*Original Research Article*

# GIS aided groundwater quality mapping of Central Brahmaputra Valley Zone of Assam, India


## Abstract:

Groundwater is an essential resource for sustainable development all over the world. To understand the use of water resources, the fundamental characteristics and recharge of the groundwater need to be analyzed. GIS is considered as an effective and powerful tool for collecting, storing, transforming the spatial information for need based site specific decision making process. Thus, GIS tools have opened new paths in land and water resource studies. In the present study, GIS based mapping of the ground water in the central Brahmaputra Valley Zone is done with a view to observe the various quality characters. The results of this investigation could be used by decision-makers for the sustainable management of ground water resources. The groundwater pH of the district was found to be within the desirable limit as recommended by WHO but 67.30% sample covering 79% of the total geographical area of the district was slightly alkaline in nature. Groundwater quality parameters that surpassed the desirable limit recommended by WHO, were electrical conductivity and nitrate which accounted 41.22% and 0.79% of the total samples. Total Dissolved Solids, calcium, magnesium, carbonate, bi-carbonate and nitrate in groundwater were recorded within the desirable limit of WHO and thus could be considered as safe. Spatial autocorrelation run for all the quality parameters with respect to their positions and values over the entire district envisaged the possibilities of forming different pattern namely CLUSTER for pH, EC, As, F, Fe, Al, Mn,$HCO_3$, RANDOM for Mg, Ca, $CO_3$, $NO_3$, $SO_4$ and DISPERSED for TDS. GIS-aided mapping of groundwater quality parameters embracing their category wise spatial distribution, area, maximum and minimum values, surface autocorrelation of observed values could give better idea to opt for suitable need based management strategy for the entire district.



Keywords: Nagaon district, Groundwater, Central Brahmaputra Valley Zone, GIS




## Introduction:

Geographic Information System has become one of the leading tools in the field of hydrogeological science, which helps in assessing, monitoring and conserving groundwater resources. Most often, surface water is utilized for agricultural purposes, whereas domestic and industrial water usage relies on the copious amount of available groundwater. Thus GIS act as an efficient tool in groundwater studies analysing and quantifying groundwater resources for its sustainable use. In recent days, GIS is considered as an effective and powerful tool for collecting, storing, transforming the spatial information for need based site specific decision making process. In the present research, GIs is used to study the spatial distribution of groundwater quality parameters. The ground water quality information maps of the entire study area was prepared using GIS spatial interpolation technique for pH, EC, TDS, calcium and magnesium, carbonate and bicarbonate and nitrate in order to find their respective ranges in the study area.

**Materials and methods:**

The entire district was first divided into grids (2.5 × 2.5 km) and a total of 883 grids were demarcated to represent the whole district. One water sample from the existing well/ tube well/ ponds (726 wells, 122 tube wells & 35 ponds) of each grid was collected as per the standard protocol outlined by WHO (1996) the locations of sampling sites were taken by using handheld global positioning (GPS) system unit (GARMIN GPS 64).Open wells and filter point wells are feasible in all area of the district. In unconsolidated sediments ring wells were constructed by excavating down to the saturated horizon. Cement or earthen rings from 0.80 to 1.20 placed one above another with weep holes in the bottom rings are likely to hold sufficient quantity of water. Depth ranged from 9 to 22 m depending upon the topographic elevation. Surroundings of all the sampling points generally encompassed with the build-up areas following rice centric agriculture with the cultivation of vegetables, oilseeds, pulses, jute etc.

- Geologically the district is underlain by rocks of Precambrian age consisting of granites and gneisses, rocks belonging to Barail and Surma series of Tertiary age and Quaternary alluvium. Hydrogeological study revealed the existence of potential aquifer zones down to the depth of 200m. The thickness of the granular zones which mainly constitute sands of various grades, clay and occasional gravel occurs in the Recent to Sub-recent alluvial formations which spread out the whole district from southern part of the river Brahmaputra to the areas around Lanka on south. Hydrologically, major water bearing formations and pebble aquifer zone found extending down to 300 m depth and weathered and fracture zones up to 100 m depth in consolidated rocks.

Cluster analysis through ***Moran's I test*** for spatial autocorrelation among different attributes to see if the attribute values of features cluster or not given their locations to other features. The mean and the variance for the attribute were calculated. The deviation from the mean for each feature was multiplied with neighbouring features to create a cross-product. If many neighbouring features have high or low cross-products, then there is clustering. These tests cater the overall result for the entire research area.

**Water quality analysis**

**pH**

The pH of the water samples was measured using Beckman glass electrode pH meter (Baruah and Barthakur, 1999).

**Electrical conductivity (EC)**

Electrical conductivity of the water samples was measured using Systronic conductivity meter (Baruah and Barthakur, 1999).

**Total dissolved solids (TDS)**

TDS was measured by the method described by Baruah and Barthakur, (1999).

**Calcium and Magnesium (Ca and Mg)**

Ca and Mg were determined by complexometric titration method (Diehl *et al*.,1950).

**Carbonate and bicarbonate ($CO_3^{2-}$ and $HCO_3^{1-}$)**

$CO_3^{2-}$ and $HCO_3^{1-}$ were determined by acidimetric titration in presence of phenolophthalin indicator (Baruah and Barthakur, 1999).

**Nitrate ($NO_3$)**

**$NO_3$**was determined by Digestion and distillation method (Jackson, 1973)

**Results and discussions:**

Altogether eight key parameters that have direct and/or indirect influences on overall groundwater quality were considered for GIS-aided mapping of Nagaon district of Assam. Parameter-wise classifications, their area coverage, mean value, critical Z-score along with spatial pattern is depicted in Table 1.

**pH**

The parameter pH generally indicates the acid or alkaline nature of any solution and usually bear direct impact on water quality. pH of all the samples were found to be within the range of 6.08 to 7.67 with their mean value 7.09 and standard deviation 0.217, respectively. However, pH value of all the samples did not surpass the desirable limit (6.5-8.5) as set by Bureau of Indian Standard (BIS) whereas few water samples were slightly alkaline in nature. Spatial variation map of pH using Geographic Information System (GIS) over the study area is depicted in Figure 2. It was observed that maximum area of

1437.48 sq. km was identified in the pH category of 7.02-7.10 while, minimum of 319.44 sq. km fell in the pH range 6.37-6.88.

Spatial autocorrelation, a tool to define distribution of features spatially, was carried out and suggested that the pattern of groundwater pH at each feature location was of clustered type. The calculated Moran’s Index and critical Z-score was found to be 0.0168 and 0.468, respectively. Positive Z-score clearly envisaged clustering of high values concentrated spatially with reference to space and value, thus providing an idea to focus on to such higher values for adoption of suitable management strategy to address this important parameter. It further revealed that there was less one percent likelihood to form clustered pattern from the results of random chance.

Although pH of the entire district ranged from 6.08 to 7.67 but 67.30 % samples covering 79 % of the total geographical area of the district was slightly alkaline in nature. This could be attributed to the fact that carbonate minerals present in the underneath soil layers increased the buffering capacity of percolating water keeping the pH close to neutral, even when acids or basic materials are added to it (Borah, 2011).The gradual increase in area with slight alkaline pH envisaged a clear reflection of leaching down of basic cation or alkaline earth metal elements that form hydroxide ions when dissolved into the groundwater. Dutta (2013) observed that most of the water samples in different small tea gardens areas of Assam were found to be acidic in nature. Slight acid nature in ground water could otherwise be due to the use of fertilizers like ammonium sulphate, urea and super phosphate in agriculture.

