIS (2009) for drinking purpose in the study area is shown in Table 3.

Groundwater Quality

pH

pH is the measure of hydrogen ion concentration value in water which indicates whether a solution is acidic, neutral or basic. The pH required has to be in the range of 6.5–8.5 for the drinking purpose (BIS, 2009). In present study pH concentration is ranges from 7.0 to 8.5 which shows that it is within the permissible limit as prescribed by BIS(2009). Spatial distribution map of pH is shown in Fig. 4 which was developed in GIS environment.

Calcium (Ca)

The high concentration of calcium ions can cause abdominal ailments and is undesirable for domestic use as it causes encrustation and scaling (Kumar et al. 2014). In the present study area calcium concentration ranges from 32.69 to 260.00 mg/l. It is found that 1.900 sq km area is having Ca beyond permissible limit for drinking purposes as shown in Fig. 5 and in Table 2.

Chloride (Cl)

Chloride in excess imparts a salty taste to water, and people who are alergic to high chloride are subjected to laxative effects (Anitha et al.2011; Sadat-Noori et al. 2014). In the study area chloride concentration ranges from 30.12 mg/l to 269.77 mg/l. In this study 149.73 sq km and 1. 27 sq km area is falling under desirable limit and maximum permissible limit respectively (Table 2 and Fig.6).

Fluoride (F)

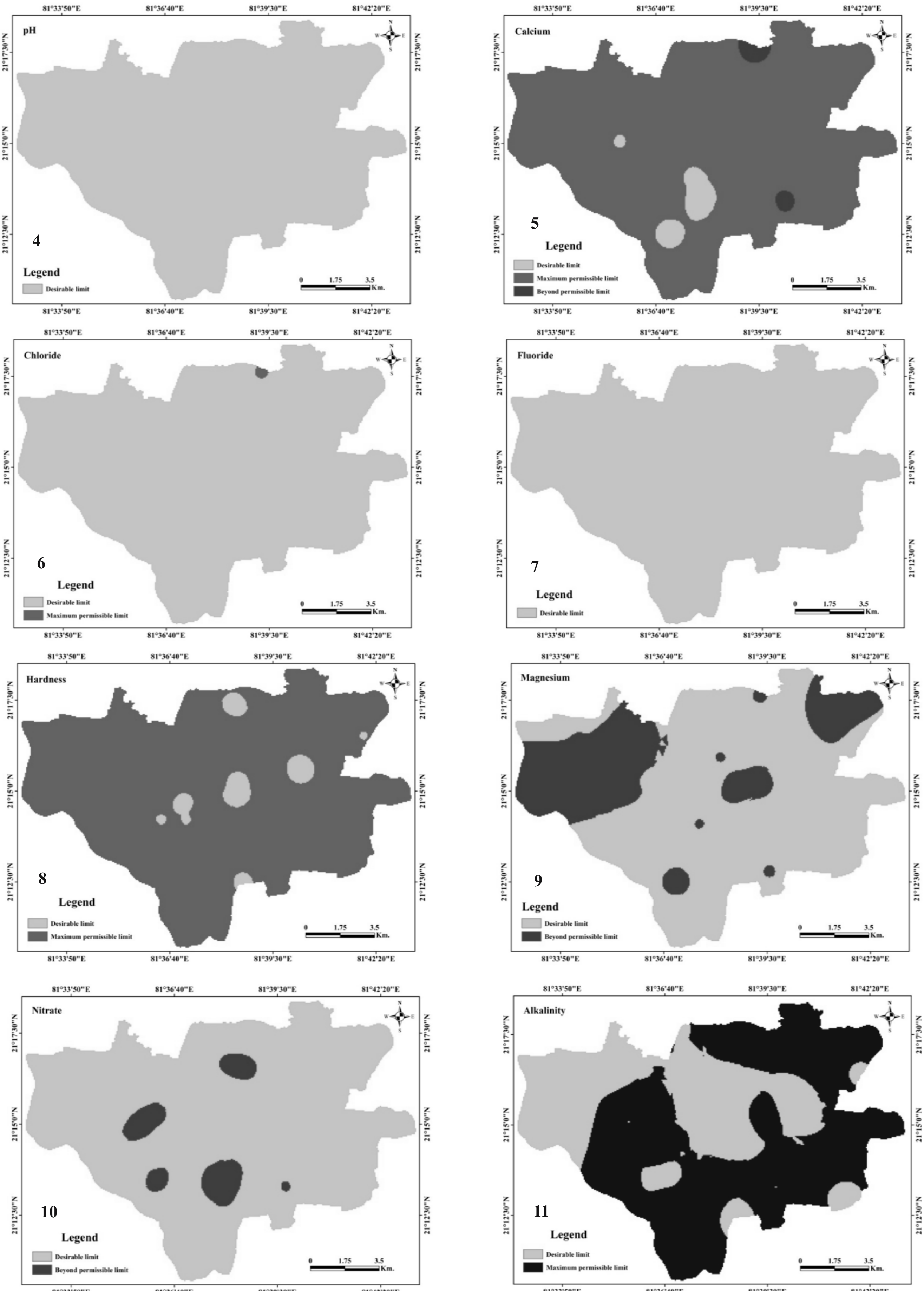
Fluoride in drinking water is mainly due to the geogenic sources. Fluoride at low concentrations has a beneficial effects on teeth by preventing and reducing the risk of tooth decay (Arumugam 2010), whereas fluoride levels above 1.5 mg/l in drinking water can cause fluorosis (BIS, 2009). In present study area, fluoride concentration ranges from 0.006 mg/l to 0.89 mg/l and is in desirable limit for drinking purposes (Fig.7).

