GROUND WATER QUALITY ANALYSIS AND MAPPING USING GIS TECHNIQUES

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Abstract:

Groundwater quality in Lucknow district has special significance and needs great attention of all concerned since it is the major alternate source of domestic, industrial, drinking and irrigation. Water Quality Index has been calculated and thematic maps of the same were also developed. The results of the water quality analysis work were presented in the form of maps which can be used for better understanding of the present water quality scenario of the study area. The overall view of the water quality index of the present study area revealed that most of the study area with <50 standard rating of water quality index exhibited excellent. The WQI ranges from 50-100 in the study area like Khujauli, Arya nagar, Lucknow and some part of Bakshi Ka Talab was good for drinking as well as irrigation purpose. Ground water quality is poor in Kathwara in Bakshi Ka Talab mandal.

Weighted overlay maps are created from the spatial distribution layers of ten water quality parameters. Quality analysis of drinking water from Water quality index, spatial distribution maps of individual water quality parameters and overlay map were found for the stress zones in Lucknow district. By using Wilcox, salinity diagrams and overlay map, the ground water in Lucknow district area was divided into suitable and unsuitable categories for irrigation purpose.

Keywords: *Ground water, Water Quality Index (WQI), Spatial Distribution, weighted overlay, Geographic Information System*

1. Introduction

Ground water is an essential and vital component of our life support system. The ground water resources are being utilized for drinking, irrigation and industrial purposes. However, due to rapid growth of population, urbanization, industrialization and agriculture activities, ground water resources are under stress. The definition of water quality is very much depending on the desired use of water. Therefore different uses require different criteria of water quality as well as standard methods for reporting and comparing results of water analysis [1]. Major chemical elements including Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-} play a significant role in classifying and assessing groundwater quality. Geographical Information System (GIS) has emerged as efficient and powerful tool in different fields of science over the last two decades. The GIS has the ability to store, arrange, retrieve, classify, manipulate, analyze and present huge spatial data and information in a simple manner [6].

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 overall quality status of water to the concerned user community and policy makers [2, 3]. Thus, it becomes an important parameter for the assessment and management of groundwater.

2. Study Area

Lucknow district, the capital of Uttar Pradesh, India, spreads over an area of 2528 sq.km, the stretch ranging from 26°30’ to 27°10’ North latitudes and 80°30’ to 81°13’ East longitudes, on both the sides of river Gomti. Total population of Lucknow is 4,588,455 as per latest provisional figures released by Directorate of Census Operations in Uttar Pradesh. This shows increase of 25.79 percent in 2011 compared to figures of 2001 census. As per census 2011, density of Lucknow District per square km is 1,815 compared to 1,443 per sq.km in 2001(fig. 2.1).

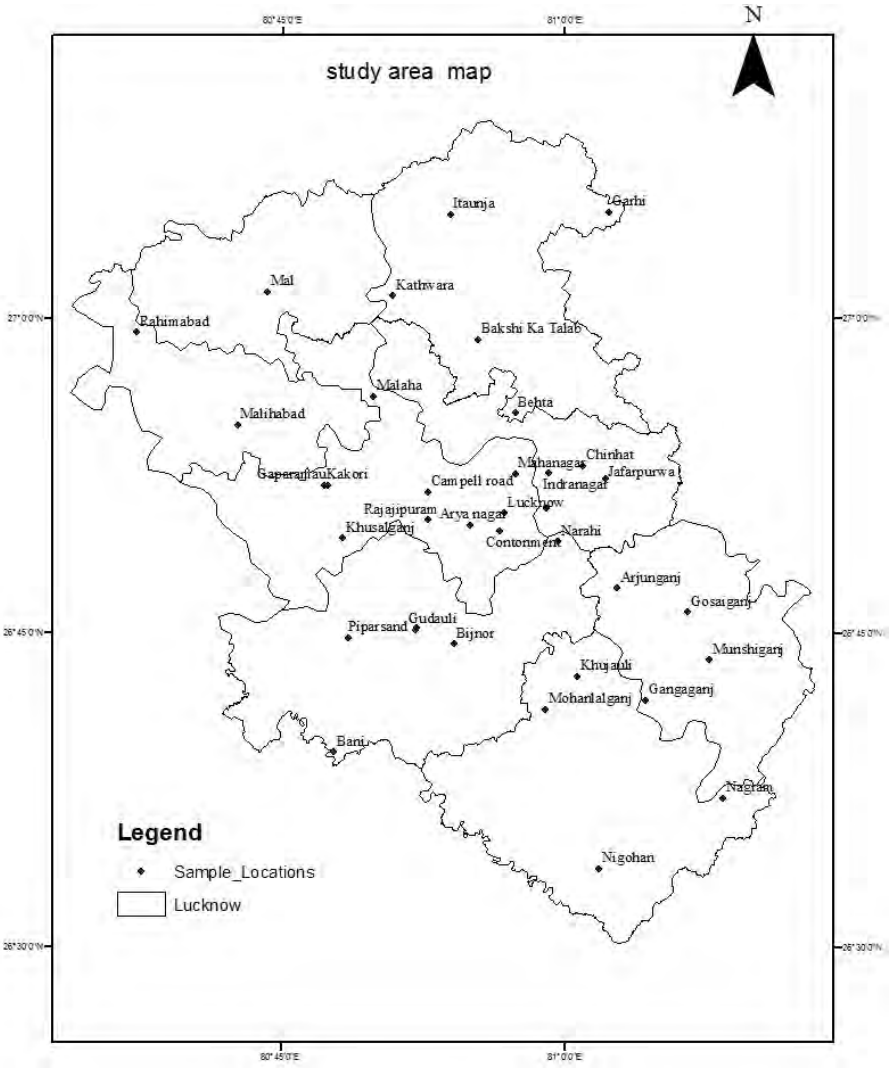

Figure 2.1 District map of Lucknow

3. Materials & Methods

The ground water samples are collected manually from the bore wells which were approximately equally distributed all over 36 locations from Lucknow district. The Parameters, which are analyzed during water analysis, are pH, conductivity, chlorides, total alkalinity, fluoride, nitrate, sulphate, total hardness, calcium hardness and magnesium hardness.

