Poll Res. 34 (2) : 417-424 (2015)

ISSN 0257–8050

GEOSTATISTICAL ANALYSIS OF GROUND WATER QUALITY INDEX AND CORROSIVITY OF WATER SUPPLY IN TEZPUR MUNICIPAL AREA USING GIS

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(Received 20 October, 2014; accepted 21 December, 2014)

ABSTRACT

A large portion of the drinking water requirements of Tezpur municipal area of Assam (India) is supplied by ground water wells. The quality of this ground water was determined by taking samples from 27 wells within a study area of 22.5 km^2. The purposes of this investigation were to provide an overview of current ground water quality and to determine spatial distribution of quality parameters in the study area using GIS tools. The thematic maps of each parameter were generated using geostatistical (Kriging) approach. Experimental values were tested for Kriging models to identify the best fitted for the eight water quality parameters (calcium, iron, nitrate, chloride, pH, TDS, total hardness and alkalinity). Concentrations of ground water quality parameters were compared with World Health Organization (WHO) and Indian Bureau of Standard (BIS) drinking water guidelines. The thematic maps of eight ground water quality parameters were used for ground water quality index (GWQI) map generation using overlay & index method. Corrosive nature of ground water was examined by using Langelier Saturation Index (LSI) model and Baylis curve procedures. The water quality indices reveal the suitability of ground water quality for drinking purposes.

KEY WORDS: Ground Water Quality Index, Geostatistics, GIS, Corrosiveness Indices, Tezpur (India)

INTRODUCTION

Ground water is the primary source of water for domestic, agricultural and industrial uses in many countries. The over dependency on ground water has led to 66 million people in 22 states at risk due to excessive fluoride and around 10 million at risk due to arsenic in six states in India (Nickson *et al.*, 2007). Ground water can become contaminated from numerous types of human activities such as residential, municipal, commercial, industrial, and agricultural usage. Ground water contamination has been recognized as one of the serious problems in north eastern Indian states of Assam (Singh *et al.*, 2008).

Geostatistical approach for assessment of quality of ground water through water quality index (WQI) studies and spatial distribution mapping for various pollutants utilizing GIS technology is important tool for developing solutions for water resources problems. It is recognized that the geostatistical approach provide unbiased predictions with minimum variance by taking account the spatial correlation between the data recorded at different locations. Geostatistical methods such as Kriging model considers the spatial correlation between the sample points and is mostly used for mapping spatial variability (Ella *et al.*, 2001; Stein, 1999). Moreover, besides interpolation, Kriging provides information on interpolation errors. Such values can be mapped to generate error surfaces which inform about the reliability of estimates. The geostatistical concepts and its applications are reported by different researchers around the world (Journel and Huijbregts, 1978; Isaaks and Srivastava, 1989; Goovaerts, 1997; Kumar and Ahmed, 2003; Webster

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and Oliver, 2007).

The main aims of this investigation are to provide an overview of present ground water quality for parameters such as pH, TDS, total hardness, alkalinity, calcium, iron, nitrate and chloride levels and determine the spatial distribution of ground water quality parameters in the study area using GIS and geostatistics techniques.

MATERIALS AND METHODS

Study Area

The city of Tezpur is an ancient city on the north banks of the river Brahmaputra and is located 171 km from Guwahati, the capital of Assam (India). The study area lies on the geographical coordinates of 26°38′0" N and 92°48′0" E. The south-east and south-west sides of the city are surrounded by rows of forested hillocks. It has humid subtropical climate with an average annual rainfall of 1870 mm and the average temperature varies from 9°C in January to 36°C in July. The total population of the municipal area of Tezpur is about 1,00,477 (Indian Census, 2011) and it is the largest of the north bank towns of Assam (India); with a surface area of 22.5 km^2. Due to the rising population and growing economy in agriculture, industry, and other sectors, the demand for fresh water is increasing rapidly in Tezpur area. As per Tezpur Municipal Board, the coverage of piped water supply in Tezpur municipal area as well as in the surrounding rural area is very poor. In municipal area the coverage is only about 6.53 per cent and in rural areas the coverage is 7.04 per cent. To meet the remaining 93 per cent of population, ground water playing a crucial role as source of drinking water for millions of rural and urban families. Because of insidious nature of ground water pollution, it is necessary to know the spatial distribution of polluted ground water as it takes many years to show its full effect in the quality of water pumped from wells.