Hardness

Hardness in groundwater is mainly due to the presence of divalent cation of calcium and magnesium. It derived largely from the soil and

Table 2. Correlation matrix between groundwater quality parameters

	pH	Alk	H	Cl	NO_3	F	Ca	Mg
pH	1							
Alk	-0.05944	1						
H	0.125141	0.51359	1					
Cl	0.032474	0.459914	0.53308	1				
NO_3	0.272711	-0.00875	0.026057	0.055867	1			
F	-0.1091	0.173546	-0.06785	-0.04484	0.018652	1		
Ca	0.050916	0.044554	0.353997	0.425719	-0.21298	-0.2684	1	
Mg	0.154179	0.249269	0.480803	0.229241	-0.02317	-0.06524	-0.13054	1



Figs. 4-11. Spatial distribution map of **(4)** pH, **(5)** Calcium, **(6)** Chloride, **(6)** Fluoride, **(7)** Hardness **(8)** Magnesium, **(10)** Nitrate and **(11)** Alkalinity.

Table 3. Status of groundwater quality parameters as prescribed by BIS (2009) for drinking purpose in the Raipur city, Chhattisgarh

Parameter	BIS Standard	Suitability for drinking purpose (area in sq. km)			Total area (sq.km)
		Maximum desirable	Maximum permissible	Beyond permissible	
Alkalinity	200 - 600	57.29	93.71	-	151.00
Calcium	75 - 200	5.00	144.10	1.900	151.00
Chloride	250-1000	149.73	1.27	-	151.00
Fluoride	1.0-1.5	151.00		-	151.00
Hardness	200 - 600	2.70	148.30	-	151.00
Magnesium	30	112.46	-	38.54	151.00
Nitrate	45	142.00	-	9.00	151.00
pH	6.5-8.5	151.00	-	-	151.00

rock formations. In general, hard waters originate in areas where the top soil is thick and limestone formations are present (Arumugam 2010). In present study hardness concentration ranges from 80.41 mg/l to 549.31 mg/l. The spatial distribution map of the study area shows that around 2.70 sq km area is falling under the maximum desirable limit and 148.30 sq km area is falling under the maximum permissible limit (Table 2 and Fig. 8).

Magnesium (Mg)

Magnesium is an essential element for human being , it is important for normal bone structure in the body. Water with high levels of magnesium or calcium is considered as hard and is undesirable for domestic purposes. In the study area magnesium concentration ranges from 4.42 mg/l to 62.47 mg/l. According to spatial distribution map of the study area around 46.95 sq km, 65.51 sq km and 38.94053 sq km area respectively is falling under the maximum desirable limit, maximum permissible limit and beyond permissible limit as per BIS (2009) drinking water standards (Table 2 and Fig.9).

