Study on Spatial Distribution of Iron Toxicity Using Geographical Information System (GIS) in Groundwater of Guwahati, Assam

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Abstract: *An attempt has been made to see the distribution of iron toxicity in groundwater of Guwahati on GIS platform. In the present study iron concentrations at very high level were noticed in specific localities of the study area leading to disuse of water for direct drinking. Study reveals that the concentration of iron in groundwater of Guwahati ranges from 0.13 to 6.5 mg/l with a mean and coefficient of variation of 1.13$\pm$1.21 mg/l, C_V 1.07 respectively and decreases with depth of groundwater level. In about 80% of samples iron concentration is exceeded the desirable limit of 0.3 mg/l as prescribed by Bureau of Indian Standards (BIS). Its concentration is widely distributed with various proportions in the urban agglomeration of the Guwahati city.*

Keywords: *Guwahati Assam, Groundwater, Iron toxicity, GIS, Brahmaputra*

1. Introduction:

Toxicity of a metal depends on its concentration which adversely affects any biological activity. The presence of such metals in natural water is a matter of serious concern and iron is one of them. Natural water which contains higher amount of iron affects public health to a great extent if it is used directly for drinking, cooking and bathing purposes. Occurrence of excess iron can cause colour change in water which may lead to a consumer rejecting such water. Iron toxicity of groundwater can result in poor drinking water quality, corrosion in water distribution system, high clean-up costs, high costs for alternative water supplies, and/or potential health problems. Iron interferes with laundering operation, imparts objectionable stains to plumbing fixtures, and causes difficulties in distribution systems by supporting growth of bacteria. Presence of iron also imparts a bitter or inky taste to water which is detectable at very low concentration. Deposition of iron in lungs with nil or minimal fibrosis creates problems in human body [11]. Long time consumption of drinking water with a high concentration of iron can lead to liver diseases (hemosiderosis) [9]. In North East Region of India the groundwater almost invariably contains excessive iron. In Assam the iron content of water varies from 0.5 to 50 mg/l. Practically all sources of water in Upper Assam yield water with excessive iron content, making it unfit for use for both domestic & industries without proper treatment. In concentrations exceeding 1-2 mg/l, iron appreciably affects the taste of beverages, while precipitation of iron salts on the food products, on fabrics, paper etc. affects the quality of these products and also increased cost of water treatment. Iron deposits can also be formed in boilers and as such iron concentrations in water to be used for industrial purposes should be low [10]. The principal reason for controlling the concentration of iron is to improve water quality both for aesthetic as well as increase the life of the water distribution systems.

Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of rural households still depend completely on untreated surface or groundwater [12]. While access to drinking water in India has increased over the past decade, the tremendous adverse impact of unsafe water on health continues [19]. Contamination of groundwater can result in poor drinking water quality, loss of water supply, high clean-up costs, high costs for alternative water supplies, and/or potential health problems. The overdependence on groundwater to meet ever-increasing demands of domestic, agriculture, and industry sectors has resulted in overexploitation of groundwater resources. Groundwater can be optimally used and sustained only when the quantity and quality is properly assessed. GIS has emerged as a powerful tool for storing, analyzing, and displaying spatial data. GIS can be used as a database system in order to prepare thematic maps of water quality according to concentration values of different chemical constituents. Prepared GIS map can be utilized to locate groundwater quality zones suitable for different usages such as drinking, domestic and irrigation. For any city, a groundwater quality map is important to evaluate the water safeness for drinking and domestic purposes and also as a precautionary indication of potential environmental health problems [17].

The objective of this study is to assess the concentrations of iron in groundwater and their spatial variability across different wards of Guwahati, Assam using GIS technique. Understanding the special distribution of iron toxicity can help to identify the quality of groundwater.

2. Study Area

The city of Guwahati, located at latitude 26°10'45" N & longitude 91° 45' 0" E in the district of Kamrup District, is considered as the gateway to the seven northeastern states known as Assam, Arunachal Pradesh, Meghalaya, Manipur, Nagaland, Mizoram and Tripura of India. The city spreads about 10 km in north south direction and 27 km in east west direction [5]. Guwahati is the largest and fast growing urban agglomeration in the north-eastern region. It is major centre of trade, commerce, education and cultural in the north eastern region of India. Apart from its importance as administrative centre, Guwahati is also considered as the economic capital of Assam. The River Brahmaputra flows through the northern half of the city, while a permanent freshwater wetland Deepar beel is situated in the south west corner of the city. The wetland was declared as Ramsar site in the year 2002. The wetland receives water from the river Brahmaputra through a canal, the *Khanajan* which also acts as both inlet and outlet. The landuse map of the Guwahati city showing the activities locations are indicated in Figure 1, whereas Table 1 provides the information related to percentage coverage of existing landuse pattern in the Guwahati city [7]. The population of the Guwahati city in 2011 was 9,63,429 with an area of 313 km^2 [4].

