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Spatial Variation of Iron (Fe) Concentration in Groundwater of Greater Sylhet District Using Geostatistical Mapping

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ABSTRACT

Groundwater is one of the important and prime sources of drinking water supply in Sylhet district (a region of Bangladesh). Iron is one of the abundant pollutants that exist significantly in this region's groundwater. Here, the study signifies the spatial distribution of iron concentration across the whole district of Sylhet by using different geostatistical methods on the basis of collected data from 351 groundwater wells. The variation in the concentration of iron in Sylhet district is represented by using Geographic Information System (GIS), an effective tool used for mapping purpose. On the basis of GIS, ordinary kriging method is executed here for the estimation of groundwater iron concentration. Iron concentrations represent a normal distribution, as well as cross validation errors are within the satisfactory level. Among the five models (Spherical, Gaussian, Exponential, K-Bassel, J-Bassel) introduced by kriging in this study, the experimental variogram of groundwater iron concentration was best fitted by exponential model. The highest concentration is found in the mid region of Sylhet district as the geostatistical map signifies. Another key reason revealed from the study that, the greater the elevation of the ground surface, the higher the concentration of iron.

INTRODUCTION

Groundwater demand is increasing rapidly due to industrialization and urbanization taking place in the Sylhet district. In addition, shortage of safe surface water source in Sylhet district also triggered this phenomenon. Groundwater is often preferable as it is less prone to chemical and biological pollution (Yusuf 2007, Hassan 2008).

In Bangladesh 90% of the drinking water (Mridha et al. 1996) and 75% of the irrigation water (Shahid et al. 2006) comes from groundwater. As a result, the importance of using safe water free from pollutants is not only the real issue of developed countries, but also a crucial fact in Bangladesh as well as in Sylhet district. The groundwater is one of the easily available and reliable sources, not only for drinking, but also for irrigation purpose. Groundwater, depending on their source and origin, contain different mineral salts and chemical compounds such as iron, manganese, calcium, fluoride, etc.

The study (Hossain & Huda 1997) of iron content in groundwater incorporates with analysing 1000 deep tube walls, covering around 86% of the total area of Bangladesh, suggested that about 41% and 22.5% of the study area exceed iron concentration of 1 mg/L and 5 mg/L. So, iron is one of the abundant chemical ions existing in this region's groundwater. The study represents the geostatistical mapping of Fe concentration in the greater Sylhet district and also allowing the viewers to identify the most vulnerable areas consisting greatest Fe concentration.

Environmental studies have been greatly influenced by the use of Geostatistical mapping or the use of GIS in this particular field. A study by Ishaku et al. (2011) represents the groundwater quality using chemical indices and GIS mapping in Jada area of Northern Nigeria. Concentration of methyl-tert-butyl-ether (MTBE) was assessed using GIS in the groundwater quality of Temecula city of California (He & Jia 2004). The study by Shamsudduha (2007) compares different statistical methods for predicting the spatial variability of arsenic concentration in groundwater of Bangladesh and ordinary kriging (OK) found to be the suitable prediction model among all. The risk of NO_3 pollution and spatial variability of groundwater quality was studied (Hu et al. 2005) effectively and efficiently. As the GIS has proven to be a better tool to identify any specific criteria, it has been predominantly used in this research to find out the variation in the concentration of iron (FE) in the ground water of Sylhet region.

STUDY AREA

The Sylhet district is situated at north-eastern side of Bangladesh and it is subdivided into twelve upazillas (Balaganj, Beanibazar, Bishwanath, Companiganj, Fenchuganj, Golapganj, Gowainghat, Jaintiapur, Kanaighat, Osmani Nagar, South Surma, SylhetSadar and Zakigonj). Total area of Sylhet district is 3452.07 km^2. Sylhet has the most complex and diverse topography apart from other regions of Bangladesh (Wikipedia). The terrain type is hilly and it has the border line with some States (Assam, Meghalaya, Tripura) of India in the east side of the district. The average annual rainfall is 3334 mm and the climate is considered as humid subtropical type. The study is conducted in 351 tube-wells around the whole district of Sylhet, as shown in the Fig. 1, for three consecutive years (2011-2013) and Fe concentration of groundwater was measured by laboratory analysis.