Nitrate (NO_3)

Nitrate concentration above 45 mg/l (BIS, 2009), causes methemoglobinemia (blue baby syndrome), gastric cancer, thyroid disease and diabetes (Krishna Kumar et al., 2011, Kumar et al. 2014). Hence, increasing nitrate contamination seriously threatens public drinking water supply and human health (Kumar et al. 2014). The main source of nitrate concentration in drinking water is anthropogenic activity. Nitrate concentration ranges from 20.00 mg/l to 74.98 mg/l in the study area. In the study area 142.40 sq km area is falling under the desirable limit whereas 9.00 sq km is under beyond permissible limit as shown in Table 2 and Fig. 10.

Alkalinity

Alkalinity is due to bicarbonate, carbonate and hydroxides ions. In the present study area, alkalinity concentration ranges from 20.32 mg/l to 389.32 mg/l. According to the spatial distribution map of the study area 57.29 sq km and 93.71 sq km area respectively is falling under the maximum desirable limit and maximum permissible limit (Table 2 and Fig.11).

Water Quality Index (WQI)

Water quality index (WQI) is an exceptionally valuable tool for evaluating the overall quality of water (Ketata et al. 2012). It reduces the large number of data into single value and facilitates easy understanding of the information. WQI is utilized to determine the suitability of the groundwater for drinking purposes (Gibrilla et al. 2011; Ketata et al. 2012). The following steps are involved in WQI determination.

Weightage factor (W_i)

In first step weight (w_i) is assigned to each parameter as per its relative significance in the water for drinking purposes. The weightage factor is calculated by following equation:

$$W_i = w_i / \Sigma_{i=1}^{n} w_i$$

Where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameter. The assigned weight for each parameter is given in Table 4.

Table 4. Weight (wi) and Relative weight (Wi) of each parameter

Parameter	BIS Standard	Weightage	Relative weight
pH	6.5 - 8.5	2	0.133
Alkalinity	200 - 600	1	0.067
Hardness	200 - 600	1	0.067
Chloride	250 - 1000	3	0.133
Nitrate	45	5	0.267
Fluoride	1.0 - 1.5	4	0.200
Calcium	75 - 200	1	0.067
Magnesium	30	1	0.067
		Σwi = 15	ΣWi = 1

Quality rating (q_i)

The quality rating is calculated by following equation:

$$q_i = (C_i - C_{io})/(Si - C_{io})* 100$$

Where, C_i is the concentration of each chemical parameter in each water sample in mg/l, C_{io} is the ideal value of the parameter in pure water and, S_i is the standard value.

WQI calculation

For calculating the WQI, sub-index is first calculated for each parameter by using the following equation:

$$SI_i = wi * qi$$

Where SI_i is the sub-index of i^{th} parameter, q_i is the rating based on concentration of i^{th} parameter and n is the number of parameters.

The overall water quality index (WQI) was figured by adding together each sub index value of each groundwater sample as follows (Ramakrishnaiah et al. 2009; Sadat-Noori et al. 2014):

$$WQI = \Sigma SI_i$$

Computed WQI values were classified into six categories excellent, good, moderate, poor, very poor and unsuitable for human consumption as given in Table 5.

RESULT AND DISCUSSION

In this study eight groundwater quality parameters viz. pH, alkalinity, calcium, magnesium, chloride, hardness, nitrate and fluoride were analyzed to assess the suitability of groundwater for drinking purpose. It is found that groundwater of some parts of the Raipur city is unsuitable due to concentration of nitrate, magnesium and calcium beyond permissible limits as prescribed by BIS (2009).

To evaluate groundwater suitability for drinking purposes water quality index of the study area was calculated using different

Table 5. Classification of Groundwater quality according to WQI range

WQI Range	Type of water
< 35	Excellent
35 - 45	Good
45 - 55	Moderate
55 - 65	Poor
65 - 75	Very poor
> 75	Not suitable for drinking water

groundwater quality parameters during May, 2015. This study found that twenty samples were falling under suitable drinking water condition while seven samples were not suitable for drinking as per WQI classification (Table 6). Water quality index map of the study area has been developed on GIS platform using inverse distance weighted (IDW) raster interpolation technique. In the Raipur city 0.045%, 7.97%, 67.75%, 22.24%, 1.92% and 0.053% area respectively falls under excellent, very good, good, poor, very poor and unfit category as per WQI classification for drinking purpose (Table 7).

Assessment Accuracy for the Prediction

The groundwater quality index map of the study area has been validated using the water quality index value determined for 34 groundwater samples. The sample names and the groundwater sample location point, WQI values of these groundwater samples are given in Table 5 and displayed on the map shown in Fig.13. The borehole locations, the expected WQI value descriptions from the map, the actual WQI descriptions obtained from the study and the agreement/disagreement between the expected/actual WQI descriptions are shown in Table 8.