**Electrical conductivity (EC)**

The Electrical Conductivity (EC) which is a measure of the ability of water to pass electric current through it due to presence of ionized inorganic substances is classified into five categories *viz.*< 0.5 ($dSm^{-1}$), 0.5-1.0 ($dSm^{-1}$), 1.0-1.5 ($dSm^{-1}$), 1.5-2.0 ($dSm^{-1}$) and >2.0 ($dSm^{-1}$). Out of the EC values analyzed for the entire area, the minimum of 0.01 (dSm-1) and the maximum of 0.12 ($dSm^{-1}$) with mean and standard deviation of 0.04 ($dSm^{-1}$) and 0.024, respectively was noticed and overall range was found under low EC classification. The spatial variation map of EC using GIS was prepared and presented in Figure 3.From the figure it has been observed that maximum area of1102.07 sq. km was found in the category 0.028-0.037 $dSm^{-1}$ while, minimum 271.52 sq.km was demarcated in the range

0.068-0.117 $dSm^{-1}$. However, the highest EC value did not exceed the recommended limit (0.3 $dSm^{-1}$)as stated by USPH.

Spatial autocorrelation for the entire range of EC representing the study area as a whole was run with respect to the positional value and direction of the attributes (EC). The pattern as depicted from the autocorrelation suggested that groundwater EC at each feature location was clustered. The calculated Moran's Index and critical value (Z-score) was found to be 0.0124 and 4.68, respectively. This positive value clearly envisaged less than one percent likelihood that the clustered pattern was the result of random chance. The higher the value of Z-score more would be the affinity of higher value to concentrate resulting intense degree of clustering with reference to space, thus giving an idea to focus on to the higher values. However, considering the overall observed values of EC within the lower limit of EC classification, no management strategy is required to address this parameter.

EC in the entire district that ranged from a minimum of 0.01 ($dSm^{-1}$) to the maximum of 0.12 ($dS\ m^{-1}$) was found to fall below 0.5 $dS\ m^{-1}$which depicted the area to fall in no problem zone based on the guideline set. These could be inferred from the facts ,namely availability of very little solute in the groundwater, rapid ion-exchange between the soil and water, or basically a poor and rather insoluble geologic rock and mineral types. These results are in close conformity to the findings outlined by Dutta *et al*., 2010.

**Total Dissolved Solid (TDS)**

As the name indicates, total dissolved solids constitute mobile charged ions, including minerals, salts or metals dissolved in a given volume of water. The concentration of dissolved mineral constituents determines the suitability of a given volume of water for different purposes. In general, natural pure water has TDS below 500 $mgL^{-1}$while value more than this indicates the water to be undesirable for drinking and other industrial uses. The ground water quality data of Nagaon district revealed that TDS ranges from a minimum of 15.46 $mgL^{-1}$ to a maximum of 184.25 $mg\ L^{-1}$ with a mean of 77.25 $mg\ L^{-1}$and standard deviation of 27.97. The TDS level of all the samples did not exceed the recommended limit of BIS. Spatial variation map of TDS using GIS of the study area is shown in Figure 4. The spatial distribution of TDS over the entire district depicted the maximum area of 1185.92 sq. km in the category of 81.57-94.14 mg $L^{-1}$ while, minimum of 359.37 sq.km in the category of 94.15-173.78 mg $L^{-1}$.

Results of the spatial autocorrelation calculated over the TDS across their positional values were found towards dispersed pattern from its random one. The calculated Moran's Index and the critical value (Z-score) were 0.011 and -1.74, showing Z score to be lower than 2.58 and thus the TDS were insignificant with reference to their respective positional dimensions. This negative value clearly envisaged that there is 5-10% likelihood about this dispersed pattern to be the result of random chance. It further attributed the tendency of distributing lower dissimilar values concentrated spatially with reference to space thus provided an idea to focus on to the lower values for adoption of suitable management option.

The total dissolved solid, which indicates the overall suitability of water for many types of uses, ranged from a minimum of 15.46 mg $L^{-1}$ to a maximum of 184.25 mg $L^{-1}$ with a mean of 77.25 mg $L^{-1}$. The concentration of dissolved solids in natural water is usually less than 500 mg $L^{-1}$, while water with more than 500 mg $L^{-1}$ is undesirable for drinking and many industrial uses. Therefore, as in the present study TDS is classified below 500 mg $L^{-1}$, it could be considered as safe for drinking and other purposes. The reason for this might be due to a lower value of EC as seen from the spatial distribution map of EC of the study area. Similar observation was earlier noticed by Danee Joycee and Santhi (2015) in Kodayar sub basin of Tamil Nadu.

**4.1.4 Calcium (Ca)**

Calcium generally is added to ground water through weathering of Ca bearing minerals present in the earth crust. These weathering processes are often invigorated due to wetting and drying of minerals containing Ca and due to heavy downpour it is more likely to be leached down making the groundwater alkaline. Thus, the presence of Ca in groundwater influence the pH and bear direct impact on water quality. Spatial distribution map of Ca using GIS is presented in Figure 5.It is seen that Ca ranged from 6.13 to 46.32 mg $L^{-1}$(mean16.31 mg $L^{-1}$), the highest and lowest being 46.32 mg $L^{-1}$ and 6.13 mg $L^{-1}$, respectively with standard deviation of 7.53. All the samples did not exceed the recommended BIS limit (200 mg $L^{-1}$) and found below the desirable limit. In regards to category-wise distribution of area to be affected by Ca in groundwater, it revealed that maximum area of 1261.788 sq. km was demarcated in the category of 13.12-15.18 mg $L^{-1}$, while minimum of 339.405 sq.km was found in the category of 19.92-36.21 mg $L^{-1}$.

Results of the spatial autocorrelation tool suggested that the pattern of groundwater Ca content was distributed randomly interpreting the distribution was neither clustered nor dispersed with respect to the positional value of Ca content over the district as a whole. The calculated Moran's Index and critical Z-score value were 0.001 and 0.04, respectively. The observed spatial pattern of feature values could very well be defined as the case of complete spatial randomness giving an idea to focus on to the whole area to adopt suitable management strategy(s) to address this parameter.

As revealed from the spatial distribution map, groundwater Ca ranged from 6.13 to 46.32 mg $L^{-1}$ with mean value of 16.31 mg $L^{-1}$ which indicated the whole study area to be safe as it fell within the desired range i.e. less than 200mg $L^{-1}$ being 46.32mg $L^{-1}$, the highest concentration obtained. All natural water, being it groundwater or other surface water generally contains Ca. When soil is adequately supplied with exchangeable Ca either in the form of lime or gypsum, its structure would improve immensely allowing the Ca-rich water to pass down to the groundwater easily. Similar observations were earlier reported by several workers (Dutta *et al*., 2010 and Dutta, 2013).

