iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** III **Month of publication:** March 2015

DOI:

www.ijraset.com Volume 3 Issue III, March 2015
IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Spatial Variability of Groundwater Chemical Quality for Drinking and Irrigation Purposes in Parts of Nagaon and Morigaon Districts, Assam, Using Geoinformatics

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***Abstract* — The spatial variability in the chemical quality of groundwater resources in parts of Nagaon and Morigaon Districts, Assam was studied by considering pre-monsoon and post-monsoon groundwater samples. Quality analysis was made through the estimation of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, iron, sulphate, chloride, TDS, electrical conductance, total hardness and pH for both pre-monsoon and post-monsoon seasons. Based on these data, certain chemical parameters such as sodium adsorption ratio (SAR), sodium percentage (%Na) and residual sodium carbonate (RSC) were derived for the evaluation of irrigation water quality. Thematic maps of selected parameters were prepared for both pre- and post-monsoon seasons in the GIS environment. The Land use / Land cover map of the study area was prepared from the satellite imageries supported with limited field check. The suitability of groundwater for drinking and irrigation purposes was verified on the basis of the spatial distribution of the chemical parameters. Different groundwater quality zones were identified based on the suitability of groundwater in the settlement area for drinking purpose and agricultural land for irrigation purpose. This was done by integrating the groundwater suitability maps with the land use / land cover map using GIS. The resultant maps revealed that groundwater from only one location requires treatment before use for drinking purposes. Similarly, irrigation water quality in ninety seven percent of the agricultural land comes within the excellent to permissible zone.**

Keywords— Groundwater, Chemical quality, Brahmaputra, Kolong, GIS, Remote Sensing

I. INTRODUCTION

Groundwater plays an important role in serving domestic purposes as well as in irrigation. With the increased demand for water and with the intensification of water utilization, the water quality problem becomes the limiting factor in the development of water resources in many parts of the world. In the developing World, 80% of all diseases are directly related to poor drinking water quality and unsanitary conditions [1]. The importance of groundwater quality in human health has recently attracted a great deal of interest [2]. The assessment of groundwater quality status is important for socio-economic growth and development [3].

In this study an attempt has been made to determine the spatial variation of groundwater quality for drinking purpose within the human settlement area and for the irrigation purpose within the agricultural land area. The resultants maps are based on integrated analysis of chemical parameter and land use / land cover maps using Geographical Information System (GIS), which will be of enormous use in sustainable development of groundwater in the area.

II. STUDY AREA

The study area represents a part of Nagaon and Morigaon districts, Assam, (Fig. 1) falling between 91º57'6"E to 93º4'46"E longitude and 26º9'21"N to 26º37'17"N latitude. It lies in the Survey of India Toposheet Nos. 78N/15, 78N/16, 83B/3, 83B/4, 83B/6, 83B/7, 83B/8, 83B/10, 83B/11, 83B/12, 83B/14, 83B/15, 83F/2 on 1:50,000 scale. The north-eastern part and the western part of the area could not be accessed for data collection. The actual area of work is around 2100 sq. km.

The area, bounded by the river Brahmaputra and Kolong, is situated on the southern bank of the Brahamaputra River and endowed with fertile land and abundant rainfall during monsoon. Precipitation is the main source of groundwater recharge in the area. The average annual rainfall in the area is about 1982 mm. The people mainly depend on dug wells and deep tube wells for domestic and agricultural use of water. The flood plains of the area are mostly occupied by sandy silt, loamy to clay loamy soils.

The study area falls in the axial belt of Brahmaputra valley. The area is underlain by unconsolidated alluvial sediments deposited on a granite gneiss basement which also outcrops as inselbergs within the alluvial terrain. The slope of the basement, over which these alluvial sediments were deposited, gradually steepened from south to north, towards Brahmaputra. In most of

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ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

the area the depth to water level ranges from 2.16 m to 5.72 m.

