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Predicting Groundwater Quality Using Geo-Statistical Approach

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ABSTRACT: The sustainable management of groundwater resources needs information on its quantity and quality in space and time. Knowledge of spatial variability of groundwater quality is essential for making reliable groundwater quality interpretations and for making accurate prediction of groundwater quality at any particular location. In this study, ground water quality of open wells was monitored in Jammu, Kathua and Udhampur districts during pre-monsoon period of 1995 to 1999. Various physico-chemical parameters viz., pH, EC, total hardness, alkalinity, chloride, nitrate, sulphate, calcium, magnesium, sodium, potassium, phosphate, etc. were determined following standard methods. Semi-variograms were developed using geo-statistical analysis for the ground water quality parameters obtained during pre-monsoon period of 1995 to 1999 to study spatial variability in the study area.

In this study, magnesium, pH and phosphate were fitted with spherical model showing distinct correlation with distance; conductance and alkalinity fitted with linear model showing moderate continuity of the variables. The semi-variograms various fitted spherical model indicated that magnesium of groundwater is spatially co-related upto a distance of 17.21 km, pH upto a distance of 55.03 km., and phosphate upto a distance of 57.1 km in the study area. A pure nugget effect was observed in the semi-variograms for calcium, chloride, potassium, sodium, nitrate, total hardness and sulphate indicating no any clear sign of spatial correlation of these variables.

In this study, kriged contour maps of different water quality parameters were developed based on various semi-variograms, which are useful to guide about prevailing groundwater quality in the study area at un-sampled locations. The results of this study would also be useful for better planning of groundwater quality monitoring network in the study area.

INTRODUCTION

Management of groundwater is very important to meet the increasing demand of water for domestic, agricultural and industrial uses. Groundwater quality deterioration is receiving much attention, particularly in densely populated regions. This has led to considerable interest in design of investigative studies and monitoring programs to describe groundwater quality over various sizes of areas. Various management measures need to know the spatial and temporal behavior of groundwater.

The knowledge of spatial variability of ground water quality is also essential for making reliable ground water quality interpretations and for making accurate predictions of ground water quality at any particular location in the aquifer. The temporal evaluation is important to monitor variation of groundwater quality particularly affected due to elapsed of time period under various anthropogenic and/or time variant geo-hydrological processes.

The study aims to analyze spatial and temporal variability of groundwater quality in Jammu, Kathua and Udhampur districts on the basis of groundwater quality data collected from shallow ground water wells during 1995–99. Twelve groundwater quality parameters (viz., pH, EC, total hardness, alkalinity, chloride, nitrate, sulphate, calcium, magnesium, sodium potassium and phosphate) were selected for this study.

STUDY AREA

The Jammu region comprises of six districts viz., Jammu, Kathua, Udhampur, Rajouri, Punch and Doda. The total geographical area of the region is 26,293 sq km and region is inhabited by 2.7 million people. The present study was conducted in Jammu, Kathua and Udhampur districts of the Jammu region for 40 open wells (Figure 1). The comparative geographical sizes of Jammu, Kathua, Udhampur districts are 12%, 10% and 17% of the region, respectively. The topography of the region lying in the Himalayas varies from foothill plains to high rugged mountains. The Region is drained by Chenab and its tributaries like Marsudhar, Bichlary, Ans and Tawi rivers. Geologically, the region very complex and consisting of number of groups of rocks ranging from Proterozoic to Recent. It comprises dolomites, quartzites, slates belonging to Proterozoic, clay and sandstone of Muree and Subathus (tertiary) and alluvium and collovium of Recent to Sub-Recent age. The lithological setup of the study area has been generalized and grouped into two broad categories of soft rock areas and hard rock areas. The soft rock areas are occupied by Siwaliks, Muree and Subathu formations comprising of slate, sandstone, boulder conglomerate, sand rock, claystone, siltstone etc. and covers 65% of the total geographical areas of the region. The hard rock areas which occupies 35% of the total area comprises mainly Proterozoic rocks represented by quartzites, phyllites, gneisses, schists, dolomite and slates. The Jammu, Kathua and Udhampur districts, are mainly occupied by soft rock formations (Mehrotra and Srivastava, 1997). The climate of the Jammu and Kathua districts is of subtropical type, and Udhampur district belongs to mountain climatic zone. The annual rainfall in the region varies from 100 cm to 140 cm, and temperature varies from –15°C to +46°C.