MATERIALS AND METHODS

Geostatistical analysis steps: The groundwater level data were collected from Department of Public Health Engineering (DPHE) and sorted these into two parts (wet & dry session based). The normal distribution checking was performed by histogram tool and QQ plot. In addition, trend analysis of the collected data was also checked and formed. kriging method, a well-known tool used in the geostatistical analysis, was executed here to generate five types of variogram. Among the variogram models generated with the groundwater data, the most suitable one was selected based on comparing different prediction errors of those models. At the end, groundwater surface map of the best model was constructed and compared with the Digital Elevation Model (DEM).

Geostatistics: In the process of using geostatistics in this research, semivariogram that has been proven as an essential tactic (Issaks & Srivastava 2001, Goovaerts 1997), was used here to quantify differences between sample data values as a function of their separation distance, h. The experimental semivariogram, y*(h) is calculated as follows:

$$y^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad ...(1)$$

In the equation (1), where N(h) is the number of sample pairs that are separated by a vector h, $z(x_i)$ and $z(x_i+h)$ are values of the variable z at locations of x_i and x_i+h respectively. However, for kriging analysis, an appropriate theoretical model should be used to fit the experimental data. In this study spherical, exponential, Gaussian, K- Bessel and J-Bessel models were used and best model among them was selected and analysed.

Ordinary kriging (OK): Ordinary kriging (OK) assumes that the mean is stationary but unknown. In addition, the OK estimator is known as the best linear unbiased estimator (BLUE) and is defined as follows (Journel & Huijbregts 1978)

$$z^*(x_0) = \sum_{i=1}^{n(u)} \lambda_i z(x_i) \ with \ \sum_{i=1}^{n(u)} \lambda_i = 1 \quad ...(3)$$

Where, $z^*(x_0)$ is the OK estimator at location x_0, $z(x_i)$ is the observed value of the variable at location xi, λ_i is the weight assigned to the known values near the location to be estimated and n(u) is the number of neighbouring observations. The values of λ_i are weighted to obtain a sum of unity, and the error variance is minimized as follows:

$$\begin{Bmatrix} \sum_{j=1}^{n(u)} \lambda_i \, \gamma\left(x_i, x_j\right) - \mu = \gamma(x_i, x_j) \quad j = 1, \ldots, n(u) \\ \sum_{j=1}^{n(u)} \lambda_j = 1 \end{Bmatrix} \quad ...(4)$$

Where, μ is the Lagrange coefficient for minimizing the OK estimation variance, $\lambda(x_i, x_j)$ is the average semivariogram value between the observed values, and $\gamma(x_i, x_0)$ represents the average semivariogram value between the location x_i and the location to be estimated (i.e., x_0). The OK estimation variance (or standard deviation) can be used as a measure of the estimation uncertainty as follows:

$$\sigma^{2*}(x_0) = \sum_{i=1}^{n(u)} \lambda_i \, \gamma\left(x_i, x_0\right) + \mu \quad ...(5)$$

Sorting procedure of best fit model: The best fitted model was selected on the basis of Average Standardized Error (ASE) and Root Mean Square Standardized Error (RMSS). The less quantity of the value of ASE, the more the suitable model it is. RMSS value close to 1 signifies the best fit model. After cumulating, the model which tends to satisfy the above criteria selected to be the best fit one. RMSS and ASE formula is given below.

$$\mathrm{RMSSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} [\{\tilde{Z}\,(Xi) - Z\,(Xi)\}/\tilde{\sigma}\,(Xi)]^2} \quad ...(6)$$

$$\mathrm{ASE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \tilde{\sigma}^2\,(Xi)} \quad ...(7)$$

Where, $\tilde{\sigma}^2(Xi)$ is the kriging variance for location Xi.