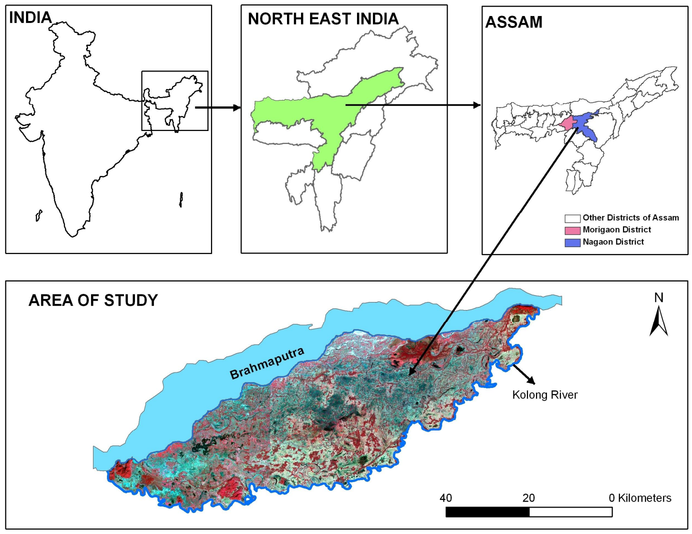

Fig. 1 Location map of the study area

III.DATABASE AND METHODOLOGY

Groundwater samples from dug wells and bore wells were collected from 36 locations of the study area. These wells are in use for both domestic as well as for irrigation purposes. Water samples were collected in both pre-monsoon (April – May) and post-monsoon (November – December) season during the year 2010 following standard norms. Their locations and numbers were plotted in Fig. 2 to show their spatial distribution. Samples were analyzed for various chemical parameters using standard methods with a view to access the drinking and irrigation water quality within the area of study. Parameters considered for analysis include pH, TDS, Total Hardness (TH), Ca, Mg, Fe, Cl, SO_4, Na, K , EC, CO_3 and HCO_3. In order to assess the water quality for irrigation purpose, different indices for irrigation uses such as Sodium Adsorption Ratio (SAR), Residual Sodium carbonate (RSC) and Percent Na (% Na) were calculated using the standard equations. Analysis values were compared with classification schemes derived from standard values recommended by Bureau of Indian Standards [4]. Suitability of groundwater for irrigation purpose was assessed following different standards after U.S. Salinity Laboratory 1954 [5], Richards 1954 [6] and Wilcox 1955 [7].

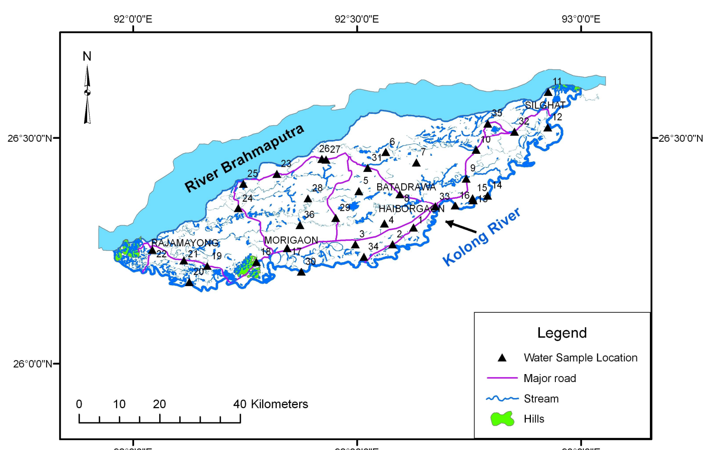

Fig. 2 Map of the study area showing groundwater sampling locations

The positions (Latitude – Longitude) of 36 water sample locations all over the study area were obtained using a handheld GPS receiver. ArcGIS platform was used for GIS database creation and analysis. Based on the positional data of sample locations, a point feature class was prepared that shows the position of 36 sample locations (Fig. 2). The water quality data thus obtained forms the non-spatial database which linked with point feature class in GIS. The spatial and the non-spatial database in vector

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ISSN: 2321-9653
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format were used for the generation of interpolated raster spatial distribution maps of various water quality parameters. For spatial interpolation Inverse Distance Weighted (IDW) approach in GIS has been used to delineate the spatial distribution of groundwater quality parameters. This interpolation works best with evenly distributed points.

Weights were assigned to each chemical parameters [8] [9] based on the importance of the parameters and ranks were assigned to various classes of each parameter depending on the quality categories of analytical values for both drinking and irrigation purposes, as given in the Tables I & II.

Table I

WEIGHTS and RANKS of QUALITY PARAMETERS USED for DRINKING PURPOSES [PARAMETER STANDARDS after BIS:10500 -1991].

Sl. No	Geochemical Parameter	Weight	Parameter Range	Classification	Rank	W x R
. 1.	pH	60	<6.5	Not Permissible	1	60
			6.5 – 8.5	Desirable	4	240
			>8.5	Not Permissible	1	60
2.	TDS (mg/l)	40	<500	Desirable	4	160
			500 – 1500	Permissible	3	120
			2000	Max. Permissible limit	2	80
			>2000	Not Permissible	1	40
3.	Total Hardness (as $CaCO_3$) mg/l	30	<200	Desirable	4	120
			200-300	Permissible	3	90
			600	Max. Permissible limit	2	60
			>600	Not Permissible	1	30
4.	Calcium (as Ca) mg/l	20	<75	Desirable	4	80
			75-100	Permissible	3	60
			200	Max. Permissible limit	2	40
			>200	Not Permissible	1	20
5.	Magnesium (as Mg) mg/l	10	<30	Desirable	4	40
			30-50	Permissible	3	30
			150	Max. Permissible limit	2	20
			>150	Not Permissible	1	10
6.	Iron (as Fe) mg/l	20	< 0.1	Desirable	4	80
			0.1- 0.3	Permissible	3	60
			1.0	Max. Permissible limit	2	40
			>1.0	Not Permissible	1	20
7.	Chloride (as Cl) mg/l	50	<250	Desirable	4	200
			250 – 600	Permissible	3	150
			1000	Max. Permissible limit	2	100
			>1000	Not Permissible	1	50
8.	Sulphate (as SO_4) mg/l	20	<200	Desirable	4	80
			200-400	Permissible	3	60
			>400	Not Permissible	1	20

Table II

WEIGHTS and RANKS of QUALITY PARAMETERS USED for IRRIGATION PURPOSES [PARAMETER STANDARDS for EC and % NA are after WILCOX, 1955, SAR AFTER RICHARDS (1955) and RSC GIVEN BY USSL STAFF, 1954].