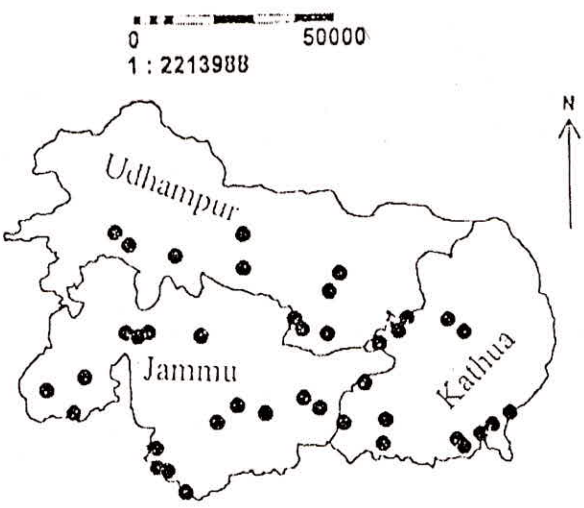

Fig. 1: Study area showing sampling sites for ground water quality monitoring

METHODOLOGY

Kriging is a geostatistical gridding technique of making optimal, unbiased estimates of regionalized variables at unsampled locations using the structural properties of the semivariogram and the initial set of data values. The variogram, $2\gamma(h)$, is the arithmetic mean of the squared difference between two experimental measures, ($Z(xi)$ and $Z(xi + h)$), at any two points separated by the vector h. For a set of N sample values,

$$2\gamma^*(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \qquad \ldots (1)$$

In which, $N(h)$ is the number of experimental pairs separated by vector h in the data. The semivariogram is calculated as,

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \qquad \ldots (2)$$

A plot of $\gamma^*(h)$ versus the corresponding value of h, also called the semivariogram, is thus a function of the vector h, and may depend on both the magnitude and the direction of h (Clark, 1979; Journel and Huijbregts, 1978). A typical variogram model represents various variogram parameters, viz. Nugget effect (C_0), sill, length/range (a), variance, pairs, etc. Nugget Effect (C_0) quantifies the sampling errors and the short scale variability (i.e. spatial variation occurring at distance closer than the sample spacing). The semivariogram (Figure 2), given in Eqn. 2 is also termed the true semivariogram of the ReV. As only one realization of the RF is available, the true semivariogram can only be estimated and this estimate is known as the experimental semivariogram. In this study, experimental semi-variograms for 12 groundwater quality parameters were computed on the basis of five years averaged values pertaining to 40 wells in Jammu, Kathua and Udhampur districts using Surfer software.

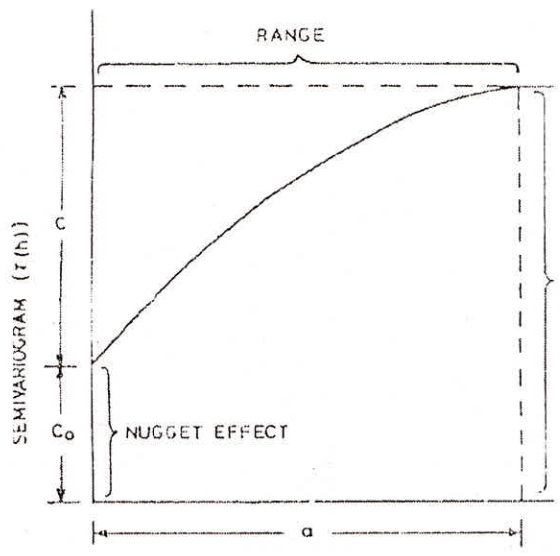

Fig. 2: A typical view of semi-variogram and its components

RESULTS AND DISCUSSION

The statistics such as the mean, variance (s^2), standard deviation (s), Coefficient of Variance (CV), skewness, minimum, median and maximum value pertaining to average groundwater quality data (1995–99) are shown in Table 1. The statistics of data show that the calcium in