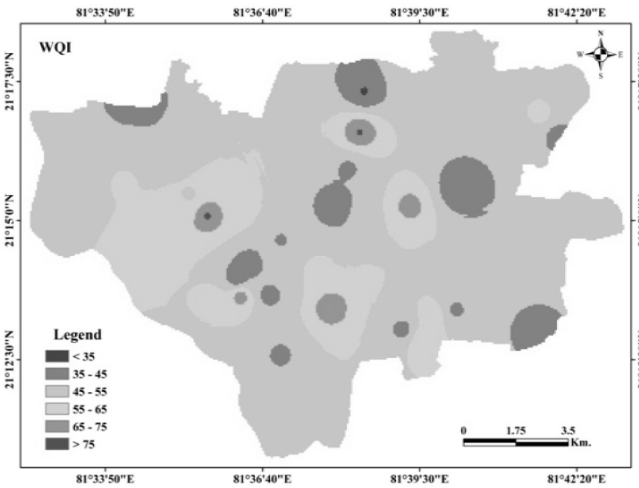


Fig.12. Water quality index map of the study area

Table 6. Water quality index value for individual groundwater sample

S. No.	Groundwater sample number	WQI value	Classification
1	RK1	62.85828	Poor
2	RK2	56.77134	Poor
3	RK3	48.97405	Good
4	RK4	46.81788	Good
5	RK5	37.9367	Very good
6	RK6	53.87258	Good
7	RK7	63.82454	Poor
8	RK8	76.57588	Unfit
9	RK9	38.25578	Very good
10	RK10	58.53402	Poor
11	RK11	44.45945	Very good
12	RK12	73.69151	Very poor
13	RK13	55.21804	Good
14	RK14	64.89952	Poor
15	RK15	41.49729	Very good
16	RK16	60.50541	Poor
17	RK17	52.07341	Good
18	RK18	41.45217	Very good
19	RK19	71.50884	Very poor
20	RK20	37.86334	Good
21	RK21	62.34844	Poor
22	RK22	44.02346	Very good
23	RK23	37.04686	Very good
24	RK24	52.4809	Good
25	RK25	44.1773	Very good
26	RK26	76.06574	Unfit
27	RK27	34.70536	Excellent
28	RK28	50.71604	Good
29	RK29	58.23151	Poor
30	RK30	44.96163	Very good
31	RK31	35.59212	Very good
32	RK32	69.9483	Very poor
33	RK33	42.87033	Very good
34	RK34	42.43748	Very good

Table 7. Water quality index range of the study area

WQI Range	Type of water	Area (Sq.km)	Area (%)
< 35	Excellent	0.069	0.045
35 - 45	Very good	12.68	7.97
45 - 55	Good	102.58	67.75
55 - 65	poor	22.69	22.24
65 - 75	Very poor	2.90	1.92
>75	Unfit	0.081	0.053

The accuracy of the prediction estimated is as follows:

Total number of groundwater sample location point = 34

The number of groundwater sample location point where there is an agreement between the expected and the actual WQI value = 33

Number of groundwater sample location point where there is disagreement between the expected and the actual WQI = 1

The accuracy of the prediction = (33/34) *100 = 97.05%.

The accuracy of prediction showed that the method applied in this study produced significantly reliable and accurate result.

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Table 8. Accuracy assessment of the developed water quality index map