The present study covers only the Tezpur Municipal Area (TMA). The total area covered under the TMA is approximately 22.5 square kilometers and the average elevation of the city is 73 m above sea level. It is located on the northern part of the Assam state. The plain of study area is made up of alluvium consisting of clays silts and sands of varying proportions ranging from pure sand near the Brahmaputra to the stiff clay. The alluvium is believed to be underlain by younger Tertiary rocks belonging to the Oligocene-Pliocene period over the Gneissic Basement Complex.

Ground Water Sampling and Analysis

Water samples were collected directly from 27 wells from different parts of the TMA as shown in Fig. 1. Plastics containers were used for the collection of water samples and analyses were carried for water quality parameters viz. Calcium, Iron, pH, Alkalinity, Total Hardness, Sodium, Nitrate, and Total Dissolve Solids in the laboratory using standards methods recommended by American Public Health Association (APHA 1995). The physical parameters like pH, Total Dissolved Solids

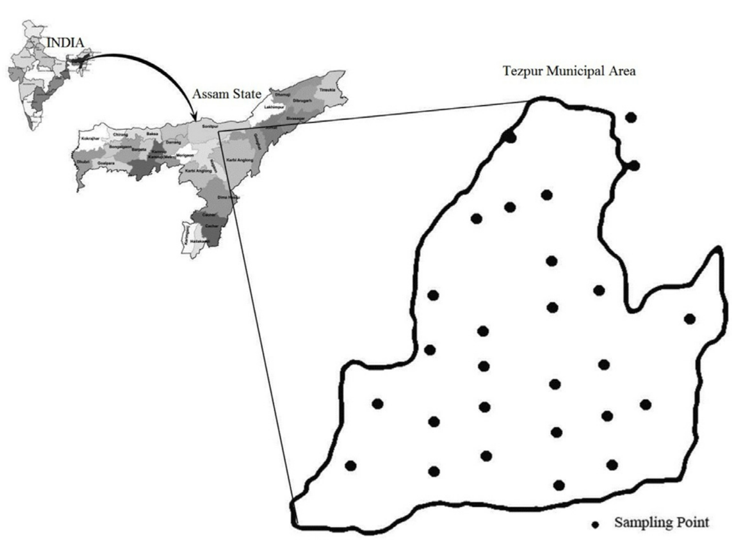

Fig. 1. Location map of the study area, Tezpur, Assam (India)

(TDS) and EC were tested in the field at the time of sample collection using portable pH meter (Eutech Instrument) and Water Testing Kit (MS Electronics, India). Analysis of Iron and Calcium was done using Atomic Absorption Spectrophotometer (Perkin Elmer, 200) whereas Nitrate content in water samples were determined using Ion Selective Electrode (Cyberscan Ion meter). All the parameters were compared with drinking water guidelines of World Health Organization (WHO) and Indian Bureau of Standard (BIS). The obtained water quality data form the attribute database which was used to generate the spatial distribution maps for the present study area.

Interpolation-GIS Model

Inverse distance weighted (IDW) raster interpolation technique of spatial analyst module in Arc GIS (2004) software was used for the present study to delineate the locational distribution of various water pollutants. The different locations of the sampling stations 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 data base file contains values of all chemical parameters in separate columns along with a sample code for each sampling station. The geo-database was used to generate the spatial distribution maps of selected water quality parameters namely pH, Alkalinity, Total Dissolved Solids (TDS), Total hardness (TH), Chlorides (Cl^-), Calcium (Ca^{2+}), Iron (Fe^{2+}), Nitrate (NO_3^-) and Water Quality Index (WQI). A systematic calculation of Karl-Pearson Correlation coefficients has also been made. Langelier Saturation Index (LSI) model and Baylis Curve was used to study the corrosivity of water supplied for drinking purposes in the study area.

Water Quality Index (WQI) Estimation

WQI is computed to reduce the large amount of water quality data to a single numerical value. WQI reflects the composite influence of different water quality parameters on the overall quality of water. The Water Quality Index (WQI) was calculated using the weighted arithmetic index method (Yisa and Jimoh, 2010). The quality rating scale for each parameter *Qi* was calculated by using the following expression-

$$Q_i = (C_i / S_i) \times 100$$

A quality rating scale (Q_i) for each parameter is assigned by dividing its concentration (C_i) in each water sample by its respective standard (S_i) and the result is multiplied by 100.

It is well known that the more harmful a given pollutant is, the smaller is its permissible value for the standard recommended for drinking water. So the 'weights' for various water quality parameters are assumed to be inversely proportional to the recommended standards for the corresponding parameters. Hence, Relative Weight (W_i) was calculated by a value inversely proportional to the recommended standard (S_i) of the corresponding parameter-

$$W_i = 1 / S_i$$

The overall Water Quality Index (WQI) was calculated by following formula-

$$WQI = \frac{\left(\sum_{i=1}^{i=n} W_i Q_i\right)}{\left(\sum_{i=1}^{i=n} W_i\right)}$$

The ground Water Quality Index map was also derived using overlay & Index method from the spatial distribution maps in GIS.