Table 1: Statistics of (A) Original Data Set (av. values 1995–99) and (B) Logarithmic Data Set

Para-meters	Data Set	Ca, mg/l	Cl, mg/l	EC, milli-mhos	HCO_3, mg/l	K, mg/l	Mg, mg/l	Na, mg/l	NO_3, mg/l	pH	PO_4, mg/l	SO_4, mg/l	TH,m g/l
Mean	A	59	39	1	287	17	27	31	6.6	7.8	0.1	32	272
	B	4	3.3	–0.1	5.6	1.6	3.2	3.2	1.4	2.1	–2	3.2	5.6
Variance	A	666	1343	0.254	8927	1324	102	514	34.53	0.05	0.01	707	8602
	B	0.2	0.7	0.3	0.1	2.2	0.2	0.5	1.3	0	0.6	0.5	0.1
Std Dev.	A	26	37	0.5	94	36	10	23	5.9	0.2	0.1	27	93
	B	0.4	0.9	0.5	0.3	1.5	0.4	0.7	1.1	0	0.8	0.7	0.3
Coeff. of Var. %	A	44	94	50	33	215	37	73	89	2.8	84	83	34
	B	10	26	444	6	93	12	23	79	1.3	32	23	6
Skewness	A	1	1.6	0.5	0.3	3.1	0.6	1.3	1	0.1	1.7	1.8	0.6
	B	0.3	0.4	–0.2	–0	0.6	–1	–0	–0.8	0	–0	0.3	0.1
Minimum	A	26	6.8	0.3	119	0.4	7.6	4.5	0.1	7.4	0.02	7	147
	B	3.3	1.9	–1.1	4.8	–0.8	2	1.5	–2.2	2	–4	2	5
Median	A	51	23	0.9	275	4.3	25	24	3.7	7.8	0.1	22	255
	B	3.9	3.1	–0.1	5.6	1.5	3.2	3.2	1.3	2.1	–2	3.1	5.5
Maximum	A	128	168	2.1	464	176	54	105	20	8.2	0.4	131	486
	B	4.9	5.1	0.7	6.1	5.2	4	4.7	3	2.1	–1	4.9	6.2

groundwater ranges from 26 to 128 with a mean of 59, chloride ranges from 7 mg/L to 168 mg/L with a mean of 39 mg/L, conductance ranges from 0.3 mmhos/cm to 2.1 mmhos/cm with a mean of 1 mmhos/cm, alkalinity ranges from 119 mg/L to 464 mg/L with a mean of 287 mg/L, potassium ranges from 0.4 mg/L to 176 mg/L with a mean of 17 mg/L, magnesium ranges from 8 mg/L to 54 mg/L with a mean of 27 mg/L, sodium ranges from 4.5 mg/L to 105 mg/L with a mean of 31 mg/L, nitrate ranges from 0.1 mg/L to 20 mg/L with a mean of 6.6 mg/L, pH ranges from 7.4 to 8.2 with a mean of 7.8, phosphate ranges from 0.02 mg/L to 0.4 mg/L with a mean of 0.1 mg/L, sulphate ranges from 7 mg/L to 131 mg/L with a mean of 32 mg/L, and total hardness ranges from 147 mg/L to 486 mg/L with a mean of 272 mg/L. The details of model fits to various groundwater quality parameters are given in Table 2.

The experimental semivariogram of calcium is horizontal form at the level of variance due to lack of spatial structure and it shows no range of dependency/continuity. Most of semivariogram values scatter around the variance for all lags. Thus, the semivariogram for calcium did not have any structure (no spatial auto-correlation) and a pure nugget effect (horizontal form at the level of variance) was observed indicating a short range of variability. Semivariogram for the chloride, potassium, sodium, nitrate, total hardness and sulphate in the groundwater has been observed similar to that of calcium i.e. pure nugget effect. The nugget effect value was approximately equal to the variance of the respective observed parameter. The lack of defined structure suggests that a random sampling scheme of the groundwater could provide the information in regard to these six groundwater quality variables.