**4.1.5 Magnesium (Mg)**

Similar to Ca, Mg is also added through weathering of magnesium bearing minerals present in the earth crust, which is more likely to be leached down the groundwater due to heavy rainfall leaving the water alkaline. Mg, being basic cation, is also responsible for raising the pH and thus bear direct influence on groundwater quality. Spatial distribution map of Mg using GIS of the study area is presented in Figure 6. As depicted, it ranged from a minimum value of 3.22 mg $L^{-1}$ to the maximum of 25.37mg $L^{-1}$with their mean value 9.87 mg $L^{-1}$ and standard deviation 3.65. Results further revealed that Mg content in all the samples did not exceed the desirable limit 30 mg $L^{-1}$ as set by BIS. In regards to area of distribution of Mg content, it was observed that maximum area of 1605.18 sq. km fell in the category 8.47-9.75mg $L^{-1}$, while minimum 171.69 sq.km in category 15.54-25.10 mg $L^{-1}$. Spatial autocorrelation of groundwater Mg content with respect to their relatively close locations on two-dimensional surface was carried out for the whole district. The data were observed to be distributed in random pattern that depicted that the spatial distribution of feature values was the result of random spatial processes. The calculated Moran's Index and the critical value (Z-score) were 0.001 and -0.51, respectively. The observed spatial pattern of feature values could very well be explored adopting the need based strategies to address the possible need based intervention.

Magnesium concentration less than 30mg $L^{-1}$ is classifies as a safer zone for drinking. In the present study concentration of Mg was found to be within the desirable limit. In groundwater the availability of magnesium may be attributed to deriving part from silicates and part from magnesium calcite or dolomite due to dissolution of biotitic granites and gneiss. The result is in consistent to the research report by Mishra and Sahoo (2003**).**In groundwater the calcium content generally exceeds the magnesium content in accordance with its relative abundance in rocks but contrary to the relative solubility's of its salts.

**4.1.6 Carbonate ($CO_3$)**

The parameter $CO_3$ generally indicates the alkalinity and hardness of water. $CO_3$ is not a self-pollutant but in combination with other basic cations it has the potential in neutralizing water acidity and that eventually determines the standard of water quality. Spatial distribution map of $CO_3$ as shown in Figure 7.showed that it ranged from 12.00 to 94.00 mg $L^{-1}$(mean 43.15 mg L-1), the maximum and minimum values being 94.00 and 12.00 mg $L^{-1}$, respectively with standard deviation 15.43. The $CO_3$ levels of all the samples were found to be below the desirable limit (200 mg $L^{-1}$) as set by BIS. $CO_3$ level in the range of 45.13-50.94 mg $L^{-1}$was noticed in the maximum area of 1293.732 sq. km while, minimum of 175.692 sq.km was observed in the category 50.95-88.44 mg $L^{-1}$.



Results of the spatial autocorrelation suggested that the pattern of groundwater $CO_3$ was randomly distributed which inferred that the spatial distribution of feature values of $CO_3$ is the result of random spatial processes. Both Moran's Index and critical value (Z-score) was found to be 0.001 and -0.55 depicting the fact that the pattern was neither clustered nor dispersed.

Carbonate in groundwater of the study area was found within the desirable limit as set by BIS which clearly indicated the area to be safe in respect to this parameter. These could be discussed in the light that $CO_3$ is added in groundwater due to dissolved carbon dioxide in rainwater. Upon entering into the soil it further dissolved more carbon dioxide in water from the organic matter during decaying process. Water charged with carbon dioxide also dissolves carbonate minerals as it passes through soil and rocks, to give bicarbonate. The range found in bicarbonate is fairly narrow because of only small variations in the partial pressure of carbon dioxide in the interstitial pores of the rocks in the aeration zone. The whole discussion is supported by the research works carried out by Dutta, 2010 and Nath, 2013.

**Bicarbonate ($HCO_3$)**

Primary source of bicarbonate ions in ground water is the dissolved $CO_2$ in rain water and when enters in the soil dissolves more $CO_2$.Spatial distribution of $HCO_3$ value in the study area is shown in Figure 8. It ranged from 10.00 to 84.00 $mgL^{-1}$with mean value 33.90 $mgL^{-1}$. The maximum and minimum value was observed to be 84.00 and 10.00 mg L-1, respectively with standard deviation 12.32. Results revealed that the maximum level did not exceed the desirable limit as per the threshold limit outlined by BIS (200 $mgL^{-1}$). The maximum area of 1173.94 sq. km fell in the category 31.96-36.26 $mgL^{-1}$whileminimum of 379.33 sq.km categorized 43.11-78.34 mg L-1.

Spatial autocorrelation was carried out that showed clustered pattern of the spatially distributed groundwater $HCO_3$ content with respect to their positions and values. Calculated Moran's Index and critical Z-score value was found to be 0.0134 and 3.39, respectively. Higher Z-score above 2.58 indicated strong clustering of comparatively higher $HCO_3$ content with reference to space giving an idea to focus on such higher values for adoption of suitable management strategy(s) to address the vulnerable area of interest. Results further envisaged less than 1percent likelihood that the clustered pattern was the result of random chance.

Bicarbonate in groundwater of the study area was found to be within the desirable limit as set by BIS which clearly indicated the area to be safe in respect to these parameters. These could be discussed in the light that Bicarbonate is added in groundwater due to dissolved carbon dioxide in rainwater. Upon entering into the soil it further dissolved more carbon dioxide in water from the organic matter during decaying process. Water charged with carbon dioxide also dissolves carbonate minerals as it passes through soil and rocks, to give bicarbonate. The range found in bicarbonate is fairly narrow because of only small variations in the partial pressure of carbon dioxide in the interstitial pores of the rocks in the aeration zone. The whole discussion is supported by the research works carried out by Dutta, 2010 and Nath, 2013.

**4.1.8 Nitrate ($NO_3$)**

Groundwater is mostly contaminated due to leaching of $NO_3$ with the percolating water and the severity of contamination is further aggravated when the sink of percolating water is from sewage and wastes enrich with nitrates. Excessive use of nitrogenous fertilizers and animal matters etc. may often lead to groundwater contamination with $NO_3$ and cause adverse effects on plant and human health. Spatial distribution map of Nitrate using GIS of the study area is presented in Figure 9. The nitrate content in the study area varied in the range 1.14 to 55.10 $mgL^{-1}$(mean 5.42 $mgL^{-1}$) with standard deviation 4.87 and found within the prescribed limit. The maximum area of 1429.499 sq. km was marked in the range 4.58-5.59 $mgL^{-1}$ while minimum of 479.16 sq.km fell in the category 14.88-54.25 $mgL^{-1}$



Results of the spatial autocorrelation revealed that the pattern of groundwater Nitrate content was randomly distributed depicting that the spatial processes promoting the observed pattern of Nitrate content was of random chance. The Moran's Index and Z-score was calculated to be 0.011 and -0.49, respectively. Negative Z-score which was found to be less than 2.58 revealed that minimum values of $NO_3$ tended to form cluster pattern from their complete randomness.

