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Assessment of Ground Water Quality using Spatial Variability Analysis

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Abstract : Groundwater is a significant source of water in many parts of India. Proper management of groundwater is very important to meet the increasing demand of water for domestic, agricultural and industrial uses. The information on the spatial variability of groundwater quality is useful for proper planning and management of groundwater resources. The knowledge of spatial variability of ground water quality is also essential for making reliable ground water quality interpretations and for making prediction of ground water quality at any un-sampled location. The spatial dependence between observations can be expressed by the semi variance, which is a measure of the average similarity between observations at a given distance apart.

In the present study, semi-variogram analysis of 12 ground water quality parameters (pH, EC, total hardness, alkalinity, chloride, nitrate, sulphate, calcium, magnesium, sodium, potassium, phosphate/fluoride) of Jammu, Kathua and Udhampur Districts was carried out for shallow ground water quality data of 40 open wells pertaining to data of 1995 and 2008, respectively. The average range values determined using above data set was found 29 km (calcium), 32.5 km (chloride), 40 km (EC), 37 km (bicarbonate), 32.5 km (potassium), 28 km (magnesium), 22 km (sodium), 31 km (nitrate), 31 km (pH), 29 km (sulphate), 36 km (total hardness), 22 km (phosphate) and 28 km (fluoride), respectively. The analysis has shown that Range/Length "a" values of semi variogram models (mostly fitted with spherical) of GWQ parameters are useful for designing appropriate GWQ monitoring network in the study area. The statistical analysis of ground water quality data has also shown increasing trend of average nitrate concentration from 7 mg/l (1995) to 19 mg/l (2008) in the shallow open wells which indicate the effect of anthropogenic/agricultural activities in the study area.

INTRODUCTION

Ground water is the main source of water supply for domestic purposes in rural as well as in urban areas of the country. The role of ground water is equally important for agriculture, industries and various other uses. Generally, the quality of ground water is considered to be relatively good in comparison to surface water, however, nowadays, this fact is losing merit. In monitoring and evaluation of the effects of point source contamination of ground water, information on the spatial and temporal variation in the background groundwater quality is needed.

The ground water quality monitoring is generally carried out by fetching water samples from existing open wells which gives point information about ground water quality of that particular well. The information on the spatial variability of groundwater quality is useful for proper planning and management of groundwater resources. 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 spatial dependence between observations can be expressed by the semi variance, which is a measure of the average similarity between observations at a given distance apart.

A regular program of water quality monitoring is required for proper planning and management of any water resource. However, regular monitoring is generally not possible due to some constraints viz., financial and technical. Under the circumstances, spatial and temporal variability analysis based on limited monitoring of water quality data may be cost effective and these results may be useful for planning and management of the ground water resource.

In this study, spatial variability of groundwater quality in Jammu, Kathua and Udhampur districts has been attempted. The study area is subjected to a lot of increasing pressure of anthropogenic activities viz., industrialization and intensive agricultural and horticultural activities. These activities are posing a risk of ground water quality deterioration. The spatial distribution of ground water quality and appropriate monitoring network is very essential for ground water quality management. Therefore, in the present study, it is proposed to study spatial variability of ground water quality in a part of Jammu Region.

REVIEW

Geostatistical estimation methods focus on providing an estimate of a spatially distributed variable at unsampled locations as a function of a set of sample values at a limited number of surrounding locations. These techniques, which are generally referred to as kriging methods, are essentially a form of least squares linear regression, and they result in a single predicted value at each spatial location (e.g., David, 1977; Journel and Huijbregts, 1978).