RESULTS AND DISCUSSION

Hydrochemistry of Ground Water

Analysis of water samples of the study area revealed that ground water is slightly acidic to alkaline with pH ranging from 6.17 to 7.40. Total Alkalinity ranges from 50 to 280 mg/L. Calcium is the most abundant cation with concentrations ranging from 3.71 to 70.61 mg/L. Total hardness is varying from 13.31 to 241.52 mg/L, and TDS was in the range of 112.5 - 480 mg/L. Among anions, Chloride was present in the range of 0.00 to 53.17 mg/L. The concentration of Nitrate (0.05- 2.80 mg/L) was found below the permissible limit of BIS for drinking water. As per BIS guidelines, the concentration of iron was found beyond permissible limit (0.3 mg/L) in some location (15.17%) of the study area. The Iron concentration in ground water ranges from 0.03 to 0.80 mg/L. The statistical value of different water quality parameters used in the study is presented in Table 1.

Box plots were also used to represent temporal concentration of the water quality parameters (Fig. 2). 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.

Table 1. Normal statistics of different water quality parameters in Tezpur area of Assam (India)

	T-Alkalinity (mg/L)	T-Hardness (mg/L)	Ca^{2+} (mg/L)	TDS (mg/L)	NO^{2-}_3 (mg/L)	Fe^{2+} (mg/L)	Cl^- (mg/L)	pH
Minimum	50	13.3	3.7	112.5	0.05	0.03	0.00	6.17
Average	142.7	125.6	28.5	267.8	0.63	0.20	7.92	6.58
Maximum	280	241.5	70.6	480	2.80	0.80	53.2	7.40
Standard Deviation	62.8	67.6	17.4	98	0.50	0.20	11.6	0.30
Coefficient of Variation	44	53.8	60.9	36.6	86.3	121.3	146.9	4.20
Median	150	124.6	25.0	280	0.60	0.10	4.80	6.50
Skewness	0.61	0.19	0.65	0.67	2.52	1.77	2.88	1.08
Kurtosis	-0.13	-0.97	-0.25	0.19	9.35	1.71	8.95	1.33
1_{st} Quartile (25_{th} percentile) Q_{25}	95	67.4	15.5	206.3	0.30	0.10	2.50	6.40
3_{rd} Quartile (75_{th} percentile) Q_{75}	175	180.8	39.5	300	0.80	0.20	7.50	6.70

