Evaluation of Ground Water Quality with more Emphasis on Arsenic Contamination in Barpeta District of Assam and Mitigation Strategy

NATIONAL INSTITUTE OF HYDROLOGY
CENTRE FOR FLOOD MANAGEMENT STUDIES
DISPUR, GUWAHATI - 781 006
2017-18

PREFACE

Ground water forms the major source of water supply for drinking purposes in most part of the country. For proper utilization of water for various purposes, understanding of geo-chemical controls and study of the extent of ground water contamination are of prime importance. The quality of ground water is particularly important to humans when the water is used for drinking water supply. The quality of ground water varies from place to place along with the depth of water table. It also varies with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it.

There has been heavy dependence on ground water in recent decades due to growth in agriculture, population and industries in many parts of our country. The situation is not so alarming at present in the North-Eastern Region of the country. However, scientific and sustainable approach is important in managing ground water resources and its quality.

The Barpeta District with its headquater at Barpeta was carved out of erstwhile Kamrup District of Assam in July 1983. The district is spread within 26°45′ to 26°49′ North latitude and 90°45′ to 90°15′ East longitude with a total geographyical area of 324500ha. The District consists of two Civil Sub-Divisions (Barpeta and Bajali). This Lower Assam District covers an area of 2645 km^2 and is bounded by Bhutan Hills and Baksa District in the North, Nalbari District in the East, Kamrup and Goalpara District in the South and Bongaigaon District in the West. The river Brahmaputra flows from east to west across the Southern part of the district. The tributaries of these river that flows through the District are Beki, Manah, Pohumara, Kaldia, Palla, Nakhanda, Marachaulkhowa and Bhelengi flowing from North to South. Rivers Pohumara and Kaldia joins near Barpeta town to form river Nakhanda whereas Palla and Beki join with Nakhanda to ultimately form Chaulkhowa river.

In this report, an attempt has been made to bring out the ground water quality status in Barpeta District of Assam with special reference to arsenic contamination and remedial measures suggested. The report will be of immense use to the planners, administrators, scientists and engineers concerned with the management and protection of ground water quality in Barpeta District.

The report has been prepared by Dr. C. K. Jain, Sc. 'G' & Head, Environmental Hydrology Division. Other scientists and staff involved in the study include Dr. S. K. Sharma, Sc. 'C' of NIH-Centre for Flood Management Studies, Guwahati and Smt. Babita Sharma, RA, Environmental Hydrology Division, NIH, Roorkee, under the work programme of 2017-18. Sri. Biren Das, MTS (M) was involved in field investigations.

(S. K. JAIN)
DIRECTOR

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The ground water quality of Barpeta District has been assessed to see the suitability of ground water for domestic and irrigation applications. Fifty ground water samples from various abstraction sources were collected during pre-monsoon season of 2017 and analysed for various water quality constituents. The hydro-chemical data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified. The analysis of data clearly indicated that the concentrations of almost all the water quality constituents are well within the permissible limits for drinking water.

The presence of heavy metals in ground water though recorded in almost all the samples but these were not significantly higher except iron, manganese and arsenic. The water quality standards have been violated for iron and manganese in more than 90% and 75% of the samples respectively. The concentration of iron varies from 262 to 12246 μg/L during pre-monsoon season as against the acceptable limit of 300 μg/L while that of manganese vary from 46 to 2731 μg/L during pre-monsoon as against the permissible limit of 300 μg/L. High concentrations of iron generally cause inky flavour, bitter and astringent taste. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration also promotes bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity. The concentration of arsenic varies from 0.10 to 569 μg/L with more than 25% of samples exceeding the acceptable limit of 10 μg/L. The concentration of copper, nickel, chromium, lead, cadmium and zinc were found well within the permissible limits in almost all the samples of Barpeta District.

An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear, Chadha's diagram and U.S. Salinity Laboratory classifications. The grouping of samples according to their hydrochemical facies indicates that majority of the samples fall under Ca-Mg-HCO_3 hydrochemical facies. Two samples belong to Na-K-HCO_3 hydrochemical facies and one sample to Na-K-Cl-SO_4 hydrochemical facies. The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR), Residual Sodium Carbonate (RSC) and boron content. In general the ground water of Barpeta District is safe for irrigation purpose. According to U.S. Salinity Laboratory classification of irrigation water, majority of the samples fall under water type C2-S1 followed by C1-S1 type.

1.0 INTRODUCTION

The quality of ground water is of great importance in determining the suitability of particular ground water for a certain use (public water supply, irrigation, industrial applications, power generation etc.). The quality of ground water is the resultant of all the processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well. Therefore, the quality of ground water varies from place to place, with the depth of water table, and from season to season and is primarily governed by the extent and composition of dissolved solids present in it.

In recent years, an increasing threat to ground water quality due to human activities has become of great importance. The adverse effects on ground water quality are the results of man's activity at ground surface, unintentionally by agriculture, domestic and industrial effluents, unexpectedly by sub-surface or surface disposal of sewage and industrial wastes.

A vast majority of ground water quality problems are caused by contamination, over-exploitation, or combination of the two. Most ground water quality problems are difficult to detect and hard to resolve. The solutions are usually very expensive, time consuming and not always effective. Ground water quality is slowly but surely declining everywhere. Ground water pollution is intrinsically difficult to detect, since problem may well be concealed below the surface and monitoring is costly, time consuming and somewhat hit-or-miss by nature.

The wide range of contamination sources is one of the many factors contributing to the complexity of ground water assessment. It is important to know the geochemistry of the chemical-soil-groundwater interactions in order to assess the fate and impact of pollutant discharged on to the ground. Pollutants move through several different hydrologic zones as they migrate through the soil to the water table. The serious implications of this problem necessitate an integrated approach in explicit terms to undertake ground water pollution monitoring and abatement programmes.

The intensive use of natural resources and the large production of wastes in modern society often pose a threat to ground water quality and have already resulted in many incidents of ground water contamination. Pollutants are being added to the ground water system through human activities and natural processes. Solid waste from industrial units is being dumped near the factories, which is subjected to reaction with percolating rain water and reaches the ground water level. The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the ground water. The problem of ground water pollution in several parts of the country has become so acute that unless urgent steps for detailed identification and abatement are taken, extensive ground water resources may be damaged.

The quality of ground water depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportions of dissolved constituents are found in ground water than in surface water because of greater interaction of ground water with various materials in geologic strata. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders.

The contamination of ground water by heavy metals and pesticides has also assumed great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The determination of the concentration levels of heavy metals and pesticides in these waters, as well as the elucidation of the chemical forms in which they appear is a prime target in environmental research today.

There has been heavy dependence on ground water in recent decades due to growth in agriculture, population and industries in many parts of our country. The situation is not so alarming at present in the North-Eastern Region of the country. However, scientific and sustainable approach is important in managing ground water resources and its quality.

The Barpeta District with its headquater at Barpeta was carved out of erstwhile Kamrup District of Assam in July 1983. The district is spread within 26°45′to 26°49′ North latitude and 90°45′ to 90°15′ East longitude with a total geographyical area of 324500ha. District consists of two Civil Sub-Divisions, Barpeta and Bajali. The district covers an area of 2645 km^2 and is bounded by Bhutan Hills and Baksa District in the North, Nalbari District in the East, Kamrup and Goalpara District in the South and Bongaigaon District in the West. The river Brahmaputra flows from east to west across the Southern part of the district. The tributaries of these river that flows through the District are Beki, Manah, Pohumara, Kaldia, Palla, Nakhanda, Marachaulkhowa and Bhelengi flowing from North to South. Rivers Pohumara and Kaldia joins near Barpeta town to form river Nakhanda whereas Palla and Beki join with Nakhanda to ultimately form Chaulkhowa river.

In this report, an attempt has been made to bring out the ground water quality status in Barpeta District of Assam. The report will be of immense use to the planners, administrators, scientists and engineers concerned with the management and protection of ground water quality in Barpeta District.

2.0 BARPETA DISTRICT

Barpeta District is located in lower Assam on north of River Brahmaputra covering an area of 3,245 km^2. For administrative convenience, the district has been divided into two sub-divisions, 12 blocks and 8 revenue circles.

The district occupies part of greater Brahmaputra basin and the mighty River Brahmaputra is flowing westernly direction through the southern boundary. The district is also drained by perennial rivers flowing from the north and joining River Brahmaputra.

The irrigation facilities mostly confined to a few lift and flow surface water schemes. However, farmers are utilising ground water for multiple cropping through shallow tube wells and as such the district is famous for its vegetable production and other Rabi crops.

The detailed hydrogeological surveys aided by exploratory drilling have been carried out in the area by Central Ground Water Board. In addition, C.G.W.B. is monitoring Ground Water Monitoring Stations and the resources prospect of the district has been assessed for future planning and development of ground water (CFWB, 2013).

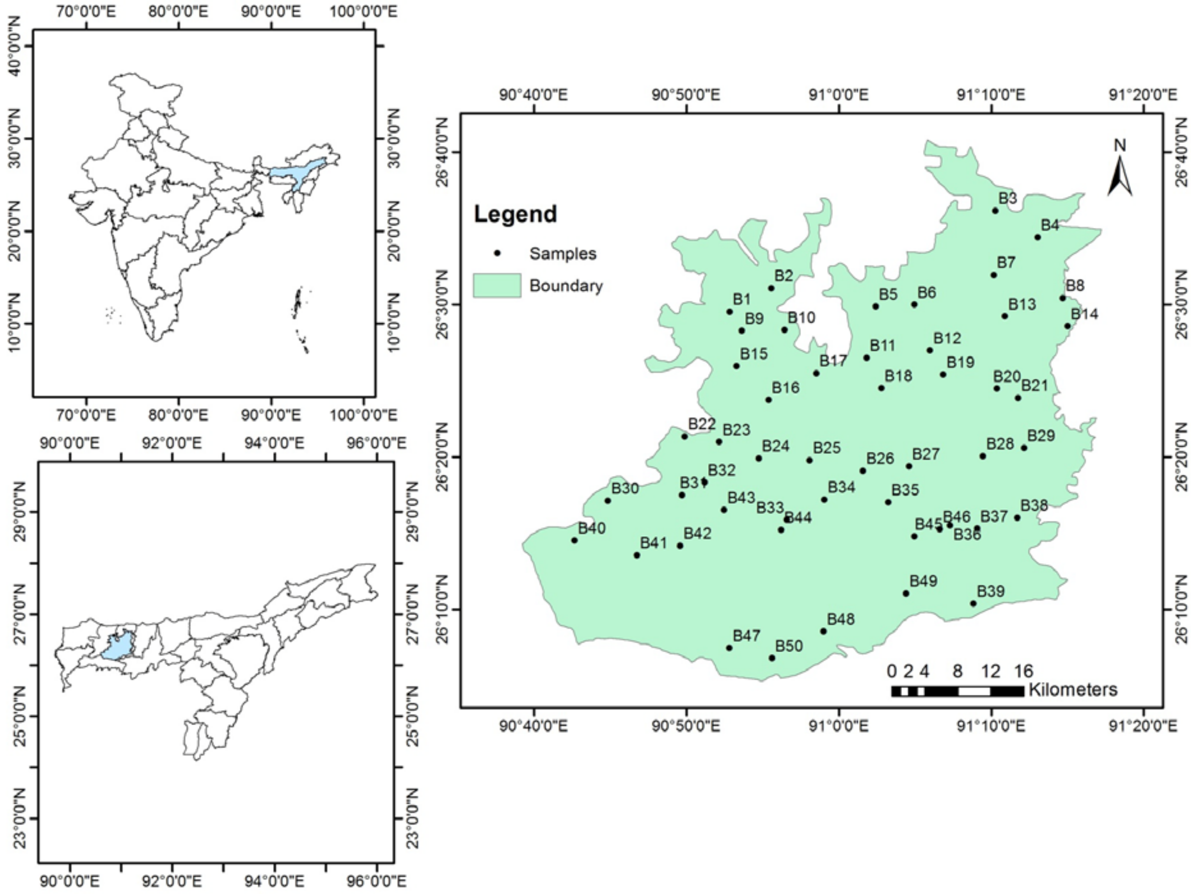

Fig. 2.1 Location of Barpeta District

2.1 Topography

The general Topography of the Barpeta District varies from low-lying plains to highland having small-hillocks in the South-West-corner of the District, namely Baghbar, Fulora and Chatala overlooking the scenic and mighty Brahmaputra River.

2.2 Climate

The climate of the district is sub-tropical and humid. The average temperature ranges from 150 to 300C. The winter season starts by November and continues till February. December/January is the coldest and July/August is the hottest period. The air is highly humid through out the year and during rainy season, the relative humidity is about 90 percent.

The area receives heavy rainfall every year and out of 2,051 mm of annual normal rainfall, 60 to 65% is received during June to September from south west monsoon. The district also receives rainfall during pre-monsoon period from March/April to May in the form of thunder showers and hail storms.

2.3 Geomorphology and Soil

Physiographically, almost the entire district is occupied by an alluvial deposit with flat topography and there is a very gentle slope towards the Brahmaputra River, which makes the southern boundary of the district. The northern parts extends up to the foothills of the Bhutan Himalayas, where high level terrace exists, commonly referred to as piedmont plain of “Bhabar Belt”, similar to the Ganga valley exhibits high slope towards south.

The district has soil cover of younger and older alluvial soil which has undergone diversified pedagogical changes. The soils are characterised by medium to high organic carbon and low to medium phosphorous and potash contents. Deep red coloured soil is developed in forested and foothill areas in the extreme northern region and the texture of these soils ranges from clay to sandy loam. The alluvial soils are light yellow to light grey in colour of Recent age. The texture of the soil ranges from sandy loam to silty loan in nature.

2.4 Hydrogeology

Hygeogeologically, the entire area of the district is occupied by alluvial sediments of Quaternary age. Piedmont deposits comprising of coarse clastic sediments like boulder, pebble, gravel associated with sand and silt from the ground water bearing formation in the northern part of the district.

Ground water occurs under unconfined condition in shallow aquifer and under semi-confined to confined condition in deeper aquifer. The aquifer is consisting of sand of various grades with little gravel in the southern part, with a very good yield prospect for both shallow and deep tube wells. The water level rests at shallow depth ranging from 2 to 4 m bgl during pre-monsoon period. The post-monsoon ground water level rests between 1 and 2 m bgl. The size of the aquifer materials gradually increases from south to north and the depth of water level is also high. The long term water level trend study shows no significant change of water level in the last 10 years.

The shallow tube wells tapping aquifers at the depth of 50 m bgl are capable of yielding 20-100 m3/he at drawdown of less than 3 m. Medium to heavy duty tube wells constructed down to 100 to 150 m bgl tapping about 25-40 m granular zones yield more than 100m3/hr.

Detailed hydrogeological surveys aided by exploratory drilling carried out by Central Ground Water Board have revealed the existence and persistence of rich aquifer system down to the depth of 300 m. The area consists of unconsolidated alluvial formation of Quaternary age, laid down by river Brahmaputra and its tributaries (CGWB, 2013).

The hydrogeological set up and availability of huge ground water resources and the present stage of ground water draft, it is concluded that the district has an ample scope for the development of ground water through construction of different ground water structures in a planned way.

2.5 Drainage

The district occupies part of greater Brahmaputra basis and the mighty river Brahmaputra is flowing westerly direction through the southern boundary. The district is also drained by perennial rivers flowing from the north and joining river Brahmaputra.

2.6 Population

In 2011, Barpeta had population of 1,693,622 of which male and female were 867,004 and 826,618 respectively. In 2001 census, Barpeta had a population of 1,394,755 of which males were 720,069 and remaining 674,686 were females. There was change of 21.43 percent in the population compared to population as per 2001. In the previous census of India 2001, Barpeta District recorded increase of 19.62 percent to its population compared to 1991.

3.0 EXPERIMENTAL METHODOLOGY

3.1 Sampling and Preservation

Fifty ground water samples were collected during pre-monsoon seasons of 2017 from various abstraction sources in clean polyethylene bottles and preserved by adding an appropriate reagent (Jain and Bhatia, 1988; APHA, 1992). The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (5 mL/lit.). All the samples were stored in sampling kits maintained at 4^{o}C and brought to the laboratory for detailed physico-chemical analysis. The details of sampling locations and source and depth wise distribution are given in Table 3.1 and 3.2 respectively and location of sampling points are shown in Fig. 3.1.

3.2 Chemicals and Reagents

All general chemicals and reagents used in the study were of analytical reagent grade (Merck/BDH). Standard solutions of metal ions were procured from Merck, Germany. De-ionized water was used throughout the study. All glassware and other containers used for trace element analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with de-ionized water several times prior to use.

3.3 Physico-chemical Analysis

The physico-chemical analysis was performed following standard methods (Jain and Bhatia, 1988; APHA, 1992). The brief details of analytical methods and equipment used in the study are given in Table 3.3. Ionic balance was determined, the error in the ionic balance for all the samples was within 5%.