3.1 Water Quality Index (WQI): [3, 6]

For computing WQI, three steps are followed

Step-1 Each of the parameters has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes (table 4.4) the maximum weight of 5 has been assigned to the parameter nitrate due to its major importance in water quality assessment. Magnesium which is given the minimum weight of 2 as magnesium by itself may not be harmful.

Step-2 The relative weight (W_i) is computed from the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (3.1)$$

Where,

W_i is the relative weight,

w_i is the weight of each parameter and

n is the number of parameters.

Step-3 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:

$$q_i = \frac{C_i}{S_i} X100 \quad (3.2)$$

Where,

q_i is the quality rating

C_i is the concentration of each chemical parameter in each water sample in mg/L

S_i is the Indian drinking water standard for each chemical

Parameter in mg/l according to the guidelines of the BIS 10500: 1991. 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

$$SI_i = W_i . q_i \quad (3.3)$$

$$WQI = \sum SI_i \quad (3.4)$$

$$WQI = \sum SI_i$$

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 computed WQI values are classified into five types, "excellent water" to "water, unsuitable for drinking".

In the Present study Method-2 was used for calculating the Water quality Index.

Irrigation water classification [5]

$$Sodium\ Absorption\ Ratio(SAR) = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}} \quad (3.5)$$

$$\text{Percent Sodium } (\%Na) = \frac{Na+K}{Ca+Mg+Na+K} \quad (3.6)$$

Table 3.1 Relative weight of chemical parameters [3]

Parameter	**standards (as per BIS)**	**w_i (Weight)**	**W_i (Relative weight)**
pH	6.5-8.5	4	0.125
Chloride (mg/l)	250	3	0.094
Total Hardness (mg/l as $CaCO_3$)	300	2	0.063
Na	150	3	0.094
Sulphate	200	4	0.125
Fluoride (mg/l)	1.5	4	0.125
Nitrate (mg/l)	45	5	0.156
Calcium (mg/l)	75	2	0.063
Magnesium (mg/l)	30	2	0.063
Electrical Conductivity (μS/cm)	2000	3	0.094
		$\sum w_i = 32$	$\sum W_i = 1.00$

Table 3.2 Water quality category [3]

WQI Value	Water quality
<50	Excellent
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Water unsuitable for drinking

3.2 Database

The study is has been carried out with the help of two major components: spatial maps and field data. Field work was conducted and groundwater samples were collected from various parts of Lucknow district with the help of the map. These samples were tested using standard procedures in the laboratory and the results were tabulated in an excel worksheet.

3.2.1 Inverse Distance Weighted

Inverse Distance Weighting (IDW) is based on the assumption that the nearby values contribute more to the interpolated values than distant observations. In other words, for this method the influence of a known data point is inversely related to the distance from the unknown location that is being estimated. The advantage of IDW is that it is intuitive and efficient. This interpolation works best with evenly distributed points. Similar to the SPLINE functions, IDW is sensitive to outliers. Furthermore, unevenly distributed data clusters results in introduced errors [4].

3.2.2 Weighted overlay

Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Overlays several raster's using a common measurement scale and weights each according to its importance.

Table 3.3: Various Parameters of ground water particular location

Location	**E.C. µsiemens /cm At 25^0C**	**pH**	**Constituents in (mg/l)**								
			Cl	***NO_3***	***SO_4***	***F***	***Ca***	***Mg***	***TH***	***Na***	***K***
Block: Mohanlalganj											
Mohanlalganj	580	7.85	18	2.7	5	0.69	32	34	220	47	6.5
Nigohan	470	7.8	11	1.1	-	0.44	20	32	180	34	0
Khajauli	560	7.75	14	206	30	0.05	14	33	l50	70	3.9
Nagram	380	7.95	11	5.8	32	0.78	8	26	125	47	5.3
Block : Mal 26											
Mal	560	8.05	32	1.4	48	0.52	36	29	210	46	4.2
Block : Bakshi Ka Talab											
Behata	410	7.95	14	0.9	7	0.79	32	33	215	16	4.7
Garhi	670	8.1	50	19	60	0.43	44	51	320	3.3	5.2
Bakshi Ka Talab	420	8	11	5.2	20	0.64	20	44	230	18	5.9
Kathwara	1120	8.05	121	196	96	0.15	56	88	500	4l	5.8
Itaunja	750	7.95	28	9.l	60	0.38	20	46	240	69	4.7
Kumrawan	590	8.1	11	1	62	0.31	16	54	260	23	8.4
Block : KAKORI											
Campbell Road	300	7.9	7.l	2.4	-	0.58	8	26	125	25	5.2
Rajajipuram	480	7.9	50	19	10	0.27	12	41	20	30	5.6
Khusalganj	490	8	14	2.4	-	0.79	24	32	190	43	7.7
Kakori	350	7.9	11	1.5	20	0.41	12	33	165	17	4
Malaha	440	7.8	14	4	22	0.54	16	36	190	22	3.3
Gaparamau	350	7.95	14	16	10	0.65	16	34	180	13	3.5
Block : CHINHAT											
Chinhat	280	8.15	14	0.9	-	0.46	16	21	125	24	4.5
Jafarpurwa	420	8.0	7.1	2.7	8	0.65	40	24	200	24.5	5.2
Indira Nagar	480	8.05	43	56	10	0 16	36	32	220	20	4 9
Gomti Nagar	260	8.1	14	2.1	-	0.25	24	15	120	12	2.5
Lucknow	820	7.8	78	47	45	0.29	20	44	230	95	6.4
Tehsil											
Mahanagar	470	7.35	36	3.5	20	0.24	12	35	175	38	5.1