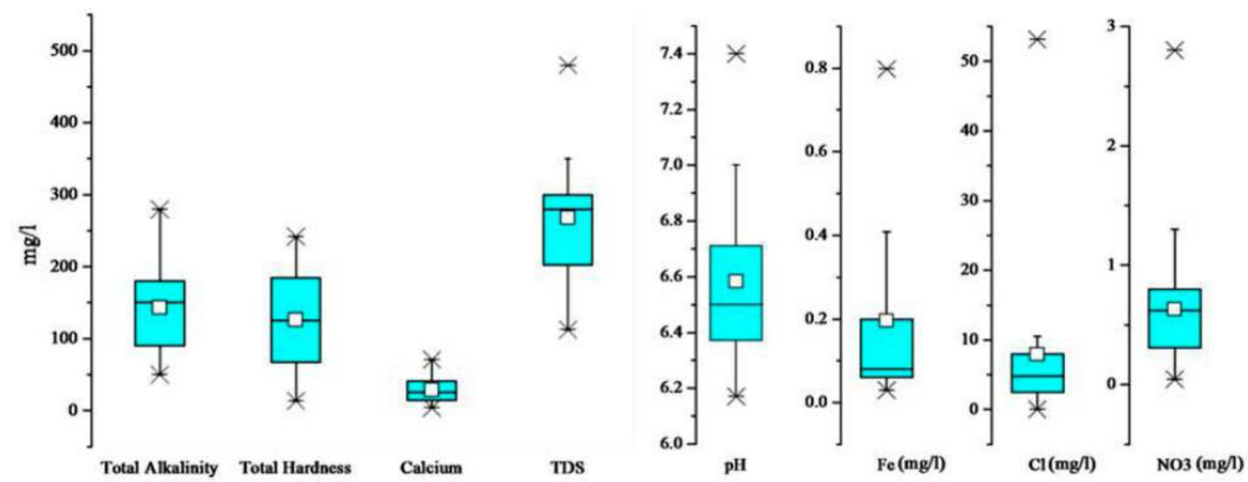

Fig. 2. Box Whisker plots of different water quality parameters

Spatial Variation of Ground Water Quality Parameters

Krigging raster interpolation technique of spatial analyst module was used in the present study to delineate the spatial distribution of various water quality parameters. The spatial distribution map (Fig. 3a and Fig. 3b) clearly reveals that the water quality levels at some places are poor with respect to the measured quality parameter like Iron, Total Alkalinity, Total hardness and pH. The result indicates that the concentrations of iron were above the drinking water standard mainly in central, north and south west portion of the study area. Similarly, the thematic maps of TDS, Calcium, Nitrate and Chloride were also generated using the corresponding best-fitted model. The concentration of these water quality parameters was found within the permissible limit as per the guideline of BIS for drinking water.

Ground Water Quality Index (WQI)

WQI is computed to reduce the large amount of water quality data to a single numerical value. It reflects the composite influence of different water quality parameters on the overall quality of water. It is a very useful tool for communicating the information on the overall quality of water (Akoteyon *et al.*, 2011). The standards for purposes of drinking have been considered for the calculation of WQI as recommended by BIS (2005) and WHO (1999).

Ground water quality index map is derived from eight thematic layers of water quality parameters. These maps were processed in GIS environment to get the output map (WQI map) as shown in Fig. 4. The water quality index was reclassified into four classes that describe the quality of ground water in the studied region. These four classes are: excellent, good, moderate, and poor. The ranges and class of

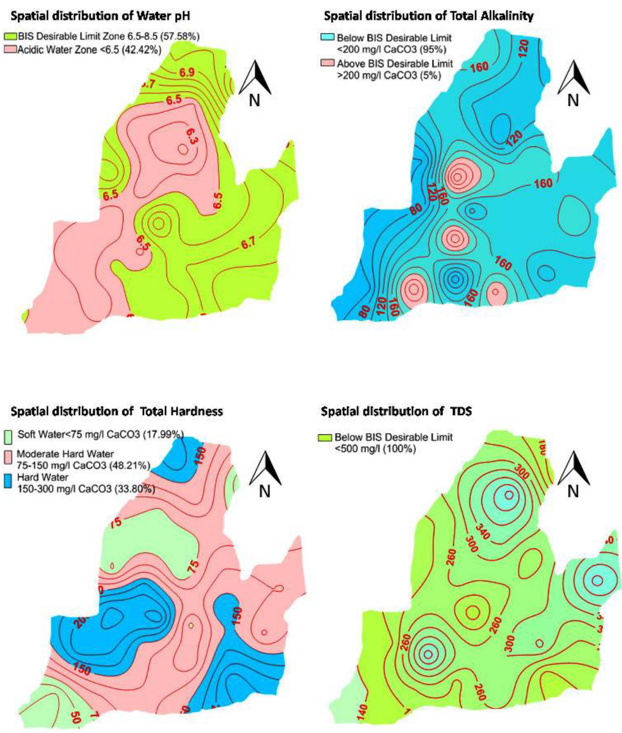

Fig. 3a. Spatial distribution map of ground water quality parameters (pH, T-Alkalinity, T-hardness and TDS)

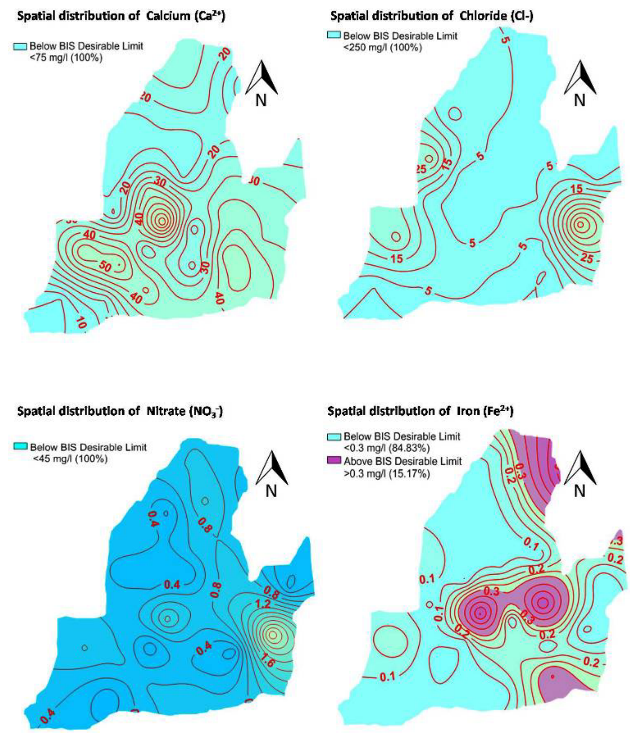

Fig. 3b. Spatial distribution map of ground water quality parameters (pH, T-Alkalinity, T-hardness and TDS)

the ground water quality index of WQI map is given in Table 2. According to the results of the ground water vulnerability assessment, the study area can be divided into three types of zones: Excellent water quality (52.14%), Good water quality (30%), and Moderate water quality (16.23%).