Groundwater nitrate accumulation is often due to leaching of this contaminant with the percolating water in the areas where excessive uses of nitrogenous fertilizers. The severity is aggravated if the source of percolating water is from water enriched with nitrate that causes adverse effects on plant and human health. The nitrate content in the study area ranged from 1.14 to 55.10 mg $L^{-1}$ with mean value 5.42 mg $L^{-1}$. However, a few samples (0.79%) of the study area were found to be above the threshold limit (45 mg $L^{-1}$) as set by BIS. The increased concentration of Nitrate might be due to excessive application of nitrogen fertilizers or decay of plants and animal residue or disposal of industrial wastewater or sewage or by increased cultivation of crops requiring more nitrogenous fertilizers (Rengaraj, 1996; Singh, 2006; Chaturvedi *et al*. (2016). The toxicity of Nitrate leads to cardiovascular effects at higher dose level and Methomoglobinemia at lower dosage limits.

## Conclusion:

The Geographic Information System (GIS) has emerged as a powerful tool in such multivariate aspects of groundwater occurrence. It is very helpful in delineation of groundwater prospect and various physiochemical properties. Through GIS technology, common information of database like classifications, horizontal variations, unique visualization could be ascertained which would be a valuable resource in public domain. In the present study spatial variation of ground water quality parameters map for the entire district were created and salient database for each of the quality parameters are highlighted. GIS-aided mapping of groundwater quality parameters embracing their category wise spatial distribution, area, maximum and minimum values, surface autocorrelation of observed values could give better idea to opt for suitable need based management strategy for the entire district. GIS-aided mapping with non-spatial data generated through laboratory analysis of certain groundwater quality parameters provided a useful format in visualizing all those information in comprehensive and presentable form for need based site-specific decision making process. The spatial water quality analysis of individual parameters revealed that all of them had different usability ranges. GIS-aided mapping of groundwater quality parameters embracing their category wise spatial distribution, area, maximum and minimum values, surface autocorrelation of observed values could give better idea to opt for suitable need based management strategy for the entire district.

Recommendations: Groundwater quality parameters that surpassed the desirable limit recommended by WHO were manganese, electrical conductivity and nitrate which accounted 73.5%, 41.22% and 0.79% of the total samples, respectively indicating thereby to strategize plan accordingly to reduce these important parameters. Total Dissolved Solids, calcium, magnesium, carbonate and bi-carbonate in groundwater were recorded within the desirable limit of WHO and thus could be considered as safe. CLUSTER pattern of spatial autocorrelation for manganese suggested focusing its higher values so as to plan suitable management strategies accordingly.

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**Tables:**

**Table 1: Classes, area coverage and spatial patterns of groundwater parameters**

| **Parameters** | **Categories** | **Area covered (sq.km)** | **Mean ± SD** | **Moran Index Z score** | **Spatial pattern** |
|---|---|---|---|---|---|
| **pH** | 6.37-6.88 | 319.44 | 7.09±0.217 | 0.017<br>0.468 | Clustered |
| | 6.89-7.01 | 519.09 | | | |
| | 7.02-7.10 | 1437.48 | | | |
| | 7.11-7.20 | 1118.04 | | | |
| | 7.21-7.60 | 598.95 | | | |
| **EC (dS $m^{-1}$)** | 0.010-0.027 | 862.48 | 0.04±0.024 | 0.012<br>4.682 | Clustered |
| | 0.028-0.037 | 1118.04 | | | |
| | 0.038-0.050 | 938.35 | | | |
| | 0.051-0.067 | 818.56 | | | |
| | 0.068-0.117 | 255.55 | | | |
| **TDS (mg $L^{-1}$)** | 26.93- | 451.20 | 77.25±27.968 | 0.011 | Dispersed |

| | | | | | |
|---|---|---|---|---|---|
| | 60.89 | | | -1.743 | |
| | 60.90-71.99 | 1014.22 | | | |
| | 72.00-81.56 | 982.27 | | | |
| | 81.57-94.14 | 1185.92 | | | |
| | 94.15-173.78 | 359.37 | | | |
| **Ca (mg $L^{-1}$)** | 7.13-13.11 | 654.85 | 16.31±7.537 | 0.001<br>0.045 | Random |
| | 13.12-15.18 | 1261.78 | | | |
| | 15.19-17.25 | 1078.11 | | | |
| | 17.26-19.91 | 658.84 | | | |
| | 19.92-36.21 | 339.40 | | | |
| **Mg (mg $L^{-1}$)** | 3.22-8.46 | 351.38 | 9.87±3.656 | 0.001<br>-0.512 | Random |
| | 8.47-9.75 | 1605.18 | | | |
| | 9.76-11.34 | 1437.48 | | | |
| | 11.35-15.53 | 427.25 | | | |
| | 15.54-25.10 | 171.69 | | | |
| **$CO_3$ (mg $L^{-1}$)** | 12.01-34.52 | 199.65 | 43.15±15.434 | 0.001<br>-0.553 | Random |
| | 34.53-40.47 | 1181.92 | | | |
| | 40.48-45.12 | 1118.04 | | | |
| | 45.13-50.94 | 1293.73 | | | |
| | 50.95-88.44 | 199.65 | | | |
| **$HCO_3$ (mg $L^{-1}$)** | 10.80-27.72 | 459.19 | 33.9±12.321 | 0.013<br>3.394 | Clustered |
| | 27.73-31.95 | 1038.18 | | | |
| | 31.96-36.26 | 1173.94 | | | |
| | 36.27-43.10 | 942.34 | | | |
| | 43.11-78.34 | 379.33 | | | |
| **$NO_3$ (mg $L^{-1}$)** | 1.40-4.57 | 806.58 | 5.42±4.869 | 0.011<br>-0.495 | Random |
| | 4.58-5.59 | 1429.49 | | | |
| | 5.59-7.70 | 898.42 | | | |
| | 7.71-14.87 | 379.33 | | | |

| | | | | | |
|---|---|---|---|---|---|
| | 14.88-54.25 | 479.16 | | | |



**Table2.Stepwise evaluation of Water Quality Index of ground water of Nagaon district, Assam**

| Parameters | Mean over locations | AssaignWt(I) | Relvwt Wi=I/W | ISO Strd (Si) | qi= (Wi/ Si)x100 | SI=Wi*qi |
|---|---|---|---|---|---|---|
| **pH** | 7.0925 | 2.75 | 0.0621 | 7.50 | 0.8286 | 0.0515 |
| **EC** | 0.0363 | 3.00 | 0.0678 | 0.02 | 338.983 | 22.9819 |
| **TDS** | 77.2495 | 3.50 | 0.0791 | 50.0 | 0.1582 | 0.0125 |
| **Ca** | 16.3132 | 2.50 | 0.0565 | 75.0 | 0.0753 | 0.0043 |
| **Mg** | 9.8659 | 2.00 | 0.0452 | 30.0 | 0.1507 | 0.0068 |
| **$CO3^{2-}$** | 43.1540 | 2.50 | 0.0565 | 200 | 0.0282 | 0.0016 |
| **$HCO3^{2-}$** | 33.9049 | 2.00 | 0.0452 | 200 | 0.0226 | 0.0010 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **$NO^{3-}$** | 5.4197 | 4.50 | 0.1017 | 15.0 | 0.6780 | 0.0689 |
| **$SO4^{3-}$** | 5.6984 | 2.50 | 0.0565 | 25.0 | 0.2260 | 0.0128 |
| **Flouride** | 0.6953 | 4.00 | 0.0904 | 1.00 | 9.0395 | 0.8171 |
| **Arsenic** | 0.0470 | 5.00 | 0.1130 | 0.05 | 226.0 | 25.54 |
| **Fe** | 0.6576 | 3.00 | 0.0678 | 0.30 | 22.5989 | 1.5321 |
| **Al** | 3.5866 | **4.00** | 0.0904 | 0.02 | 451.98 | 40.8567 |
| **Mn** | 0.5181 | 3.00 | 0.0678 | 0.10 | 67.797 | 4.5964 |
| **Total** | **44.25** | | | **96.48** | | |