Semivariograms have been used for spatial modeling of the regional groundwater data by Myers et al (1982). Seyhan et al (1987) have applied geostatistical techniques for spatial analysis of hydrochemical variables and groundwater levels in two different areas. Rouhani and Hall (1988) have used geostatistics for the design of a groundwater quality monitoring network for a shallow aquifer in the Dougherty Plain, Georgia. Candela et al. (1988) used kriging to judge the sampling efficiency of a ground water quality control observation network in the Llobregat delta deep aquifer. Cooper and Istok (1988a, b) reviewed the applicability of geostatistical estimation methods to groundwater contamination, and presented a case study to estimate concentrations of six contaminants at the Chem-Dyne Superfund site Ohio. Bjerg and Christensen (1992) have used geostatistics to study the spatial variation in the groundwater quality of a shallow sandy aquifer in the western part of Denmark. Istok et al. (1993) presented a case study of the use of a multivariate geostatistical method (co-kriging) to estimate concentrations of nitrate and herbicide in a contaminated groundwater aquifer in an agricultural area. Rautman and Istok (1996) reported probabilistic assessment of groundwater contamination on the basis of geostatistical techniques in order to identify and model the spatial continuity of contamination at a site (variography) and to develop alternate plausible simulations of contamination fields. Various studies have also been reported on application of geostatistical techniques to the groundwater quality data of different places (Kumar and Omkar, 1998-99; Adhikary et al, 2009; Adhikary, and Dash, 2010; Mehrjardi et al, 2008).

STUDY AREA

The present study was conducted in Jammu, Kathua and Udhampur districts of the Jammu region for 40 open wells. 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. The Jammu, Kathua and Udhampur districts, are mainly occupied by soft rock formations (Mehrotra & Srivastava, 1997). In the Jammu region climate is very much influenced by relief which varied from 400m to > 3000m. The region can be divided into three different relief zones such as <1000m, 1000-3000m & >3000m, indicating monsoon dominated zone, mountain climatic zone and cold dry climatic zone, respectively. 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 100cm to 140cm.

The soils of Jammu region show considerable heterogeneity. The soils of the foot-hills and areas adjacent to them comprises of loose boulders and gravel with ferruginous clay. The plains of Jammu and Kathua districts are of alluvial nature. The sub-surface soils around village Ramkot, Tehsil Billawar which represents hilly and undulating area of Kathua district are predominant in Sandy clay loam texture. The soils of R.S. Pura Tehsil, which represents plains of Jammu district was classified as Langotian (silty loam to silty clay loam), Bansultan (sandy loam to silt loam) and Kotli soil (silty clay loam to silty clay) series (Singh, 1986; 1991). In the Udhampur district, the texture in general is coarse to medium, the soils are moderately deep to deep on mid hills and plateaus, whereas, deep to very deep at the foothills.

The major part of the study area lies within the Piedmont deposits of outer plains of Jammu and Dun belt of outer Himalayas. Ground water under Piedmont Deposits of outer plains of Jammu (plain about 120 km long and 25 km wide lying between river Ravi in the east and river Munawar Tawi in the west) occurs under four different regimes, viz., (i) Ground water in recent river terraces and present day flood plains, (ii) Ground water in the Kandi (Bhaber) zone, (iii) Ground water in Sirowal (Terai) zone, (iv) Ground water in the transitional zone between Kandi and Sirowals. The Dun belt occurs as a series of terraces across the outer most hills of Jammu and is enclosed within the Lesser Himalayas. This belt extends from Basholi (Kathua district) in the east to Reasi in the west. Groundwater present in this area is limited either as perched water bodies or localised water bodies. Minor seepage in the form of small springs and, dug wells cater to the water supply of the respective areas.

METHODOLOGY

The present study is based on ground water quality data of 12 parameters (viz., pH, EC, total hardness, alkalinity, chloride, nitrate, sulphate, calcium, magnesium, sodium, potassium, phosphate) pertaining to 40 shallow open wells for the years 1995 (NIH) and 2008 (CGWB) respectively of Jammu, Kathua and Udhampur Districts. The spatial variability analysis was carried out using Surfer (Golden Software Inc). The analysis is based on behavior of regionalized variables in a spatial structure. If a variable is distributed in space, it is said to be "regionalized" (Journel and Huijbregts, 1978). A regionalized Variable (ReV) is defined by Matheron (1963) as the variable that spreads in space and exhibits certain spatial structure. Such variables show a complex behaviour. Their variations in space are erratic and often unpredictable from one point to another; however, these are not completely random as these exhibit some spatial correlation. So, a ReV is simply a function of space, but generally a very irregular function. All the parameters generally used in groundwater hydrology, such as transmissivity, hydraulic conductivity, piezometric heads, precipitation, vertical recharge, quality etc. can be called regionalized variables.