3.4 Metal Ion Analysis

Metal ion concentrations were determined using Inductively Coupled Plasma – Mass Spectrometer (ICP-MS). Operational conditions were adjusted in accordance with the manufacturer’s guidelines to yield optimal determination. Quantification of metals was based upon calibration curves of standard solutions of respective metals. These calibration curves were determined several times during the period of analysis.

Table 3.1 Details of Sampling Locations in Barpeta District

S.No.	Sample ID	Location	Lat	Long	Source	Depth (m)	Land Use
1	B1	Saruo Gorakhiathan Temple	26.492	90.881	HP	9.14	Agriculture
2	B2	Satbhanituk High School	26.501	90.940	HP	12.19	Agriculture
3	B3	Gargoan, Bhagmara Temple	26.603	91.171	HP	9.14	Agriculture
4	B4	Bhatadev School, Bishankushi	26.574	91.217	HP	12.19	Dense Trees
5	B5	Dakin Bhalaguri School	26.498	91.040	HP	21.34	Dense Trees
6	B6	Sarupeta Railgate	26.500	91.082	HP	18.29	Agriculture
7	B7	Bamakhata Vetinary Hospital	26.532	91.169	HP	22.86	Agriculture
8	B8	Patharkuchi MPHC Hospital	26.507	91.245	HP	54.86	forest
9	B9	Saruo Dakhingari	26.471	90.894	HP	9.14	Agriculture
10	B10	Dhupguri ME School	26.472	90.940	HP	10.67	Agriculture
11	B11	Kujarapati Prathmik School	26.442	91.030	HP	15.24	Agriculture
12	B12	Bhawanipur Shiv Temple	26.450	91.099	HP	9.14	Dense Trees
13	B13	Titkagaria Krishna Temple	26.487	91.181	HP	18.29	Agriculture
14	B14	Konimara High School	26.476	91.250	HP	32.61	Dense Trees
15	B15	Dakin Anokpari	26.433	90.888	HP	10.67	Dense Trees
16	B16	Banglipara	26.396	90.923	HP	9.14	Agriculture
17	B17	Howly Club	26.425	90.975	HP	15.24	Agriculture
18	B18	Borbola Masjid	26.408	91.046	HP	13.72	Agriculture
19	B19	Pakaibarimala High School	26.423	91.114	HP	9.14	Agriculture
20	B20	Parakushipam Bridge	26.408	91.173	HP	12.19	Agriculture
21	B21	Satrabari Nakshatra	26.398	91.196	HP	15.24	Agriculture
22	B22	Majulija	26.356	90.831	HP	24.38	Dense Trees
23	B23	Hububari Jama Masjid	26.350	90.869	HP	12.19	Agriculture
24	B24	Jania Charali	26.332	90.912	HP	9.14	Agriculture
25	B25	Jania Road	26.330	90.968	HP	10.67	Agriculture
26	B26	Kirtanghar Barapeta Town	26.318	91.026	HP	12.19	Urban
27	B27	Khoropara Memorial Academy	26.323	91.077	HP	7.62	Agriculture
28	B28	Gortari	26.334	91.157	HP	9.14	Agriculture
29	B29	Belbari Girls ME School	26.343	91.202	HP	15.24	Agriculture
30	B30	Devkura Commerce College	26.285	90.747	HP	15.24	Agriculture
31	B31	Nabajyoti College	26.292	90.828	HP	12.19	Agriculture

32	B32	Guniaguri	26.305	90.853	HP	15.24	Dense Trees
33	B33	Mandia Panchayat Village	26.264	90.943	HP	10.67	Agriculture
34	B34	Borpalli Bazzar	26.287	90.984	HP	9.14	Agriculture
35	B35	Omura Central School	26.284	91.054	HP	9.14	Agriculture
36	B36	Tarabari High School	26.258	91.121	BW	12.19	Dense Trees
37	B37	Bahri Shiva Satra	26.255	91.151	HP	45.72	Agriculture
38	B38	Malipara Prathamik School	26.267	91.195	HP	12.19	Agriculture
39	B39	Kanpulimari	26.173	91.147	HP	9.14	Agriculture
40	B40	Langla Madhyanik School	26.242	90.711	HP	12.19	Agriculture
41	B41	Chinimari Tinali	26.226	90.779	HP	12.19	Agriculture
42	B42	Abbas Ali High School	26.236	90.826	HP	9.14	Agriculture
43	B43	Bhagbhor	26.275	90.874	HP	15.24	Agriculture
44	B44	Bordalini Village	26.254	90.937	HP	10.67	Agriculture
45	B45	Barsuha Temple	26.246	91.082	HP	9.14	Agriculture
46	B46	Katdua Masjid	26.254	91.110	HP	12.19	Agriculture
47	B47	Bokuradiki	26.124	90.880	HP	9.14	Agriculture
48	B48	Rangapani	26.142	90.983	HP	12.19	Agriculture
49	B49	Sontuli	26.147	91.122	HP	9.14	Agriculture
50	B50	Masjid Jagalisor	26.113	90.927	HP	12.19	Agriculture

Table 3.2 Source and Depth Wise Distribution of Sampling Sites in Barpeta District

Source structure	Depth range			Total number
	0-20 m	20-40 m	> 40 m	
Hand Pumps	1,2,3,4,6,9,10, 11,12,13,15,16, 17,18,19,20,21, 23,24,25,26,27 28,29,30,31,32 33,34,35,38,39, 40,41,42,43,44, 45,46,47,48,49, 50	5,7,8,14,22,37	-	49
Dug Wells	-	-	-	0
Bore Wells	36	-	-	1
Total	44	6	-	50

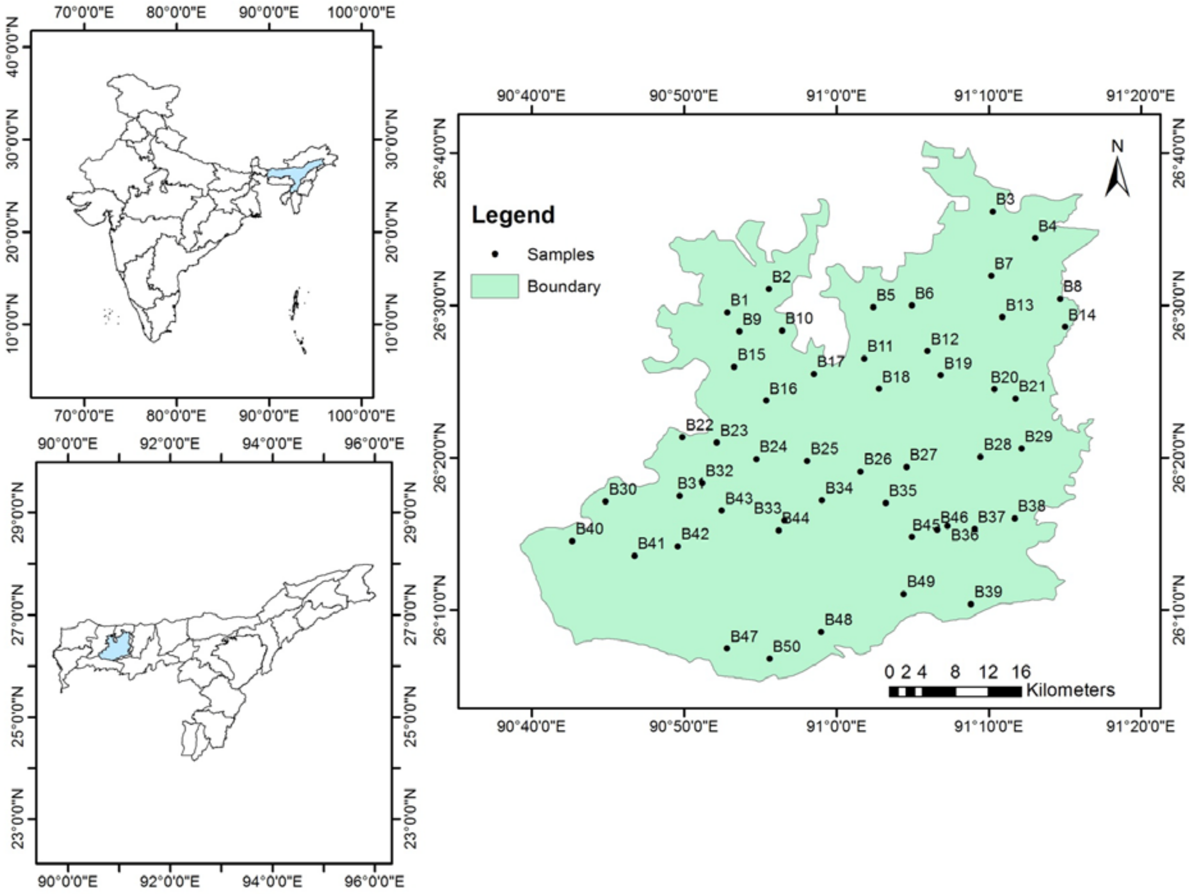

Fig. 3.1 Barpeta District Showing Location of Sampling Points

Table 3.3 Analytical Methods and Equipment Used in the Analysis

S.No.	**Parameter**	**Method**	**Equipment**
A.	**Physico-chemical**		
1.	pH	Electrometric	pH Meter
2.	Conductivity	Electrometric	Conductivity Meter
3.	TDS	Electrometric	Conductivity/TDS Meter
4.	Alkalinity	Titration by H_2SO_4	-
5.	Hardness	Titration by EDTA	-
6.	Chloride	Titration by $AgNO_3$	-
7.	Sulphate	Turbidimetric	Turbidity Meter
8.	Nitrate	Ultraviolet screening	UV-VIS Spectrophotometer
9.	Fluoride	SPADNS	UV-VIS Spectrophotometer
10.	Sodium	Flame emission	Flame Photometer
11.	Potassium	Flame emission	Flame Photometer
12.	Calcium	Titration by EDTA	-
13.	Magnesium	Titration by EDTA	-
14.	Boron	Carmine	UV-VIS Spectrophotometer
B.	**Heavy Metals**		
15.	Iron	Digestion followed by Atomic Spectrometry	Inductively Coupled Plasma Mass Spectrometer (ICP-MS)
16.	Manganese		
17.	Copper		
18.	Nickel		
19.	Chromium		
20.	Lead		
21.	Cadmium		
22.	Zinc		
23.	Mercury		
24.	Arsenic		

4.0 RESULTS AND DISCUSSIONS

4.1 Drinking Water Quality

The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institution (ISI) has laid down the standard specifications for drinking water (BIS, 2012). In order to enable the users, exercise their discretion towards water quality criteria, the permissible limit has been prescribed especially where no alternate source is available. The national water quality standards describe acceptable and permissible characteristics required to be evaluated to assess suitability of water for drinking purpose.

The hydro-chemical data of the samples collected from the Barpeta District during pre-monsoon season are presented in Table 4.1. Distribution of different water quality constituents with depth and season are given in Table 4.2-4.10 and distribution maps are presented in Figs. 4.1 to 4.10.

Table 4.1 Hydro-chemical Data of Ground Water Samples in Barpeta District (Pre-monsoon 2017)

Characteristics	Min	Max	Average
pH	6.3	8.5	7.6
Conductivity, µS/cm	88	947	425
TDS, mg/L	56	606	272
Alkalinity, mg/L	18	449	186
Hardness, mg/L	24	467	185
Sodium, mg/L	2.0	56	10
Potassium, mg/L	0.9	39	4.7
Calcium, mg/L	7.3	120	48
Magnesium, mg/L	1.4	41	16
Chloride, mg/L	0.3	59	9.0
Sulphate, mg/L	0.1	51	7.1
Nitrate, mg/L	0.0	27	2.5
Fluoride, mg/L	0.04	0.69	0.17
Boron, mg/L	0.01	0.03	0.02
Iron, µg/L	262	12246	3696
Manganese, µg/L	46	2731	749
Copper, µg/L	0.18	40	3.12
Nickel, µg/L	0.41	7.04	3.20
Chromium, µg/L	0.00	3.33	0.60
Lead, µg/L	0.04	73	2.85
Cadmium, µg/L	0.00	3.02	0.32
Zinc, µg/L	3.18	1919	166
Arsenic, µg/L	0.10	569	31

N=50

Table 4.2 TDS Distribution in Ground Water of Barpeta District

S. No.	TDS range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-500	< 20	1,3,4,6,9,10,11,12,13,15,16,18,19,20,21, 23,24,25,26,27,28,29,31,33,34,35,36,38, 39,40,41,42,43,44,45,46,47,48,49,50	92
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	501-2000	< 20	2,17,30,32	8
		20-40	-	
		> 40	-	
3.	> 2000	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.3 Alkalinity Distribution in Ground Water of Barpeta District

S. No.	Alkalinity range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-200	< 20	1,3,9,13,16,19,20,21, 25,27,28,29,31,33, 34,35,36,37,38,41,43,44,45,46,47,49,50	62
		20-40	7,8,14,22,37	
		> 40	-	
2.	201-600	< 20	2,4,6,10,11,12,15,1718,23,24, 26,30,32,39,40,42,48	38
		20-40	5	
		> 40	-	
3.	> 600	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.4 Hardness Distribution in Ground Water of Barpeta District

S. No.	Hardness range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-200	< 20	1,3,9,12,13,16,19,20,21,25,27,28,29,31,33, 34,35,36,41,43,44,45,46,47,49,50	62
		20-40	7,8,14,22,37	
		> 40	-	
2.	201-600	< 20	2,4,6,10,11,15,17,18,23,24,26,30,32,38, 39,40,42,48	38
		20-40	5	
		> 40	-	
3.	> 600	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.5 Calcium Distribution in Ground Water of Barpeta District

S. No.	Calcium range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-75	< 20	1,3,4,6,9,11,12,13,15,16,18,19,20,21,24,25, 26,27,28,29,31,33,34,35,36,38,39,40,41,43, 44,45,46,47,49,50	82
		20-40	7,8,14,22,37	
		> 40	-	
2.	76-200	< 20	2,10,17,23,30,32,42,48	18
		20-40	5	
		> 40	-	
3.	> 200	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.6 Magnesium Distribution in Ground Water of Barpeta District

S. No.	Magnesium range, mg/L	Depth Range, M	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-30	< 20	1,3,4,6,9,10,11,12,13,15,16,17,18,19,20, 21,23,24,25,26,27,28,29,31,33,34,35,36, 38,39,40,41,42,43,44,45,46,47,48,49,50	94
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	31-100	< 20	2,30,32	6
		20-40	-	
		> 40	-	
3.	> 100	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.7 Chloride Distribution in Ground Water of Barpeta District

S. No.	Chloride range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-250	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20, 21,23,24,25,26,27,28,29,30,31,32,33,34,35, 36,38,39,40,41,42,43,44,45,46,47,48,49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	251-1000	< 20	-	-
		20-40	-	
		> 40	-	
3.	> 1000	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.8 Sulphate Distribution in Ground Water of Barpeta District

S. No.	Sulphate range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-200	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20, 21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,46,47,48, 49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	201-400	< 20	-	-
		20-40	-	
		> 40	-	
3.	> 400	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.9 Nitrate Distribution in Ground Water of Barpeta District

S. No.	Nitrate range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-45	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20, 21,23,24,25,26,27,28,29,30,31,32,33,34,35, 36,38,39,40,41,42,43,44,45,46,47,48,49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	> 45	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.10 Fluoride Distribution in Ground Water of Barpeta District

S. No.	Fluoride range, mg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-1.0	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20, 21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,46,47,48, 49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	1.1-1.5	< 20	-	-
		20-40	-	
		> 40	-	
3.	> 1.5	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