Location	**E.C.** µsiemens /cm.) at 25^0c		**Constituents in (mg/l)**								
		pH	***Cl***	***NO_3***	***SO_4***	***F***	***Ca***	***Mg***	***TH***	***Na***	***K***
Block : Sarojini Nagar											
Gundauli	660	8.10	18	12	25	0.48	68	21	255	49	7.3
Piparsand	570	7.85	28	13	20	0.62	32	36	230	3l	7.26
Bani	240	7.75	7.l	4.8	-	0.42	20	73	80	14	2.7
Bijnor	480	7.85	14	2.8	12	0.52	14	40	200	33	7.1
Narahi	680	8.15	43	38	45	0.16	12	44	210	67	7.2
Sarojininagar	340	8.05	14	1.7	28	0.71	32	24	180	8	3.7
Cantonment	480	8.10	50	160	20	0.46	12	47	225	24	4.6
Arya Nagar	610	8.15	57	70	25	0.39	16	57	275	32	5.5
Block : Gosaiganj											
Arjunganj	720	7.95	14	3.7	60	0.59	8	39	180	94	5.6
Gosaiganj	320	8.00	14	2.2	15	0.5	28	21	155	17	3.4
Munshiganj	440	8.05	7.1	1.1	5	0.72	20	41	220	0	5.1
Gangaganj	280	7.75	3.6	4	5	0.71	12	22	1 0	16	3.5
Block : Malihabad											
Rahimabad	610	7.85	50	0.9	72	0.62	12	36	180	77	6.5
Malihabad	420	7.90	7.1	0.95	25	0.41	40	36	160	37	7.7

Table 3.4: Na%, EC, SAR, WQI of ground water particular location

Location	**E.C. microsiemens/cm. At 25^0C**	**Na %**	**SAR**	**WQI**	**Drinking water Classification According to WQI**
Block : Mohanlalganj					
Mohanlalganj	580	44.770	8.182	39.209	Excellent
Nigohan	470	39.535	6.668	32.406	Excellent
Khajauli	560	61.125	14.440	102.730	poor
Nagram	380	60.603	11.399	36.024	Excellent
Block : Mal					
Mal	560	43.576	8.069	39.716	Excellent
Block : Bakshi Ka Talab					
Behata	410	24.154	2.807	36.492	Excellent
Garhi	670	8.213	0.479	54.396	Good
Bakshi Ka Talab	420	27.190	3.182	39.285	Excellent
Kathwara	1120	24.528	4.832	128.785	poor

Itaunja	750	52.756	1.648	46.896	Excellent
Kumrawan	590	30.966	3.888	41.333	Excellent
Block : Kakori					
Campbell Road	300	47.041	6.063	29.369	Excellent
Rajajipuram	480	40.181	5.828	37.048	Excellent
Khusalganj	490	47.516	8.126	37.378	Excellent
Kakori	350	31.818	3.584	31.233	Excellent
Malaha	440	32.730	4.315	23.484	Excellent
Gaparamau	350	24.812	2.600	38.433	Excellent
Block : Chinhat					
Chinhat	280	43.511	5.580	27.781	Excellent
Jafarpurwa	420	79.631	48.310	48.666	Excellent
Indira Nagar	480	26.803	3.430	52.604	Good
Gomti Nagar	260	27.103	2.717	24.843	Excellent
Lucknow	820	61.306	16.794	61.350	Good
Mahanagar	470	47.836	7.839	33.140	Excellent
Block : Sarojini Nagar					
Gundauli	660	38.747	7.345	25.562	Excellent
Piparsand	570	36.006	5.316	43.092	Excellent
Bani	240	37.955	3.789	37.372	Excellent
Bijnor	480	42.614	6.351	36.104	Excellent
Narahi	680	56.989	12.662	52.855	Good
Sarojininagar	340	17.282	1.512	34.131	Excellent
Cantonment	480	32.648	4.419	93.655	Good
Arya Nagar	610	33.937	5.297	67.038	Good
Block : Gosaiganj					
Arjunganj	720	67.940	19.391	43.959	Excellent
Gosaiganj	320	9.395	3.435	30.658	Excellent
Munshiganj	440	29.152	3.621	35.653	Excellent
Gangaganj	280	36.449	3.881	27.254	Excellent
Block :Malihabad					
Rahimabad	610	63.498	15.718	43.320	Excellent
Malihabad	420	37.034	6.002	35.641	Excellent