RESULTS AND DISCUSSION

Histogram tool: The iron concentration in groundwater for the years 2011 to 2013 was checked with histogram tool and presented in the Fig. 2. As the mean and median values

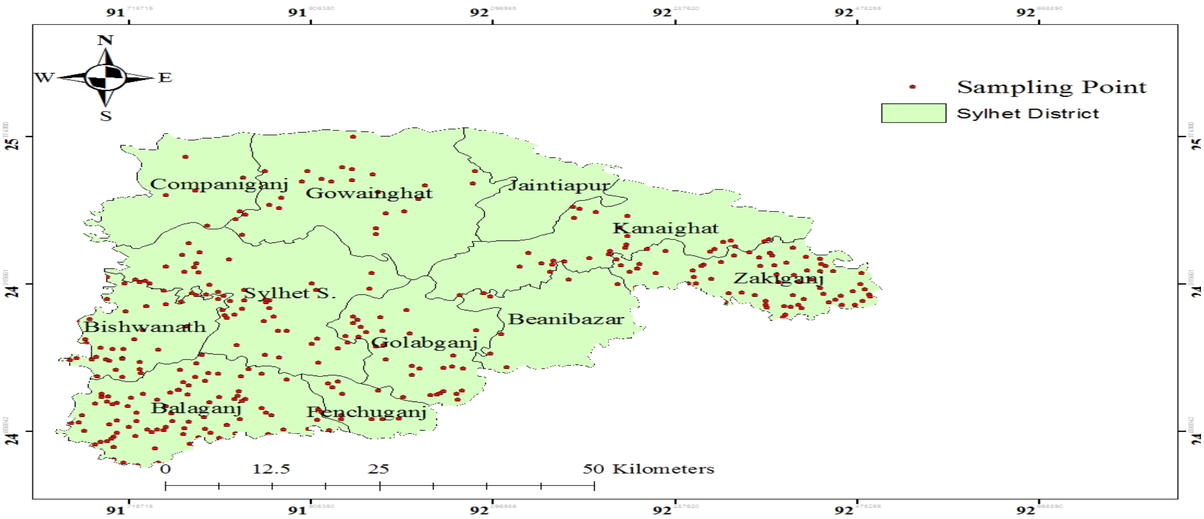

Fig. 1: Study area showing the location of groundwater iron concentrations (mg/L).

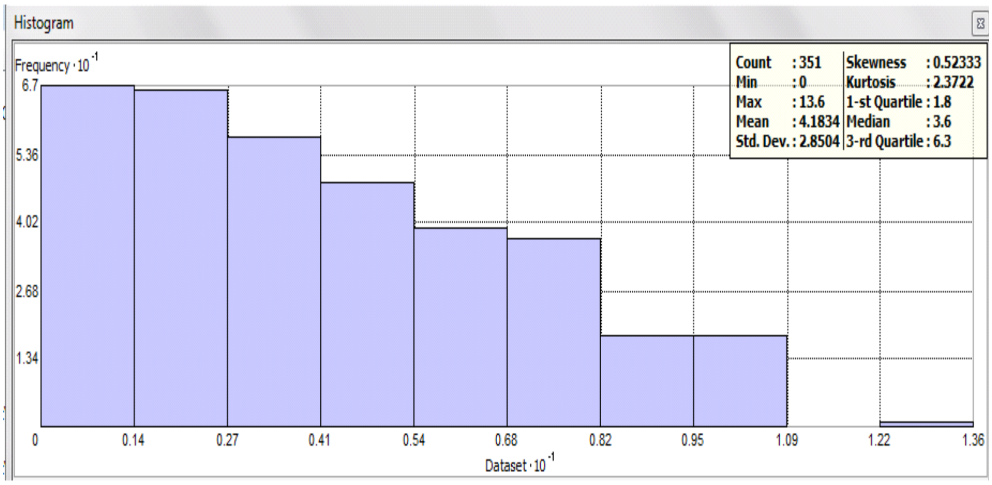

Fig. 2: Histogram plot of iron concentration (mg/L).