Table 1: *Existing landuse pattern*

Landuse	% of Total Area	% Cumulative Area
Water bodies	2.53	2.53
Thick vegetation	9.68	12.21
Sparse vegetation	21.98	34.19
Built-up land	49.95	84.14
Barren land	15.86	100.00

The city is extended more in an E-W trend occupying the position between the Brahmaputra River towards north and Precambrian hills of Shillong Plateau towards south. The north, south and eastern sides of the city are surrounded by rows of forested hillocks. The city enjoys a subtropical humid climate with an average annual rainfall of 1600 mm. April to September are the months that receive abundant rainfall occasionally causing flash flood in many parts of the city. The temperature varies between 10 to 38 °C with maximum summer temperature between 30 to 38 °C and minimum winter temperature between 17 to 10 °C.

The present study area, measuring about 216.79 km^2, encompasses southern part of the Guwahati Municipality in Kamrup (Urban) district of Assam. It is bounded by longitude 91°34' to 91°52' E and latitude 26°05' to 26°12' N. It is sub-divided into 60 wards (Figure 2). The city of Guwahati has witnessed a rapid growth in population particularly during the last one and half decades. In Guwahati, dependency on groundwater is currently very high and it is preferred for drinking and domestic purposes by large number of the population. Because of the inadequacy and concern over quality of tap water, groundwater will continue to be a significant source of domestic water supply for this city. Although the mighty river Brahmaputra flows through the northern periphery of the city, water supply depends heavily on the dugwells, handpumps and deep tubewells. Increased industrialization and urbanization with high growth of built up areas and filling up of natural low laying areas have adversely affected groundwater quality of Guwahati [13]. In this background, it is of vital importance to identify desirable quality zones of the groundwater taking into account the iron toxicity factor.

3. Materials:

- Survey of India Toposheet No. 78 N/16, 78 N/12.
- Path Finder (Handbook of Road Networks of Guwahati City) [18].
- Ward Map of Guwahati Municipal Area, Govt.of Assam.
- Official reports and published papers.
- GIS Software: ArcGIS 9.0[1].
- Available groundwater quality data from different organizations.

These collected data were compiled together and integrated in GIS environment to create an iron variation zone map to characterize the terrain of the Guwahati city in terms of inherent iron toxicity.

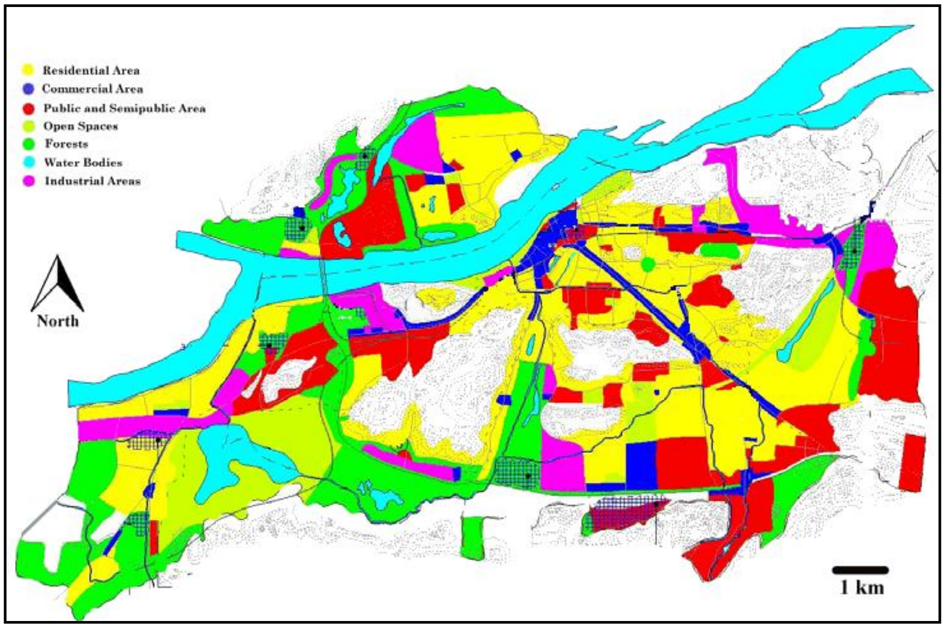

Figure 1. Map of Guwahati (Source: GMDA).