3.2.3 Methodology:

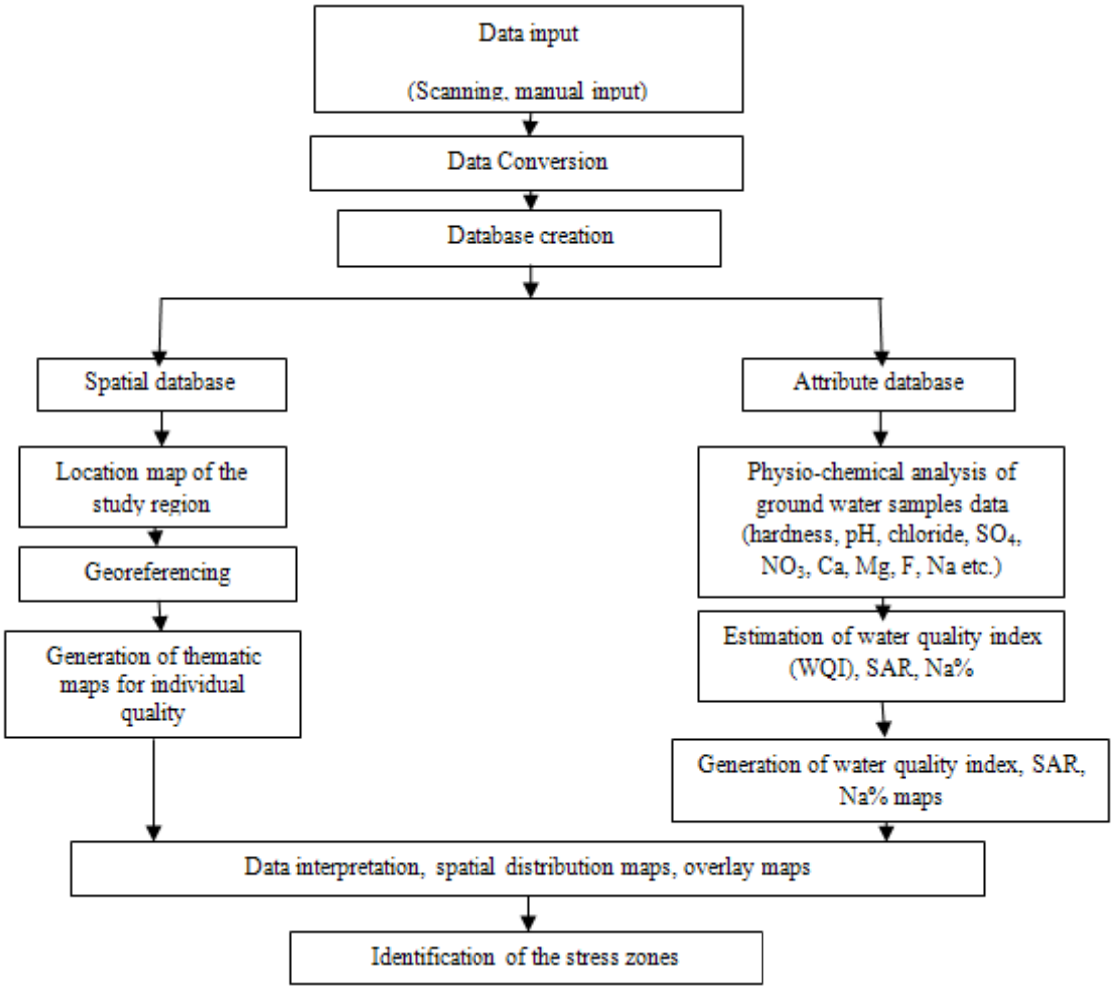

Figure 3.1 Flow chart showing the process flow

4. Results and Discussions

4.1 Groundwater Quality Variation

i. Electrical Conductivity (EC) spatial distribution map

Fig. 4.1 shows, Except Kathwara and surrounding area, remaining area of Lucknow district water quality is excellent and good. Above 750 µ Siemens/cm water quality is doubtful. From the above map Kathwara, Lucknow areas ground water quality is doubtful.

ii. Total Hardness spatial distribution map

From fig. 4.2, Kathwara, Bhani in Bakshi Ka Talab mandal ground water total hardness above the desirable limit i.e. 300 mg/l as $CaCO_3$. The remaining area of Lucknow district within the limits. Softening is required to impart palatability to water.