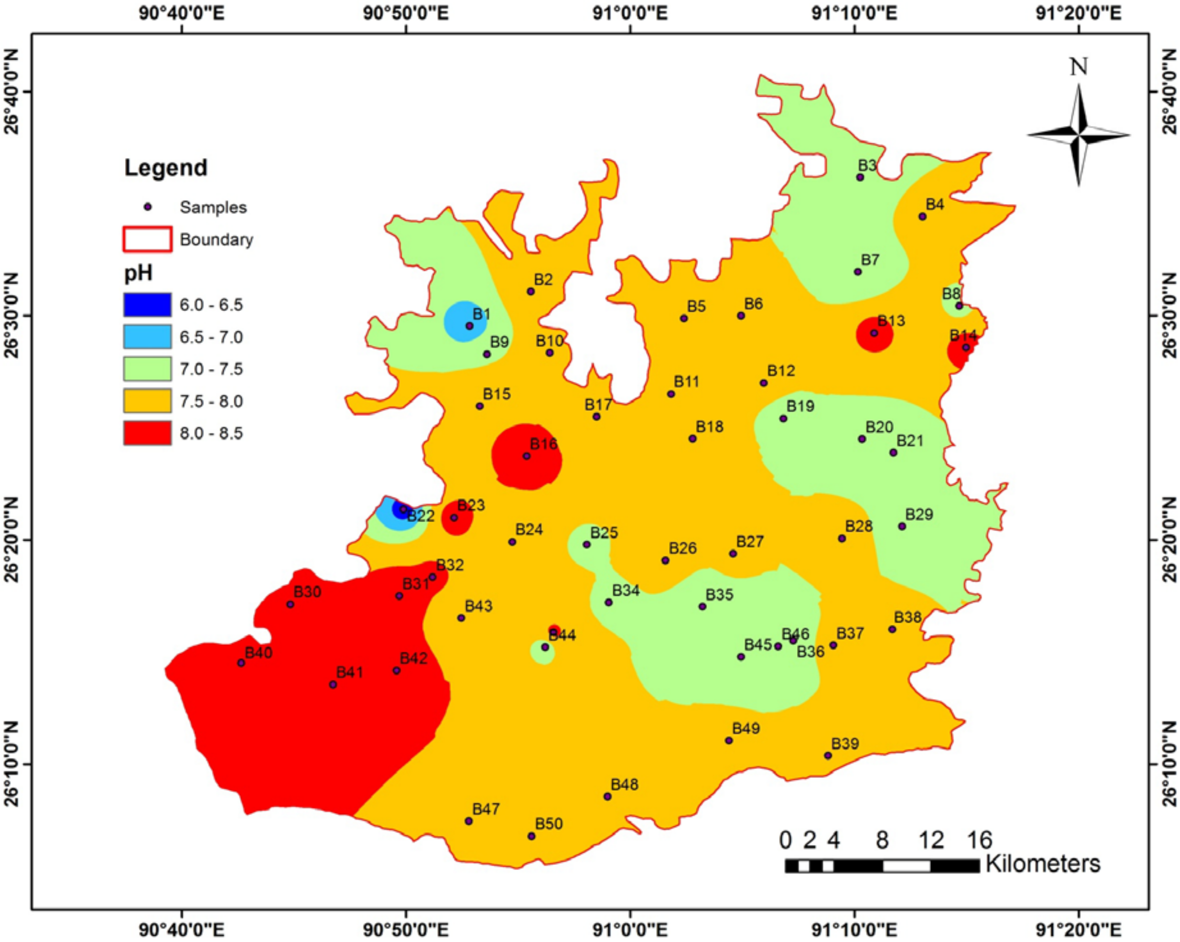

Fig. 4.1 pH Distribution in Ground Water of Barpeta District

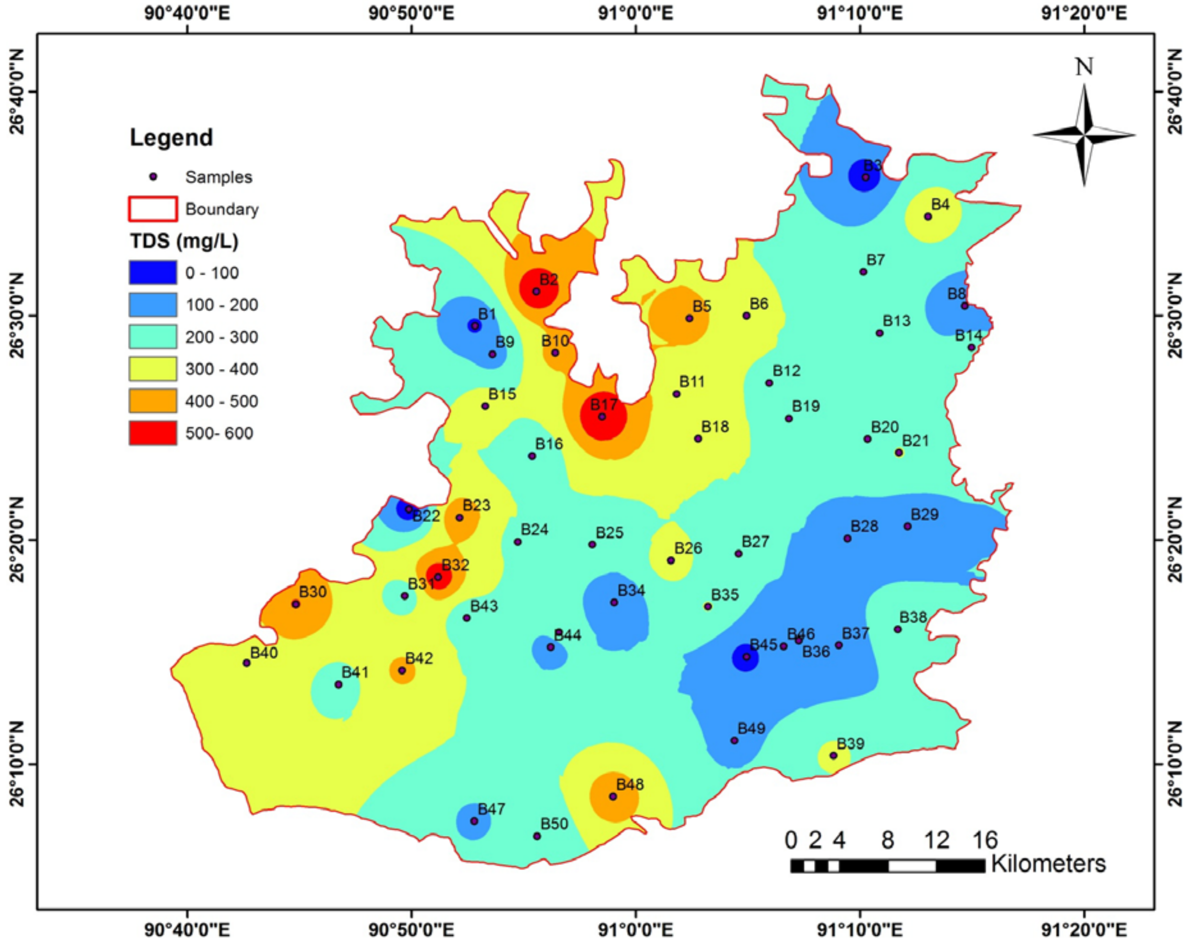

Fig. 4.2 TDS Distribution in Ground Water of Barpeta District

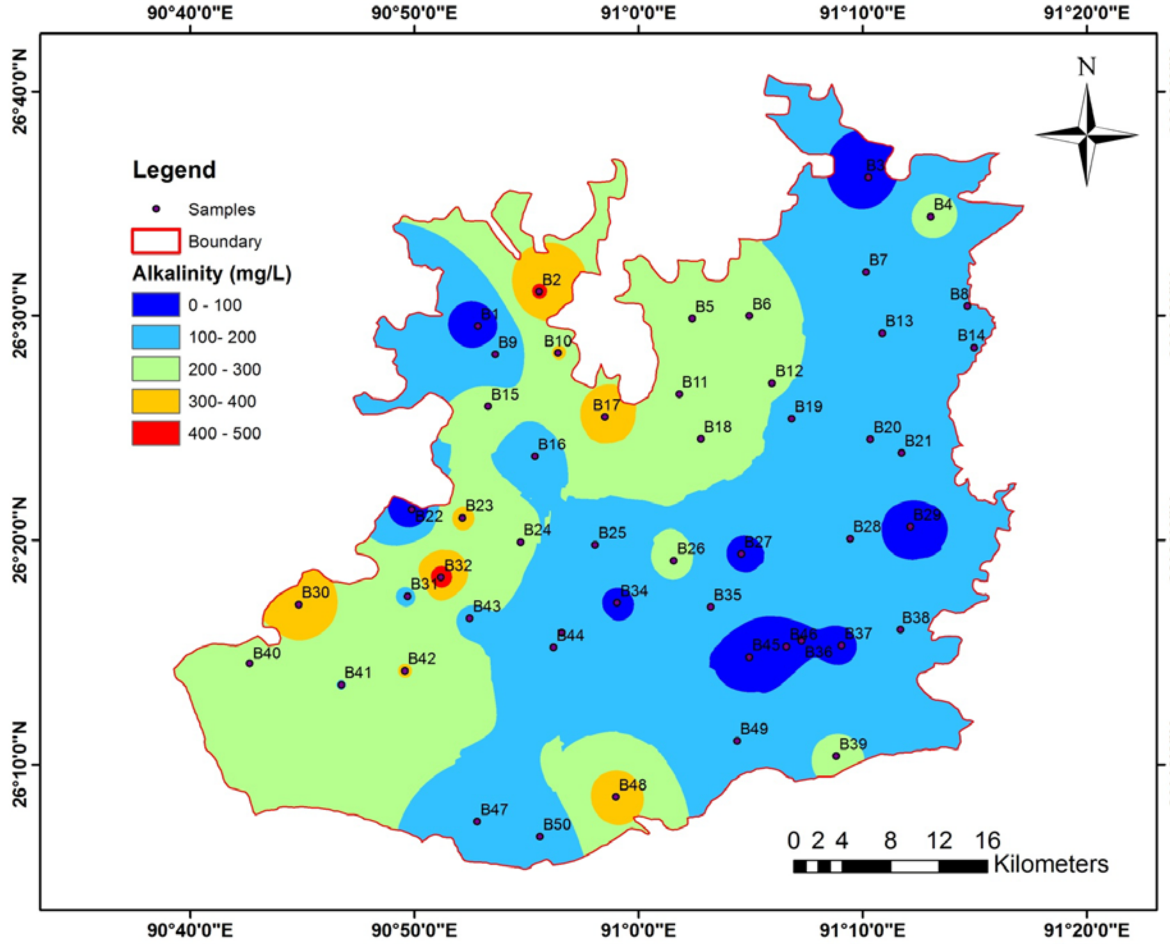

Fig. 4.3 Alkalinity Distribution in Ground Water of Barpeta District

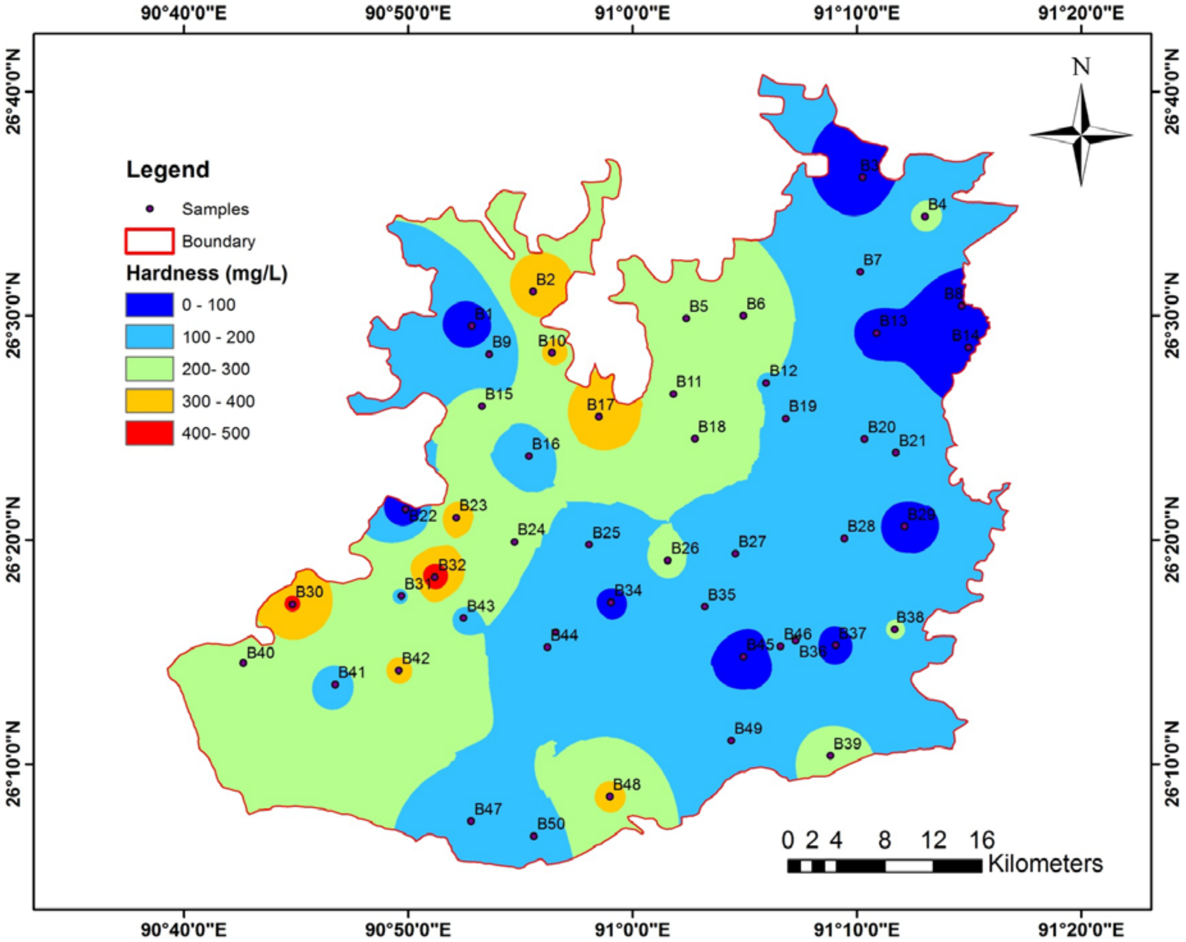

Fig. 4.4 Hardness Distribution in Ground Water of Barpeta District

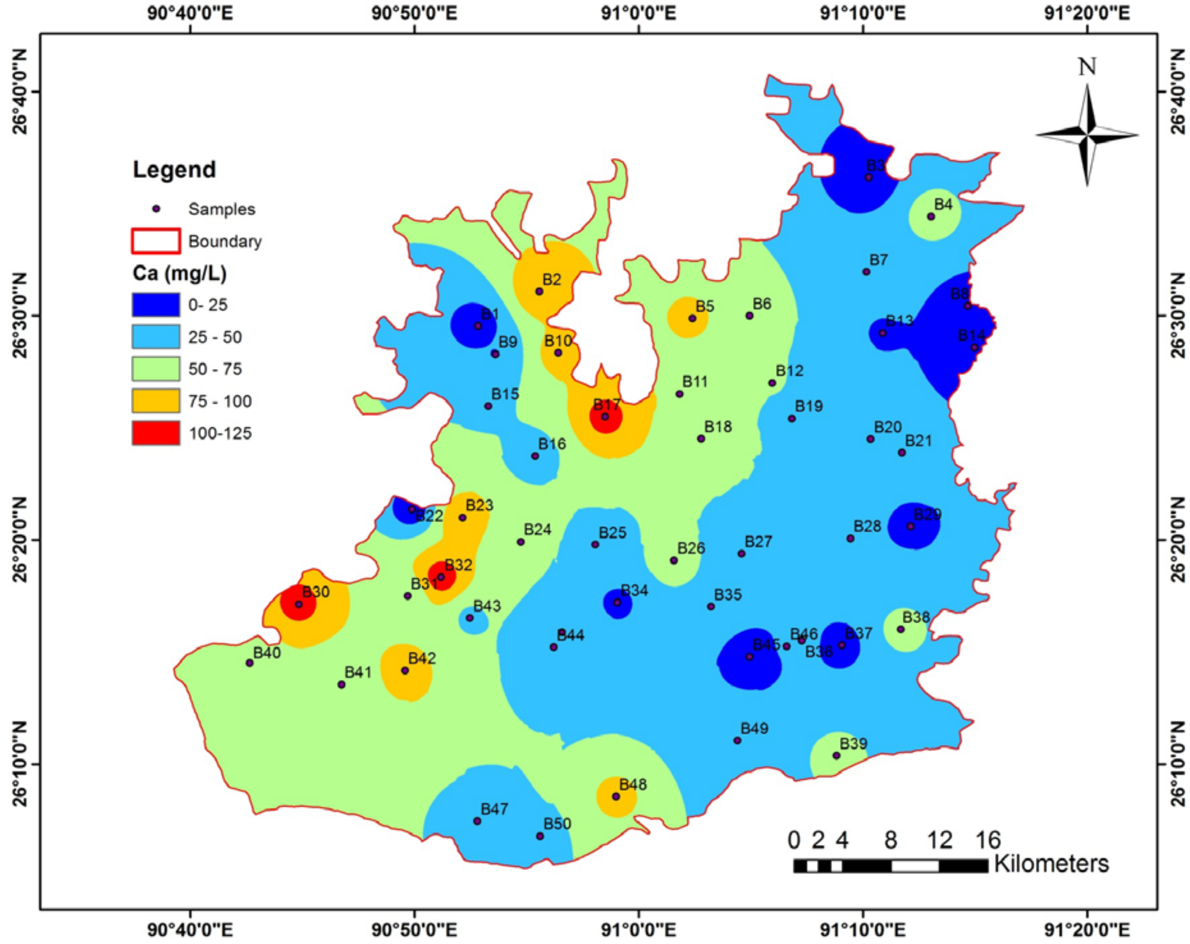

Fig. 4.5. Calcium Distribution in Ground Water of Barpeta District

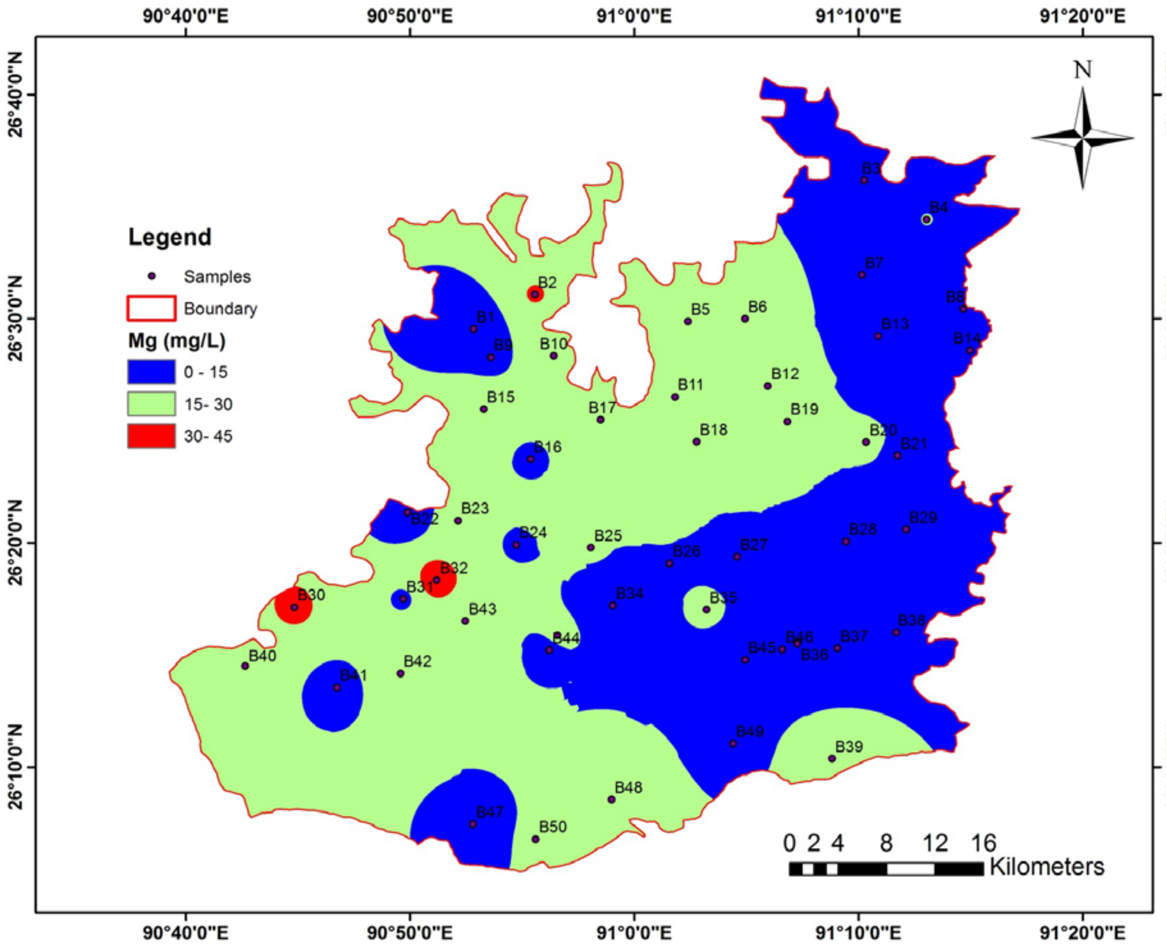

Fig. 4.6 Magnesium Distribution in Ground Water of Barpeta District

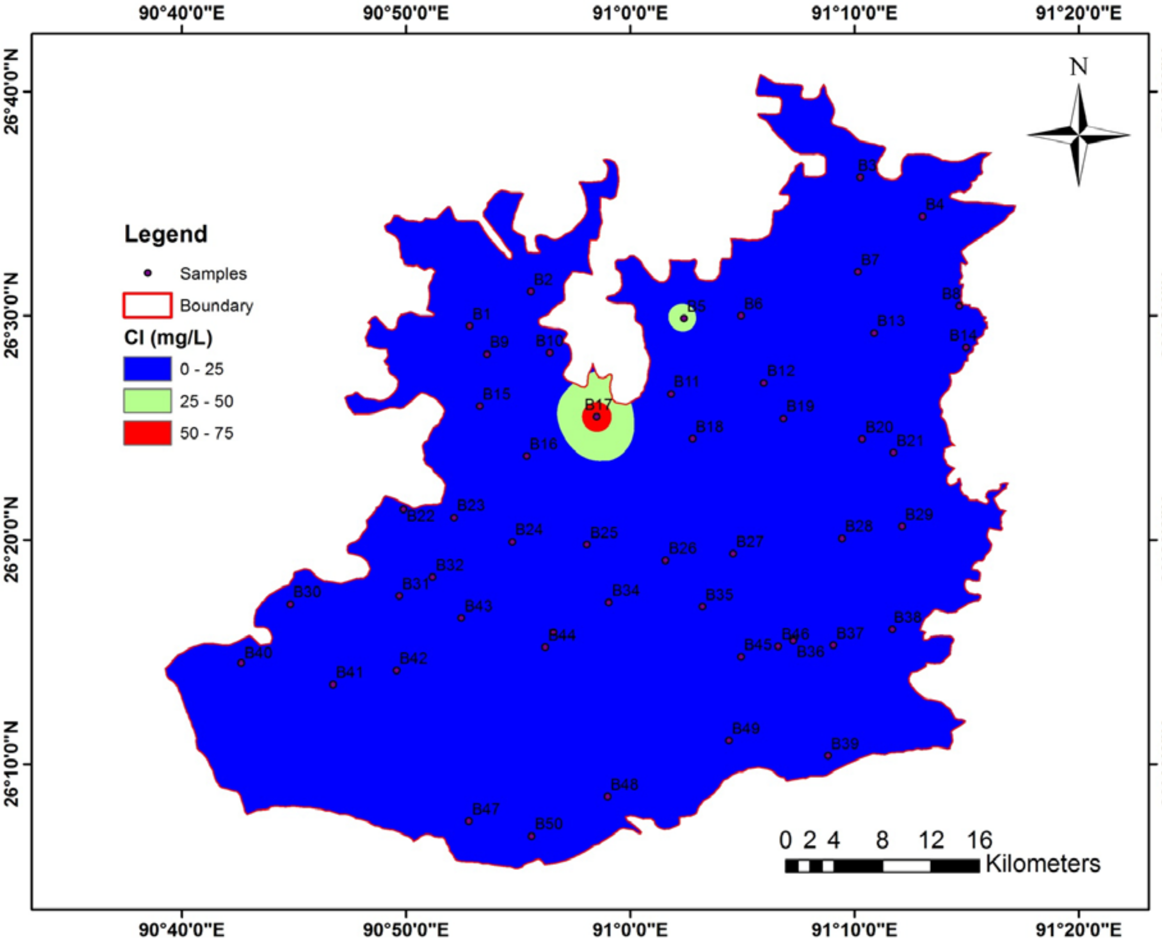

Fig. 4.7 Chloride Distribution in Ground Water of Barpeta District

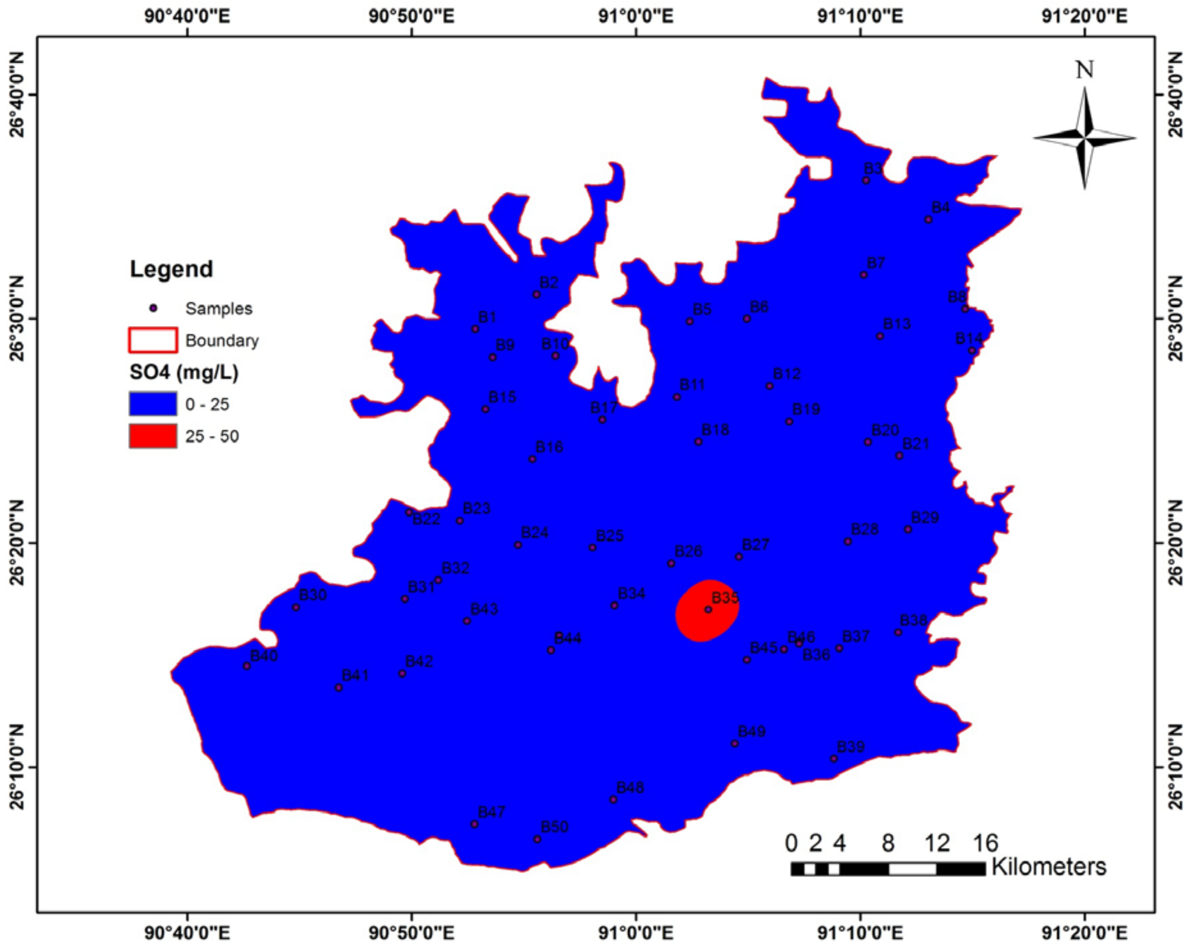

Fig. 4.8 Sulphate Distribution in Ground Water of Barpeta District

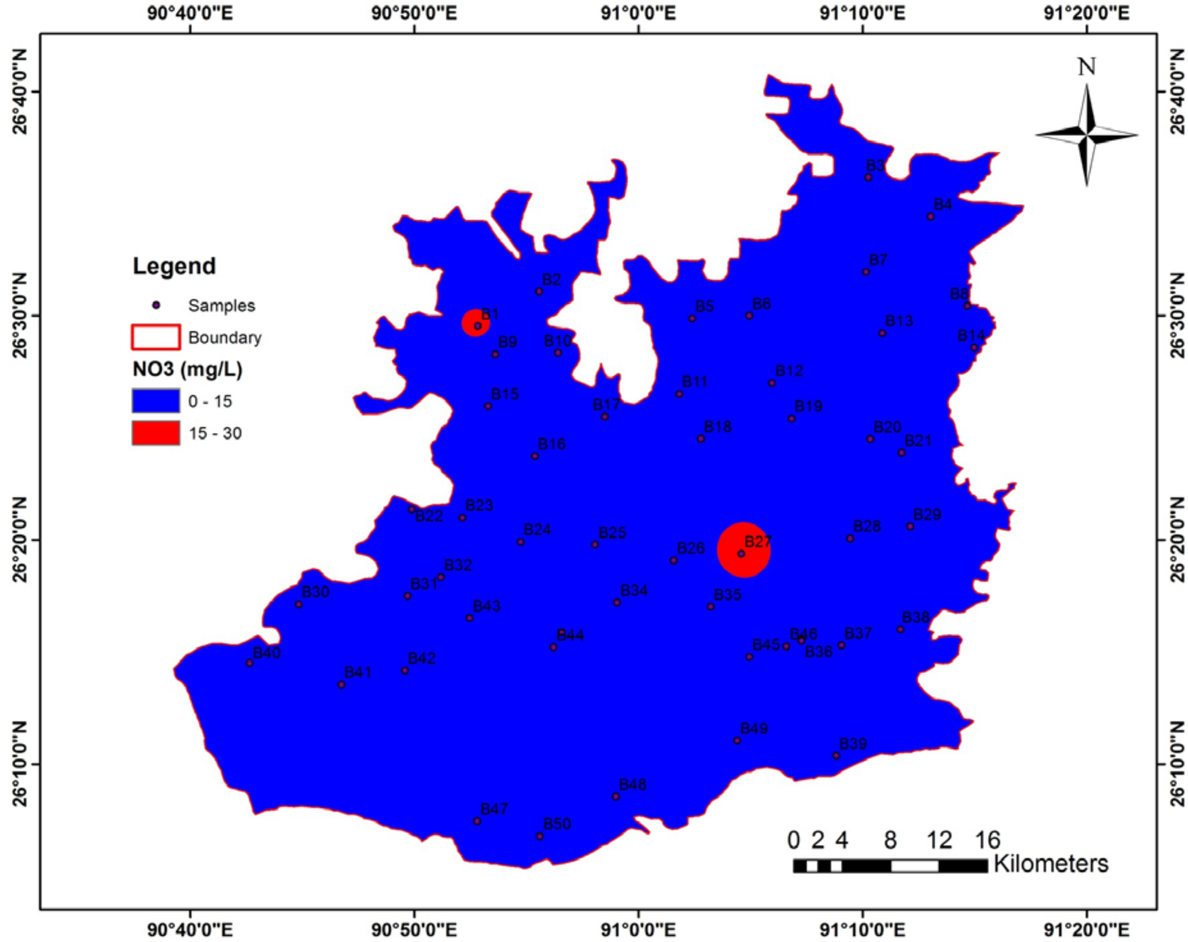

Fig. 4.9 Nitrate Distribution in Ground Water of Barpeta District

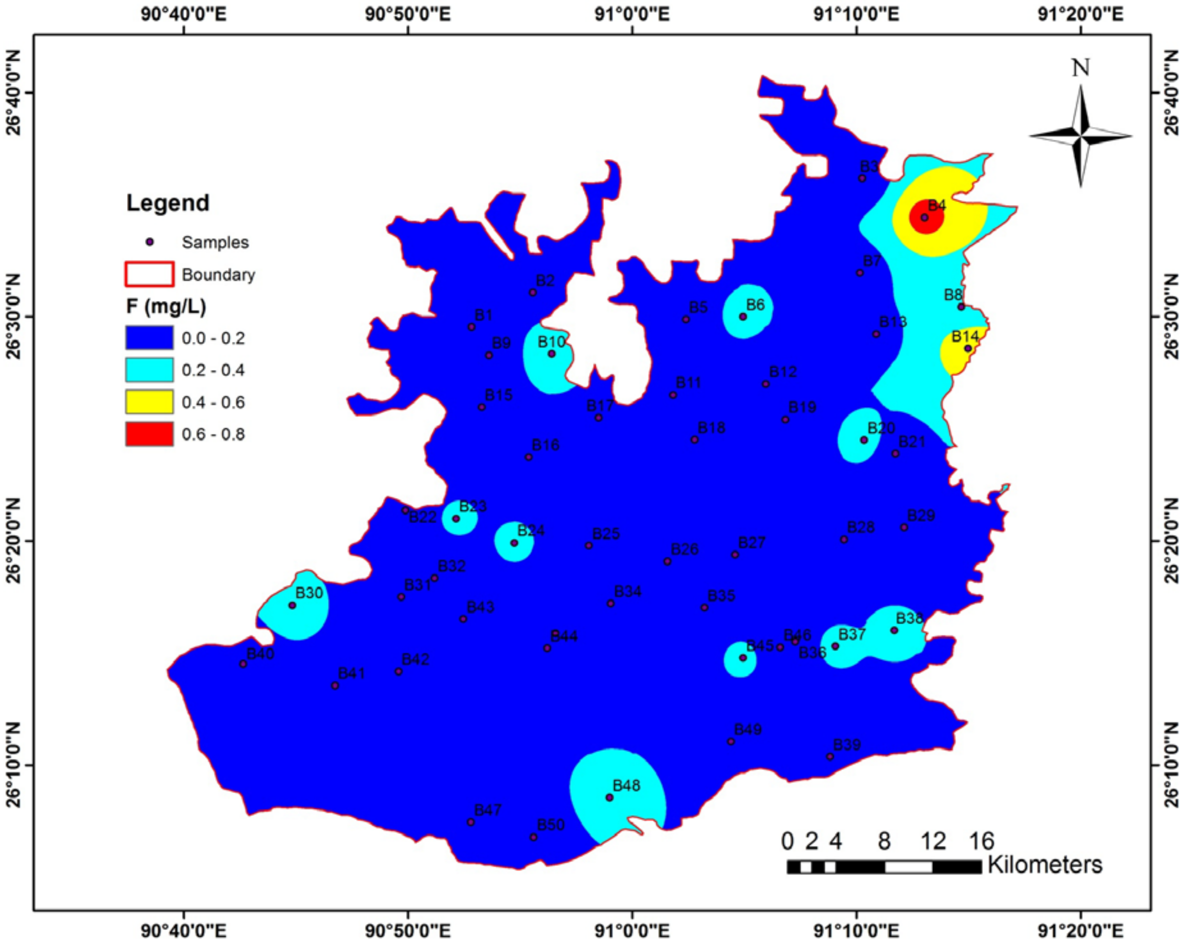

Fig. 4.10 Fluoride Distribution in Ground Water of Barpeta District

4.1.1 General Characteristics

The pH values in the ground water of Barpeta District are mostly confined within the range 6.3 to 8.5. The pH values for all the samples are well within the limits prescribed by BIS (2012) and WHO (1996) for various uses of water including drinking and other domestic supplies. The pH distribution map is shown in Fig. 4.1.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the Barpeta District vary from 88 to 947 µS/cm.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 56 to 606 mg/L indicating low mineralization in the area. Majority of the samples (except three) were found within the acceptable limit of 500 mg/L. It may be concluded that there is low mineralization of ground water. The TDS distribution map is shown in Fig. 4.2. Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 2012). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 2012).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 18 to 449 mg/L. The alkalinity distribution map is shown in Fig. 4.3.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 200 mg/L as acceptable limit and 600 mg/L as permissible limit for total hardness has been recommended for drinking water (BIS, 2012). The total hardness values in the study area range from 24 to 467 mg/L with thirty one samples falling within the acceptable limit of 200 mg/L and remaing in the permissible limit of 600 mg/L. The hardness distribution map is sown in Fig. 4.4.