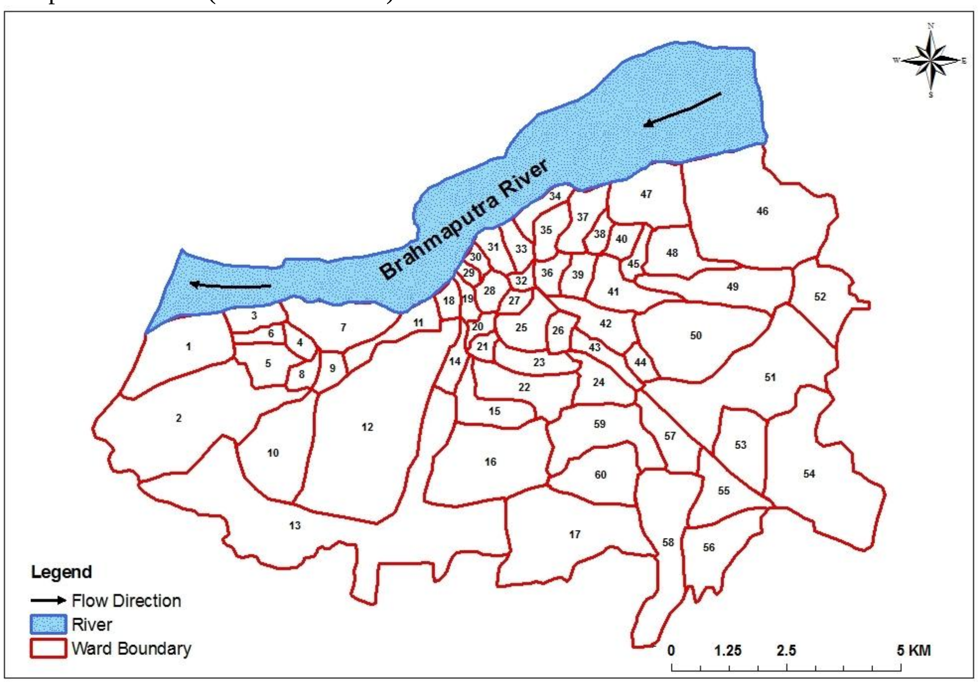

Figure 2. Study area map showing its municipal ward boundary.

4. Methodology:

Available groundwater quality data from academic institutes and different central and state goverment organizations have been used to prepare the spatial variation map of iron content in groundwater using GIS platform since no such information was available for Guwahati area. A total of 53 groundwater quality data in and around Guwahati city were collected and analyzed. Table 2 highlights the normal statistics of iron content in groundwater of Guwahati.

Krigging raster interpolation technique of spatial analyst module has been used in the present study to delineate the spatial distribution of iron in groundwater of Guwahati. The different locations were imported into GIS software through point layer. Each sample point was assigned by a unique code and stored in the point attribute table. The geodatabase was used to generate the spatial distribution map of selected water quality parameter namely iron. Kriging is based on the presence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) [15; 8] . In this method the experimental variogram measures the average degree of dissimilarity between unsampled values and a nearby data value [3] and thus can depict autocorrelation at various distances. Some advantages of this method are the incorporation of variable interdependence and the available error surface output.

The main objective of the study is to make quality assessment of groundwater using GIS, based on the available data of iron content in groundwater from different organizations in Guwahati city. The purposes of this assessment are (1) to determine spatial distribution of iron in groundwater and (2) to generate groundwater quality zone map for the Guwahati city on the basis of BIS classification.

Table 2: *Normal statistics of iron in groundwater*

Minimum	0.13
Average	1.13
Maximum	6.50
Standard Deviation	1.21
Variance	1.44
Median	0.76
Skewness	2.59
Kurtosis	8.23
Coefficient of Variation	1.07
1_{st} Quartile (25^{th} percentile) Q_{25}	0.42
3_{rd} Quartile (75^{th} percentile) Q_{75}	1.45

5. Results & Discussions:

The concentration of iron in natural water is controlled by both physico chemical and microbiological factors. An additional factor involved in the mobility of iron in groundwater is the presence of bacteria. Iron, the second most abundant element by weight in the earth’s crust, is normally present in groundwater in the ferrous form (Fe^{2+}), which is a soluble state and easily oxidized to trivalent ferric iron (Fe^{3+}). Aeration of iron can affect the quality of both groundwater and surface water. Use of iron rich groundwater for irrigation would affect the soil drainage with the deposition of ferric hydroxide on the surface. Dissolution of iron occurs as a result of oxidation and decrease of pH [14]. The cause of high concentration of iron in groundwater is attributed to the occurrence of high iron bearing minerals in the Pre-Cambrian and Tertiary geological formations. Iron in groundwater is one of the major problems in North Eastern States. The presence of iron in water beyond the desirable limit, affects taste/ appearance and has adverse effect on domestic use, water supply structures, and promotes iron bacterial growth. Detection of iron is very simple as it can be detected by the colour of red mud precipitate settled at the bottom of water storage containers. The iron determination is helpful in assessing the extent of corrosion and aiding in the solution of these problems [16]. Iron must be removed to avoid the growth of iron bacteria and rusting problems in the water distribution systems. Excessive iron content makes the water turbid and imparts an astringent taste to water. As per the standards set by BIS, the desirable level of iron for potable water is 0.3 mg/l which may be extended up to 1.0 mg/l in absence of alternative sources [2].