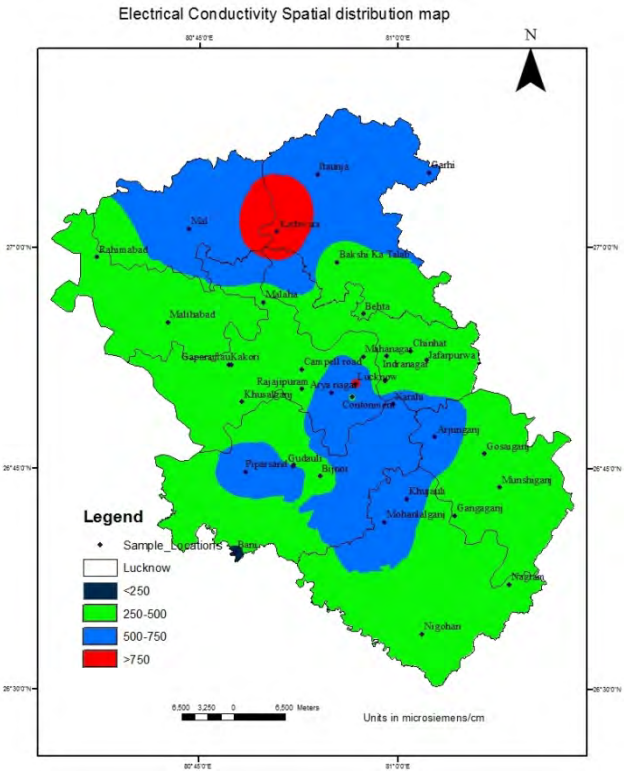

Figure 4.1 Electrical conductivity spatial map distribution map

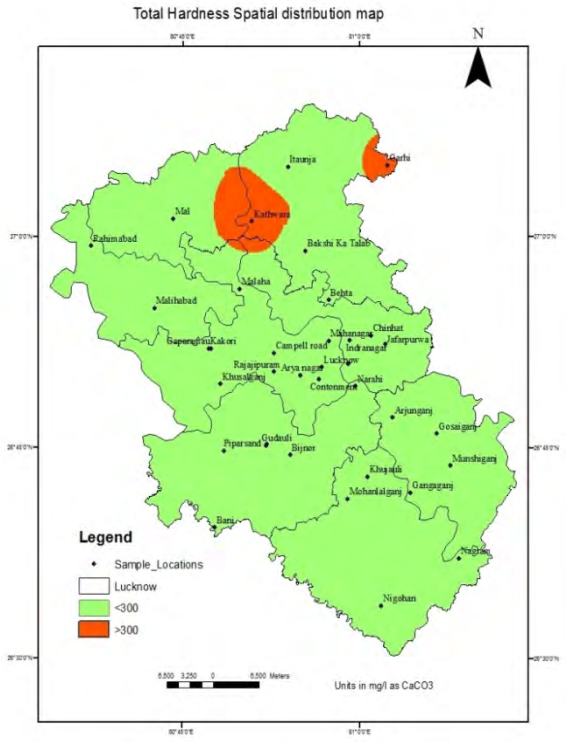

Figure 4.2 Total Hardness spatial distribution

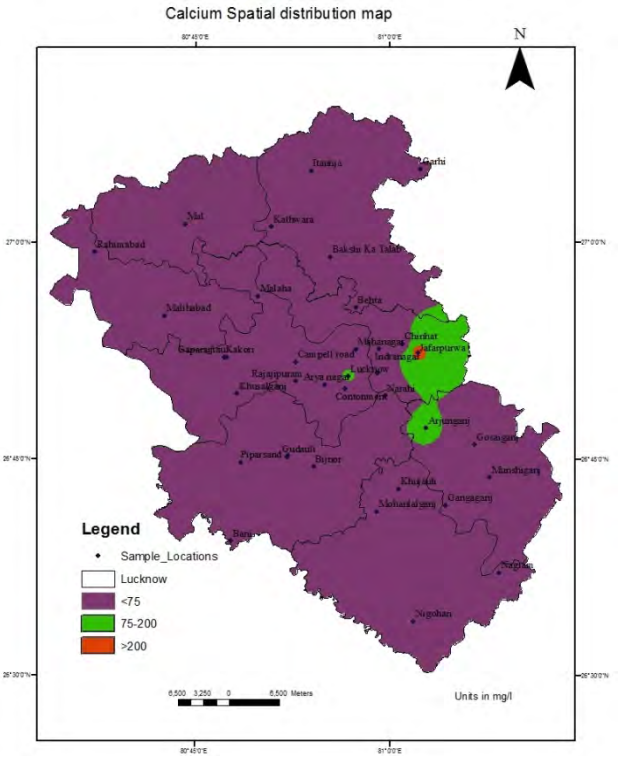

Figure 4.3 Calcium spatial distribution map

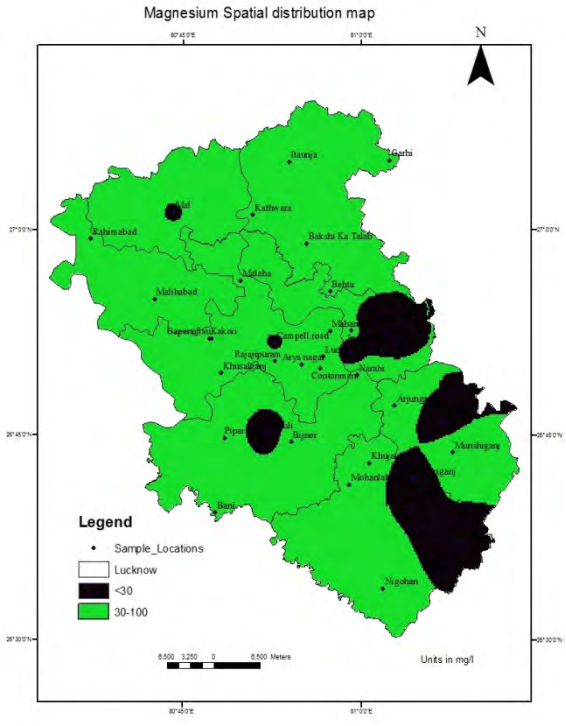

Figure 4.4 Magnesium spatial distribution map

iii. **Calcium (Ca) spatial distribution map**

From fig. 4.3, the calcium concentration was in below 75mg/l in the most of the area of Lucknow district. High concentration of calcium was found in the village Jafarpurwa in Chinhat mandal. Lucknow, part of Chinhat mandal, Arjunganj is above the desirable limit of calcium concentration in ground water.

iv. **Magnesium (Mg) spatial distribution map**

From fig.4.4, most of the area in Lucknow district, magnesium concentration in ground water having above the permissible limit i.e. >30 mg/l. The concentration of magnesium was found to be within the permissible limits in Nagram, Gosaiganj, Gudauli, Chinhat, Mal etc.

v. **Chlorides (Cl) spatial distribution map**

In potable water, the salt taste is produced by chloride concentrations. At concentrations above 250 mg/l, water acquires salty taste which is objectionable to many people. Bureau of Indian Standards prescribes 250 mg/l as permissible limit and 1000 mg/l as desirable limit in the absence of alternate source. From fig. 4.5, the concentration of chloride was found to be within permissible limit in Lucknow district.

vi. **Sulphates (SO_4) spatial distribution map**

From fig. 4.6, the ground water sulphate in the Lucknow district was within the desirable limits. As per Indian standard of permissible limit is 250 mg/l.

vii. **Fluorides (F) spatial distribution map**

From the spatial distribution map fig. 4.7, the deficiency of fluoride concentration in the ground water is observed in Nagram, Lucknow, Bakshi Ka Talab mandal and Malihabad mandal etc(<.5mg/l), Mohanlalganj, Gosaiganj and in some parts of Sarojini Nagar mandal having within the permissible limit.

viii. **Nitrate spatial distribution map**

From fig. 4.8, the Nitrate concentration in the present study area of the ground water within the permissible limit (<45mg/l). The Nitrate concentration was in between 45-100 mg/l in the areas like Lucknow, Aryanagar etc. Higher Nitrate concentration of more than 100 mg/lit were found in Areas like Contonment, Kathwara, Khujauli etc.

ix. **Na spatial distribution map**

From fig. 4.9, In Lucknow district the ground water quality with respect to Na concentration within the permissible limit except Jafarpurwa area.

x. **WQI spatial distribution map**

From fig. 4.10, the water quality index (WQI) of major villages and cites in Lucknow district was found to be excellent and good. The WQI ranges from 50-100 in the study area like Khujauli, Aryanagar, Lucknow and some part of Bakshi Ka Talab was good for drinking. Kathwara in Bakshi Ka Talab mandal and Khujauli in Mohanlalganj of ground water is poor. Treatment should be required while using as drinking water from ground water.