Kriging has been used to analyze ground water quality data of the study area. 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, 2g (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,

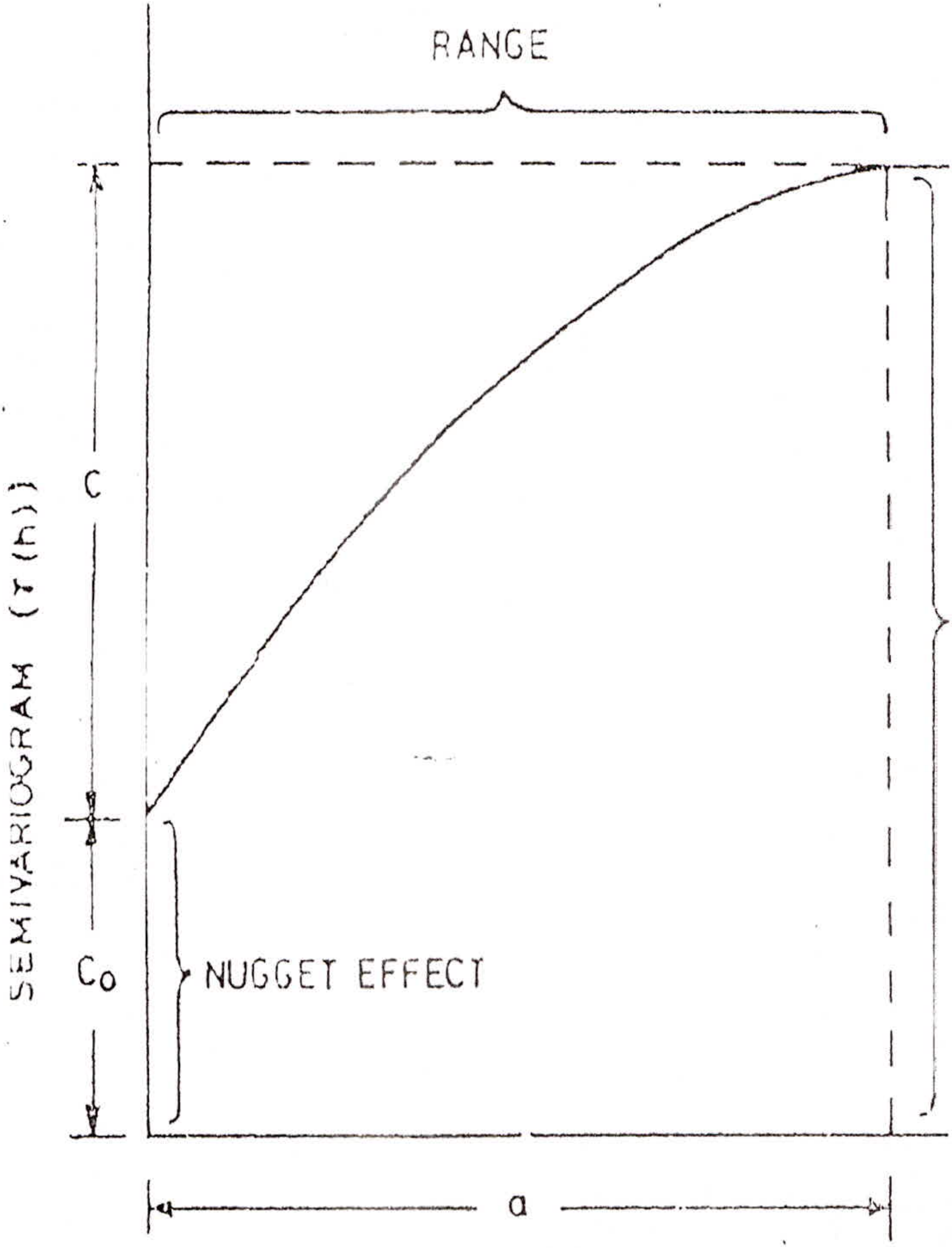

Fig. 1. A typical view of semi-variogram and its components

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

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

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

A plot of g*(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 & 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 (Fig. 1), given in Eq.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 semivariograms for 12 groundwater quality parameters were computed on the basis of ground water quality data for 1995 and 2008 pertaining to 40 wells in Jammu, Kathua and Udhampur districts using Surfer software (Golden Software, Inc. (1999) .