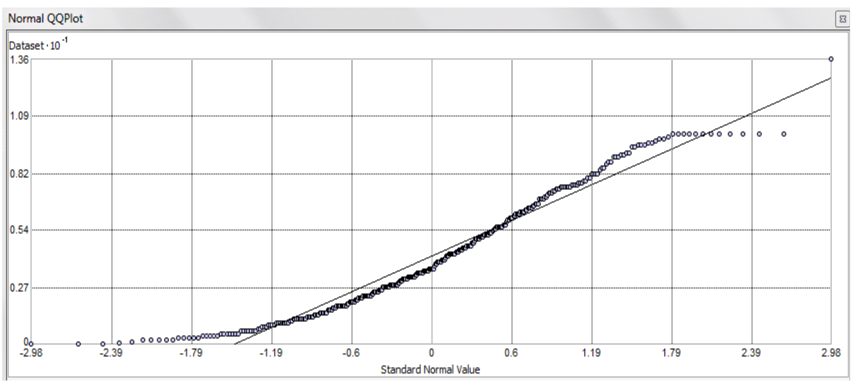

Fig. 3: Q-Q Plot of groundwater iron concentrations.

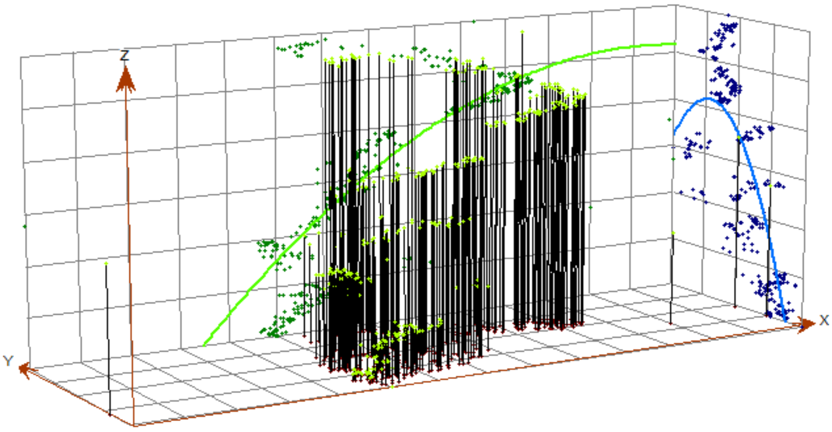

Fig. 4: Trend analysis of groundwater iron concentrations.

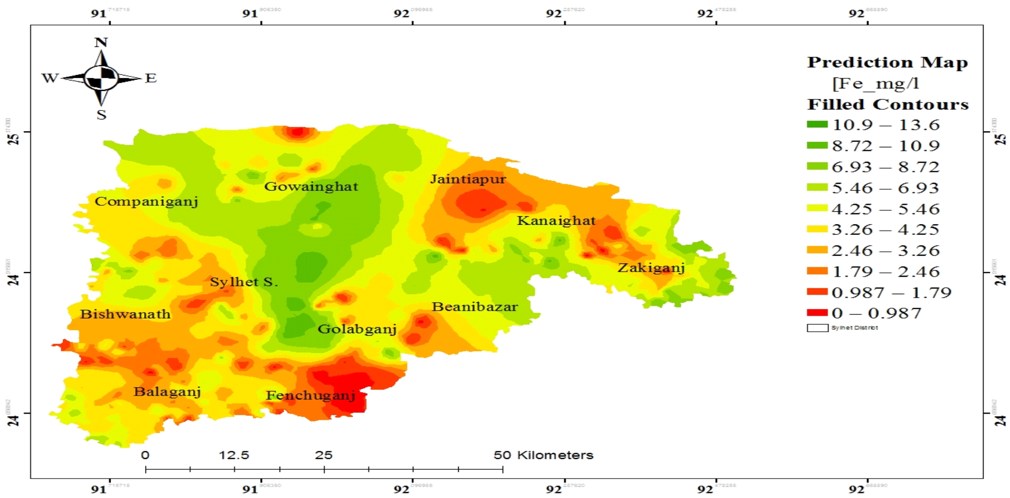

Fig. 5: Spatial distribution map of groundwater iron concentrations.