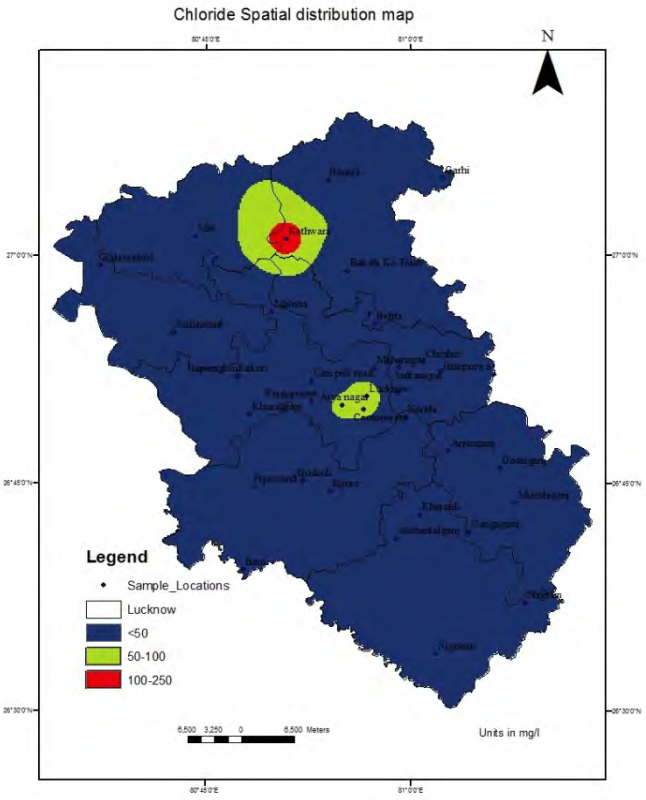

Figure 4.5 Chloride spatial distribution map

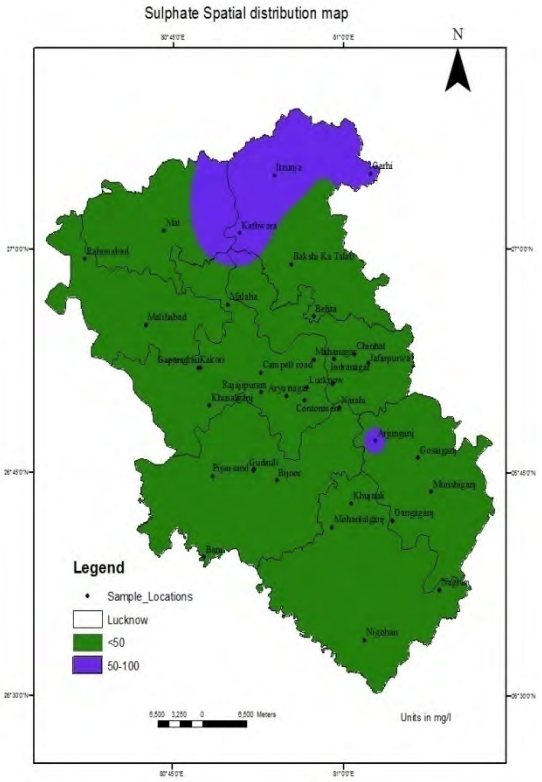

Figure 4.6 sulphate spatial distribution map

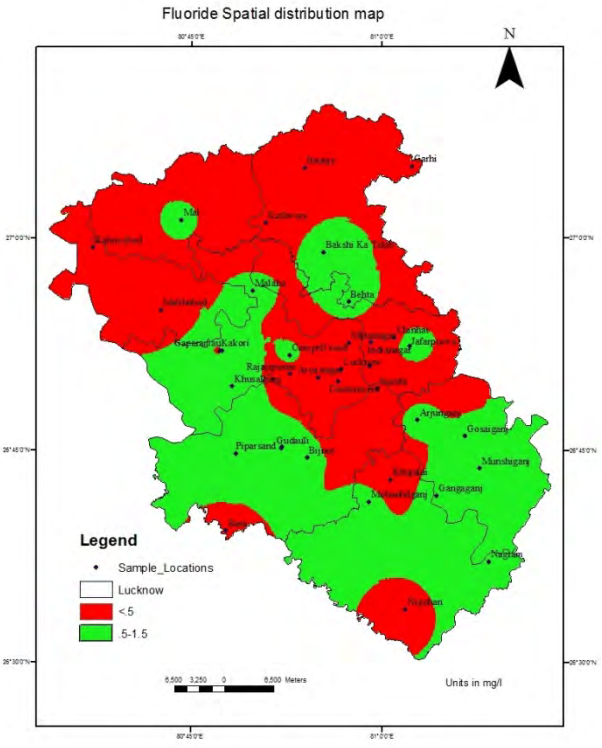

Figure 4.7 Fluoride spatial distribution map

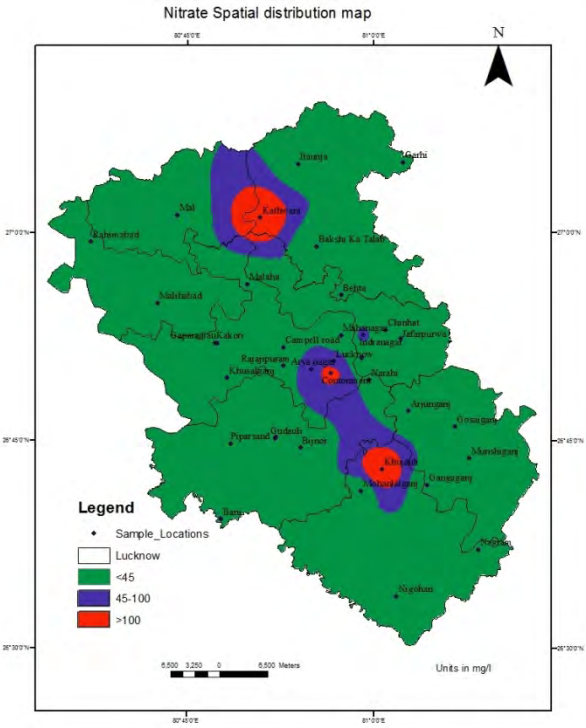

Figure 4.8 Nitrate spatial distribution map

xi. **Overlay map (pH, Cl, TH, Na, SO_4, NO_3, F, Mg, Ca, EC)**

From the WQI spatial distribution map it gives only upper limit or permissible limit of fluoride but from (fig. 4.11) overlay map gives lower, upper limits of all 10 water quality parameters with relative weight as percent of influence, shows the Lucknow district divided into categories are suitable, unsuitable.

xii. **Na % spatial distribution map**

From fig. 4.12, high sodium percent (above 60%) and are not suitable for irrigation purposes like Rahimabad, Nagram, Jafarpurwa, Khujauli etc. High percentage of Na^+ with respect to (Ca^{2+}+Mg^{2+}+Na^+) in irrigation water, causes deflocculating and impairing of soil permeability.

xii. **SAR (Sodium absorption ratio) spatial distribution map**

From fig. 4.13, sodium absorption ratio (SAR) in most of the areas of Lucknow district is excellent i.e. SAR value is below 10. Khujauli, Nagram, Narahi and Lucknow are having good quality of water. Arjunganj in Gosaiganj mandal ground water is doubtful for irrigation purpose.

4.2 **Water quality analysis for irrigation purpose**

I. Salinity diagram

From the graph (Fig 4.14), salinity diagram for classification of irrigation water, the plot of data on the US salinity diagram shows that the water samples were found mostly confined in four classes of water type: i.e., C2-S1, C2-S1 and C2-S2 and C4-S4. Due to low sodium and medium salinity water of C2-S1 class can be used for irrigation on almost all soils with little danger of sodium problem. G1 (Arjunganj), C5 (Lucknow) Sample locations are having C2-S3, C3-S3 category which is high salinity.

II. Wilcox diagram

According to Wilcox diagram the Lucknow district water samples fall almost in all classes even some water samples fall beyond the limits of the diagram. Most of the water samples are in category of excellent to good and good to permissible quality and may be used for irrigation purposes. C2 (jafarpurwa), G1 (Arjunganj), L (Lucknow) water samples having the category of permissible to doubtful (From fig. 4.15).