RESULTS AND DISCUSSION

Variation of Water Quality Parameters

The basic statistics such as minimum, maximum, mean, median, standard deviation (s) and variance (s^2) for the groundwater quality data of 1995 is shown in Table 1a, which show calcium variation from 26 to 128 (mean: 59 mg/l), chloride from 7 mg/l to 168 mg/l (mean: 39 mg/l), electrical conductivity from 0.3 mmhos/cm to 2.1 mmhos/cm (mean: 1.0 mmhos/cm), bicarbonate from 119 mg/l to 464 mg/l (mean: 287 mg/l), potassium from 0.4 mg/l to 176 mg/l (mean: 17 mg/l), magnesium from 8 mg/l to 54 mg/l (mean: 27 mg/l), sodium from 5 mg/l to 105 mg/l (mean:31 mg/l), nitrate from 0.1 mg/l to 20 mg/l (mean: 7 mg/l), pH from 7.4 to 8.2(mean of 7.8), phosphate from 0.02 mg/l to 0.4 mg/ (mean: 0.1 mg/l), sulphate from 7 mg/l to 131 mg/l (mean:32 mg/l) and total hardness from 147 mg/l to 487 mg/l (mean of 272 mg/l), respectively. The basic statistics for the groundwater quality data of 2008 (CGWB, Jammu) is shown in Table 1b. The variation of ground water quality parameters from year 1994 to 2008 appears to be significant. The effect of anthropogenic activities/ practicing the intensive agricultural practices utilizing mostly chemical fertilizers for enhancing the crop yield has been witnessed in the study area because the average values of nitrate was found to be increased from 7 mg/l (1995) to 19 mg/l (2008), respectively.

Table 1a. Statistics of ground water quality data of Jammu, Kathua and Udhampur Districts (1995)

Statistics	pH	EC mmho	Total Hardness	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	Cl mg/l	SO_4 mg/l	PO_4 mg/l	NO_3 mg/l
Minimum	7.4	0.3	147	26	8	4.5	0.4	119	7	7	0.02	0.1
Maximum	8.2	2.1	486	128	54	105	176	464	168	131	0.4	20
Average	7.8	1	272	59	27	31	17	287	39	32	0.1	7
Median	7.8	0.9	255	51	25	24	4.3	275	23	22	0.1	3.7
Std. Dev.	0.2	0.5	93	26	10	23	36	94	37	27	0.1	5.9
Variance	0.05	0.254	8602	666	102	514	1324	8927	1343	707	0.01	34.5

Table 1b: Statistics of ground water quality data of Jammu, Kathua and Udhampur Districts (2008)

Statistics	pH	EC µmho	TDS Mg/l	Total Hardness	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	Cl mg/l	SO_4 mg/l	NO_3 mg/l
Minimum	7.25	316	202	130	36	9	5	0.5	122	11	0	0
Maximum	8.2	3220	2061	800	160	136	305	320	1049	440	330	116
Average	7.69	820	525	300	73	29	45	27	367	60	29	19
Median	7.68	705	451	295	74	21	26	3	354	35	12	5.2
Std. Dev.	0.22	539	345	136	32	25	55	75	180	80	57	28.3
Variance	0.05	290454	118970	18374	1033	603	3022	5553	32505	6347	3251	799

Semivariogram Analysis

In the present study, spatial variability analysis of 12 ground water quality parameters (pH, EC, total hardness, bicarbonate, chloride, nitrate, sulphate, calcium, magnesium, sodium, potassium, phosphate/fluoride) pertaining to 40 shallow wells was carried out for the study area using data set of 1995 and 2008, respectively. Accordingly, experimental semivariograms of the groundwater quality parameters were computed and fitted with Spherical/Gaussian type models. The details of model fits viz., nugget (C_0), scale (C), range/length (a), sill (C_0+C) and variance pertaining to various groundwater quality parameters are given in Table 2 (for 1995 data) & Table 3 (for 2008 data), respectively. The sample diagram of semi-variogram for calcium, EC and pH have been shown in Figs. 2 to 7, for 1995 and 2008, respectively.