Sl. No	Geochemical Parameter	Weight	Parameter Range	Classification	Rank	W x R
1	Electrical Conductivity (EC) (µS/cm)	40	<250	Excellent	5	200
			250 – 750	Good	4	160
			750 – 2000	Permissible	3	120
			2000 – 3000	Doubtful	2	80
			>3000	Unsuitable	1	40
2.	Sodium Adsorption Ratio (SAR in meq/l)	30	<10	Excellent	5	150
			10 – 18	Good	4	120
			18 – 26	Permissible	3	90
			>26	Unsuitable	1	30
3	Residual Sodium Carbonate (RSC in meq/l))	20	<1.25	Excellent	5	100
			1.25 – 2.50	Permissible	3	60
			>2.50	Unsuitable	1	20
4.	Percent Sodium (%Na)	10	<20	Excellent	5	50
			20 – 40	Good	4	40
			40 – 60	Permissible	3	30
			60 – 80	Doubtful	2	20
			>80	Unsuitable	1	10

A. Generation of groundwater suitability maps for drinking purpose

The spatial distribution maps for drinking water quality were prepared by considering the eight parameters viz. hydrogen ion concentration (pH), total dissolved solids (TDS), total hardness (TH), calcium, magnesium, iron, sulphate and chloride for both pre-monsoon and post-monsoon period. Thematic maps of the chemical parameters for both the periods are shown in Fig. 3. The maps show the spatial variation of the chemical components within the study area.

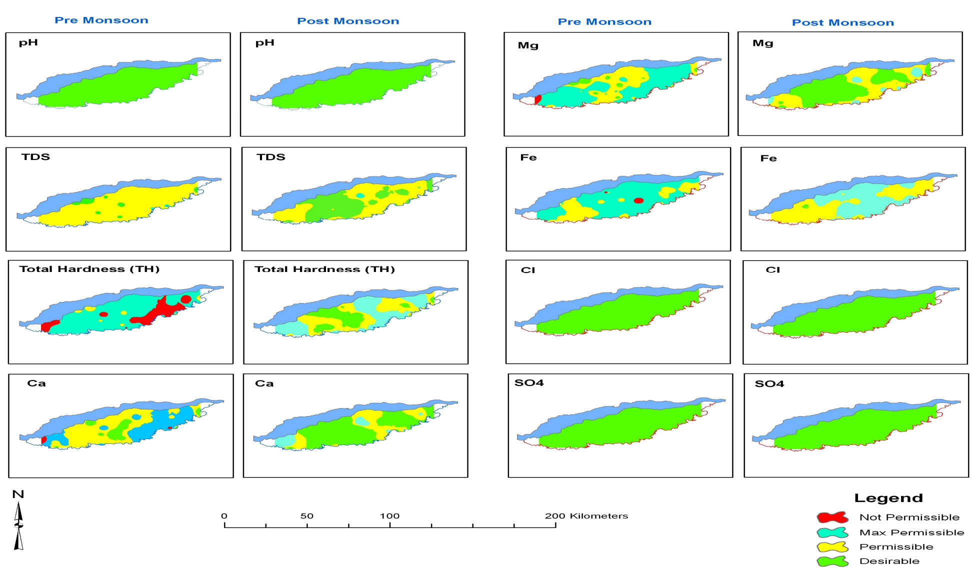

Fig. 3 Spatial distribution of some important chemical parameters used for drinking water quality (Units are in mg/l except pH)

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

These eight thematic raster layers were integrated by Raster Index Overlay technique in GIS to create a groundwater suitability maps for drinking purpose. In the index overlay technique, the values were calculated using the following formula -

$$S = \sum Sij\ Wi / \sum Wi \qquad \text{(Eq.1)}$$

where, S = Weighted score of a pixel
Wi = Weight for the ith output map
Sij = Rank of the jth class of the ith map
Values of j depend on the class occurring at the current location.

In the groundwater suitability maps (Fig. 4), four zones viz. Excellent, Good, Permissible and Not Permissible, within the study area were delineated for the Pre- and Post-monsoon seasons based on the quality of the groundwater for drinking purpose.

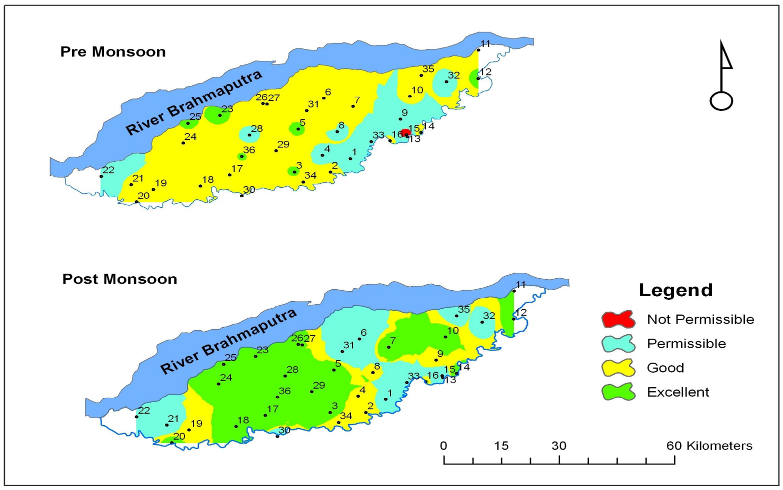

Fig. 4 Groundwater Suitability maps for drinking purpose in the study area.

B. Generation of groundwater suitability maps for Irrigation

The spatial distribution maps were prepared considering the four parameters viz. EC, Na%, SAR and RSC which are relevant for the irrigation water quality (Fig. 5). Using the same Raster Index Overlay technique these four parameters were integrated (using Eq.1) to generate the groundwater suitability maps for irrigation purpose (Fig. 6). In these groundwater suitability maps, the study area was delineated into five zones as Excellent, Good, Permissible, Doubtful and Not Permissible, based on the irrigation water quality.