The experimental semivariogram for magnesium has a clear spatial structure (spatial dependence), with the semivariogram exhibiting nugget (C_0), sill ($C_0 + C$) and range/length (a). However, its nugget effect, or apparent failure of the semivariogram to go through the origin, is indicative of a regionalised variable that is highly variable over distances less than the sampling interval (Davis, 1986). The semivariogram for magnesium shows that the variance is reaching a constant value at a distance of about 17.21 km. The point at which semivariogram remained constant or leveled out is taken as the point where the range of dependency ends. Structural analysis has been carried out on this experimental semivariogram. Spherical model fitted for semivariogram of magnesium with nugget of 4.039, sill of 100.309 and a range of 17.21 km was found best after attempting various models and a number of iterations. A range of 17.21 km indicates that magnesium of groundwater is spatially related upto a distance of 17.21 km.

Table 2: Details of Models Fitted to Different Groundwater Quality Parameters

S.No.	*Parameter*	*Model fitted*	*Nugget (C_0)*	*Scale (C)*	*Range (a)*	*Sill*	*Variance*
1.	Ca	Pure Nugget	0.17	–	–	0.17	0.17
2.	Cl		0.75	–	–	0.75	0.75
3.	K		2.16	–	–	2.16	2.16
4.	Na		0.59	–	–	0.59	0.54
5.	NO_3		1.25	–	–	1.25	1.25
6.	TH		0.11	–	–	0.11	0.11
7.	SO_4		0.51	–	–	0.51	0.52
8.	Mg	Spherical	4.04	96.27	17.21	100	102
9.	pH		0.0	0.06	55.03	0.05	0.04
10.	PO_4		0.22	0.43	57.1	0.65	0.65
11.	EC	Linear	C_0	Slope (b)			0.25
			0.25	0.00131			
12.	HCO_3		0.07	0.000478			0.12

The semivariogram for the pH was similar to that of magnesium. In this case, a spherical model having a nugget of 0.0, sill of 0.05466 and a range of 55.03 km best fit the semivariogram. So, the pH in the groundwater was found spatially related upto a distance of 55.03 km. Similarly, semivariogram of the phosphate in the groundwater fitted spherical model with a nugget of 0.221, sill of 0.651 and a range of 57.1 km. This range indicates that phosphate of groundwater was spatially related upto a distance of 57.1 km. The above spatial structure analysis of the groundwater quality parameters indicate that the distance between observation points should be at least equal to the range of the variable to get the value of respective variables that are spatially independent.

The experimental semivariogram for the conductance was not reaching a constant value and its value goes on increasing. A linear model (moderate continuity of regionalised variable) with a nugget of 0.254 and a slope of 0.00131 was fitted the experimental semivariogram. This shape of semivariogram indicates that there is no defined range with constant semivariance. The semivariogram for the alkalinity was found similar to that of conductance, therefore, a linear model with a nugget of 0.0739 and a slope of 0.000478 was fitted the experimental semivariogram.

From this study, it may be inferred that semivariograms fitted with pure nugget (horizontal line equal to the variance) lacks spatial structure and do not show clear sign of correlation and, if any, the range must be less than the smallest spacing of 2.43 km. The semivariograms fitted with spherical model show a clear spatial structure (spatial dependence) their variances are reaching a constant value particular distance. The semivariograms fitted with linear model indicate that there is no defined range with constant semivariance and it indicates moderate continuity of the regionalised variables. The nugget effect was observed in all parameters (except pH) in this study, which indicates that all regionalised variables except pH are erratic over a very short distance that the semivariogram goes from zero to the level of the nugget effect in a distance less than the sampling interval. The semi-variogram for pH and phosphate are given in Figures 3 and 4, respectively.

Based upon the model parameters, the kriging was applied for interpolated estimation of groundwater quality variables at unsampled location. The study area was divided into 5400 grids (grid size: 54 row and 100 column) having its minimum and maximum coordinates of the wells as x, y (14.521, 5.817) and x, y (129.502, 68.249), respectively, with individual grid spacing of 1.1614 km in x-direction and 1.1779 km in y-direction. Groundwater quality was estimated at each of the grid nodes using the fitted model and average data of 40 wells obtained during (1995–99) for the various parameters. In case of variables that showed a pure nugget effect, the values were interpolated using the inverse square method of interpolation, which is designated as an exact interpolator. These estimated quality values were used with the Surfer 7 software to draw the contour maps. The kriged contour maps of the pH and phosphate are shown in Figures 5&6, respectively.