The average range values "a" showing spatial dependence of different ground water quality parameters based on ranges/lengths of 1998 & 2008 data has been plotted in Figs. 8, which indicate, the average range values 29 km (calcium), 32.5 Km (chloride), 40 Km (EC), 37 Km (bicarbonate), 32.5 Km (potassium), 28 Km (magnesium), 22 Km (sodium), 31 km (nitrate), 31 Km (pH), 29 km (sulphate), 36 Km (total hardness), 22 Km (phosphate) and 28 Km (fluoride), respectively. The analyzed parameter of Range/

Table 2. Results of semi-variogram models of different groundwater quality parameters in Jammu, Kathua and Udhampur Districts (1995)

Sl.	Parameter	Model fitted	Nugget (C_0)	Scale (C)	Range (a)	Sill	Variance
1	Ca	Spherical	5	1470	28	1475	1303
2	Cl	Spherical	30	1130	30	1160	1129
3	K	Spherical	10	990	33	1000	987
4	Na	Spherical	0	749	22	749	702
5	NO_3	Spherical	0	60	28	60	60
6	TH	Spherical	0	12200	36	12200	1077
7	SO_4	Spherical	0	2220	28	2220	2100
8	Mg	Spherical	18	167	26	185	186
9	pH	Spherical	0.01	0.27	32	0.28	0.23
10	PO_4	Gaussian	0.004	0.0124	22	0.0164	0.016
11	EC	Spherical	0	0.1	36	0.10	0.10
12	HCO_3	Spherical	10	19420	36	19430	19006

Table 3. Results of semi-variogram models of different groundwater quality parameters in Jammu, Kathua and Udhampur Districts (2008)

Sl.	Parameter	Model fitted	Nugget (C_0)	Scale (C)	Range (a)	Sill	Variance
1	Ca	Spherical	9	1070	30	1079	1003.5
2	Cl	Spherical	40	6000	35	6040	6165.0
3	K	Spherical	10	6070	32	6080	
4	Na	Spherical	50	2160	23	2210	2936.0
5	NO_3	Spherical	0	850	34	850	776.6
6	TH	Spherical	0	17885	36	17885	17848.7
7	SO_4	Spherical	400	2870	30	3270	3158.0
8	Mg	Spherical	0	670	30	670	585.0
9	pH	Spherical	0.006	0.58	30	0.586	272.8
10	F	Spherical	0	0.069	28	0.069	0.052
11	EC	Spherical	100	273000	49	273100	282155
12	HCO_3	Spherical	0	34000	38	34000	31576.7

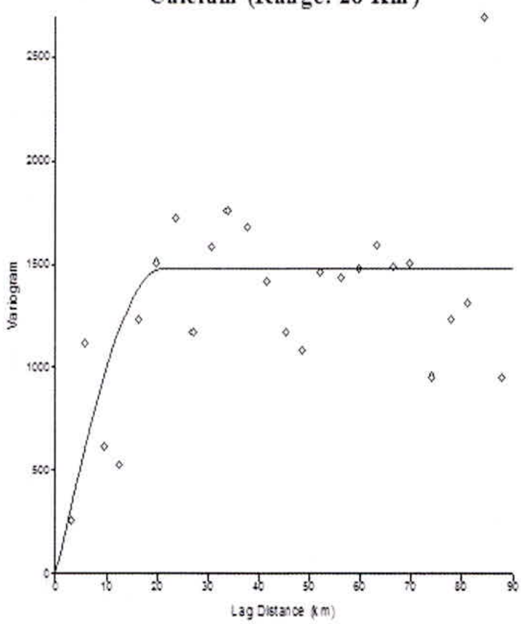

Fig.2. Semi variogram of calcium of GWQ data of Jammu, Kathua and Udhampur (1995)