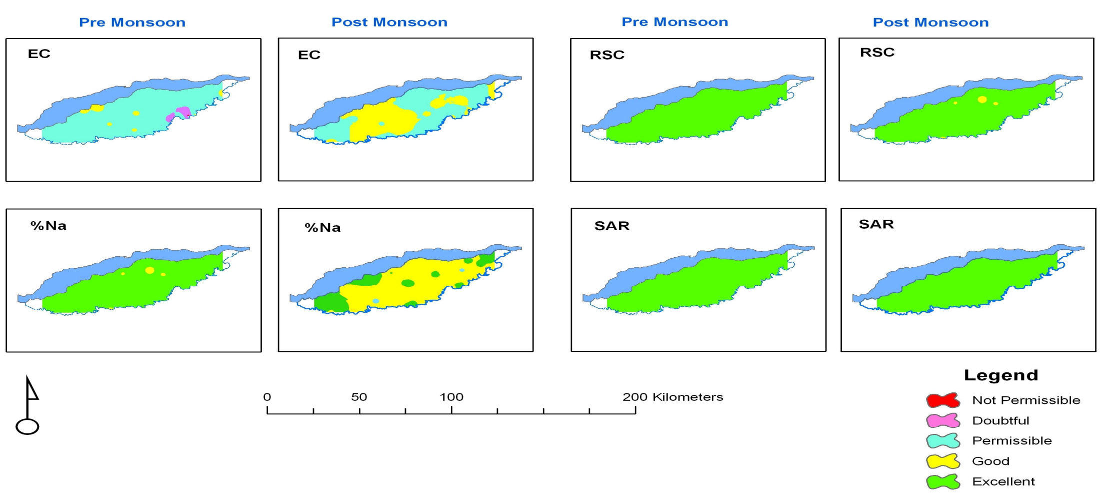

Fig. 5 Spatial distribution of important chemical parameters of Groundwater used for irrigation water quality. (Units of EC in µS/cm and RSC & SAR in meq/l)

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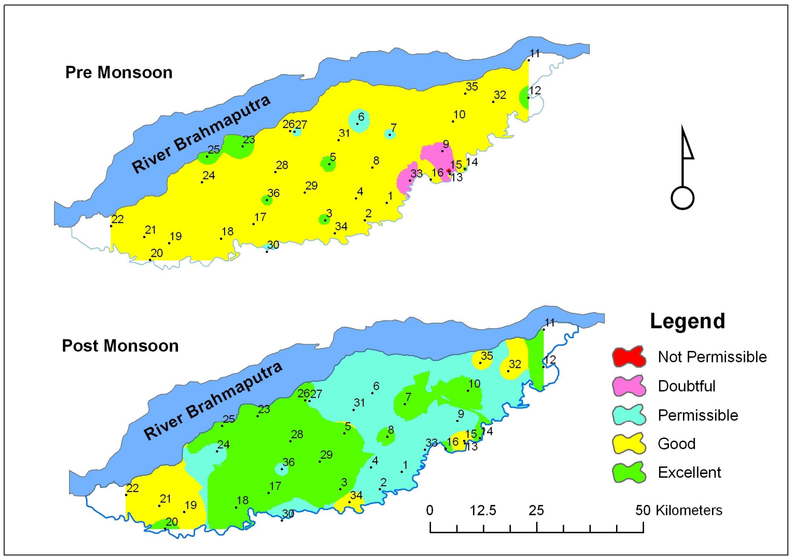

Fig. 6 Groundwater Suitability maps for Irrigation purposes in the study area.

C. Generation of Land use / Land cover Map

Land use / Land cover map (Fig. 7) of the study area was prepared from the satellite imageries (IRS LISS-III and PAN) supported with limited field check. IRS LISS III (2007) four bands multispectral image with 23.5 m resolution and PAN image (2007) of 5.8 m resolution was procured in digital format. The study area was categorized into five land use categories viz. Agricultural land, Forest land, Settlement area, Wet land and River/Stream. Purpose of the land use map is to verify the spatial and temporal variation of drinking water quality within the human settlement area and the irrigation water quality within the agricultural land area. For this purpose the settlement category of the land use / Land cover classification map was integrated with the pre- and post-monsoon groundwater quality map for the drinking purpose, by raster overlay technique, to obtain the spatial and temporal variation of groundwater quality within the settlement area (Fig. 8). Similarly, the spatial and temporal variation of groundwater quality for irrigation purpose was obtained within the agricultural land area (Fig. 9).