The acceptable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 2012). In ground water of the Barpeta District, the values of calcium and magnesium range from 7.3 to 120 and 1.4 to 41 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in pre-monsoon season. The calcium and magnesium distribution maps are shown in Fig. 4.5 and 4.6 respectively.

The concentration of sodium in the study area varies from 2.0 to 56 mg/L. The Bureau of Indian Standards has not included sodium in drinking water standards. The concentration of potassium in ground water of the Barpeta District varies from 0.9 to 39 mg/L. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, all but two samples fall within the prescribed limit of 10 mg/L.

The concentration of chloride varies from 0.3 to 59 mg/L with all the samples falling within the acceptable limit of 250 mg/L. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as acceptable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 2012). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution map for the pre-monsoon season is shown in Fig. 4.7.

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 0.1to 51 mg/L. Bureau of Indian standard has prescribed 200 mg/L as the acceptable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, all the samples analysed fall well within the acceptable limit of 200 mg/L. The sulphate distribution map is shown in Fig. 4.8.

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the Barpeta District varies from 0.0 to 27.1 mg/L indicating that all the samples of the study area falls within the acceptable limit of 45mg/L. As such, no such health hazard is expected in ground water of Barpeta District. The nitrate distribution map for the pre-monsoon season is shown in Fig. 4.9.

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (2012) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The fluoride content in the ground water of the study area varies from 0.04 to 0.69 mg/L with all the samples falling within the acceptable limit 0f 1.0 mg/L. The fluoride distribution map for the pre monsoon season is shown in Fig. 4.10. The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man’s activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentrations of almost all the water quality constituents are well within the permissible limits for drinking water and no sample exceed the permissible limit.

4.1.2 Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- monsoon season is given in Tables 4.1. The distribution of different metals with depth is presented in Tables 4.11 to 4.19 and graphically shown in Fig. 4.11 to 4.19. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

Table 4.11 Iron Distribution in Ground Water of Barpeta District

S. No.	Fe range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-300	< 20	16	2
		20-40	-	
		> 40	-	
2.	> 300	< 20	1,2,3,4,6,9,10,11,12,13,15,17,18,19,20,21, 23,24,25,26,27,28,29,30,31,32,33,34,35,36 38,39,40,41,42,43,44,45,46,47,48,49,50	98
		20-40	5,7,8,14,22,37	
		> 40	-	
Total number of samples			50	100

Table 4.12 Manganese Distribution in Ground Water of Barpeta District

S. No.	Mn range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-100	< 20	16,33,46,50	10
		20-40	22	
		> 40	-	
2.	101-300	< 20	6,13,18,29,31	12
		20-40	14	
		> 40	-	
3.	> 300	< 20	1,2,3,4,9,10,11,12,15,17,19,20,21,23,24,25 26,27,28,30,32,34,35,36,38,39,40,41,42,43 44,45,47,48,49	78
		20-40	5,7,8,37	
		> 40	-	
Total number of samples			50	100

Table 4.13 Copper Distribution in Ground Water of Barpeta District

S. No.	Cu range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-50	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20,21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,46,47,48, 49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	51-1500	< 20	-	-
		20-40	-	
		> 40	-	
3.	> 1500	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.14 Nickel Distribution in Ground Water of Barpeta District

S. No.	Ni range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-20	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20,21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,46,47,48, 49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	> 20	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.15 Chromium Distribution in Ground Water of Barpeta District

S. No.	Cr range, µg/L	Depth Range, M	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-50	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20,21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,46,47,48, 49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	>50	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.16 Lead Distribution in Ground Water of Barpeta District

S. No.	Pb range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-10	< 20	1,3,4,6,9,10,11,12,13,15,16,17,18,19,20,21,23 24,25,26,27,28,29,30,31,32,34,35,36,38,39,40 41,42,43,44,45,46,47,48,49,50	96
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	>10	< 20	2,33	4
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.17 Cadmium Distribution in Ground Water of Barpeta District

S. No.	Cd range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-3	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20,21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,47,48, 49,50	98
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	> 3	< 20	46	2
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.18 Zinc Distribution in Ground Water of Barpeta District

S. No.	Zn range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-5000	< 20	1,2,3,4,6,9,10,11,12,13,15,16,17,18,19,20, 21,23,24,25,26,27,28,29,30,31,32,33,34, 35,36,38,39,40,41,42,43,44,45,46,47,48, 49,50	100
		20-40	5,7,8,14,22,37	
		> 40	-	
2.	5001-15000	< 20	-	-
		20-40	-	
		> 40	-	
3.	> 15000	< 20	-	-
		20-40	-	
		> 40	-	
Total number of samples			50	100

Table 4.19 Arsenic Distribution in Ground Water of Barpeta District

S. No.	An range, µg/L	Depth range, m	Sample numbers	Areal distribution, %
			Pre-monsoon	Pre-monsoon
1.	0-10	< 20	2,3,6,9,11,13,15,16,17,18,19,21,24,25,27,28,29,31,32,33,34,35,36,40,43,44,45,46,47,49,50	74
		20-40	5,7,8,14,22,37,	
		> 40	-	
2.	11-50	< 20	1,4,10,12,20,23,26,30,38,39,41,42,48	26
		20-40	-	
		> 40	-	
Total number of samples			50	100