The purpose of the present study is to see the groundwater quality in the Guwahati city and thematically represent it using Geographic Information System (GIS) to realize the present scenario at a glance. GIS software package ArcGIS is used to map and analyze the groundwater quality data.

The following zones were quantified with respect to iron toxicity in groundwater of Guwahati:

1. under BIS desirable limit i.e. free from iron toxicity or risk free zone (upto 0.3 mg/l).
2. within desirable and maximum permissible limit (0.3-1.0 mg/l) (may be used for drinking purpose in absence of alternate source).
3. above maximum permissible limit (>1.0 mg/l) i.e iron toxic zone (unfit for direct drinking purpose and needs treatment before use).

Results of 53 samples in the study area show that iron concentration in groundwater is varying from 0.13 to 6.5 mg/l (Table 2 and Figure 3). Its concentration is widely distributed with various proportions in the study area. In about 80% of samples iron concentration is exceeded the BIS desirable limit of 0.3 mg/l (Figure 4 & 5). From the observation it is found that only 18.87% samples having the iron content upto 0.3 mg/l (the BIS desirable limit in potable water).

Box-Whisker plot is also used to represent temporal concentration of the studied water quality parameter viz. iron (Figure 6). The upper and lower quartiles of the data define the top and the bottom of a rectangle box. The line inside the box represents the median value and the size of the box represents the spread of the central value.

The area covered under each of the above three risk zones has been calculated and a pie graph showing the same is presented in Figure 7.