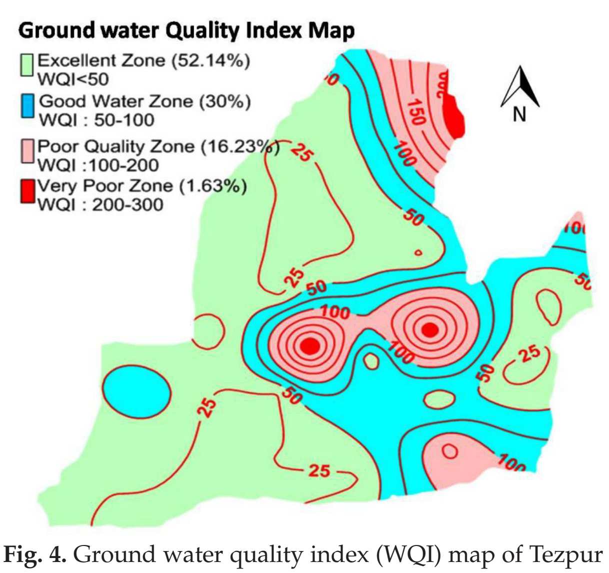

Fig. 4. Ground water quality index (WQI) map of Tezpur municipal area of Assam (India)

Table 2. Water quality classification based on WQI value in Tezpur area of Assam (India)

WQI range	Water Quality Class	Percentage of Area
< 50	Excellent	52.14
50-100	Good	30.00
100-200	Moderate	16.23
>200	Poor	1.63

Correlation Matrix for Different Ground Water Parameters

A systematic calculation of Karl-Pearson Correlation coefficients was also done and shown in Fig. 5. Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables. Pearson's correlation coefficient is a measure of linear association among different variables (Pearson, 1896). Correlation coefficient ranges between -1 (a perfect negative relationship) and +1 (a perfect positive relationship). A value of 0 indicates no linear relationship. If the correlation coefficient is nearer to +1 or -1, it shows the probability of linear relationship between the variables. Since the directions of association of the measured variables are unknown in advance, the significance of the observed correlation coefficients have been tested by using 't--test'.

Results of correlation coefficient matrix between studied water quality parameters of ground water are presented in Table 3. A good relationship was observed between Ca^{2+}-TH, Fe^{2+}-pH and NO^{2-}_{3}-Cl^{-} (r = 0.79, 0.64 and 0.60). A comparison of the depth of the hand pumps and tube wells installation indicated that deep installations were better than the shallow installations with respect to the water quality in the study area. Out of a total of 36 correlations between water quality parameters, 3 were found to have significant at the 0.01 level (TH-Ca^{2+}, Fe^{2+}-pH and NO^{2-}_{3}-Cl^{-}). The inverse correlations were found in 18 cases.

Corrosivity of Water Supply

Domestic water supply is considered stable when it is just saturated with calcium carbonate. In this condition the water will neither dissolve nor deposit calcium carbonate. Thus, in this water the calcium carbonate is in equilibrium with the hydrogen-ion concentration. If the pH of water is raised from the equilibrium point (pHs), the water becomes scale forming and will deposit calcium carbonate. If the pH is lowered from the equilibrium pH point the water turns corrosive. Further, if corrosion is not prevented then it can also damage hand pumps, tube wells and degrade the performance of water distribution with component failure.