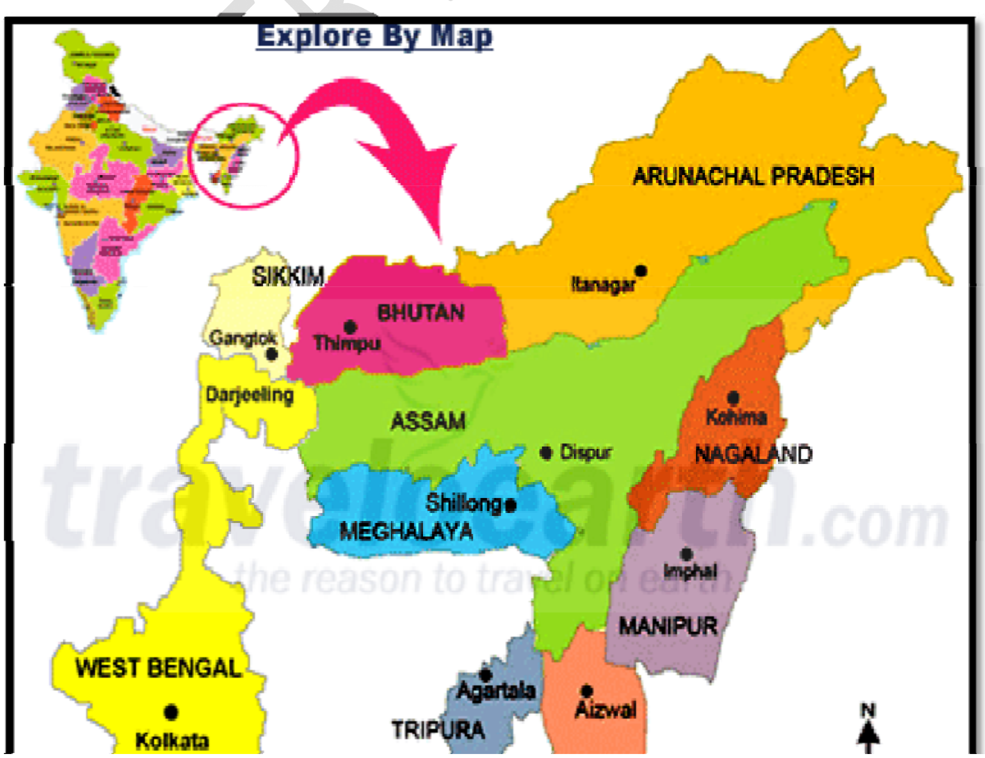


**Fig. 1a.Map showing location of the experimental site**

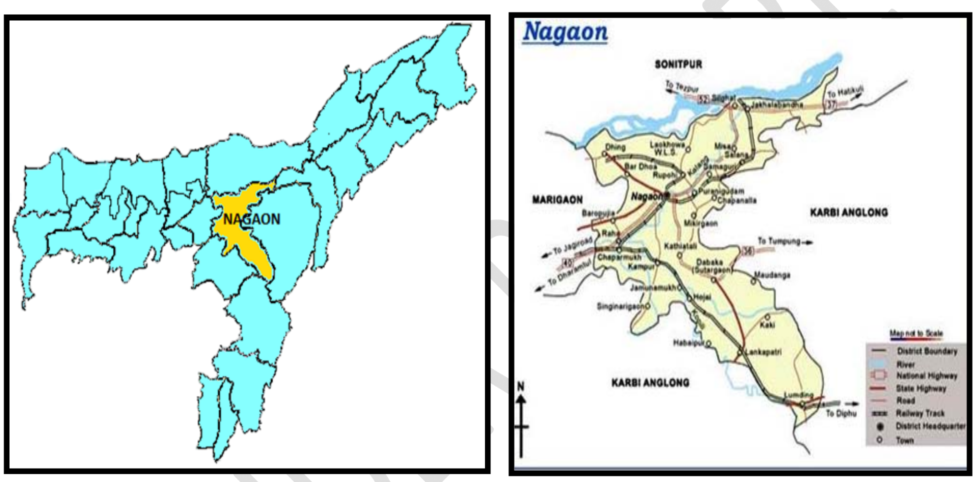



**Fig. 1b.Map showing location of the experimental site**

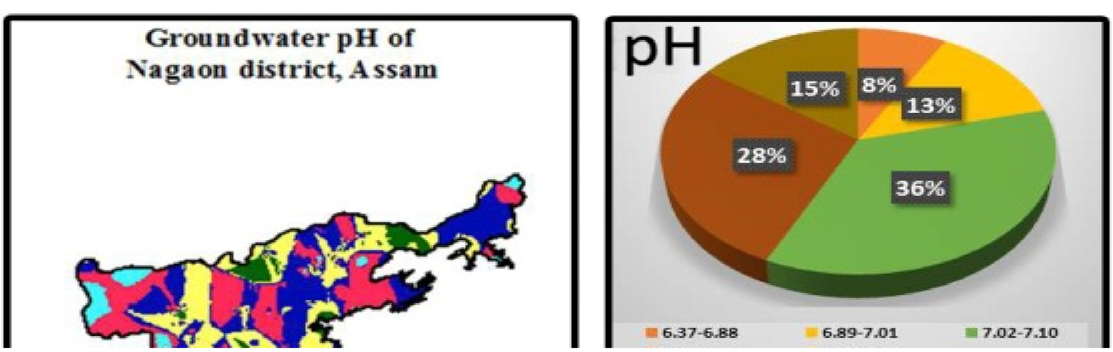
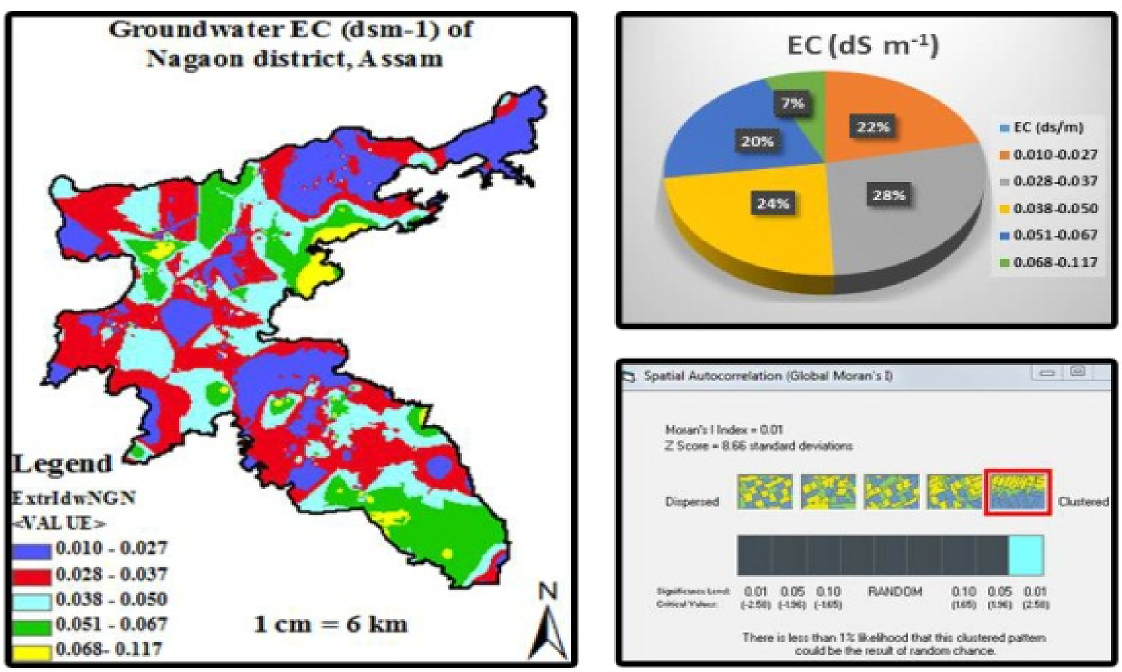