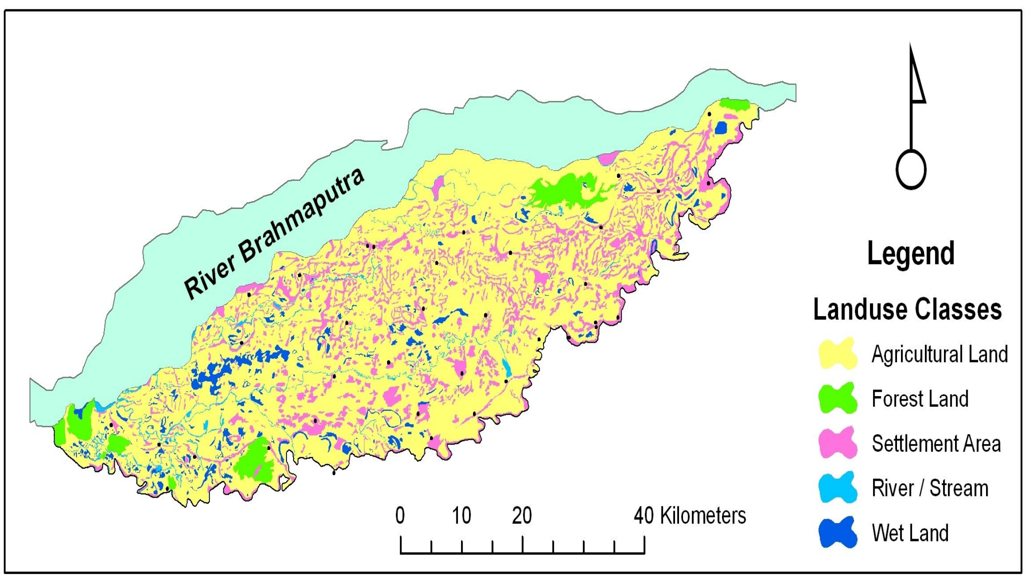

Fig. 7 Land use / Land cover map of the study area.

The derived statistical data of the spatial distribution of various land use/land cover classes with their areal extent within the study area is given in Table III.

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IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Table III
AREAL EXTENT of VARIOUS LAND USE / LAND COVER CLASSES within the STUDY AREA

Land use Classes	Area	
	in sq.km	in %
Settlement area	345.92	16.47
Agricultural land area	1584.92	75.47
Forest land	66.04	3.14
Wet land	77.01	3.67
River/Stream	26.11	1.24

IV. RESULTS AND DISCUSSIONS

The chemical analysis data of the geochemical parameters of the 36 groundwater samples were statistically analyzed and the results are presented in the form of minimum, maximum, mean and standard deviation (Table IV).

Table IV
SUMMARY of the PARAMETERS USED for EVALUATION of DRINKING WATER QUALITY and IRRIGATION WATER QUALITY

Parameter	Pre-Monsoon				Post-Monsoon			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
pH	7.4	8.6	7.9	0.20	7	8.5	7.81	0.25
EC (µmhos/cm)	582	3600	1268.5	626.16	328	1800	810	385.25
TDS (mg/l)	372	2305	812	401.36	210	1312	538	258.65
Hardness as $CaCO_3$	229	1550	530	320.75	116	580	293	131.35
Ca (mgl)	52	320	105.2	55.20	28.8	158	69.2	32.46
Mg (mgl^{-})	16.2	240	66	49.87	6.7	72	31.7	18.87
Fe (mgl^{-})	0.1	1.3	0.48	0.34	0.08	1	0.36	0.28
Cl (mgl^{-})	16	250	55	47.66	12	232	83.4	52.58
SO_4 (mgl^{-})	7.7	232	30.4	47.31	2	204	41.1	39.89
Na (mgl^{-})	5.4	49.7	19.6	13.35	5.1	84.6	33.8	19.21
K (mgl^{-})	0.45	24.4	7.1	6.62	1.25	87.7	14.2	16.33
CO_3 (mgl^{-})	0.78	6.3	2.62	1.42	0.39	4.48	1.92	0.99
HCO_3 (mgl^{-})	195	1255	524.8	266.38	101.3	854.2	257.27	169.53
SAR (meq/l)	0.04	1.05	0.38	0.268	0.18	1.84	0.841	0.408
%Na	2.64	24.69	9.981	6.462	8.18	43.15	23.22	9.25
RSC (meq/l)	-25.99	0.18	-1.98	4.49	-7.87	0.94	-1.809	1.94

A. pH

pH value of groundwater within the study area in both pre- and post-monsoon period is within the desirable limit for drinking purpose, which ranges from 6.5 to 8.5, except in location no. 33 (Hoiborgaon) with pH value 8.6, which belongs to not-permissible category (Fig. 3).

B. Electrical Conductivity (EC)

EC is a good measure of salinity hazard to crops. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil [10]. EC values in post-monsoon period were within the permissible limit (<2000 µmhos/cm) but in pre-monsoon period groundwater from 3 locations come under doubtful category and 1 location comes under unsuitable category for irrigation purpose (Fig. 5).

C. Total Dissolved Solids (TDS)

TDS values of groundwater samples in the study area, except from two locations in the pre-monsoon period, are within the permissible limit (below 1500 mg/l). The TDS values at location number 33 (Hoiborgaon) is 1552 mg/l and at location number 15 (Karhaligaon) is 2303 mg/l, which come under maximum permissible category and not permissible category respectively (Fig. 3).

D. Total Hardness (TH)

In this study area, as per the classification given by Sawyer and McCarty [11], about 78% of groundwater samples from pre-monsoon period and 42% samples from post-monsoon period belong to very hard category (above 300 mg/l as $CaCO_3$) . In the spatial distribution map for Total Hardness (Fig. 3), it has been observed that 28% sample locations fall under not suitable category and rest of the sample locations come under permissible to maximum permissible category for drinking purpose in the pre-monsoon period. However, the situation is much improved in the post-monsoon period due to the dilution of groundwater after the monsoon.

E. Cations and Anions

Presence of calcium and magnesium is a cause for hardness in water. Concentration of calcium in the area come under the maximum permissible category except in the location number 15 (Karhaligaon) which is beyond the maximum permissible limit (>200 mg/l). The magnesium concentration in the groundwater samples is within the maximum permissible limit, except at location number 22 (Rajamayong) which is found beyond the maximum permissible limit (>150 mg/l).