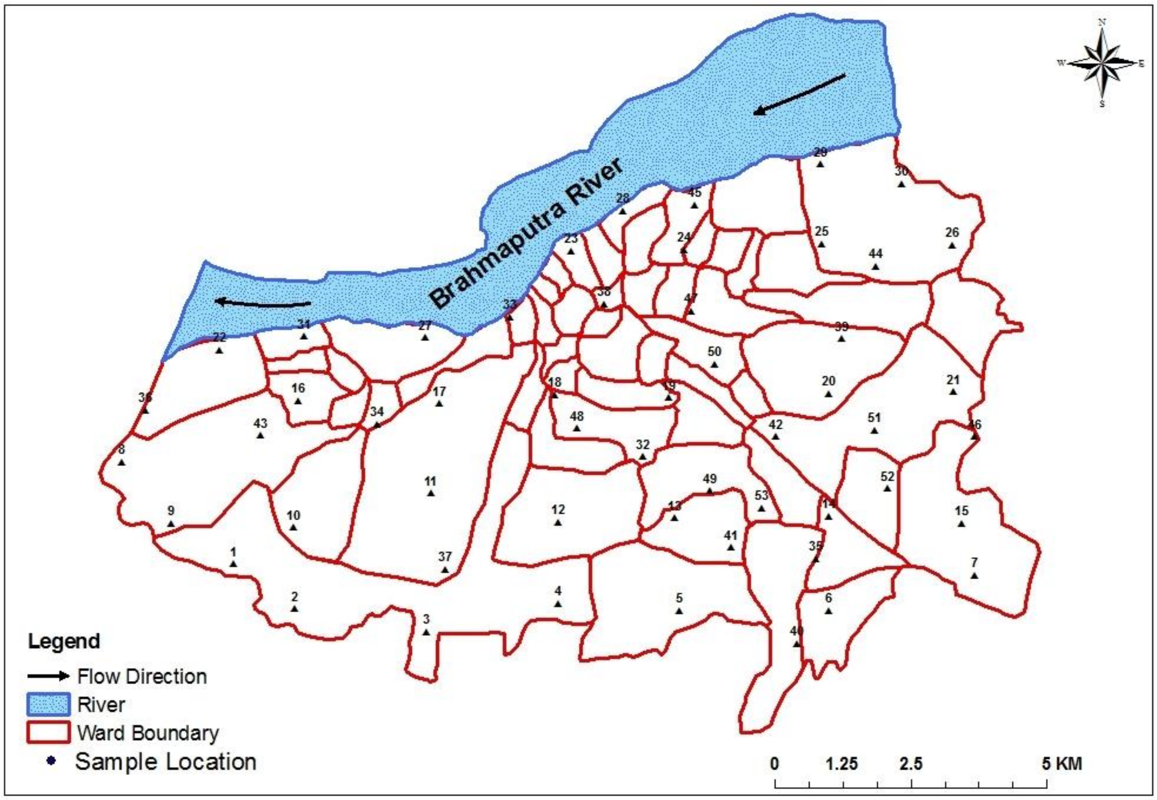

Figure 3. Distribution of sampling locations under study area

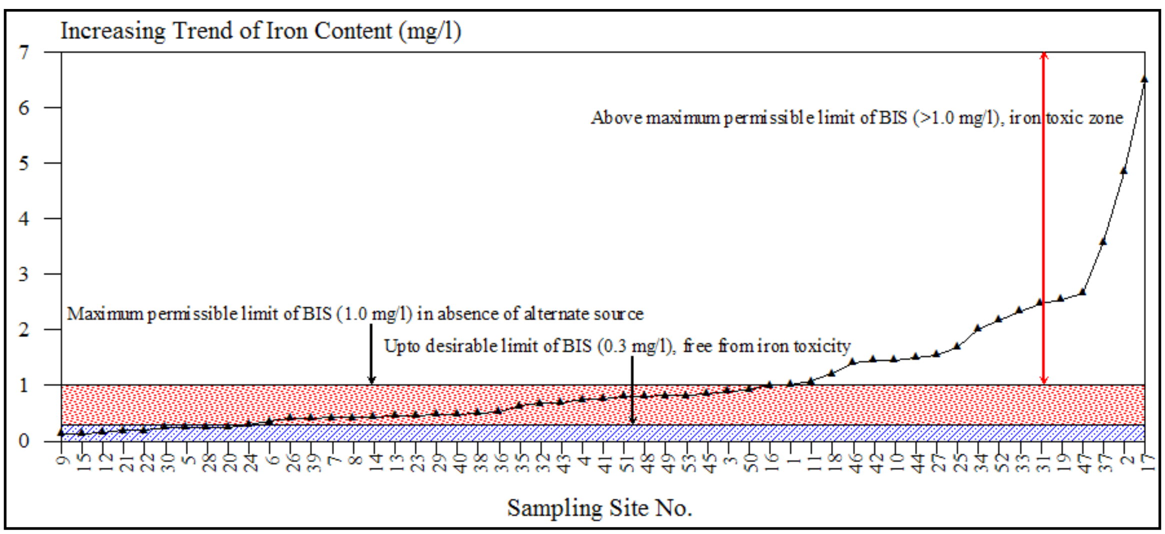

Figure 4. Increasing trend of iron concentration in groundwater of Guwahati

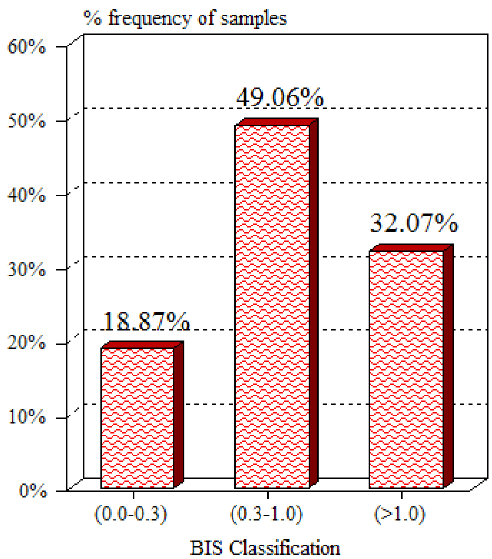

Figure 5. BIS classification for iron toxicity and % frequency of samples

5.1 Groundwater quality mapping using GIS:

Quality of groundwater bodies in a region can be studied by plotting the results of analysis of water samples on maps and by means of lines of equal concentration of specific ions (i.e. contour lines). Using these techniques, areas of concentration of specific elements and problematic zones can be identified and corrective measures can be employed. The water quality maps may be shaded to identify areas of water having particular range of concentration. The prepared map projects the regional behavior with areal extent of particular concentration zone in very simple visualize way. In that way any general public can know the quality of groundwater and their behavior and effects on different applications in his locality with reference to iron concentration. Groundwater quality monitoring and management is an area, which can benefit from integration with GIS map. The tremendous capabilities of GIS map in groundwater quality monitoring and management can be exploited for (i) surveillance and monitoring; (ii) pollution management and source allocation; (iii) forecasting and modelling; (iv) for development of environmental information system.

The results obtained after analysis of the data are presented in the form of GIS based maps (Figure 7 & 8) and data tables (Table 3, 4 & 5).

Comprehensive information about % status of study area showing the desirable quality of iron content in groundwater is presented in Table 3 to 5. 93.203% of the total study area has groundwater with iron concentration values above desirable limit limits of BIS (Table 4), whereas only 6.797% of the total study area contained iron content within desirable limit of BIS (Figure 7). This clearly indicates the precarious status of groundwater in Guwahati. From the Figure 7, it is clearly visible that iron toxic zone (>BIS' maximum permissible limit, 1.0 mg/L) in groundwater of Guwahati is spread out within central portion of the study area.

The different wards falling under different risk zones were also identified by overlaying the ward map of the GMC area on the prepared GIS map (Figure 8).