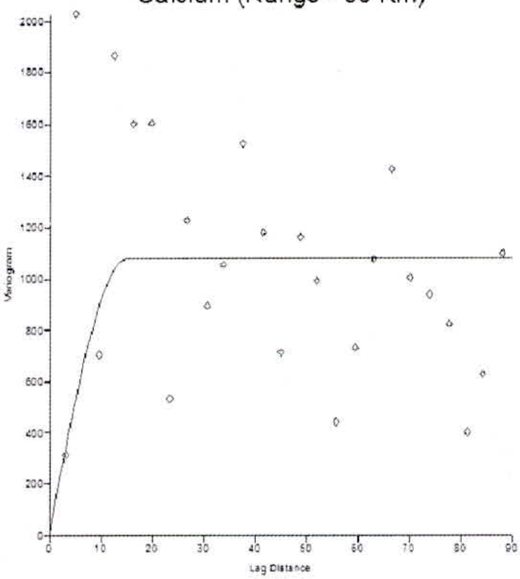

Fig. 3. Semi variogram of calcium of GWQ data of Jammu, Kathua and Udhampur (2008)

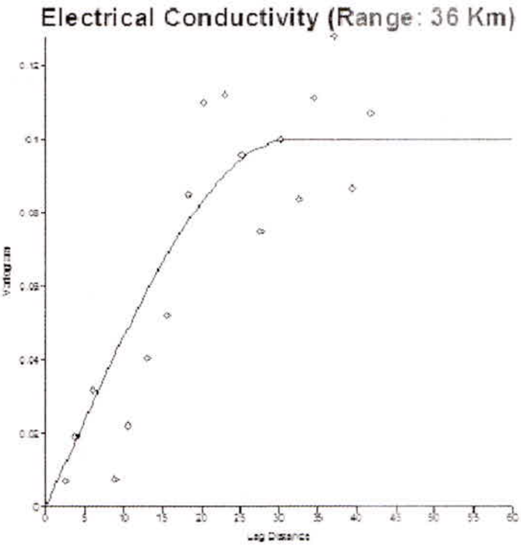

Fig. 4. Semi variogram of EC of GWQ data of Jammu, Kathua and Udhampur (1995)

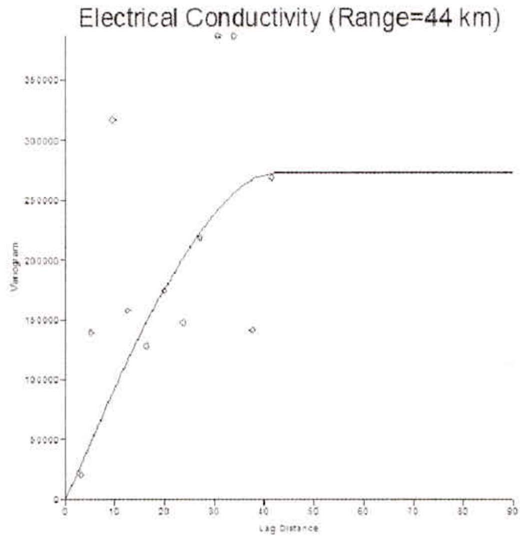

Fig. 5. Semi variogram of EC of GWQ data of Jammu, Kathua and Udhampur (2008)

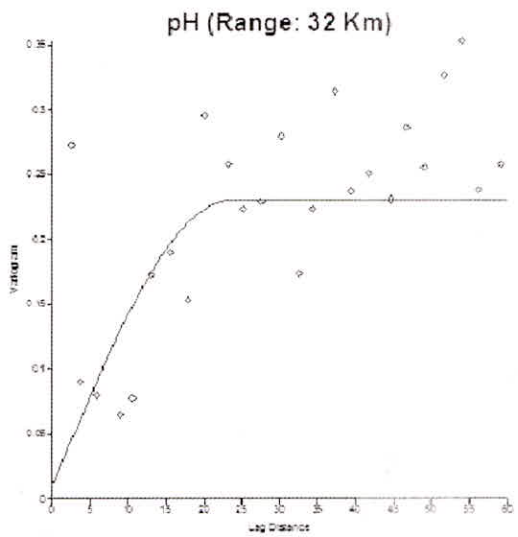

Fig. 6. Semi variogram of pH of GWQ data of Jammu, Kathua and Udhampur (1995)