The iron contents in the groundwater samples of the study area are on a higher side. From pre-monsoonal samples only 36% fall under permissible category and rest 64% samples are above the permissible limit. Post monsoonal situation is slightly improved with 53% samples fall under permissible category and 47% are above the permissible limit. Moirabari (location number 26) is the location where iron content in both pre- and post-monsoon period was found to be beyond permissible limit.

The chloride values in the study area varies from 12 mg/l to 250 mg/l in both pre- and post-monsoon seasons (Figure 4) which are within the permissible limit (<200 mg/l). The sulphate values range from 7.7 mg/l to 232 mg/l in pre-monsoon and 2 mg/l to 204 mg/l in post-monsoon season (Figure 4) which come under permissible limit (<600 mg/l).

Sodium and Potassium concentration values (in mille equivalents) were used to calculate the parameters such as SAR and %Na, to determine the quality of groundwater for irrigation purpose. The bicarbonate and carbonate values (in milliequivalents) were used to calculate the parameter RSC to indicate the quality of groundwater for irrigation purpose.

F. Sodium Absorption Ratio (SAR)

There is a close relationship between SAR values in irrigation water and the extent to which Na^+ is absorbed by the soil [12]. The sodium or alkali hazard in the use of water for irrigation was determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). It can be calculated by the following equation given by Richards [6]:

$$SAR = \frac{Na^+}{\sqrt{\{(Ca^{2+} + Mg^{2+})/2\}}} \qquad \text{(Eq. 2)}$$

where, all the ions are expressed in meq/l.

According to Richards [6], irrigation waters are rated based on SAR values. The groundwater within the study area in both pre-monsoon and post-monsoon season is excellent because in none of the sample locations the value of SAR exceeded 10 (Fig. 5).

G. Precent Sodium (%Na)

According to Wilcox [7] percent sodium plays an important role in adjudging the quality of water for irrigation. Sodium content is usually expressed in terms of percent sodium (%Na), defined by [13]:

$$\text{Percent Sodium (\%Na)} = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100 \qquad \text{(Eq. 3)}$$

where, all ionic concentrations are expressed in meq/l.

%Na values of ground water in the study area ranges from 2.64 to 24.69 for Pre-monsoon and from 8.18 to 43.15 for Post-monsoon. Therefore, based on the values of %Na, groundwater quality in the study area for irrigation purposes was found to be excellent to permissible category (<60) (Fig. 5).

H. Residual Sodium Carbonate (RSC)

Eaton [14] suggested determination of bicarbonate hazard on the basis of RSC, which is calculated as:

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ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$$RSC = (CO_3^{-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad \text{(Eq. 4)}$$

where, RSC and the concentration of the constituents are expressed in meq/l.
A high value of RSC in water leads to an increase in the adsorption of sodium on soil [14]. The RSC values in groundwater in the study area indicate that the water from the area is suitable for irrigation purpose (Fig. 5).

I. Groundwater Quality zones for drinking purposes in the study area

The groundwater suitability maps for drinking purposes (Fig. 5), were classified into four zones. Table V shows the area in square kilometer and percentage that comes under the various categories of groundwater for drinking purpose within the 2,100 sq.km of study area, in both pre- and post-monsoon periods.

Table V

AREA UNDER the VARIOUS CATEGORIES of GROUNDWATER for DINKING PURPOSE in PRE- and POST-MONSOON PERIODS

Categories	Pre Monsoon		Post Monsoon	
	Area in sq.km	% of area Covered	Area in sq.km	% of area Covered
Excellent	71.75	3.42	1039.98	49.52
Good	1563.64	74.46	478.22	22.77
Permissible	459.86	21.9	581.8	27.7
Not-Permissible	4.75	0.23	Nil	Nil

J. Spatial and Temporal Variation of Drinking water Quality within the Settlement Area

The spatial and temporal variation of groundwater quality within the settlement area can be observed in Fig. 8. Out of 345.92 sq.km settlement area, in the pre-monsoon period it was observed that groundwater quality of excellent category for drinking purpose occupies 23.11 sq.km (6.68%) areas. Groundwater in 225.62 sq.km (65.22%), 96.13 sq. km (27.79%) and 1.06 sq. km (0.31%) area belongs to good, permissible and not-permissible category respectively for drinking purpose. In post-monsoon period, groundwater of excellent quality occupies 79.09 sq. km (22.86%) area. Groundwater of Good and permissible quality for drinking purpose occupies 83.86 sq. km (24.24%) and 182.97 sq. km (52.89%) area respectively.