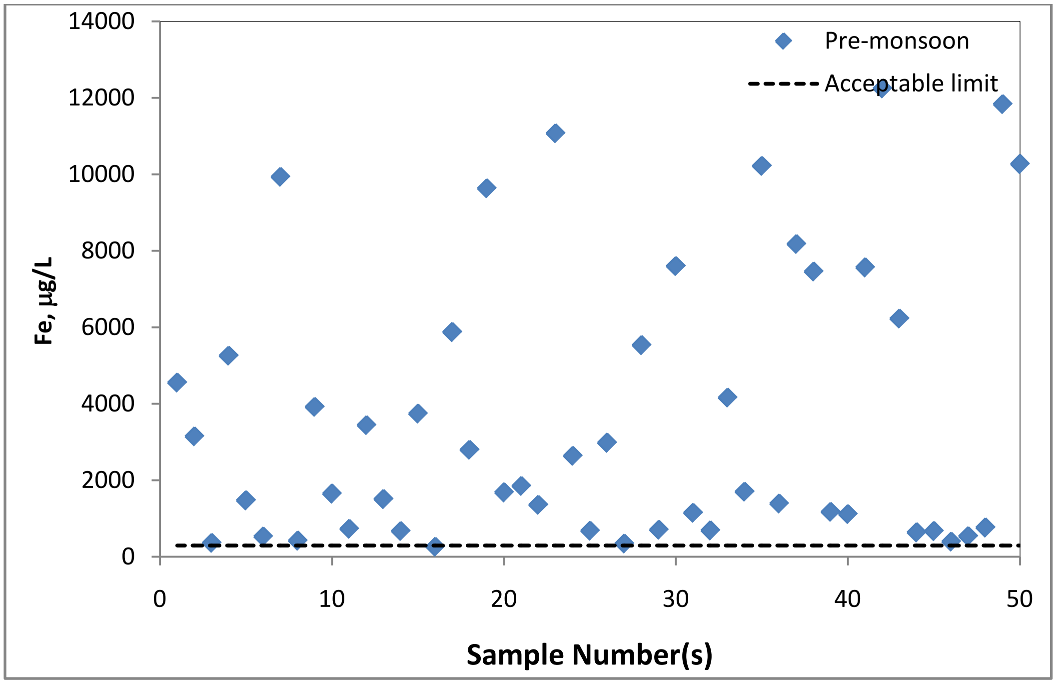

Fig. 4.11 Distribution of Iron at Different Sampling Sites

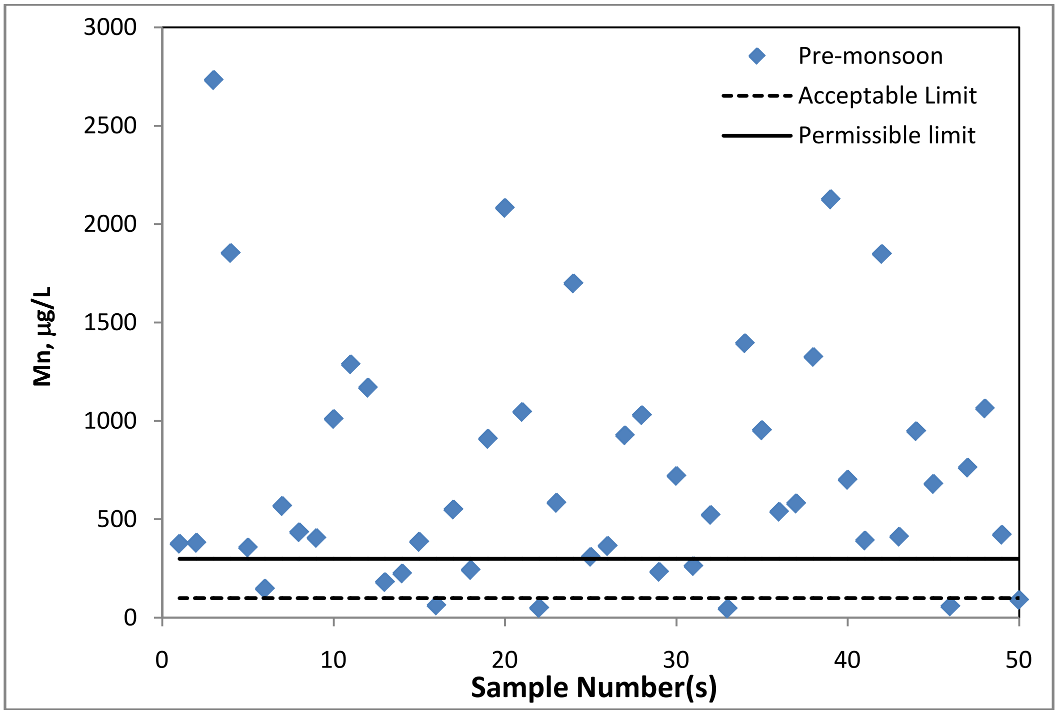

Fig. 4.12 Distribution of Manganese at Different Sampling Sites

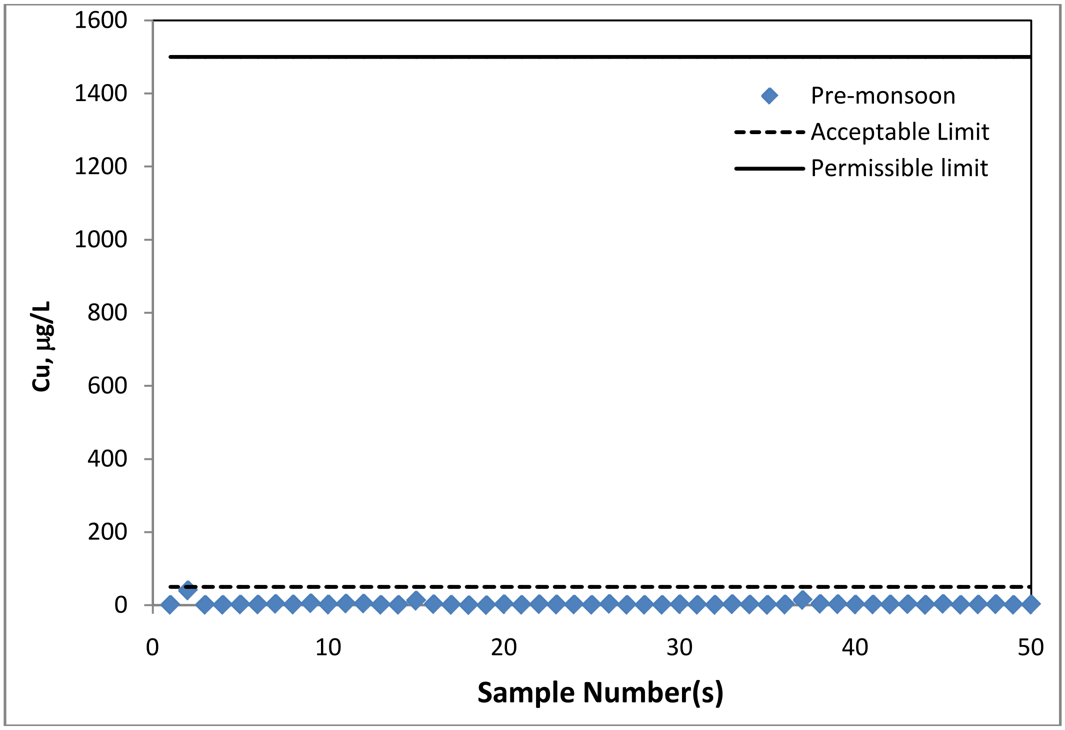

Fig. 4.13 Distribution of Copper at Different Sampling Sites

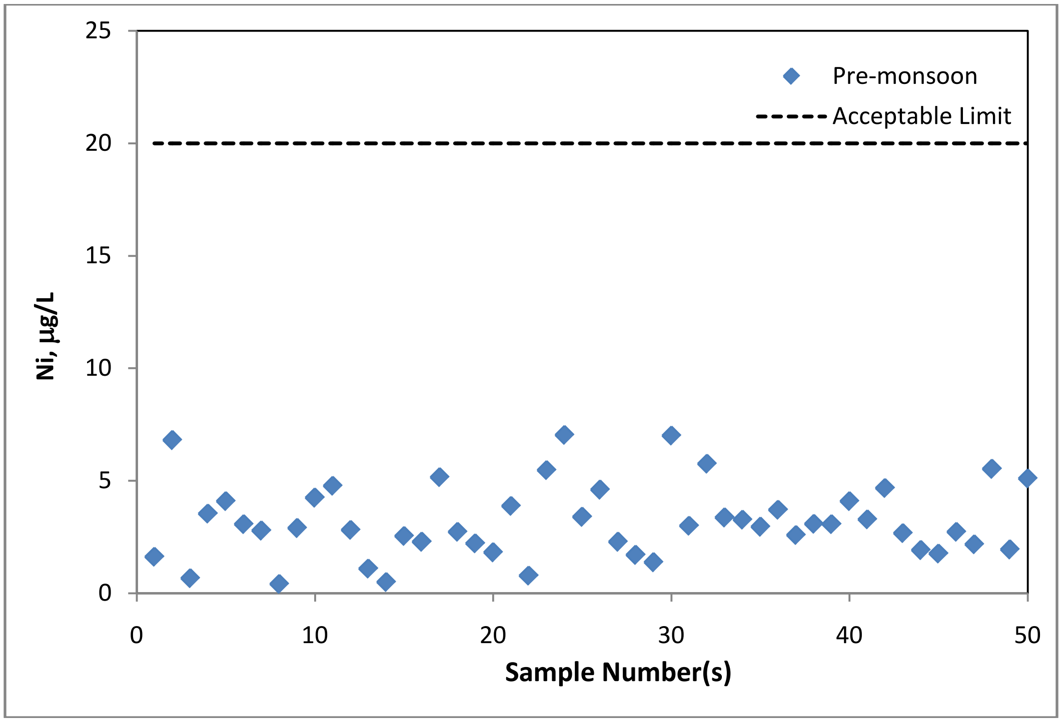

Fig. 4.14 Distribution of Nickel at Different Sampling Sites

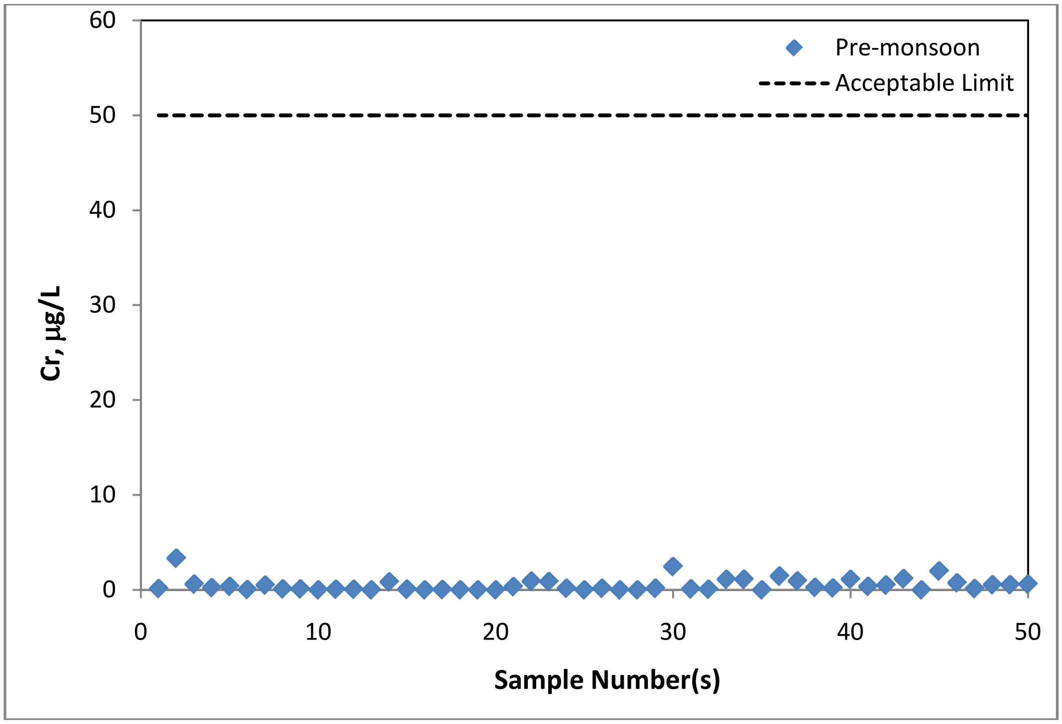

Fig. 4.15 Distribution of Chromium at Different Sampling Sites

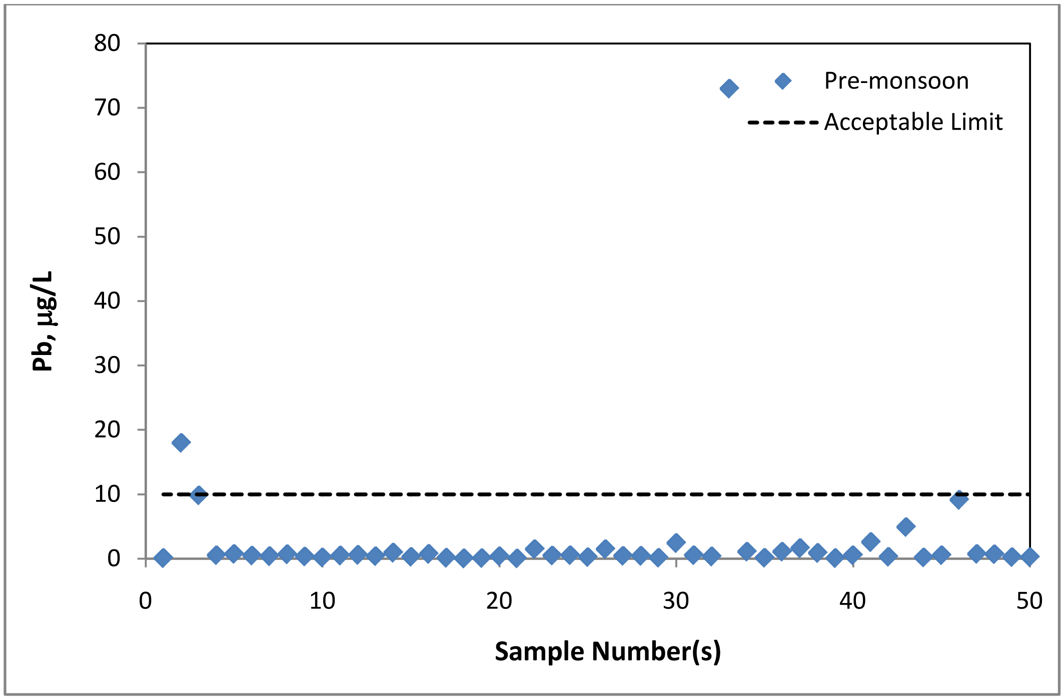

Fig. 4.16 Distribution of Lead at Different Sampling Sites

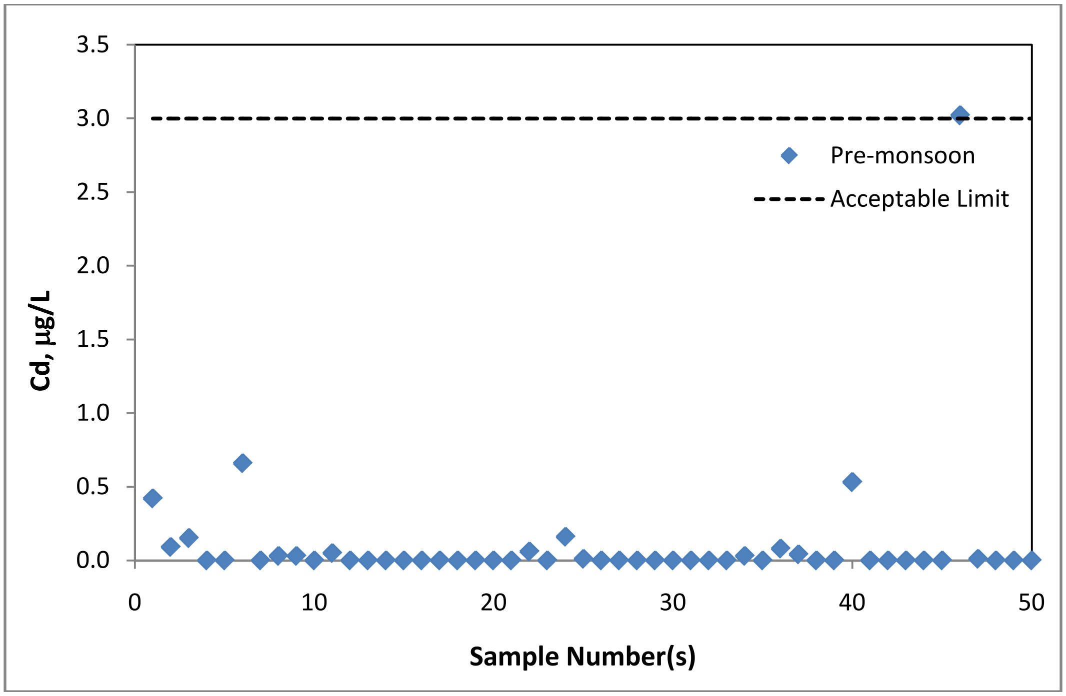

Fig. 4.17 Distribution of Cadmium at Different Sampling Sites

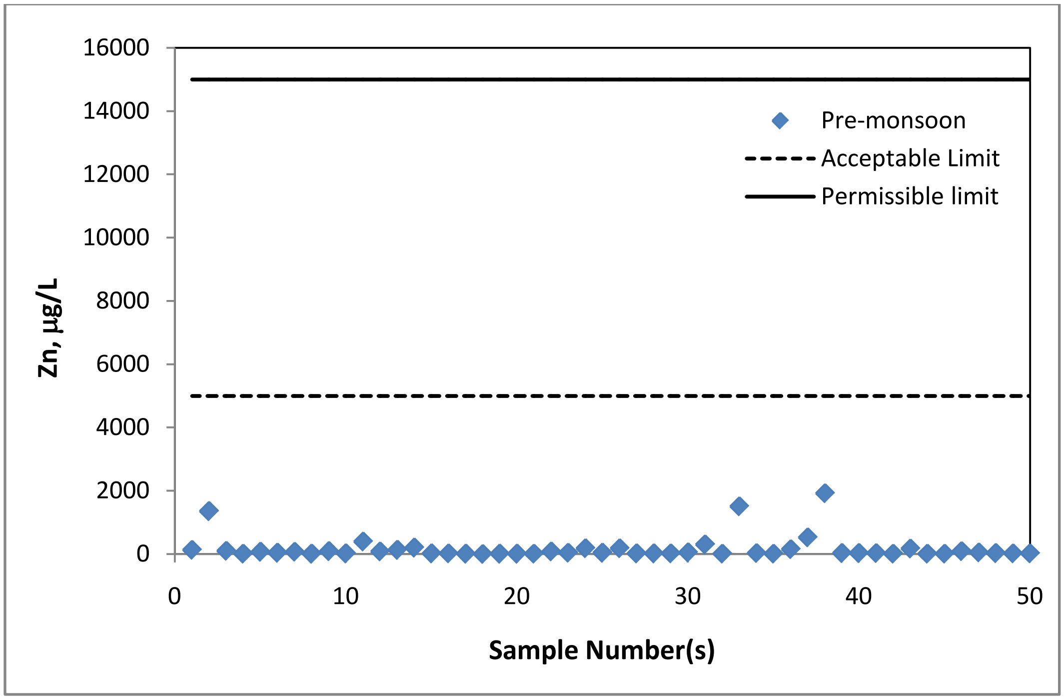

Fig. 4.18 Distribution of Zinc at Different Sampling Sites

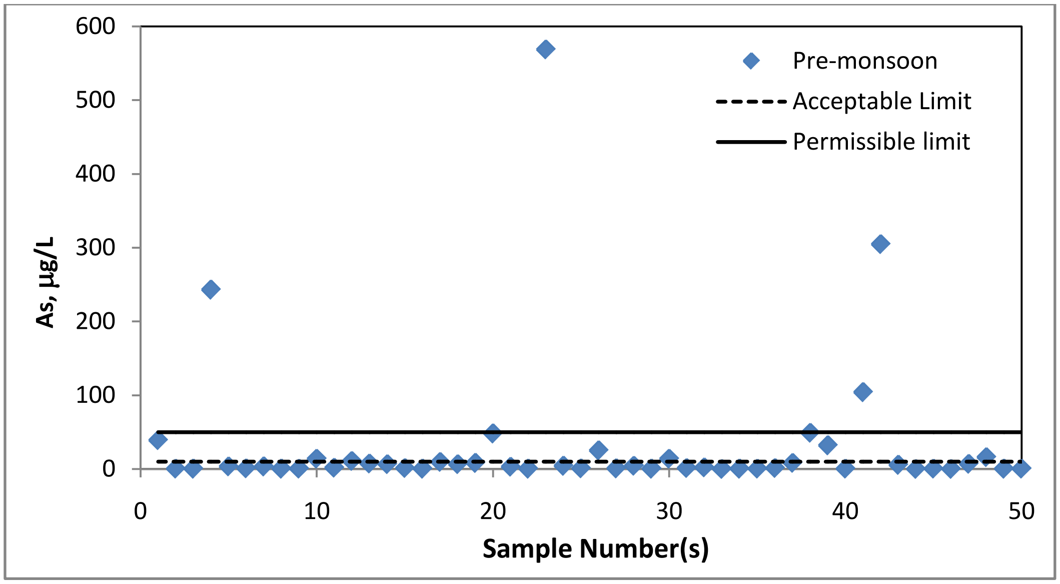

Fig. 4.19 Distribution of Arsenic at Different Sampling Sites

Iron (Fe): The concentration of iron in the ground water of Barpeta District ranges from 262 to 12246 µg/L. The distribution of iron at different sites is shown in Fig. 4.11. The Bureau of Indian Standards has recommended 300 µg/L as the acceptable limit for drinking water (BIS, 2012). It is evident from the results that more than 90% of the samples exceed the acceptable limit of 300 µg/L during pre-monsoon seasons. High concentrations of iron generally cause inky flavour, bitter and astringent taste. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The “red rot” disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. The weathering of rock and discharge of waste effluents on land are generally considered the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous (Fe^{2+}) and Ferric (Fe^{3+}) forms.

Manganese (Mn): The concentration of manganese varies from 46 to 2731µg/L during pre-monsoon season. The distribution of manganese at different sites during pre-monsoon season is shown in Fig. 4.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general, concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a acceptable limit and 300 μg/L as the permissible limit in the absence of alternate source for drinking water (BIS, 2012). WHO has prescribed 500 μg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that only 10% of the samples of Barpeta District fall within the acceptable limit of 100 μg/L, 12% of the samples crosses the acceptable limit but are within the permissible limits and about 78% of the samples even exceeds the permissible limit of 300 μg/L and are not suitable for drinking purpose. High concentration of manganese at many locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

Copper (Cu): The concentration of copper varies from 0.18 to 40 μg/L during pre-monsoon season. The distribution of copper at different sites during pre-monsoon season is shown in Fig. 4.13. The Bureau of Indian Standards has recommended 50 μg/L as the acceptable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 2012). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In Barpeta District, all the samples fall below the acceptable limit of 50 μg/L during pre-monsoon season. As such the ground water of Barpeta District can be safely used as a source of drinking water supplies. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

Nickel (Ni): The concentration of nickel in the study area varies from 0.41 to 7.04 μg/L during pre-monsoon season.The distribution of nickel at different sites during pre-monsoon season is shown in Fig. 4.14. The Bureau of Indian Standards has recommended 20 μg/L as the acceptable limit for drinking water (BIS, 2012). World Health Organization has also recommended 20 μg/L as the guideline value for drinking water (WHO, 1996).

In Barpeta District, all the samples fall within the acceptable limit as prescribed by BIS and WHO for drinking water. Nickel at trace level is essential to human nutrition and no systemic poisoning from nickel is known in this range. The level of nickel usually found in food and water is not considered a serious health hazard. Some of the important nickel minerals include Garnierite, nickeliferous limonite and pentiandite. Certain nickel compounds have carcinogenic effects on animals, however, soluble compounds are not currently regarded as human or animal carcinogens.

Chromium (Cr): The concentration of chromium in the study area recorded a maximum level of 3.33 µg/L during pre-monsoon season. The distribution of chromium at different sites during pre-monsoon season is shown in Fig. 4.15. A concentration of 50 µg/L has been recommended as a acceptable limit for drinking water (BIS, 2012). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the study area, all the samples fall well within the acceptable limit as prescribed by BIS (2012) and WHO (1996) for drinking water.

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

Lead (Pb): The concentration of lead in the study area varies from 0.04 to 73 µg/L during pre-monsoon season. The distribution of lead at different sites during pre-monsoon season is shown in Fig. 4.16. The Bureau of Indian Standards has prescribed 10 µg/L lead as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In Barpeta District, almost all the samples (except two samples) were found within the acceptable limits as prescribed by BIS (2012) for drinking water. It is obvious, therefore, that the ground water of Barpeta District does not present any lead hazard to humans. The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

Cadmium (Cd): Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 0 to 3.02 µg/L during pre-monsoon season. The distribution of cadmium at different sites during pre- monsoon season is shown in Fig. 4.17. The Bureau of Indian Standards has prescribed 3 µg/L cadmium as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996).

In Barpeta District, forty nine samples were found within the acceptable limit of 3 µg/L as prescribed by BIS for drinking purpose with only one sample exceeding the acceptable limit. The levels of cadmium in public water supplies are normally very low since generally only small amounts exist in raw water and many conventional water treatment processes remove much of the cadmium. The drinking water having more than 10 µg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

Zinc (Zn): The concentration of zinc in the study area ranges from 3.18 to 1919 µg/L during pre-monsoon season. The distribution of zinc at different sites during pre-monsoon season is shown in Fig. 4.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the acceptable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the study area, all the samples analysed were found within the acceptable limit prescribed by BIS (2012) and WHO (1996) for drinking water.

Arsenic (As): The concentration of arsenic in the study area varies from 0.10 to 569 µg/L during pre-monsoon season. The distribution of arsenic at different sites is shown in Fig. 4.19. The Bureau of Indian Standards has prescribed 10 µg/L arsenic as the acceptable limit and 50 µg/L as the maximum permissible limit for drinking water (BIS, 2012). WHO has prescribed 10 µg/L as the guideline value for drinking water (WHO, 1996). In the study area, more than 25% of the samples even exceed the acceptable limit of 10 µg/L and such water cannot be used for drinking purpose.