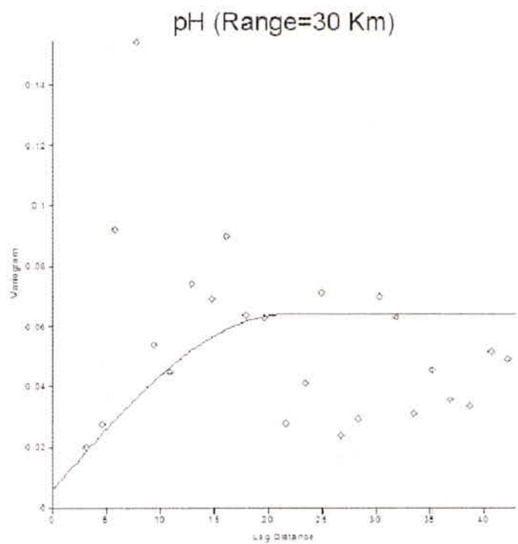

Fig. 7. Semi variogram of pH of GWQ data of Jammu, Kathua and Udhampur (2008)

Length "a" values of semi variogram models (mostly fitted with spherical) of GWQ parameters may be useful for appropriate GWQ monitoring network design in study area. The sample diagram of contour maps for TDS and Nitrate variation during 2008 in the study area are shown in Figs. 9 & 10, respectively. These maps are useful for making a reasonable assessment of ground water quality at unsampled location in the study area.

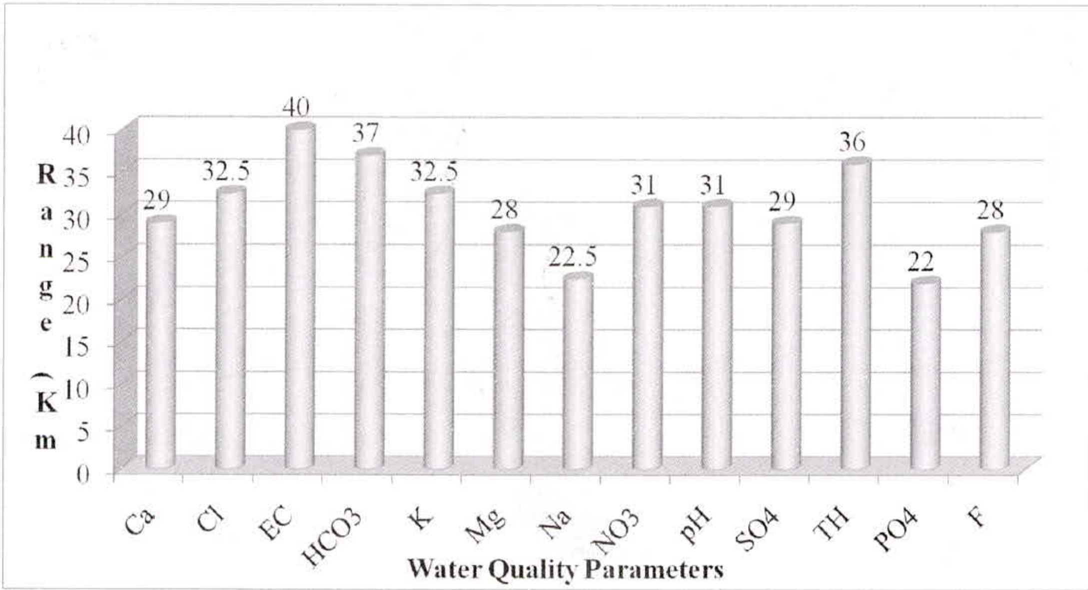

Fig. 8. Average range/length values (Km) of different GWQ parameters of Jammu, Kathua and Udhampur Districts