**Fig. 2. GIS map, area coverage and spatial pattern of ground water pH of Nagaondistrict, Assam**





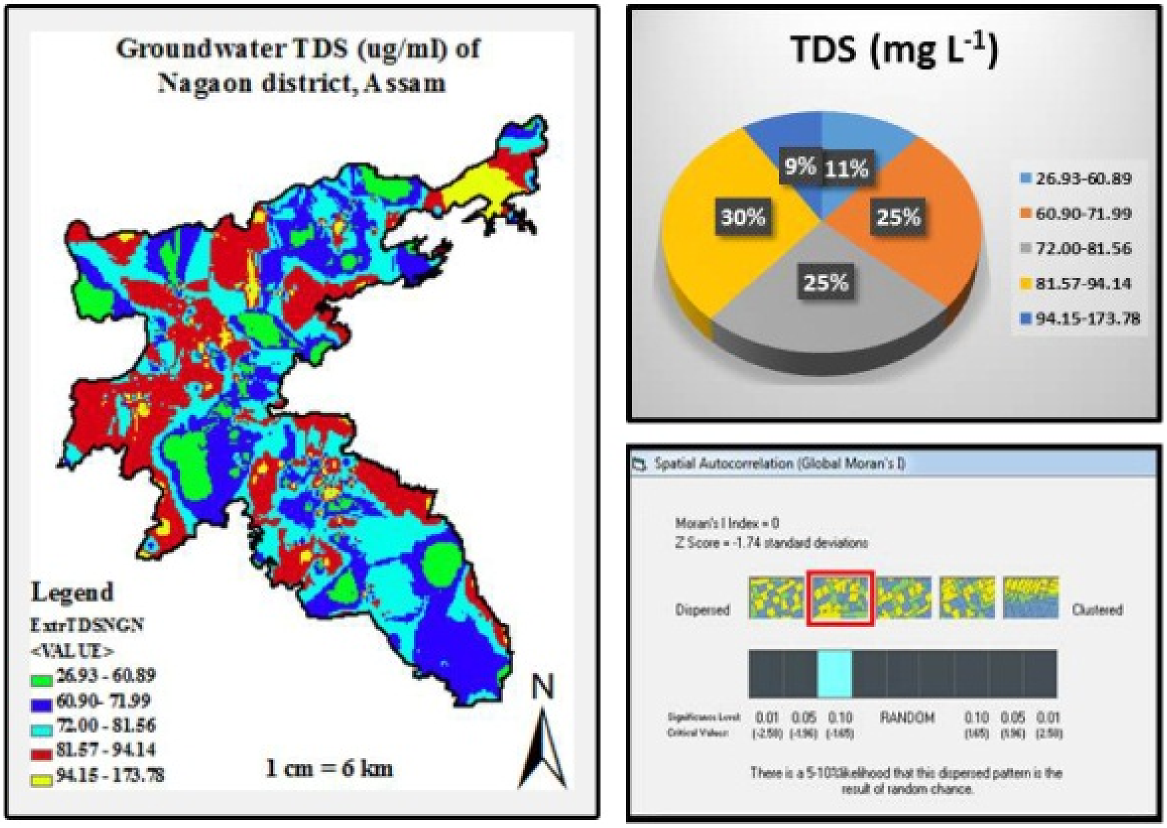
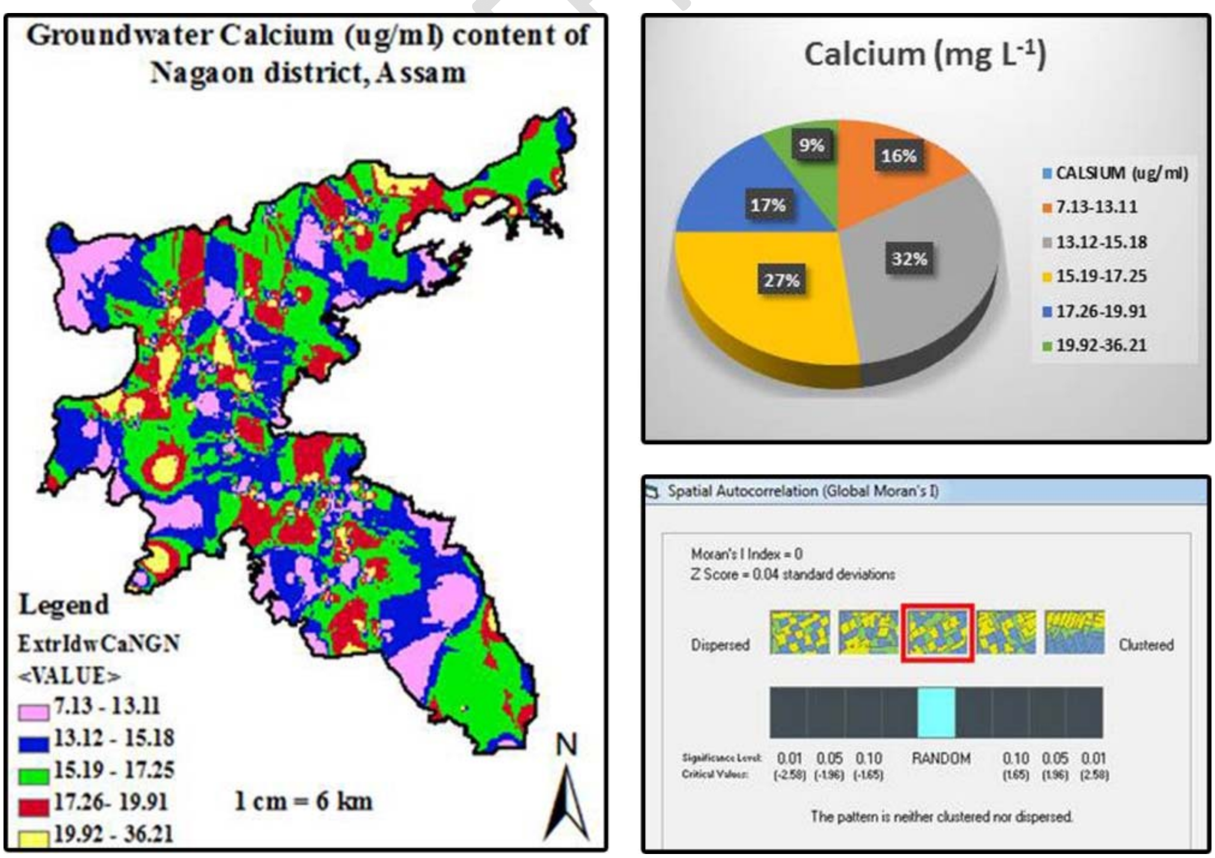