III. Overlay map of Na%, SAR, EC

From the Salinity, Wilcox diagrams on X-axis electrical conductivity, on Y-axis Na% or SAR, Both should be required for water classification. But overlay map it includes EC, SAR, Na% on one map only by giving percent of influence and scale value for every layer. From the fig. 4.16, ground water in most of the areas of Lucknow district is suitable for irrigation. The water present in the Jafarpurwa, Arjunganj, Lucknow was found to be doubtful for irrigation purpose.

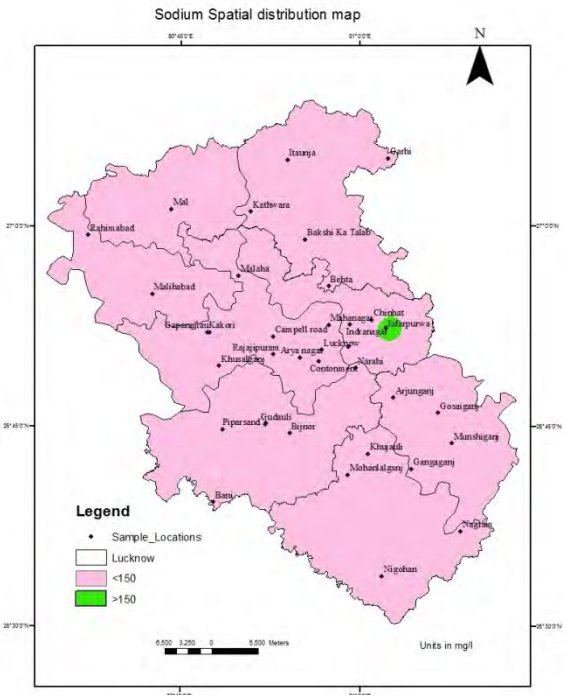

Figure 4.9 Na spatial distribution map

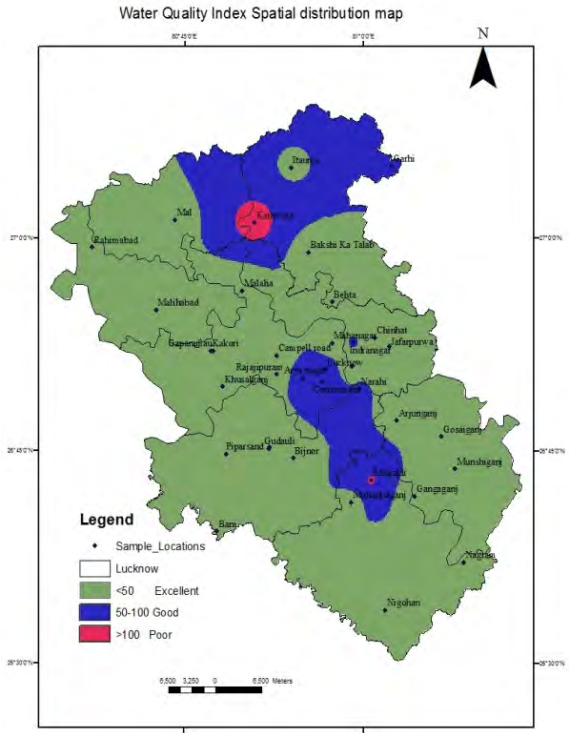

Figure 4.10 WQI spatial distribution map

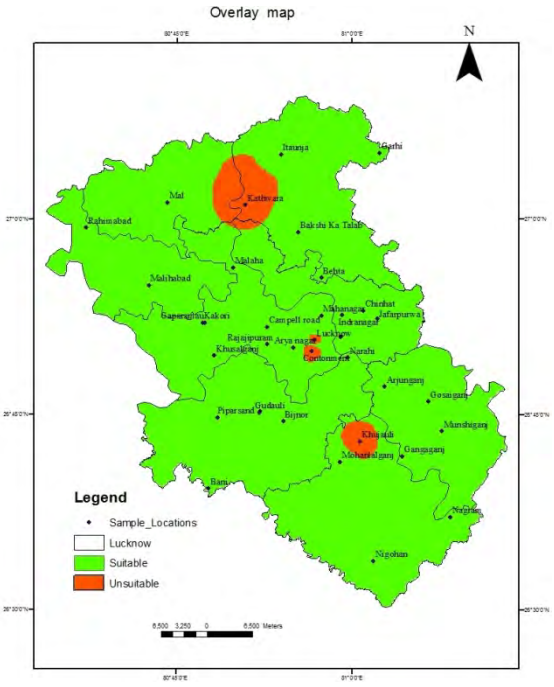

Figure 4.11 Overlay map (pH, Cl, TH, Na, SO_4, NO_3, F, Mg, Ca, EC)