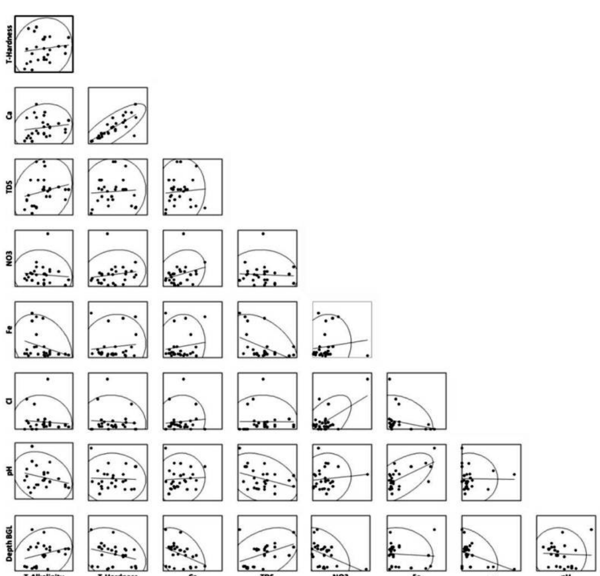

Fig. 5. Pearson's correlation plots between different water quality parameters

Although a variety of useful corrosion indexes have been developed, the Langelier Saturation Index (LSI) is the most commonly used measure (Langelier, 1936). The LSI is a calculation that compares the actual pH to a theoretical pH based on physical and chemical properties of ground water (AWWA, 1982). The LSI values range from negative to positive. Negative numbers indicate a potential for corrosion and positive numbers predict scale formation. Values close to zero indicate that the water is balanced and there should not be problems from either corrosion or scaling. The intensity of either corrosiveness or scaling can be predicted using the LSI range values (Singley *et al.,* 1984).

According to the analysis of ground water of the study area, all LSI values (Fig. 6) were found negative and ranged from -0.81 (mild corrosive but non-scale forming) to -3.07 (serious corrosive). This means that the water is undersaturated with calcium carbonate at ambient temperature and it is corrosive. In order to see the severity of corrosion in different parts of the studied area, GIS map has also been developed from the calculated value of LSI and presented in Fig. 7. According to the LSI criteria of corrosion and scaling, 13.75 per cent area of the study area fall under LSI value between -0.5 to -1.0 (mild corrosion), while 84.40 per cent area fall under LSI limit between -1.0 to -3.0 (moderate corrosive nature). Remaining 1.85 per cent area of the city has LSI values between -3.0 to -5.0 (very severe corrosive zone). The severity of corrosion is more noticeable in north-central, south-west and south segment of the studied area.

Baylis curve procedure was also used to detect whether the pH and alkalinity are properly adjusted to produce stable and noncorrosive water. Baylis (1926) provided a tool for establishing chemical feed rates in order to avoid deposition and corrosion in the water supply line. Plotting the pH and alkalinity of the water on this graph indicates whether the water is corrosive or not (Ripp, 1991). If the point where the pH and alkalinity cross is below the curve (brown area), the water is corrosive and will attack metal tanks and pipes in the water supply system. If the point is above the curve, the water is not corrosive but does have excessive amounts of alkalinity present, which will cause the formation of lime scale in the lines (light blue area). When the point falls within the neutral water area (purple area), the water is stable and will not cause corrosion problems. In the present study, water quality parameters reflected on the Baylis curve (Fig. 8) also indicates corrosive nature of ground water in the study area.

CONCLUSIONS

Ground water is an essential water source in the area of study and approximately 93 per cent of the water consumption is being supplied from ground water wells. Geostatistical analyses were carried out for distribution analysis of various water quality parameters. Results showed that deterioration of ground water quality in study area is not very serious problem except few areas. The water quality index (WQI) map clearly reveals the suitability of ground water quality for drinking purposes. About 82 per cent of ground water wells come under excellent to good category as revealed by the WQI studies. The results of Langelier Saturation Index (LSI) and Baylis curve indicated that ground water is mild to moderate corrosive in nature. Using

Table 3. Multivariate analysis between different water quality parameters

		TA	TH	Ca^{2+}	TDS	NO^{2-}_3	Fe^{2+}	Cl^-	pH	Depth (BGL)
TA	Pearson Correlation	1.00								
	Significance (2-tailed)									
TH	Pearson Correlation	0.14	1.00							
	Significance (2-tailed)	(0.49)								
Ca^{2+}	Pearson Correlation	0.15	0.79**	1.00						
	Significance (2-tailed)	(0.45)	(0.00)							
TDS	Pearson Correlation	0.24	0.06	0.07	1.00					
	Significance (2-tailed)	(0.22)	(0.75)	(0.71)						
NO^{2-}_3	Pearson Correlation	-0.09	0.17	0.30	-0.06	1.00				
	Significance (2-tailed)	(0.65)	(0.39)	(0.13)	(0.79)					
Fe^{2+}	Pearson Correlation	-0.30	0.11	0.14	-0.45*	0.13	1.00			
	Significance (2-tailed)	(0.13)	(0.59)	(0.50)	(0.02)	(0.52)				
Cl^-	Pearson Correlation	-0.08	-0.07	0.09	-0.01	0.60**	-0.25	1.00		
	Significance (2-tailed)	(0.69)	(0.74)	(0.65)	(0.96)	(0.00)	(0.20)			
pH	Pearson Correlation	-0.26	-0.04	0.06	-0.36	0.10	0.64**	-0.02	1.00	
	Significance (2-tailed)	(0.18)	(0.83)	(0.78)	(0.06)	(0.60)	(0.00)	(0.93)		
Depth BGL	Pearson Correlation	0.28	-0.28	-0.41*	0.44*	-0.43*	-0.08	-0.39*	-0.04	1.00
	Significance (2-tailed)	(0.16)	(0.15)	(0.03)	(0.02)	(0.03)	(0.70)	(0.04)	(0.84)	