**Fig. 4. GIS map, area coverage and spatial pattern of ground water TDScontent(mg L$^{-1}$) of Nagaon district, Assam**



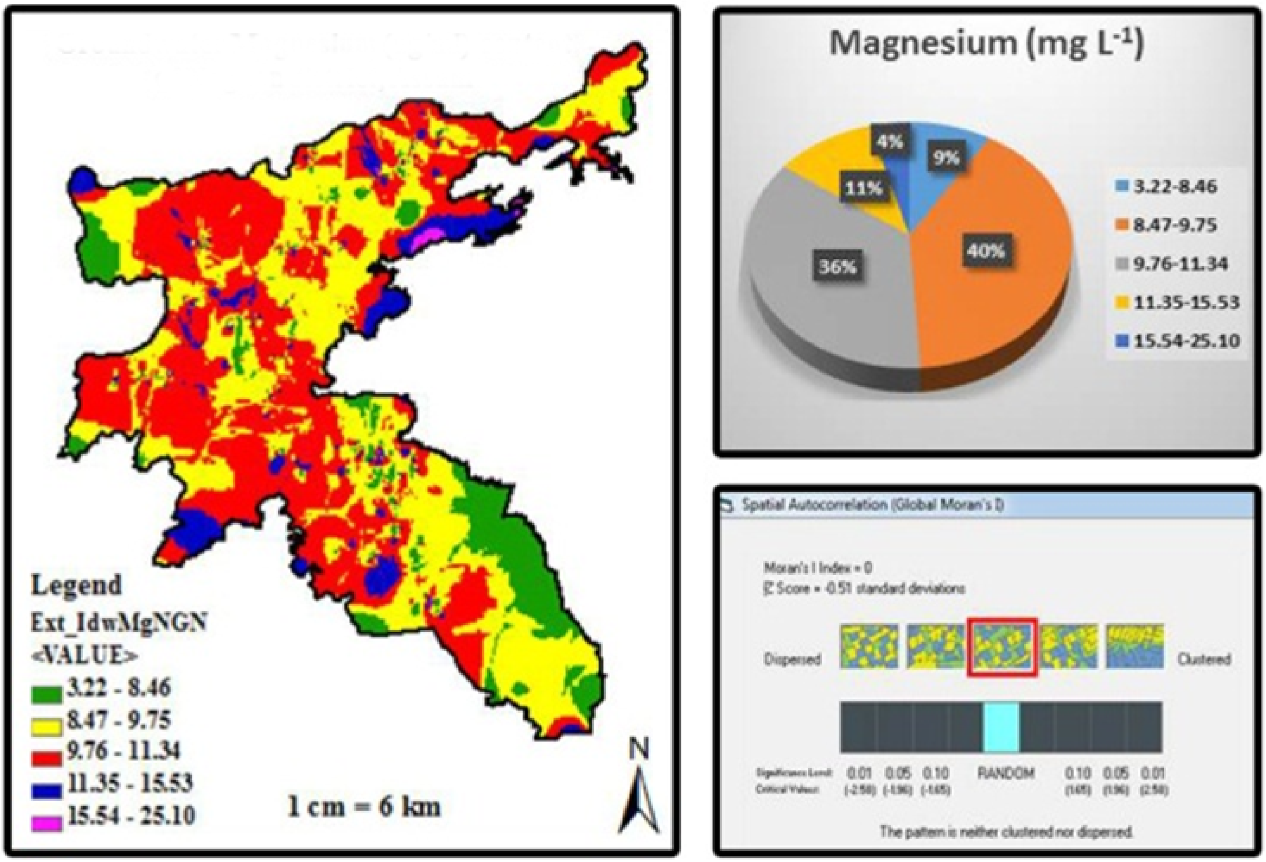



**Fig. 6. GIS map, area coverage and spatial pattern of ground water Magnesiumcontent(mg $L^{-1}$) of Nagaon district, Assam**

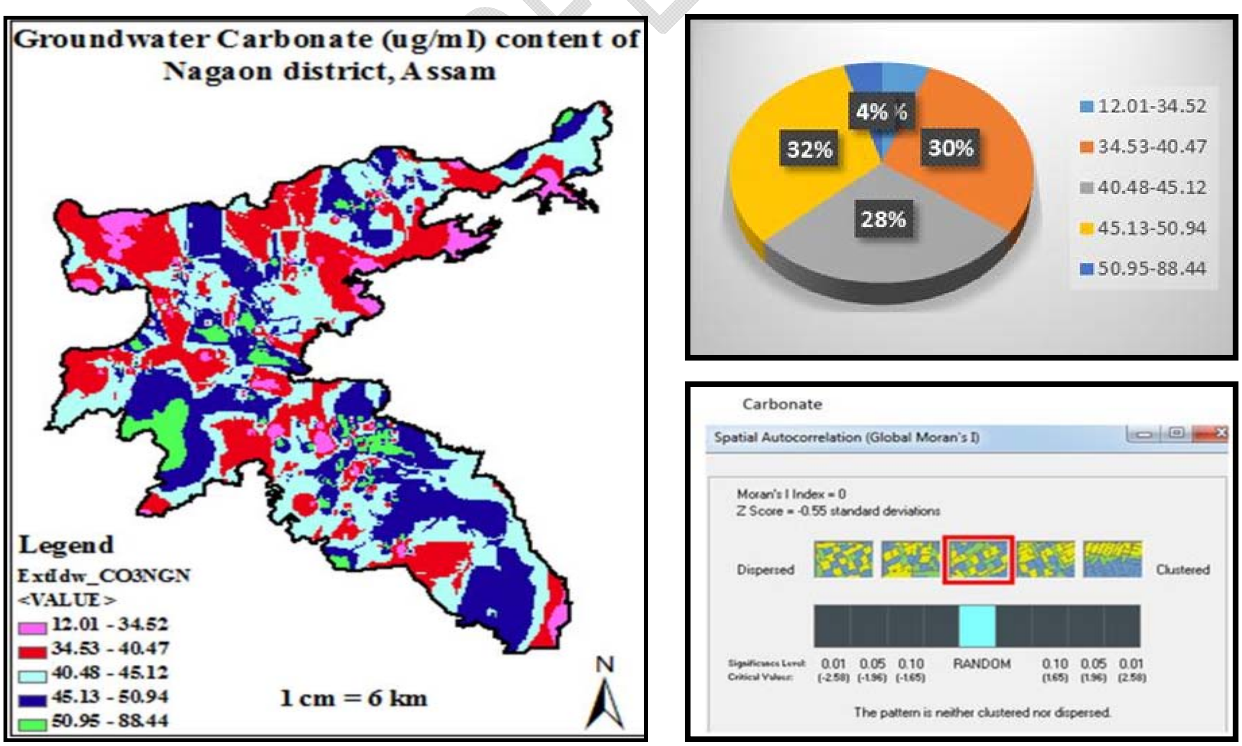



**Fig. 7. GIS map, area coverage and spatial pattern of ground water Carbonate content(mg $L^{-1}$) of Nagaon district, Assam**