Table 3: *BIS desirable limit and % of study area*

Desirable limit mg/l	**% Study area upto desirable limit (i.e. safe zone)**	
	Area occupied km^2	% of Total area
0.3	14.74	6.797%

Table 4: *BIS maximum permissible limit and % of study area*

Maximum permissible limit mg/l	**% Study area above the desirable limit but below the maximum permissible limit**	
	Area occupied km^2	% of Total area
1.0	101.02	46.601%

Table 5: *Above BIS max. permissible limit and % of study area*

Above BIS maximum permissible limit mg/l	**% Study area above maximum permissible limit (i.e. toxic zone)**	
	Area occupied km^2	**% of Total area**
>1.0	101.03	46.602%

5.2 Stability field of iron on pH-ORP diagram:

Dissolved carbon dioxide, pH and ORP status of water affects the nature of aqueous iron species present in the water. In a more complex system where pH can change, other ions are present, and one of several solids could form, it would be useful to have a way of presenting the essential features of the redox and solid phase chemistry. ORP-pH diagram serves this purpose nicely [6]. Using this diagram it is possible to get some idea about stable field of iron ion on pH-ORP relations in groundwaters of Guwahati. pH-ORP diagram prepared for iron ion in groundwater of the study area and shown in Figure 9. The upper and lower lines on the field represent the oxidation of water to O_2 and the reduction of water to H_2. These two half-reactions define the upper and lower limits for oxidation or reduction. The other lines are boundaries for what are known as stability fields. These fields are labeled with one dominant ion or solid for the specified ORP and pH. When an ion dominates, the element is mobile because a relatively small proportion of the metal occurs as a solid. Iron normally occurs in groundwaters in two oxidation states, the ferrous (Fe^{2+}) and Fe^{3+} (ferric) forms. The form of iron however may be altered as a result of oxidation or reduction due to the growth of bacteria in the water during storage, usually the ferric form is predominant in the most of the natural waters. Iron in water may be either in true solution, or in a colloidal state or in the form of relatively coarse suspended particles.

Iron compounds are subject to hydrolysis and the hydrated iron oxides formed in these reactions, particularly the ferric form, have very low solubility. In the pH range 5-8, the most common form of iron in groundwater (H_2O-CO_2-iron) system is the Fe^{2+} form [10]. Iron usually exists in natural water both in ferrous and ferric forms. The form of iron however may be altered as a result of oxidation or reduction due to the growth of bacteria in the water during storage, usually the ferric form is predominant in the most of the natural waters. Iron in water may be either in true solution, or in a colloidal state or in the form of relatively coarse suspended particles.

Redox reaction influences the mobility of metal ions in solution. The redox conditions encountered along a flow system are important in controlling the chemistry of metal ions and solids species or solids containing sulfur and dissolved gases containing carbon. It is possible in some flow system to define redox zones. These zones are parts of an aquifer in which ORP is controlled by a dominant redox couple. Stability fields of Fe-CO_2-S species as function of pH & ORP shows clearly that iron content in the groundwater of Guwahati is in the form of ferrous (Fe^{2+}) iron (Figure 9). Ferrous iron is easily converted to ferric (Fe^{3+}) on oxidation (aeration) and since $Fe(OH)_3$ has quite low solubility, the removal of excessive ferrous iron from groundwaters of Guwahati can easily be accomplished by spraying the groundwater on beds of gravel and sand or on coke beds, settling the precipitated ferric hydroxide and draining off of the supernatant clear water. Otherwise marble or calcite beds may also be used to increase the pH value, which will also lead to faster precipitation of ferric hydroxide.

5.3. Variation in iron concentration with depth of groundwater level:

Depth wise variation in the iron composition of the ground water samples from Guwahati is also presented in Figure 10. Observation reveals that the concentration of iron in groundwater of Guwahati decreases with depth of groundwater level.