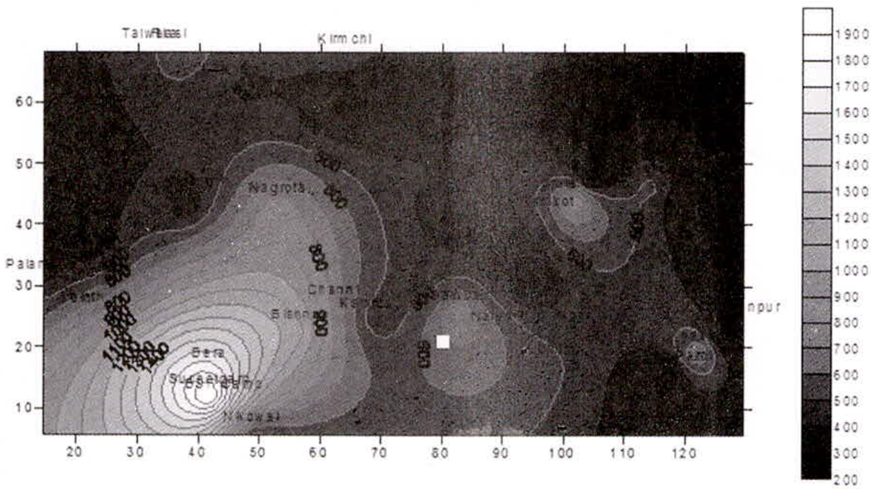

Fig. 9. Contour map of total dissolved solids in Jammu, Kathua and Udhampur (2008)

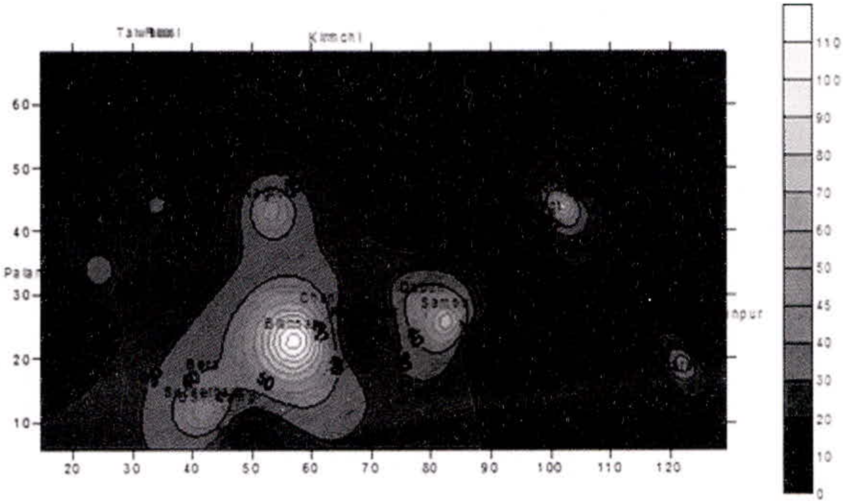

Fig. 10. Contour map of nitrate concentration in Jammu, Kathua and Udhampur Districts (2008)

CONCLUSIONS

In this study, spatial variability of groundwater quality in Jammu, Kathua and Udhampur districts has been carried out using ground water quality data of 1995 and 2008. The statistical analysis of ground water quality data pertaining to increasing nitrate concentration has shown that the study area is subjected to increasing pressure of anthropogenic activities. The spatial distribution of ground water quality and appropriate monitoring network is essential for ground water quality management. Therefore, in the present study, spatial variability analysis and application of for appropriate ground water quality monitoring network has been attempted. The analysis of GWQ has shown that Range/Length (a) values of GWQ parameters are useful for appropriate GWQ monitoring network design in study area. Spatial variability maps are also useful for prediction and management of GWQ at unsampled location in the study area for various designated uses. Moreover, selection of appropriate GWQ monitoring network may also reduce the cost of sampling and analysis. Thus, the findings of the study are useful for better planning and management of ground water resources in the area.

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