The heavy metals in ground water except iron, manganese and arsenic, which are present in appreciable concentration in ground water, have been below the prescribed acceptable / permissible limits. The concentration of iron varies from 262 to 12246 µg/L during pre-monsoon season as against the acceptable limit of 300 µg/L while that of manganese vary from 46 to 2731 µg/L as against the acceptable limit of 100 µg/L. The concentration of arsenic varies from 0.10 to 569 µg/L as against the acceptable limit of 10 µg/L for drinking water (BIS, 2012). The concentration of copper, nickel, chromium, lead, cadmium and zinc were found well within the permissible limits in almost all the samples of the study area.

4.2 Irrigation Water Quality

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 4.20. The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to electrical conductivity, sodium content, Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are given in Table 4.21. The values of sodium percentage (Na%), SAR and RSC in ground water of Barpeta District are given in Table 4.22.

Table 4.20 Safe Limits of Electrical Conductivity for Irrigation Water

S.No.	**Nature of soil**	**Crop growth**	**Upper permissible safe limit of EC, μS/cm**
1.	Deep black soil and alluvial soils having clay content more than 30% soils that are fairly to moderately well drained	Semi-tolerant	1500
		Tolerant	2000
2.	Having textured soils having clay contents of 20-30% soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3.	Medium textured soils having clay 10-20% internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4.	Light textured soils having clay less than 10% soil that have excellent internally and surface drainage system	Semi-tolerant	6000
		Tolerant	8000

Source: CGWB and CPCB (2000).

Table 4.21 Guidelines for Evaluation of Irrigation Water Quality

Water class	**Na, %**	**EC, μS/cm**	**SAR**	**RSC, meq/l**
Excellent	< 20	< 250	< 10	< 1.25
Good	20-40	250-750	10-18	1.25-2.0
Medium	40-60	750-2250	18-26	2.0-2.5
Bad	60-80	2250-4000	> 26	2.5-3.0
Very bad	> 80	> 4000	> 26	> 3.0

Source: CGWB and CPCB (2000).

Table 4.22 SAR, Na% and RSC Values in Ground Water in Barpeta District

S.No.	Location	Source	Depth m	SAR	Na (%)	RSC
1	Saruo Gorakhiathan Temple	HP	9.14	0.783	52.351	-0.116
2	Satbhanituk High School	HP	12.19	0.603	14.991	0.718
3	Gargoan, Bhagmara Temple	HP	9.14	0.594	49.749	0.292
4	Bhatadev School, Bishankushi	HP	12.19	0.373	12.758	0.193
5	Dakin Bhalaguri School	HP	21.34	0.302	9.974	-0.650
6	Sarupeta Railgate	HP	18.29	0.052	2.826	-0.436
7	Bamakhata Vetinary Hospital	HP	22.86	0.509	20.640	-0.131
8	Patharkuchi MPHC Hospital	HP	54.86	1.256	44.727	0.877
9	Saruo Dakhingari	HP	9.14	0.269	12.600	0.096
10	Dhupguri ME School	HP	10.67	0.274	8.860	-0.169
11	Kujarapati Prathmik School	HP	15.24	0.128	5.101	-0.200
12	Bhawanipur Shiv Temple	HP	9.14	0.129	7.068	0.095
13	Titkagaria Krishna Temple	HP	18.29	2.116	55.350	1.765
14	Konimara High School	HP	32.61	4.183	78.368	2.493
15	Dakin Anokpari	HP	10.67	0.283	11.178	0.312
16	Banglipara	HP	9.14	0.115	6.994	-0.181
17	Howly Club	HP	15.24	0.438	11.168	-0.780
18	Borbola Masjid	HP	13.72	0.108	5.658	-0.006
19	Pakaibarimala High School	HP	9.14	0.366	12.652	-0.036
20	Parakushipam Bridge	HP	12.19	0.259	11.556	-0.011
21	Satrabari Nakshatra	HP	15.24	0.612	39.459	0.370
22	Majulija	HP	24.38	0.431	31.832	-0.181
23	Hububari Jama Masjid	HP	12.19	0.354	9.563	-0.394
24	Jania Charali	HP	9.14	0.103	5.279	-0.063
25	Jania Road	HP	10.67	0.189	9.917	-0.150
26	Kirtanghar Barapeta Town	HP	12.19	0.393	18.921	0.328
27	Khoropara Memorial Academy	HP	7.62	0.452	18.463	-0.969
28	Gortari	HP	9.14	0.152	9.288	-0.054
29	Belbari Girls ME School	HP	15.24	0.551	26.103	-0.221
30	Devkura Commerce College	HP	15.24	0.195	5.681	-0.135
31	Nabajyoti College	HP	12.19	0.191	8.631	-0.108
32	Guniaguri	HP	15.24	0.065	2.929	-0.346
33	Mandia Panchayat Village	HP	10.67	0.162	8.325	0.284
34	Borpalli Bazzar	HP	9.14	0.233	14.450	-0.016
35	Omura Central School	HP	9.14	0.474	16.270	-0.941
36	Tarabari High School	BW	12.19	0.441	19.154	-0.322
37	Bahri Shiva Satra	HP	45.72	0.366	19.492	0.154
38	Malipara Prathamik School	HP	12.19	0.281	10.788	-0.165
39	Kanpulimari	HP	9.14	0.200	7.824	-0.564
40	Langla Madhyanik School	HP	12.19	0.142	6.746	0.185
41	Chinimari Tinali	HP	12.19	0.089	6.930	0.494
42	Abbas Ali High School	HP	9.14	0.083	5.020	-0.191
43	Bhagbhor	HP	15.24	0.199	9.072	-0.126
44	Bordalini Village	HP	10.67	0.192	10.426	-0.083
45	Barsuha Temple	HP	9.14	0.361	26.900	0.106

46	Katdua Masjid	HP	12.19	0.253	13.702	-0.219
47	Bokuradiki	HP	9.14	0.136	7.942	-0.057
48	Rangapani	HP	12.19	0.135	5.342	0.759
49	Sontuli	HP	9.14	0.185	10.642	0.039
50	Masjid Jagalisor	HP	12.19	0.127	6.810	-0.553

HP – Hand Pump; BW – Bore Well

4.2.1 Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top. The electrical conductivity values in Barpeta District are well within the prescribed limits and therefore safe for irrigation purpose.

4.2.2 Relative Proportion of Sodium to other Cations (SAR)

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

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

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of Barpeta District vary from 0.05 to 4.48 during pre-monsoon season. As evident from the SAR values, the ground water of the study area falls under the category of low sodium hazard, which reveals that ground water of the study area is free from any sodium hazard. The sodium percentage in the study area was found to vary from 2.8 to 78% indicating that almost all the samples are well within the permissible limit of irrigation water and does not create any sodium hazard.

4.2.3 Residual Sodium Carbonate (RSC)

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of Barpeta District is not having any residual sodium carbonate hazard.

4.2.4 Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant.

4.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram and U.S. Salinity Laboratory classification have been used in the present study to classify the ground water. Piper trilinear (Piper, 1944) and Chadha's diagrams (1999) are used to express similarity and dissimilarity in the chemistry of water based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955) is used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage characteristics, quantity of water used, climate and salt tolerance of crop. The results of all the aforesaid classifications are compiled in Table 4.23 and discussed in the following sections.

Table 4.23 Summarized Results of Water Classification in Barpeta District

Classification/Type	Sample Numbers
Piper Trilinear Classification	
Ca-Mg-HCO_3 (Group 5)	2,3,4,5,6,7,8,9,10,11,12,15,16,1718,19,20,21,22,23,24, 25,26,27,28, 29,30,31,32,33,34,35,36,37,38,39 40,41,42,43,44,45,46,47,48,49,50
Ca-Mg-Cl-SO_4 (Group 6)	-
Na-K-Cl-SO_4 (Group 7)	1
Na-K-HCO_3 (Group 8)	13,14
Chadha's Diagram	
Ca-Mg-HCO_3 (Group 5)	2,3,4,5,6,7,8,9,10,11,12,15,16,1718,19,20,21,22,23,24, 25,26,27,28, 29,30,31,32,33,34,35,36,37,38,39 40,41,42,43,44,45,46,47,48,49,50
Ca-Mg-Cl-SO_4 (Group 6)	-
Na-K-Cl-SO_4 (Group 7)	1
Na-K-HCO_3 (Group 8)	13,14
U.S. Salinity Laboratory Classification	
C1-S1	1,3,8,9,28,29,34,37,44,45,46
C2-S1	4,5,6,7,10,11,12,13,14,15,16,18,1920,21,22,23,24,25, 26,27,31,33,35,36,38,39,40,41,42,43,47,48,49,50
C3-S1	2,17,30,32
C4-S1	-

4.3.1 Piper Trilinear Classification

Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot.

The diagram combine three distinct fields by plotting two triangular fields at the lower left and lower right respectively and an intervening diamond-shaped field. All three fields have scales reading in 100 parts. In the triangular fields at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na+K) are plotted as a single point according to conventional trilinear coordinates. The three anion groups (HCO_3, SO_4, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a ground water. The central diamond-shaped field is used to show the overall chemical character of the ground water by a third single point plotting, which is at the intersection of rays projected from the plotting of cations and anions. The position of this plotting indicates the relative composition of a ground water in terms of cation-anion pairs that correspond to the four vertices of the field. The three areas of plotting show the essential chemical character of ground water according to the relative concentrations of its constituents.

The chemical analysis data of all the samples collected from Barpeta District have been plotted on trilinear diagram (Fig. 4.20) and results have been summarized in Table 4.23.

The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-HCO_3 hydrochemical facies. Only two samples belong to Na-K-HCO_3 hydrochemical facies and only one sample belong to Na-K-Cl-SO4 hydrochemical facies.

4.3.2 Chadha’s Diagram

The diagram is a somewhat modified version of the piper trilinear diagram. In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plottings from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms, so the diagram lacks certain logic. This method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the Piper diagram in the representation of some geochemical processes.

In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydrochemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

1. Alkaline earth exceeds alkali metals.
2. Alkali metals exceed alkaline earth.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness. The position of data points in the diagram represent Ca^{2+} -Mg^{2+}-HCO_3^- type, Ca^{2+} -Mg^{2+}- dominant HCO_3^- type, or HCO_3^- - dominant Ca^{2+} -Mg^{2+}- type waters.
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The position of data points in the diagram represents Ca^{2+} -Mg^{2+}-Cl^- type, Ca^{2+} -Mg^{2+}- dominant Cl^- - type or Cl^- - dominant Ca^{2+} -Mg^{2+}- type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The position of data points in the diagram represent Na^+-Cl^-- type, Na_2SO_4- type, Na^+-dominant Cl^--type, or Cl^--dominant Na^+-type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the diagram represent Na^+- HCO_3^- -type, Na^+-dominant HCO_3^- -type, or HCO_3^- -dominant Na^+-type waters.

The Chadha's diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The chemical analysis data of all the samples collected from Barpeta District have been plotted on Chadha's diagram (Fig. 4.21) and results have been summarized in Table 4.23. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-HCO_3

hydrochemical facies. Two samples of the study area belong to Na-K-HCO_3 hydrochemical facies and one to Na-K-Cl-SO4 hydrochemical facies. The Chadha's diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

4.3.3 U. S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). The diagram for use in studying the suitability of ground water for irrigation purposes is based on the sodium adsorption ratio (SAR) and electrical conductivity of water expressed in μS/cm (Table 4.24).

Table 4.24 U.S. Salinity Laboratory Classification

Salinity	
Low Salinity (C1)	Low salinity water (C1) can be used for irrigation with most crops on most soils.
Medium Salinity (C2)	Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
High Salinity (C3)	High salinity water (C3) can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected.
Very High Salinity (C4)	Very high salinity water (C4) is not suitable for irrigation water under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate and irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected.
SAR	
Low SAR (S1)	Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.
Medium SAR (S2)	Medium sodium water will present an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. This water may be used on coarse-textural or organic soils with good permeability.
High SAR (S3)	High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions.
Very High SAR (S4)	Very high sodium water is generally unsatisfactory for irrigation purposes.

The chemical analysis data of ground water samples of Barpeta District has been processed as per U.S. Salinity Laboratory classification (Fig. 4.22) and the results have been summarized in Table 4.23.

It is evident from the results that about 22% of the samples fall under water type C1-S1 (low salinity and low SAR) during pre-monsoon season, such water can be used for irrigation with most crops on most soils and 70% of the samples fall under water type C2-S1 (medium salinity and low SAR), such water can be used if a moderate amount of leaching occurs and plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

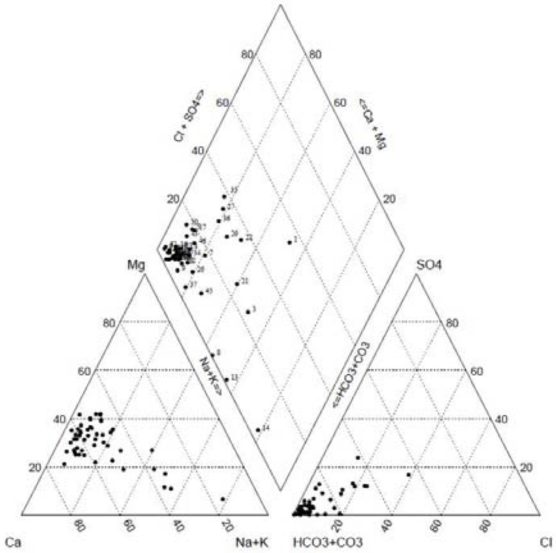

Fig. 4.20 Piper Trilinear Diagram Showing Chemical Character of Ground Water

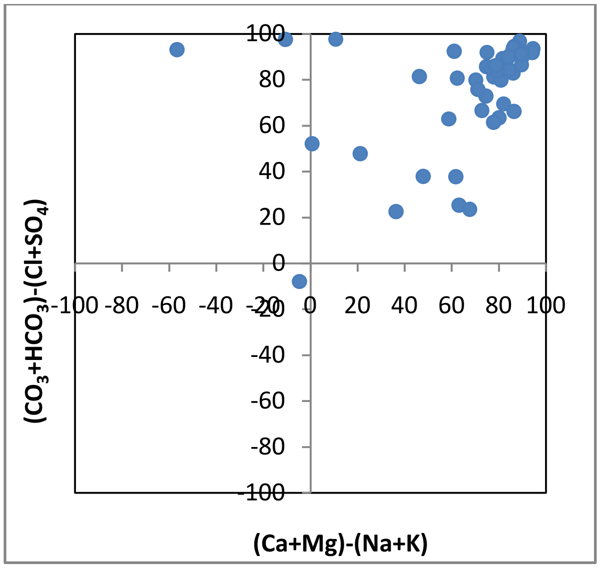

Fig. 4.21 Chadha's Diagram Showing Chemical Character of Ground Water in Barpeta District

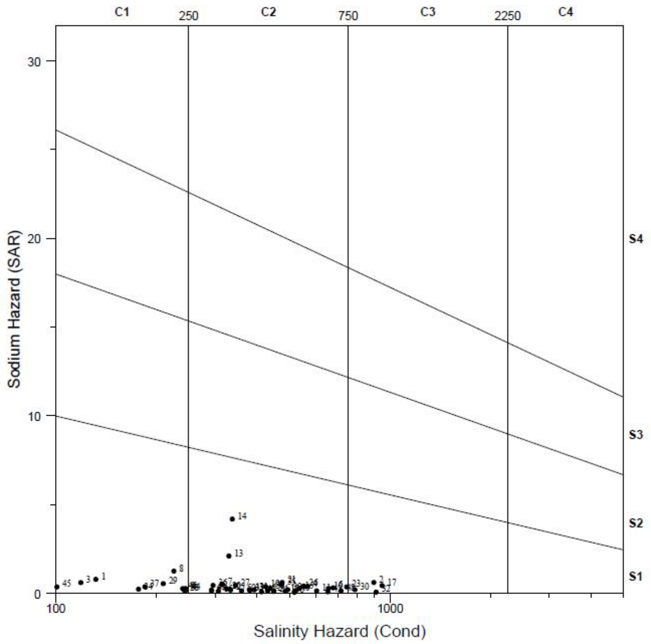

Fig. 4.22 U.S. Salinity Laboratory Classification

4.4 Arsenic Mitigation Strategy

Arsenic toxicity has no known effective medicine for treatment, but drinking of arsenic free water can help the arsenic affected people to get rid of the symptoms of arsenic toxicity. Hence, provision of arsenic free water is urgently needed to mitigate arsenic toxicity and protection of health and well being of people living in acute arsenic problem areas. The basic objective of mitigation of arsenic problem is to supply safe water to the community. The technological options for safe water supply in the arsenic affected areas could be one of the following:

a) Removal of arsenic from ground water,
b) Supply of surface water by using conventional treatment system through piped network,
c) Upgrading surface water sources like ponds through the application of HRF-SSF technology,
d) Rainwater harvesting, and
e) Tapping alternative safe aquifer for arsenic free ground water.

The alternative options available for water supply in the arsenic affected areas include arsenic avoidance and treatment of arsenic contaminated ground water. Treatment of surface waters by low-cost methods, rain water harvesting and water from deep aquifers would be potential sources of water supply to avoid arsenic ingestion through shallow tube well water. However, the use of alternative sources will require a major technological shift in water supply. On the other hand, treatment of arsenic contaminated well water is an alternative option to make use of a huge number of hand pumps or tube wells likely to be declared abandoned for yielding water with high arsenic content.