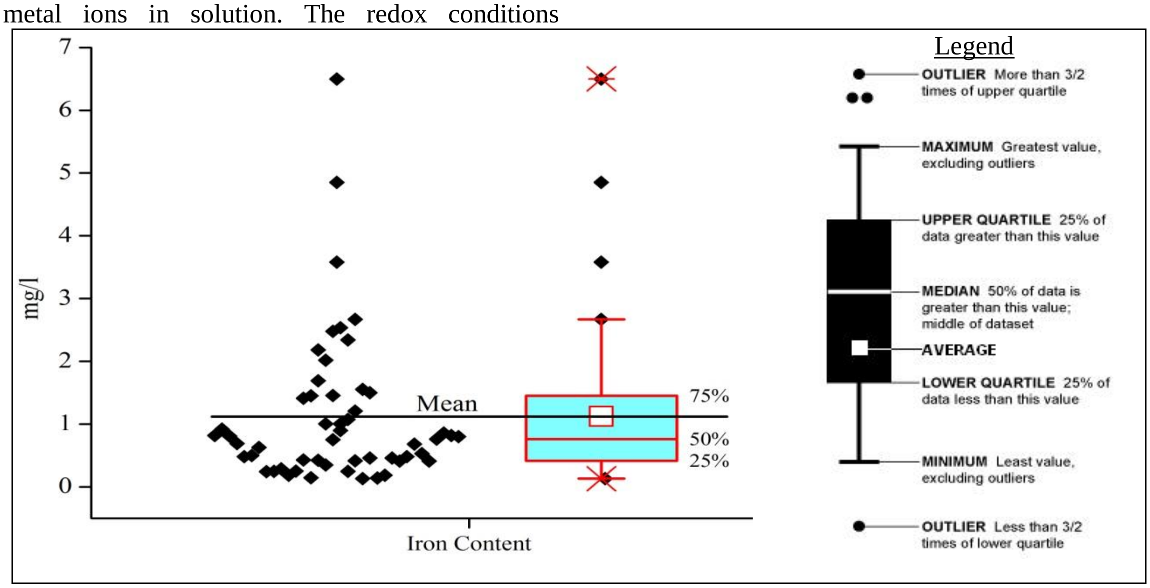

Figure 6. Variation of iron on Box-Whisker plot

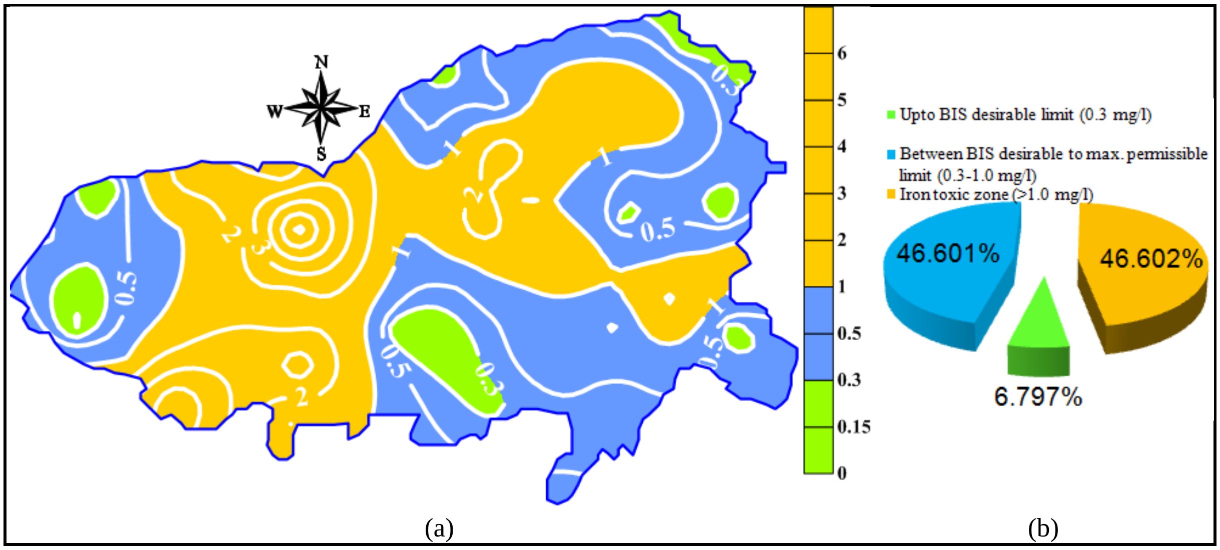

Figure 7. Variation status of iron concentration over (a) GIS map and (b) % pie diagram