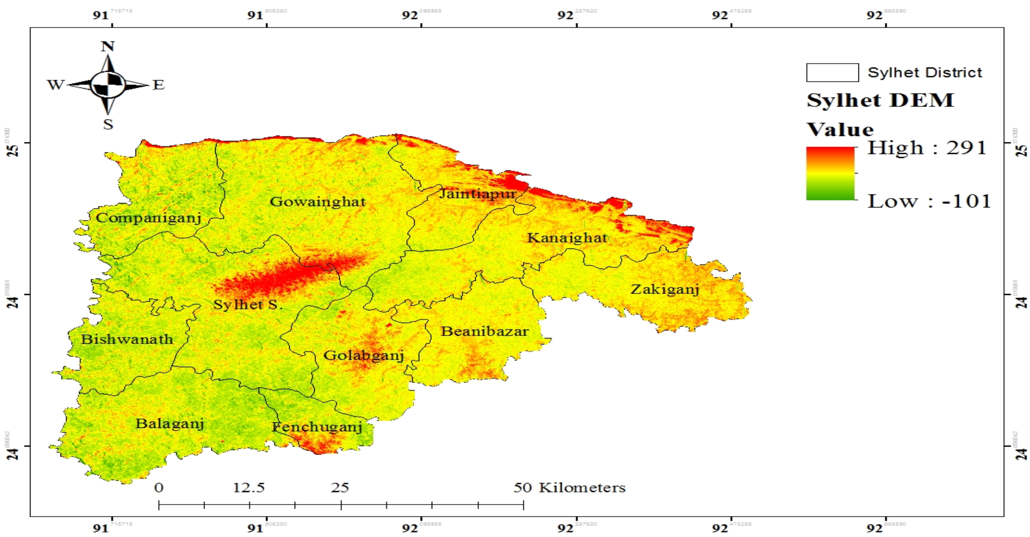

Fig. 6: Digital elevation model of the greater Sylhet district.

Table 1: Prediction errors of the groundwater iron concentrations.

Model/Error	J-Bessel	K-Bessel	Exponential	Gaussian	Spherical
Regression function	0.33x+2.67	0.33x+2.68	0.290x+2.91	0.336x+2.66	0.337x+2.67
Mean	0.0123	0.0110	0.0123	0.0096	0.0119
Root-mean-square	2.4888	2.4898	2.4860	2.4917	2.4823
Mean standardized	0.0030	0.0025	0.0031	0.0020	0.0029
Root-Mean-Square Standardized	1.0479	1.0451	1.0441	1.0453	1.0493
Average Standard Error	2.3740	2.3807	2.3355	2.3820	2.3631

Table 2: Semivariance parameters for the groundwater iron concentrations.

Type	Nugget	Major Range	Partial Sill	Nugget/Sill
J-Bessel	5.007369	0.230106	2.965155	1.688738
K-Bessel	5.016367	0.176248	3.186702	1.574156
Exponential	3.008795	4.551061	4.819176	0.624338
Gaussian	4.038484	3.118339	5.019176	0.804611
Spherical	4.449962	3.630714	5.019176	0.886592

become very close and that is the reason of not transforming the data into log form. All the data for other years are checked with histogram tool. The untransformed data of iron concentrations were plotted in the above figure with a normal distribution curve. This showed that the statistical distribution of the untransformed data for groundwater iron concentrations was positively skewed. Skewness and kurtosis represents the spreading of data. The skewness value close to zero means it matches with the normal distribution.