Various technologies available for removal of arsenic from contaminated water are based mainly on four principles:

- i) Oxidation and Co-precipitation: Oxidation of As(III) to As(V) by adding suitable oxidizing agent followed by coagulation, sedimentation and filtration (co-precipitation).
- ii) Adsorption: Activated Alumina, Iron filings (zero valent iron) and hydrated iron oxide.
- iii) Ion exchange through suitable cation and anion exchange resins.
- iv) Membrane Technology: Reverse osmosis, nanofiltration and electrodialysis.

The most treatment methods available for removal of arsenic from water are effective in removing arsenic in pentavalent form, so a pretreatment step of oxidation of trivalent to pentavalent arsenic is required.

Pretreatment Step (Pre-Oxidation): Arsenic is normally present in ground water in As(III) and As(V) states in different proportions. Most treatment methods are effective in removing arsenic in pentavalent state and hence include an oxidation step as pretreatment to convert As(III) to As(V). Following oxidizing agents can be used for conversion of arsenite to arsenate:

- Oxygen (process is very slow);
- Powdered active carbon and dissolved oxygen (catalytic oxidation);
- UV irradiation;
- Chemicals (free chlorine, hypochlorite, bleaching powder, ozone, permanganate, hydrogen peroxide etc.);
- Sunlight.

Although, arsenite can be oxidized to arsenate by oxygen, catalytic oxidation, UV irradiation, chemicals (free chlorine, hypochlorite, bleaching powder, ozone, permanganate, hydrogen peroxide etc.) and sun light but air oxidation of arsenic is very slow and can take weeks for oxidation. Chlorine dioxide and monochloramine are ineffective in oxidizing As(III). Ultraviolet (UV) light, by itself, is also ineffective. However, if the water is spiked with sulfite, UV photo-oxidation shows promise for As(III) conversion. Based on these considerations, only chlorine, permanganate and ozone are effective oxidizing agents for oxidizing As(III) to As(V) over wide range of working condition.

4.4.1 Oxidation and Filtration

Oxidation/filtration normally refers to processes that are designed to remove naturally occurring iron and manganese from water. The processes involve the oxidation of the soluble forms of iron and manganese to their insoluble forms and then removal by filtration. If arsenic is present in the water, it can be removed via two primary mechanisms: adsorption and co-precipitation. First, soluble iron and As(III) are oxidized. The As(V) then adsorbs onto the iron hydroxide precipitates that are ultimately filtered out of solution.

Although some arsenic may be removed by adsorption/co-precipitation with manganese, iron is much more efficient for arsenic removal. The arsenic removal efficiency is strongly dependent on the initial iron concentration and the ratio of iron to arsenic. In general, the Fe:As mass ratio should be at least 20:1. These conditions customarily result in an arsenic removal efficiency of 80-95%. In some cases, it may be appropriate to add ferric coagulant in the beginning of the iron removal process to optimize arsenic removal.

The common iron/manganese methods consist of (i) air oxidation or chemical oxidation followed by media filtration and (ii) potassium permanganate oxidation followed by a greensand media filter. The latter process is commonly referred to as the greensand process. The greensand process can be operated on an intermittent regeneration basis or on a continuous feed basis. With intermittent regeneration operational procedure, the greensand filter is periodically regenerated with potassium permanganate following the back washing of the filter. In the continuous feed mode, permanganate or chlorine is continuously added to the feed water ahead of greensand filter.

In the air/chemical oxidation filtration iron removal process, the iron is oxidized with either air (aeration tower) or with an oxidizing chemical, usually chlorine. Because of the limitations of air to oxidize As(III), chlorine is normally used in order for the process to be effective for arsenic removal. Once the water is oxidized, it is filtered with a granular media to remove the iron hydroxide precipitates that contain the adsorbed arsenic. The effectiveness of the granular media is important because any iron particles that manage to get through the filter media will contain some arsenic.

The greensand process is a special case of pressurized granular-media filtration where the granular media, greensand, catalyzes the oxidation and precipitation of iron and manganese. In the greensand process, operated on intermittent regeneration basis, the water is passed through a column of greensand media, which adsorbs and catalyzes the oxidation of the iron and manganese. In order for greensand to retain its adsorption and catalytic oxidation capabilities, the media must be regenerated with permanganate or chlorine. When operated on an intermittent regeneration basis, the greensand filter column is taken off line and the media is soaked in a solution of permanganate. In the continuous feed mode, permanganate or chlorine is continuously added to the feed water ahead of greensand filter where they provide continuous oxidation of the iron and As(III) and regeneration of the greensand. If the arsenic in the ground water is not already oxidized to As(V), it is recommended that continuous feed process using chlorine or permanganate be used to provide continuous oxidation of the iron, manganese and As(III).

In all oxidation/filtration processes, the filter media must be periodically backwashed to dislodge solids and restore hydraulic capacity.The specific amount of solids will depend on several factors, including raw water iron levels, coagulant addition (if any), filter run length and background solids concentration.

4.4.2 Co-precipitation

Co-precipitation has been the most frequently used method to treat arsenic contaminated water, including ground water, surface water, drinking water and wastewater in numerous pilot- and full-scale applications. In order to remove arsenic by co-precipitation, a coagulant is to be added. Water treatment with coagulants such as alum [$Al_2(SO_4)_3$.18H2O], ferric chloride [$FeCl_3$] and ferric sulfate [$Fe_2(SO_4)_3.7H_2O$] are effective in removing arsenic from water. Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider range of pH. In both cases pentavalent arsenic can be more effectively removed than trivalent arsenic. The following steps are involved in the co-precipitation process for removal of arsenic:

- Addition of bleaching powder / hypochlorite,
- Addition of alum / ferric sulphate,
- Rapid mixing of chemical followed by slow mixing,
- Sedimentation, and
- Filtration.

In the coagulation-flocculation process, aluminium sulfate or ferric chloride or ferric sulfate is added and dissolved in water under efficient stirring for few minutes. The water is then gently stirred for few minutes for agglomeration of micro-flocs into larger easily settable flocs. During this flocculation process all kinds of micro-particles and negatively charged ions are attached to the flocs by electrostatic attachment. As trivalent arsenic occurs in non-ionized form, it is not subject to significant removal. Oxidation of As(III) to As(V) is thus required as a pretreatment for efficient removal. This can be achieved by addition of bleaching powder (chlorine) or potassium permanganate. The co-precipitation technique for removal of arsenic can be applied for following system:

- Central Arsenic Removal Plant (ARP) attached with tube wells for piped water supply,
- Arsenic Removal Plant (ARP) attached with Hand Pump, and
- Domestic Arsenic Removal Units using Earthen Pots, Plastic Buckets, Bucket Treatment Units, Modified BTUs, Stevens Institute Technology, Fill and Draw Units, Naturally Occurring Iron, Chemical Packages, etc.)

4.4.3 Adsorption

Adsorption is the most prospective technology for removal of arsenic. Adsorption technology has been widely used to treat ground water and drinking water containing arsenic. Its effectiveness is sensitive to a variety of untreated water contaminants and characteristics. In adsorption technology, solutes (contaminants) concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The adsorption media is usually packed into a column. As the contaminated water is passed through the column, contaminants are adsorbed. When adsorption sites become filled, the column must be regenerated or disposed of and replaced with new media.

Several adsorbents are available for removal of arsenic from water, viz., activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, silicium oxide and many natural and synthetic adsorbents. The efficiency of sorptive media depends on the use of oxidizing agent as aids to sorption of arsenic. Saturation of media by different contaminants and components of water takes place at different times of operation depending on the specific sorption affinity of the medium to the given component.

Adsorption technology largely depends on capital cost, operation and maintenance cost, operational procedure and user-friendliness. The following media may be used for removal of arsenic through adsorption technique:

- Activated alumina (AA),
- Activated Carbon (AC)
- Iron Based Sorbents (Granular Ferric Hydroxide, Iron Coated Sand, etc.),
- Indigenous Filters, and
- Cartridge Filters.

Several constituents can interfere with the adsorption process, either by competing for adsorption sites or clogging the media with particulate matter. The presence of suspended solids in the feed water could gradually clog the media and therefore pre-filtration is recommended for sources where the turbidity exceeds 0.3 NTU.

Activated alumina is a low cost chemical (Rs. 100/- to Rs. 110/- per kg.) and it can be regenerated by washing with acid and alkali. Activated alumina has a useful life expectancy and after which fresh activated alumina will replace the exhausted alumina. The technologies and market for alumina-based adsorptive media is continuously expanding. There are several emerging proprietary media, commonly referred to as modified AA, which contain alumina in a mixture with other substances such as iron and sulfur. In some instances, these media have greater overall adsorptive capacities, enhanced selectivity towards arsenic, and/or greater overall operational flexibility than conventional AA, thus making them more cost-effective.

4.4.4 Ion Exchange

Ion exchange is a physical-chemical process in which ions are swapped between a solution phase and solid resin phase. The solid resin is typically an elastic three-dimensional hydrocarbon network containing a large number of ionizable groups electrostatically bound to the resin. These groups are exchanged for ions of similar charge in solution that have a stronger exchange affinity (i.e., selectivity) for the resin. In drinking water treatment, this technology is commonly used for softening and nitrate removal. The technology typically can reduce arsenic concentrations to less than 50µg/L and in some cases to below 10µg/L. Its effectiveness is sensitive to a variety of untreated water contaminants and characteristics. It is used less frequently than precipitation/ coprecipitation and is most commonly used to treat ground water and drinking water. Arsenic removal is accomplished by continuously passing water under pressure through one or more columns packed with exchange resin.

Different categories of synthetic resins can be used for arsenic removal. The process is similar to that of adsorption; just the medium is a synthetic resin of more well defined ion exchange capacity. However, the resins need to be replenished after use and renewal interval is dependent on the quantity of arsenic in water.

4.4.5 Membrane Technology

Membrane technology can remove a wide range of contaminants from water. This technology typically can reduce arsenic concentrations to less than 50µg/L and in some cases to below 10µg/L. However, its effectiveness is sensitive to a variety of untreated water contaminants and characteristics. It also produces a larger volume of residuals and tends to be more expensive than other arsenic treatment technologies. Therefore, it is used less frequently than precipitation/coprecipitation, adsorption and ion exchange.

Membrane techniques are capable of removing all kinds of dissolved solids including arsenic from water. They can address numerous water quality problems while maintaining simplicity and ease of operation. In this process, water is allowed to pass through special filter media which physically retain the impurities present in water. The water, for treatment by membrane techniques, should be free from suspended solids and the arsenic in water shall be in pentavalent form. Most membranes, however, can not withstand oxidizing agent.

There are four types of membrane processes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). All the four processes are pressure-driven and are categorized by the size of the particles that can pass through the membranes or by the molecular weight cut off (i.e., pore size) of the membrane. The force required to drive fluid across the membrane depends on the pore size; NF and RO require a relatively high pressure (50 to 150 psi), while MF and UF require lower pressure (5 to 100 psi). The low pressure processes primarily remove contaminants through physical sieving and the high pressure processes through chemical diffusion across the permeable membrane.

Because arsenic species dissolved in water tend to have relatively low molecular weights, only NF and RO membrane processes are likely to effectively treat dissolved arsenic. MF has been used with precipitation/coprecipitation to remove solids containing arsenic. MF generates two treatment residuals from the influent waste stream: a treated effluent (permeate) and a rejected waste stream of concentrated contaminants (reject).

RO is a high pressure process that primarily removes smaller ions typically associated with total dissolved solids. The molecular weight cut off for RO membranes ranges from 1 to 20,000, which is a significantly lower cut off than for NF membranes. The molecular weight cut off for NF membranes ranges from approximately 150 to 20,000. NF is a high pressure process that primarily removes larger divalent ions associated with hardness but not monovalent salts. NF is slightly less efficient than RO in removing dissolved arsenic from water. Reverse Osmosis (RO) units can be used as stand-alone arsenic treatment under most water quality conditions.

4.5 Options for North East Region

As the ground water of North East Region including Barpeta District has appreciable amount of iron, oxidation/filtration technique can be successfully applied for removal of arsenic from ground water. Oxidation/filtration normally refers to processes that are designed to remove naturally occurring iron and manganese from water. The processes involve the oxidation of the soluble forms of iron and manganese to their insoluble forms and then removal by filtration. If arsenic is present in the water, it can be removed via two primary mechanisms: adsorption and co-precipitation. First, soluble iron and As(III) are oxidized. The As(V) then adsorbs onto the iron hydroxide precipitates that are ultimately filtered out of solution.

Although some arsenic may be removed by adsorption/co-precipitation with manganese, iron is much more efficient for arsenic removal. The arsenic removal efficiency is strongly dependent on the initial iron concentration and the ratio of iron to arsenic. In general, the Fe:As mass ratio should be at least 20:1. These conditions customarily result in an arsenic removal efficiency of 80-95%. In some cases, it may be appropriate to add ferric coagulant in the beginning of the iron removal process to optimize arsenic removal.

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. The ground water quality in Barpeta District varies from place to place and with the depth of water table. The analysis of data clearly indicated that the concentrations of almost all the general water quality constituents are within the permissible limits for drinking water and no sample of the study area exceed the maximum permissible limit.
2. The ground water of Barpeta District recorded very high concentration of iron and manganese during pre-monsoon season. The concentration of iron varies from 262 to 12246 μg/L during pre-monsoon season as against the acceptable limit of 300 μg/L while that of manganese vary from 46 to 2731μg/L during pre-monsoon season as against the permissible limit of 300 μg/L. The water from ground water should be treated before being used for drinking purpose.
3. The concentration of arsenic varies from 0.10 to 569 µg/L during pre-monsoon season with more than 25% of samples exceeding the acceptable limit of 10 µg/L and such water cannot be used for drinking purpose.
4. The interpretation of the results of the analysis shows that ground water is fresh and suitable for both domestic and irrigation purposes except higher content of iron, manganese and arsenic which requires treatment before being used for drinking purposes.
5. Provision of arsenic free water is urgently needed to mitigate arsenic toxicity and protection of health and well being of people living in acute arsenic problem areas.
6. The hand pumps and wells, which have been identified as having suspected water quality should be painted red to indicate and warn the public that the water drawn from the source is not fit for human consumption.
7. In the absence of alternate safe source of water, the water with excessive undesirable constituents must be treated with specific treatment process before its use for human consumption.
8. In general the ground water of Barpeta District is safe for irrigation purpose.
9. Major programmes should be launched for comprehensive assessment of surface and ground water quality mapping, its relative vulnerability for pollution and identification of degraded water quality zones for identifying the source of pollution and taking remedial measures.
10. State of the art Water Quality Laboratories are required to be established at different locations in NE region. Capacity building programme should be taken up for having the trained man power to carry out the water quality monitoring and testing.
11. The mass awareness programmes should be launched in a big way in NE region to create awareness among the people about the quality of water for different uses and its present status, the effect on human health and responsibilities of public to safeguard water resources.

6.0 REFERENCES

1. APHA (1992), Standard Methods for the Examination of Water and Waste Waters, American Public Health Association, 18th Edition, Washington, DC.
2. BIS (2012), Drinking Water Specifications, IS:10500:2012, Bureau of Indian Standards, New Delhi.
3. CGWB (2013), Ground Water Information Booklet, Barpeta District, Assam, Central Ground Water Board, North Eastern Region, Guwahati, November 2013.
4. CGWB and CPCB (2000), Status of Ground Water Quality and Pollution Aspects in NCT-Delhi, January 2000.
5. Chadha, D. K. (1999), A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data, Hydrogeology Journal, 7(5), 431-439.
6. Jain, C. K. and Bhatia, K. K. S. (1988), Physico-chemical Analysis of Water and Wastewater, User's Manual, UM-26, National Institute of Hydrology, Roorkee.
7. Piper, A. M. (1944), A Graphical Procedure in the Geochemical Interpretation of Water Analysis, Trans. Am. Geophysical Union, Vol. 25, 914-923.
8. Richards, L. A. (ed.) (1954), Diagnosis and improvement of saline and alkali soils, Agricultural Handbook 60, U.S. Dept. Agric., Washington, D.C., 160 p.
9. Wilcox, L. V. (1955), Classification and Use of Irrigation Water, U.S. Dept. of Agr. Circular 969, Washington, D.C., 19 p.

DIRECTOR	**Dr. S. K. JAIN**
HEAD/COORDINATOR	**Dr. RAKESH KUMAR**

STUDY GROUP

Dr. C. K. Jain, Sc. 'G'
Dr. S. K. Sharma, Sc. 'C'
Mrs. Babita Sharma, RA

SUPPORTING STAFF

Sri. Biren Das, MTS (M)

NATIONAL INSTITUTE OF HYDROLOGY
CENTRE FOR FLOOD MANAGEMENT STUDIES
DISPUR, GUWAHATI - 781 006