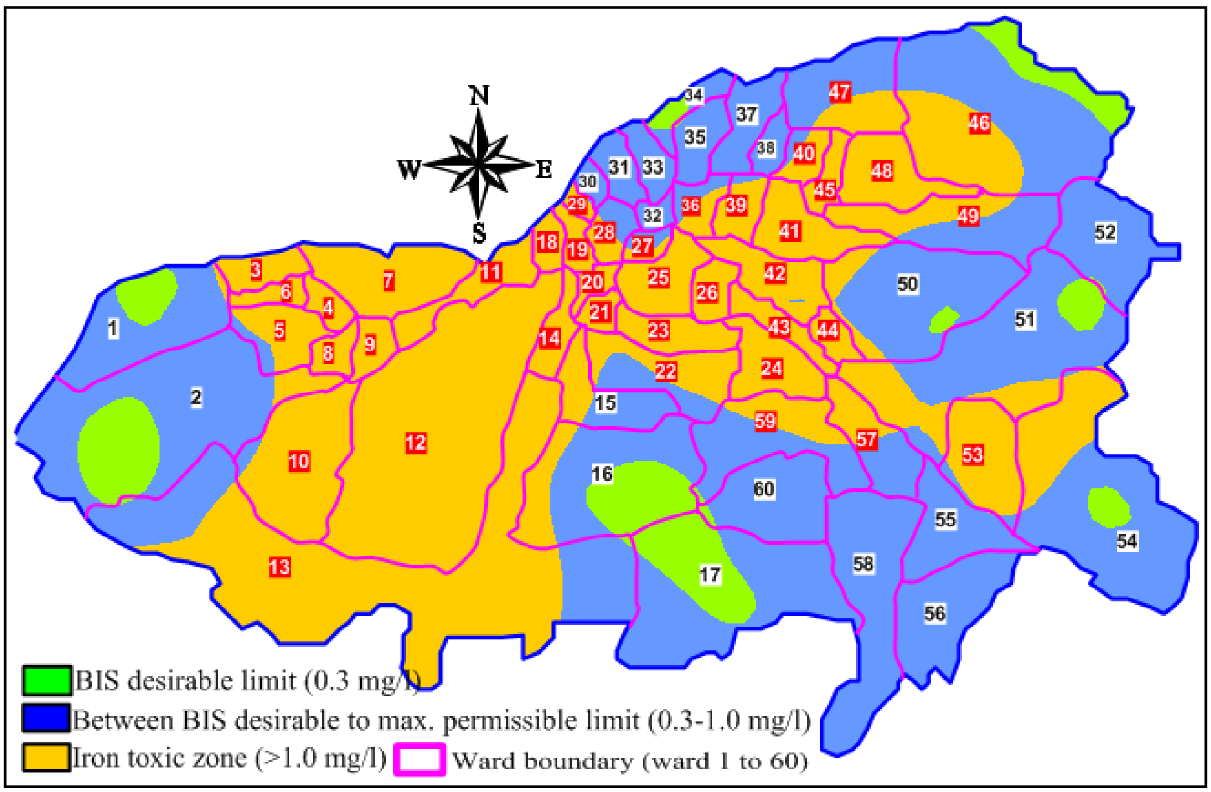

Figure 8. Ward wise scenario for variation of iron concentration

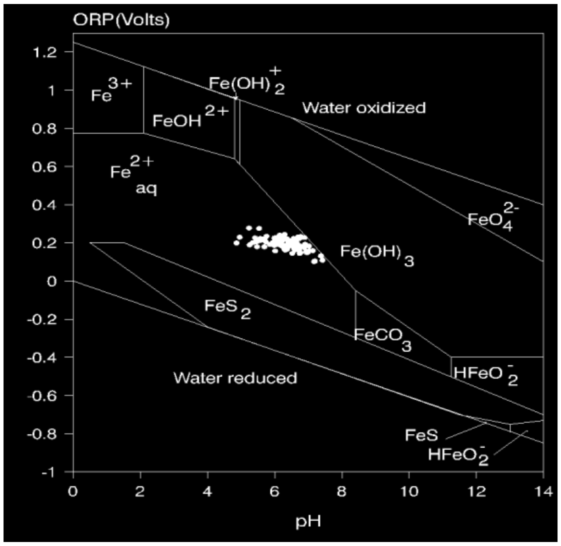

Figure 9. Stability field of iron ion in the study area over pH-ORP diagram

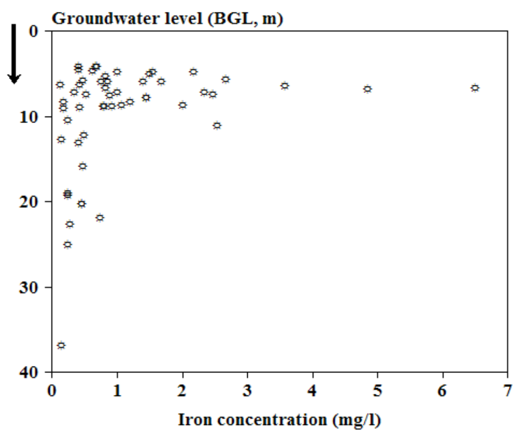

Figure 10. Decreasing trend in iron concentration with groundwater level

6. Conclusions:

GIS can be used as a powerful tool for assessing groundwater quality. Groundwater is the major source of drinking water in rural and semi-urban areas of Assam. The spatial distribution maps generated for iron content in groundwater of Guwahati using GIS techniques could be useful for planners and decision makers for initiating groundwater quality development in the area.

The widespread occurrence of iron in groundwater makes the water non potable without some sort of treatment. Proper water resource management and rainwater harvesting may reduce the iron toxicity problem in groundwater of Guwahati.

Groundwater quality maps are useful in assessing the usability of the water for different purposes. The results obtained with respect to iron distribution in groundwater will be helpful for monitoring and managing groundwater quality in the Guwahati city.

7. Acknowledgements:

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