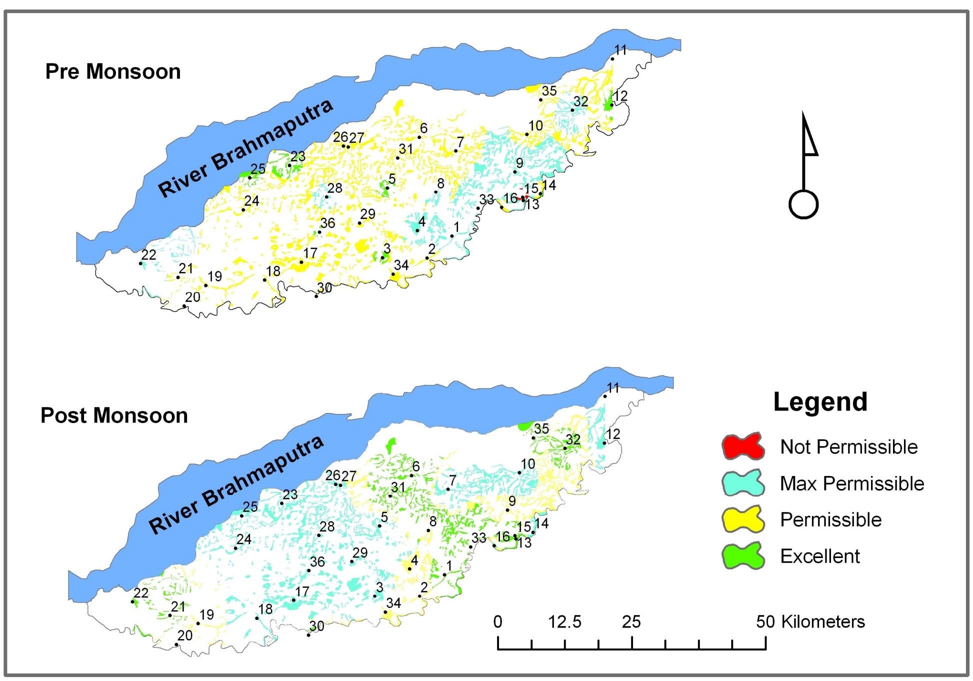

Fig. 8 Drinking water quality within the settlement area

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ISSN: 2321-9653
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K. Groundwater Quality zones for irrigation purposes in the study area

The groundwater suitability maps for irrigation purposes in pre- and post- monsoon seasons (Fig. 6), were classified into five zones. Table VI shows the area in square kilometer and percentage that comes under the various categories of groundwater for irrigation purpose within the 2100 sq.km of the study area, in both pre and post monsoon periods.

Table VI

AREA UNDER the VARIOUS CATEGORIES of GROUNDWATER for IRRIGATION PURPOSE in PRE- and POST-MONSOON PERIODS

Categories	Pre Monsoon		Post Monsoon	
	Area in sq.km	% of area Covered	Area in sq.km	% of area Covered
Excellent	71.46	3.40	860.33	40.97
Good	1930.98	91.95	941.13	44.82
Permissible	31.67	1.51	298.54	14.22
Doubtful	65.15	3.10	Nil	Nil
Not-Permissible	0.74	0.04	Nil	Nil

L. Spatial and Temporal Variation of Groundwater Quality within the Agriculture Land

Fig. 9 indicates the spatial and temporal variation of groundwater quality within the agricultural land for irrigation purposes. It was observed that out of 1584.92 sq.km of agricultural land, groundwater quality of excellent category for irrigation purpose occupies only 47.19 sq.km (2.98%) area. For the rest 1459.86 sq.km (92.11%), 25.19 sq.km (1.59%), 52.03 sq.km (3.28%) and 0.66 sq.km (0.04%) area, groundwater comes under good, permissible, Doubtful and not-permissible category respectively in the pre-monsoon period. However, in post-monsoon period, 664.52 sq.km (41.93%) area belongs to excellent category and the rest 691.97 sq.km (43.66%) and 228.43 sq.km (14.41%) area belongs to Good and permissible category respectively.

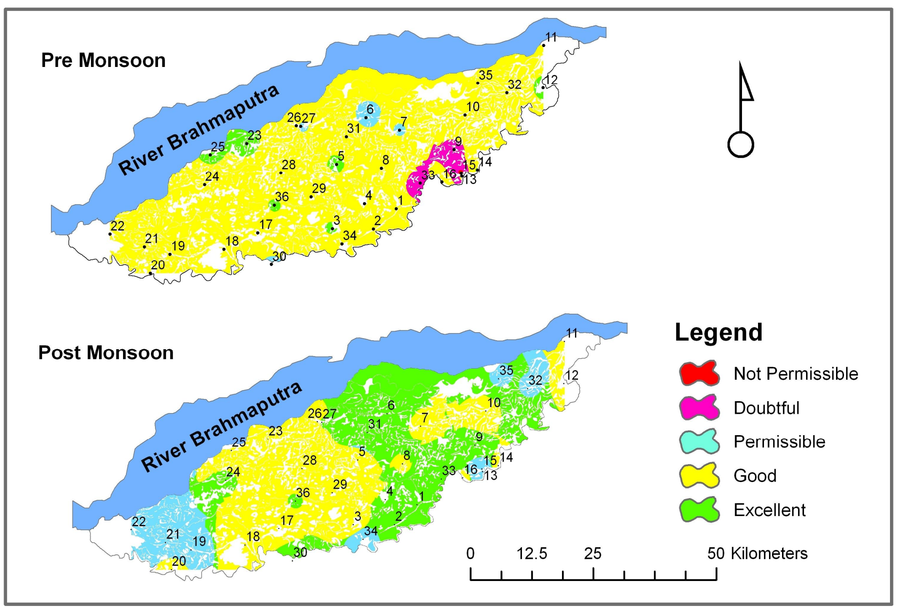

Fig. 9 Irrigation water quality within the Agricultural land area.

V. CONCLUSION

Groundwater is the primary source for drinking water and irrigation in the study area and hence data pertaining to the chemical quality of groundwater is very much essential for planning and implementation of groundwater supply in the area for both drinking as well as irrigation purposes.