S. No.	Coordinates		Actual WQI value of each borewell	Agreement between expected and actual value	Expected WQI description from developed map	Actual data description
	Latitudes	Longitudes				
1	81.58832	21.252752	62.85828	Agree	poor	poor
2	81.569855	21.262015	56.77134	Agree	poor	poor
3	81.572573	21.274632	48.97405	Agree	good	good
4	81.583153	21.271963	46.81788	Agree	good	good
5	81.573635	21.283215	37.9367	Agree	very good	very good
6	81.589174	21.257271	53.87258	Agree	good	good
7	81.603101	21.254236	63.82454	Agree	poor	poor
8	81.594514	21.251273	76.57588	Agree	Very poor to unfit	unfit
9	81.606845	21.236773	38.25578	Agree	very good	very good
10	81.596204	21.227398	58.53402	Agree	poor	poor
11	81.61665	21.20991	44.45945	Agree	very good	very good
12	81.63136	21.22394	73.69151	Agree	very poor	very poor
13	81.645452	21.208889	55.21804	Agree	good	good
14	81.65902	21.21386	64.89952	Agree	poor	poor
15	81.65336	21.21721	41.49729	Agree	very good	very good
16	81.627082	21.234868	60.50541	Agree	poor	poor
17	81.618879	21.236667	52.07341	Agree	good	good
18	81.613084	21.227648	41.45217	Agree	very good	very good
19	81.604515	21.227173	71.50884	Agree	very poor	very poor
20	81.603441	21.232727	37.86334	Agree	good	good
21	81.662375	21.221526	62.34844	Agree	poor	poor
22	81.669048	21.223156	44.02346	Agree	very good	very good
23	81.669969	21.25962	37.04686	Agree	very good	very good
24	81.64121	21.251709	52.4809	Agree	good	good
25	81.636956	21.265586	44.1773	Agree	very good	very good
26	81.640378	21.276338	76.06574	Disagree	Very poor	unfit
27	81.641795	21.288653	34.70536	Agree	excellent	excellent
28	81.654489	21.293515	50.71604	Agree	good	good
29	81.694851	21.28169	58.23151	Agree	poor	poor
30	81.616741	21.24408	44.96163	Agree	very good	very good
31	81.633671	21.253893	35.59212	Agree	very good	very good
32	81.655367	21.254455	69.9483	Agree	very poor	very poor
33	81.699623	21.275692	42.87033	Agree	very good	very good
34	81.692506	21.21628	42.43748	Agree	very good	very good

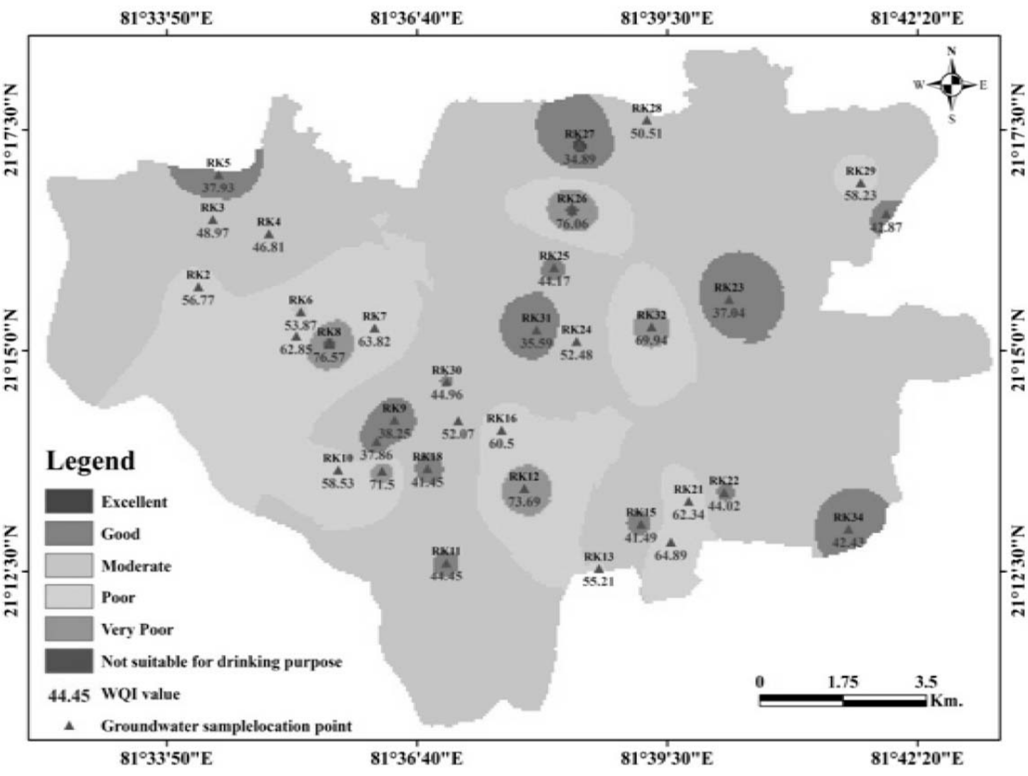

Fig. 13. Water quality index and well location point and WQI values for accuracy assessment.

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