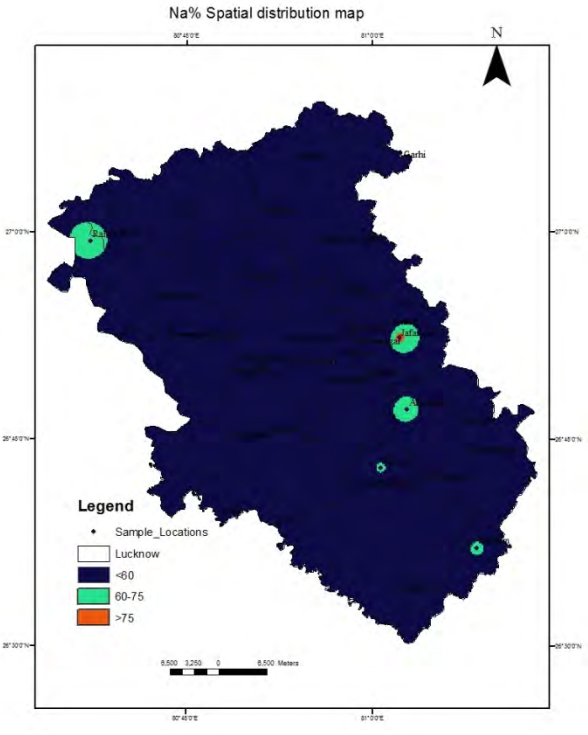

Figure 4.12 Na % spatial distribution map

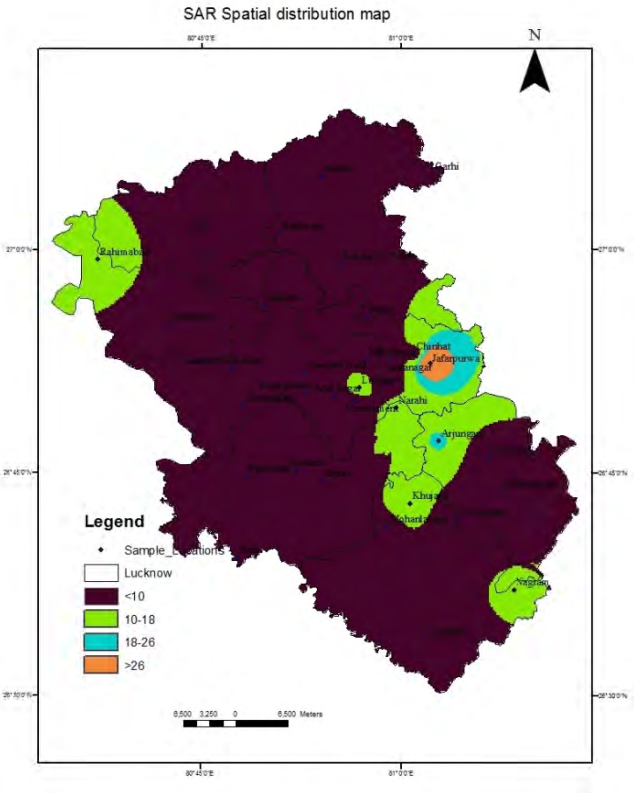

Figure 4.13 SAR spatial distribution map

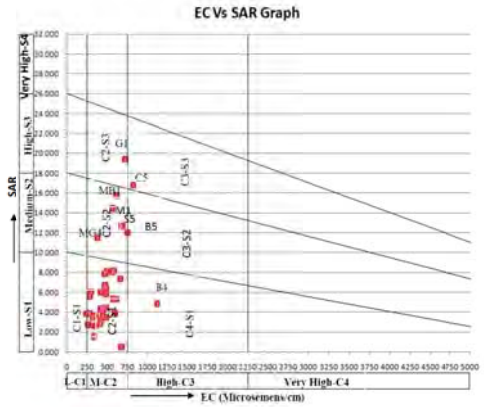

Figure 4.14 Salinity diagram

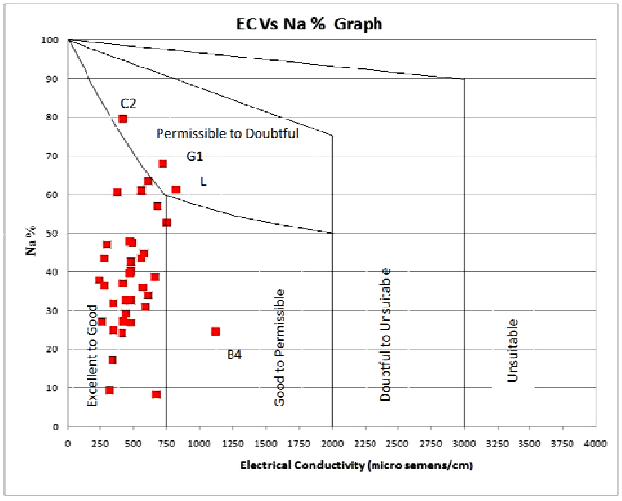

Figure 4.15 Wilcox diagram

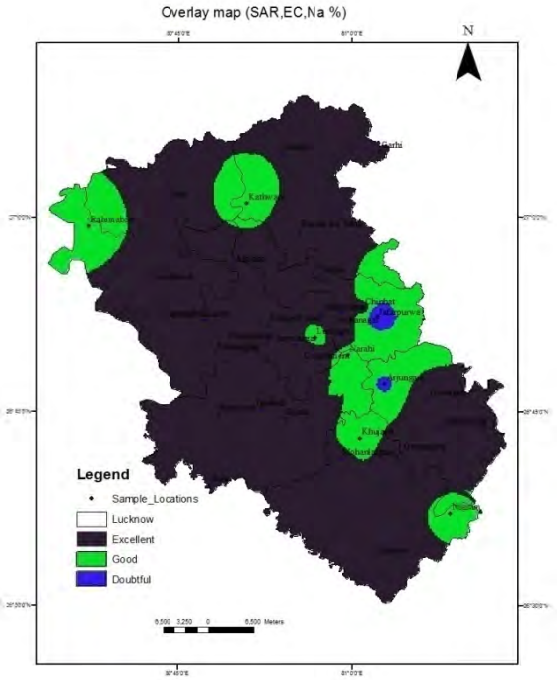

Figure 4.16 Overlay map of Na%, SAR, EC

CONCLUSIONS

The study has demonstrated the utility of GIS technology combined with analysis in evaluation and mapping of groundwater quality in Lucknow district. According to the findings of this study, the groundwater in the entire study area is fit for direct drinking with respect to, pH, SO_4^{2-}, Cl within the desirable limits. Na in the ground water is within the desirable limit except Jafarpurva. Fluoride level in the Lucknow district is below the 0.5mg/l. It creates dental cavities, so fluoridation should be required in areas like Malihabad, Rahimabad, Bakshi Ka Talab, Chinhat etc. Most of the area study comes under excellent and good class. Kathwara, Khujauli areas have poor water quality category revealed by the WQI studies. The final output has been given in the thematic representation of ground water quality. The analysis suggests that the groundwater of the stress zones needs some degree of treatment before consumption. The study helps us to understand the quality of the water as well as to develop suitable management practices to protect the ground water resources.

Wilcox and Salinity diagrams reveal that except the Jafarpurwa, Arjunganj, Lucknow parts of study area, most of the groundwater samples are suitable for irrigation purposes under normal condition. The salinity hazard for water wells is classified as medium, high while some places show very high salinity. Alkali hazard also is classified from low hazard to very high. For the salinity, Wilcox diagram overlay map of ground water in the Lucknow district lies mostly under the category excellent and good but Jafarpurwa, Arjunganj and Lucknow locations are having water quality, which is doubtful for irrigation purposes.

Future Scope: Bacteriological examination of water would reveal the potability conditions of the water as per BIS standards. Ground water quality can be correlated with the land cover & land use practices in the study area.

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