Note: **Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed).

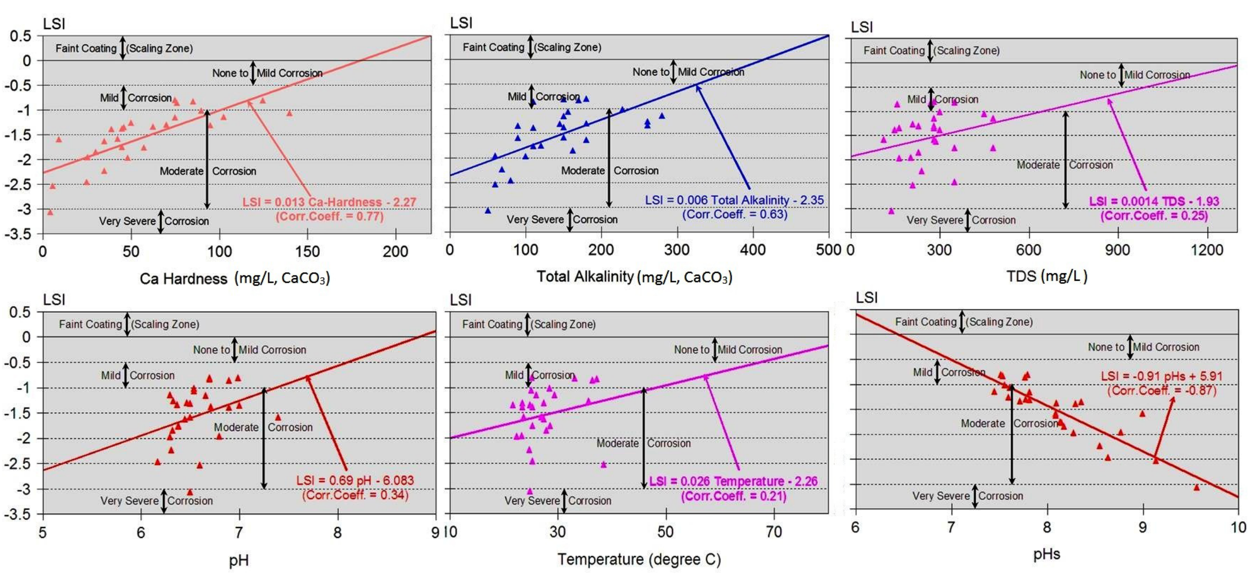

Fig. 6. Scatter plot of Langelier Saturation Index (LSI) and different water quality parameters

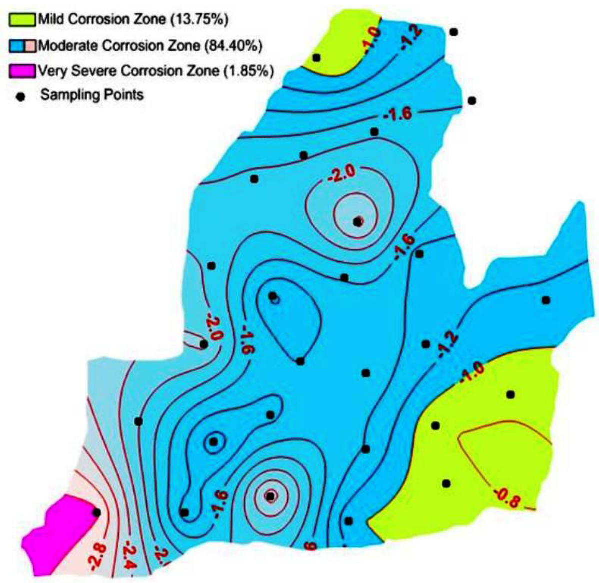

Fig. 7. LSI spatial distribution map of Tezpur municipal area of Assam (India)