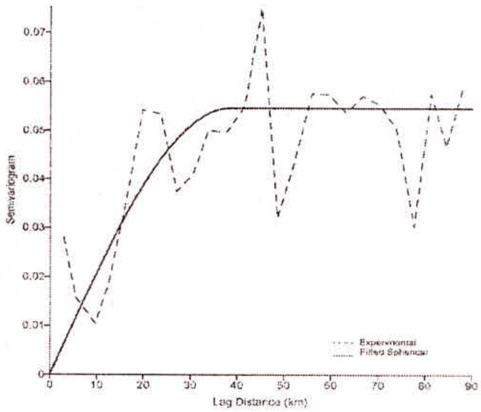

Fig. 3: Semi-variogram for pH in ground water quality under study area

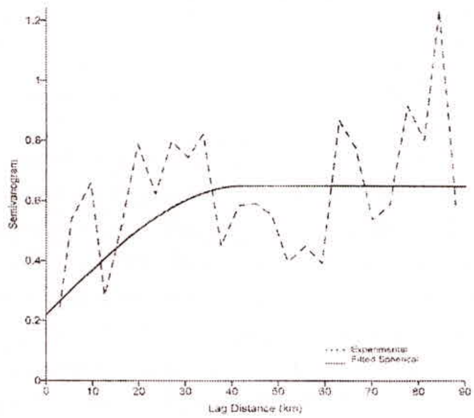

Fig. 4: Semi-variogram for phosphate in ground water quality under study area

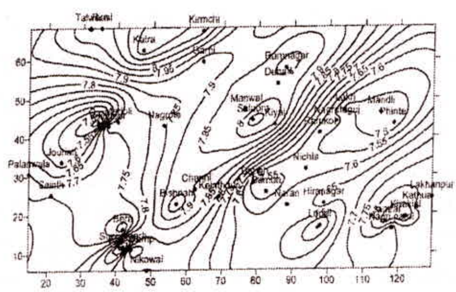

Fig. 5: Kriged contour map for pH in ground water quality under study area

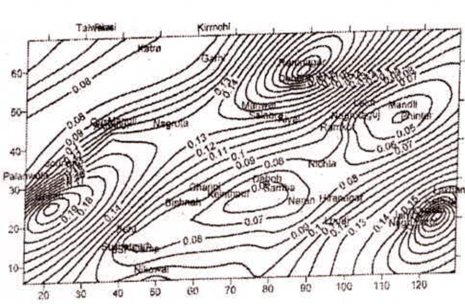

Fig. 6: Kriged contour map for phosphate in ground water quality under study area

CONCLUSIONS

In this study, geostatistical technique has been applied to study the spatial variability of 12 groundwater quality parameters in parts of Jammu region on the basis of five years pre-monsoon data. The majority of variograms (viz., calcium, chloride, alkalinity, potassium, sodium, nitrate, phosphate, sulphate and total hardness) have been computed on log transformed data except for conductance, magnesium and pH due to log-normal distribution type of data as shown in respective probability plots. Semivariograms for calcium, chloride, potassium, sodium, nitrate, total hardness and sulphate were fitted with pure nugget effect which seem to be uncorrelated with distance; magnesium, pH and phosphate fitted with spherical model, which show distinct correlation with distance; while conductance and alkalinity were fitted with linear models shown undefined range. Magnesium in groundwater is spatially related upto a distance of 17.21 km., pH upto a distance of 55.03 km, and phosphate upto a distance of 57.1 km. Thus, the semivariograms fitted with pure nugget lacks spatial structure and do not show clear sign of correlation and, if any, the range must be less than the smallest spacing of 2.43 km. The semivariograms fitted with spherical model show a clear spatial structure (spatial dependence) their variances are reaching a constant value at particular distance. The semivariograms fitted with linear model indicate that there is no defined range with constant semivariance.

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