Q-Q plot: The Q-Q (probability-probability) plot is another useful tool to check the normality of the distribution of groundwater iron concentrations showed in Fig. 3. The Q-Q plot represents here the clusters of data around the straight line and signifies the normal distribution of data (Wang et al. 2009).

Trend analysis: Global trend of input data is identified by trend analysis. Any trend existing behind the input values has been removed for executing the kriging trend. The data on groundwater iron concentrations are plotted on trend analysis tool. By applying 30°C rotation, it is found that there is U shaped curve present. This indicated that the second degree trend is present in the data. This trend is removed for generating a smooth surface in ordinary kriging method. The trend analysis provides a three dimensional perspective of the data as shown in Fig. 4. The points are projected onto the perpendicular planes, an east west and a north-south plane. A best-fit line (a polynomial) is drawn through the projected points, which model trends in specific directions. If the line is flat, it would indicate that there would be no trend (Cay & Uyan 2009). But it appears a quadratic trend at the white and black lines (Fig. 4). We saw that the data exhibited a trend using the ArcGIS Trend Analysis tool in Fig. 4.

The five models (J-Bessel, K-Bessel, Exponential, Gaussian, Spherical) generated with groundwater iron concentration performed fairly well and their cross-validation parameters were compared with each other. The Root Mean Square Standardized Error (RMSS) of exponential model is nearly adjacent to 1 than any other model given in Table 1, and that signifies the most suitable model among all.

Nugget-Sill ratio can be used in the classification of spatial dependency (Table 2). The Nugget-Sill rate of a variable less than 0.25 demonstrates that the variable has strong spatial dependency and if it is within the range of 0.25-0.75, illustrates about the variable has moderate spatial dependency. Any other value rather than these proves to be a weak spatial dependency (Ahmadi & Sedghamiz 2007). Among the model executed here, only the exponential model has the Nugget-Sill ratio (0.62434) within 0.25-0.75 (Table 2), which proves to have a moderate spatial dependency. All other models had out of range ratios of Sill-Nugget and showed weak spatial dependency.

The spatial distribution map (Fig. 5) illustrates briefly about the variation in Fe concentration in groundwater of the whole Sylhet district. The concentration of Fe was estimated by using kriging method. Iron (Fe) concentration was found to be greatest at the heart of the map, consisting Sylhet Sadar and some part of Gowainghat and Golabganj upazilla. The lowest concentration was found predominantly in the Fenchuganj and Jaintapur region. Only the lowest range showed in the map (0-0.987 mg/L) is within the permissible limit of drinking water quality standard. The permissible iron concentration is 0.3-1 mg/L (Bangladesh Standard 1997) and 0.3 mg/L (WHO 2008). In a nutshell, the map clearly indicates that most of the regions in Sylhet district are in great risk with Fe concentration and it can be used significantly to control the spreading of Fe contaminants.

Another crucial factor that has been revealed from the analysis of digital elevation map of Sylhet district (Fig. 6) was that, greater the elevation, higher the Fe concentration. The greatest elevation was found in the middle of the district (Fig. 6), and concentration of Fe also exists in higher amount at the heart of the district basically where Sylhet Sadar upazilla is situated. As the land of Sylhet district is considered as a hilly terrain, so there may be some kind of geological formation of iron (Fe) existing beneath the land. At the end, it can be easily sort out that the elevation of land is playing a significant role in the concentration of iron (Fe).

CONCLUSION

This research basically reflects the variation in concentration of iron (Fe) in the whole Sylhet district using geostatistical techniques, basically ordinary kriging. Groundwater iron (Fe) concentrations were normally distributed and exponential model sneaked the highest attention as it was the most valid model among the other four models. The spatial distribution map derived from the best suited model showed highest concentration of Fe mostly held at the middle of the district. As the middle region is found to be more vulnerable, it also got highest elevation that described delicately in the Digital Elevation Model formed by using the elevation data of the whole District.

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