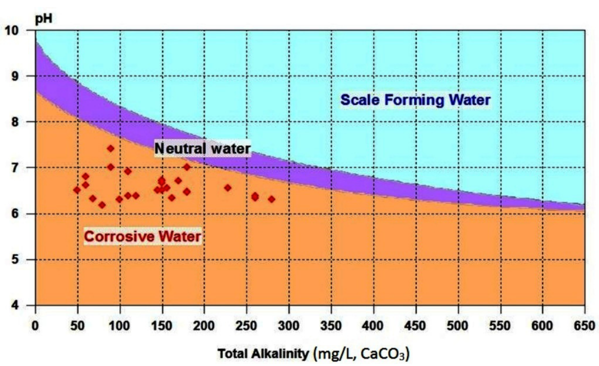

Fig. 8. Relationship between pH, alkalinity and water stability on Baylis curve

chlorinated polyvinyl chloride (CPVC) pipes in the house and non-corrosive fixtures may eliminate corrosion related problems in water distribution system. The study illustrates the geostatistical techniques for water quality assessment and investigating spatial variations of water quality as an effort toward a more effective ground water quality management.

REFERENCES

Akoteyon, I.S., Omotayo, A.O., Soladoye, O. and Olaoye, H.O. 2011. Determination of water quality index and suitability of urban river for municipal water supply in Lagos-Nigeria. *Eur. J. Sci. Res.* 54 (2) : 263-71

ArcGIS. 2004. *GIS software, version 9.0*. ESRI, New York.

APHA. 1995. *Standard Methods for the Examination of Water and Waste Waters.* American Public Health Association, 16th Edition, New York.

AWWA Research Foundation, 1982. *Research News: Corrosion Control*, No. 32. Colo: Denver.

Baylis, J.R. 1926. Factors other than oxygen influencing the corrosion of iron pipes. *Ind. Engg. Chem.* 18 : 370

BIS. 2005. *Bureau of Indian Standards, Drinking Water Specification*. IS10500:2004. 2nd Revision, ICS No. 13.060.20.

Ella, V.B., Melvin, S.W. and Kanwar, R.S. 2001. Spatial analysis of NO_3-N concentration in glacial till. *Transact. ASAE.* 44 : 317-27.

Goovaerts, P. 1997. *Geostatistics for Natural Resources Evaluation*. Oxford University Press, New York.

Isaaks, E.H. and Srivastava, R.H. 1989. *An Introduction to Applied Geostatistics*. Oxford University Press, New York.

Journel, A.G. and Huijbregts, C.J. 1978. *Mining Geostatistics*. Academic Press, London.

Kumar, D. and Ahmed, S. 2003. Seasonal behaviour of spatial variability of ground water level in a granitic aquifer in monsoon climate. *Curr. Sci.* 84 : 188-96.

Langelier, W.F. 1936. The analytical control of anticorrosion water treatment. *JAWWA*, 28 : 1500-21.

Nickson, R., Sengupta, C., Mitra, P., Dave, S.N. and Banerjee, A.K. 2007. Current knowledge on the distribution of arsenic in ground water in five states of India. *J. Environ. Sci. Health A Tox Hazard Subst. Environ. Eng.* 42:1707-08.

Singh, A.K., Bhagowati, S., Das, T.K., Yubbe, D., Rahman, B., Nath, M., Obing, P., Singh, W.S.K., Renthlei, C.Z., Pachuau, L. and Thakur, R. 2008. Assessment of arsenic, fluoride, iron, nitrate and heavy metals in drinking water of northeastern India. *ENVIS Bulletin: Himalayan Ecol.* 16 (1) : 5-12

Stein, M.L. 1999. *Interpolation of spatial data: Some theory for kriging.* Springer, Berlin.

Pearson, K. 1896. Mathematical contributions to the theory of evolution III: Regression, heredity and panmixia. *Philos. Trans. R. Soc.* 187 : 253-318.

Ripp, Kevin M. 1991. Causes and cures of distribution system corrosion. *Opflow Publications Award. AWWA.* 17 (5) : 1-3.

Singley, J.E. 1984. *Corrosion manual for internal corrosion of water distribution systems.* USEPA. Rep. No. EPA 570/9-84-001, Office of Drinking Water, Washington, DC.

Webster, R. and Oliver, M.A. 2007. *Geostatistics for Environmental Scientists*. Statistics in practice. Wiley, Chichester.

WHO. 1999. *Guidelines for Drinking Water Quality*. World Health Organisation, Geneva.

Yisa, J. and Jimoh, T. 2010. Analytical studies on water quality index of river Landzu, *Am. J. Appl. Sci.* 7 (4): 453-458.