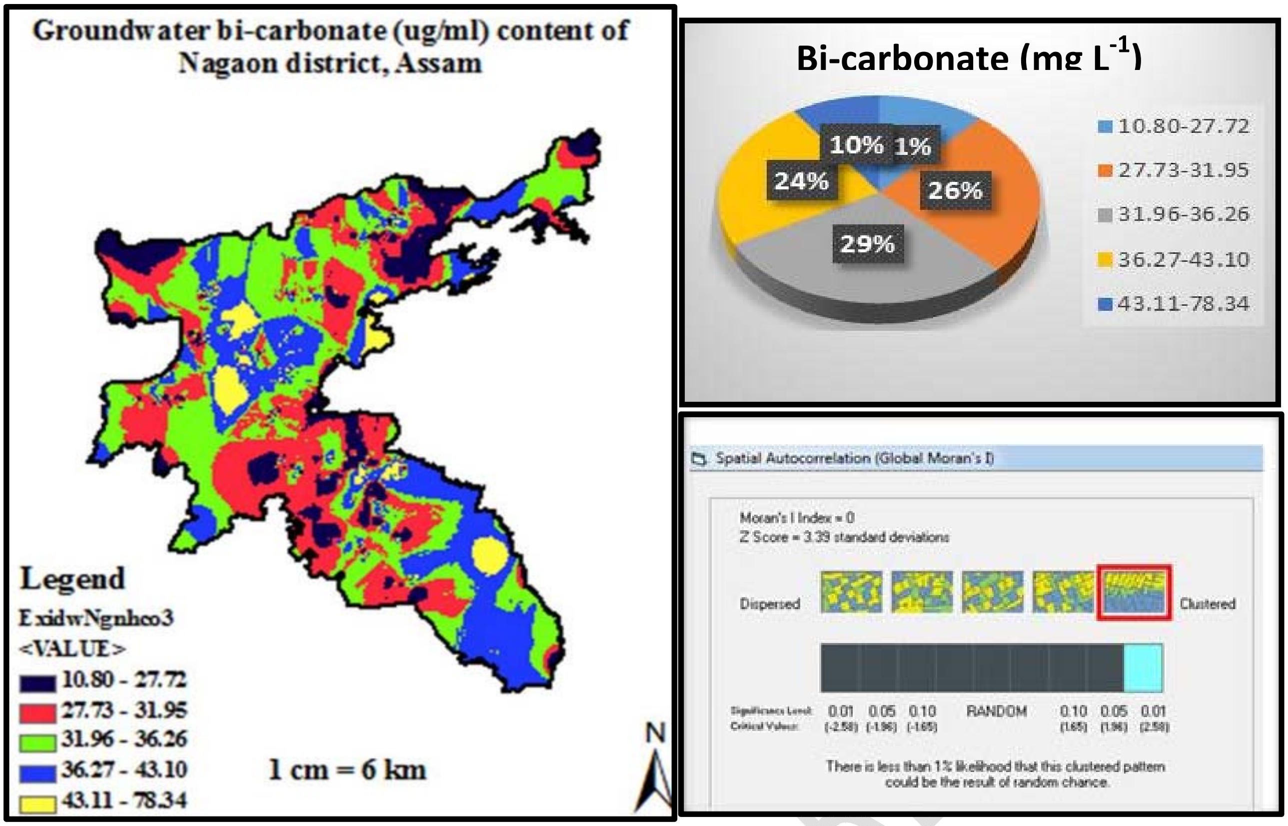



**Fig. 8. GIS map, area coverage and spatial pattern of ground water bi-Carbonate content(mg L$^{-1}$) of Nagaondistrict, Assam**

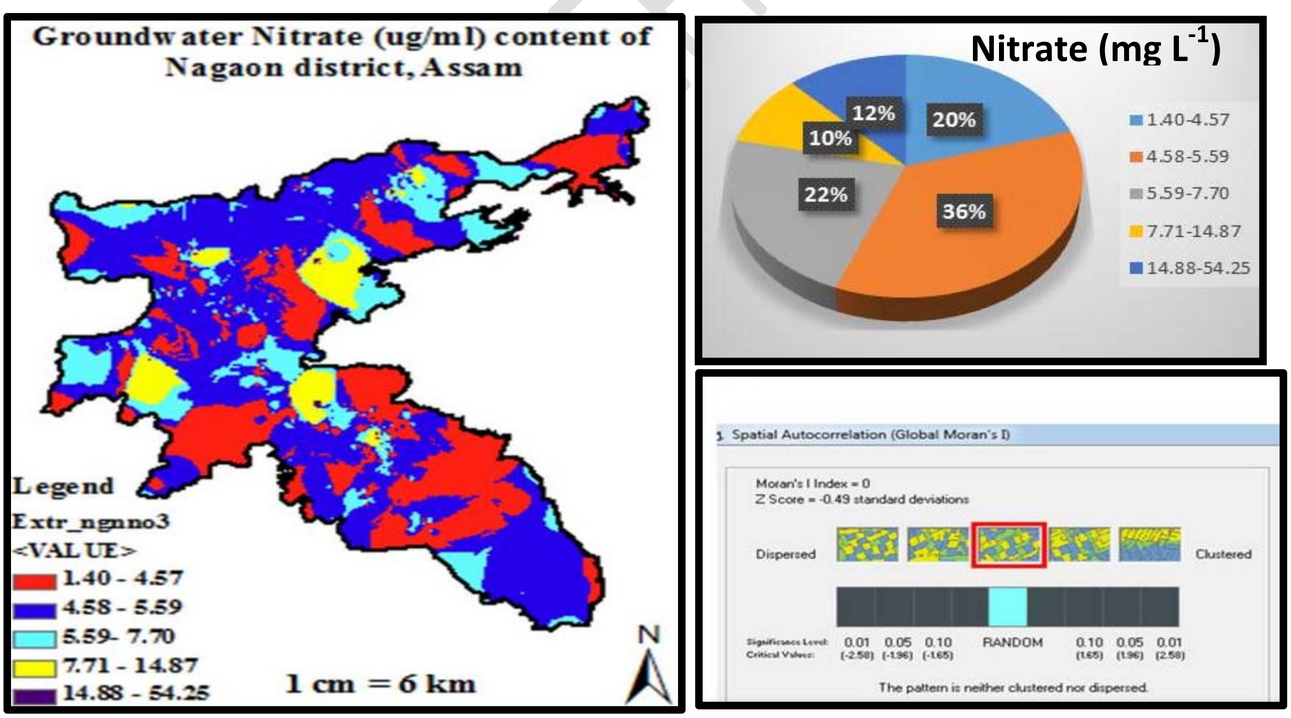



**Fig. 9. GIS map, area coverage and spatial pattern of ground water Nitrate content(mg L$^{-1}$) of**