The suitability of groundwater for drinking and irrigation purposes has been verified on the basis of the spatial distribution of the chemical parameters with reference to the available standards. Different quality zones were identified based on the suitability of groundwater in the settlement area and agricultural land for drinking and irrigation purpose respectively by integrating the suitability maps with the land use / land cover map using GIS.

The groundwater quality in the study area in post-monsoon period was found to be improved than in pre-monsoon period. The dilution and quality enhancement of groundwater in a few locations in the study area during the post-monsoon period indicate effects of rainfall recharge.

The resultant map of drinking water quality within the settlement area (Fig. 8) revealed that the settlement area comes under the excellent to permissible category zone in both pre- and post-monsoon period except in sample location number 15 (Karhaligaon) which comes under not-permissible category in the pre-monsoon period and requires treatment before use for drinking purposes. Similarly, the resultant map of irrigation water quality within the agricultural land (Fig. 9) revealed that except only 3% agricultural land in the pre-monsoon period which is beyond permissible limit, the agricultural land comes under excellent to permissible category zone in both pre- and post-monsoon period.

Thus the integrated groundwater quality maps for drinking water quality within the settlement area (Fig. 8) and irrigation water quality within the agricultural land (Fig. 9) could be useful for sustainable groundwater development in the area.

VI. ACKNOWLEDGEMENT

The first author S. Kataki is thankful to the University Grant Commission, New Delhi (India) for financial support under Minor Research Project. The author is also thankful to Pollution Control Board, Guwahati, Assam, for carrying out the chemical analysis of the groundwater samples.

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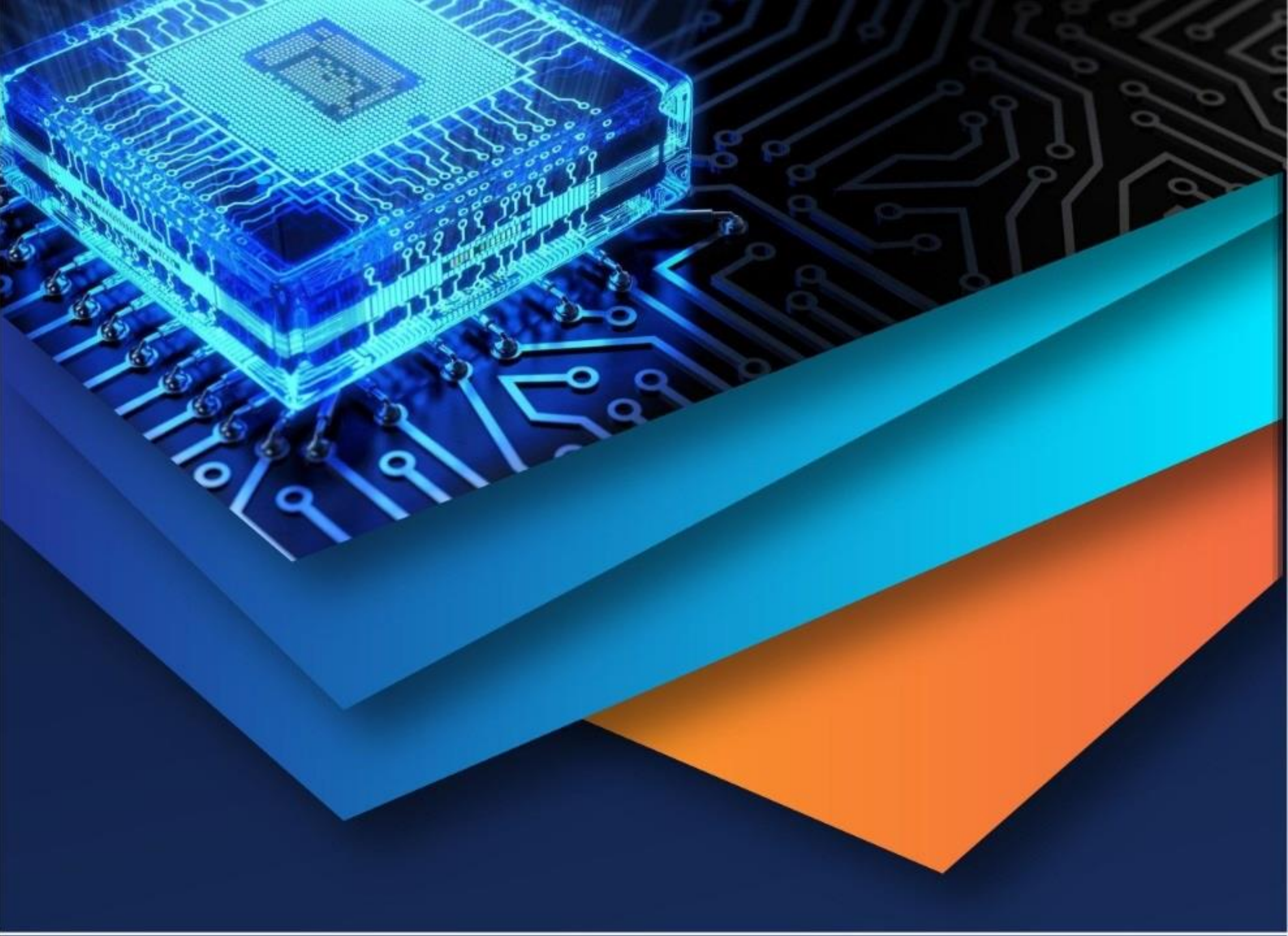

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