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# STUDY OF SPATIAL VARIABILITY OF GROUND WATER DEPTH AND QUALITY PARAMETER IN HARIDWAR DISTRICT OF UTTARAKHAND

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## Abstract

Ground water is a key source of drinking water that is essential to life on Earth. Assessing the quality of groundwater is important to ensure sustainable safe use of these resources. Geostatistical methods have been used widely as a convenient tool for assessing groundwater depth and ground water quality parameters. The objective of the study is to determine the groundwater quality and to assess the risk of groundwater pollution in Haridwar district of Uttarakhand, India by using geostatistics technique. The groundwater quality parameter (electrical conductivity) was analyzed from the existing wells of the Haridwar district and the thematic maps were generated using geostatistical concepts. Ordinary kriging was used to analyze the spatial variability of groundwater depth and quality parameter (electrical conductivity) with concentration equal or greater than their respective groundwater pollution cut-off value, whereas indicator kriging was used to analyze groundwater quality parameters equal to or greater than the pollution threshold values. It was observed that the semi-variogram parameters fitted well in the spherical for water depth and in the exponential model for water quality parameter. (Electrical conductivity and groundwater depth followed a log-normal distribution and demonstrated a moderate spatial dependence according to the nugget ratio). The indicator kriging method is useful to assess the risk of groundwater pollution by giving the conditional probability of concentrations of different chemical parameters exceeding their cut-off values. Thus, risk assessment of groundwater pollution is useful for proper management of groundwater resources and minimizing the pollution threat.

Keywords: Geostatistics, Groundwater quality, Semi-variogram, Indicator kriging.

## 1. Introduction

Groundwater is a significant source of water in many parts of India. About 50% of the total irrigated area is dependent on groundwater and about 60% of the irrigated food production depends on irrigation from groundwater wells (CWC 2006). As we know the importance of groundwater and also know that human beings are totally dependent upon groundwater. Rural and urban households and public water supplies depend on wells and groundwater; farmers too use groundwater for irrigating crops and for their animals. Industries and commercial business also depend on groundwater for their processes and operations. Other industries rely on groundwater for the production of electric power, food, beverages, paper, and material production. Due to increase in population density the consumption of water from the ground is increased, pressure on it also increases, and this leads to decrease in groundwater level. The mining of groundwater through over-pumping can create an almost irreversible groundwater drought even under normal and good rainfall conditions. The human assault on the groundwater comes from many different directions. Population explosion is also a major concern for the degradation of groundwater level and quality. As we know that the level of groundwater is decreasing due to exploitation of groundwater. As we know that the level of groundwater is going down due to exploitation of groundwater. Another problem of groundwater is that it gets contaminated by various agents. Contamination degrades its water quality. There are many reasons of contamination in groundwater. It includes both anthropogenic and natural factors. Natural factor includes geology of that area (e.g. rock types). Groundwater is also contaminated because of the careless disposal of human and animal wastes, haphazard disposal of wastes from industrial mining and oil operation, leaks from storage tanks, pipelines or disposal ponds, leachates from sanitary landfills, and daily activities such as farming and solid waste disposal. The main source of biological contamination is from human and animal sewage, or wastewater.

For assessing the groundwater quality electrical conductivity is an important indicator and it is widely used to indicate the total ionized constituents of water. Electrical conductivity is closely linked with salt concentration and is directly associated to the sum of the cations (or anions) as determined chemically. "Depth to water is important as it determines the distance that contaminants have to travel before reaching the groundwater. Deep groundwater is less vulnerable than shallow aquifers" (Baalousha, 2010). For assessing the groundwater quality electrical conductivity is an important indicator and it is widely used to indicate the total ionized constituents of water. Electrical conductivity is closely linked with salt concentration and is directly associated to the sum of the cations (or anions) as determined chemically.

Spatial distribution of groundwater and pollutants distribution is not homogenous. Distribution patterns can vary with change in environmental as well as anthropogenic factors. It is very useful in understanding distribution of groundwater level and electrical conductivity through factors such as pollutants, extraction of groundwater by its expanding population, lithology, precipitation, aspect and slope, wastewater from sewage treatment plants, urban runoff from roads. Groundwater depth and pollutant concentration values of every possible location of an area are rarely available. Considering time and cost involved in data collection sometimes the measurement of pollutants concentration at every location is not feasible. Hence, one of the alternatives is to predict the values at other locations based upon selectively measured values of the few locations that have been measured. Here, in this context, geostatistics techniques can be used to predict the concentration of pollutants at unmeasured locations.

"Geostatistics can be regarded as a collection of numerical techniques that deal with the characterization of spatial attributes, employing primarily random models in a manner similar to the way in which time series analysis characterizes temporal data"(Olea, 1999). Many researchers all around the world (Journel and Huijbregts, 1978; Bierkens and Burrough, 1993 a,b; Webster and Oliver, 2001; Kumar and Ahmed, 2003) have used the geostatistical concepts and its applications. In mapping the pollutants many researchers have used these techniques. To measure the spatial and temporal structure of groundwater level fluctuation, geostatistics is used as a management and decision tool by many researchers.

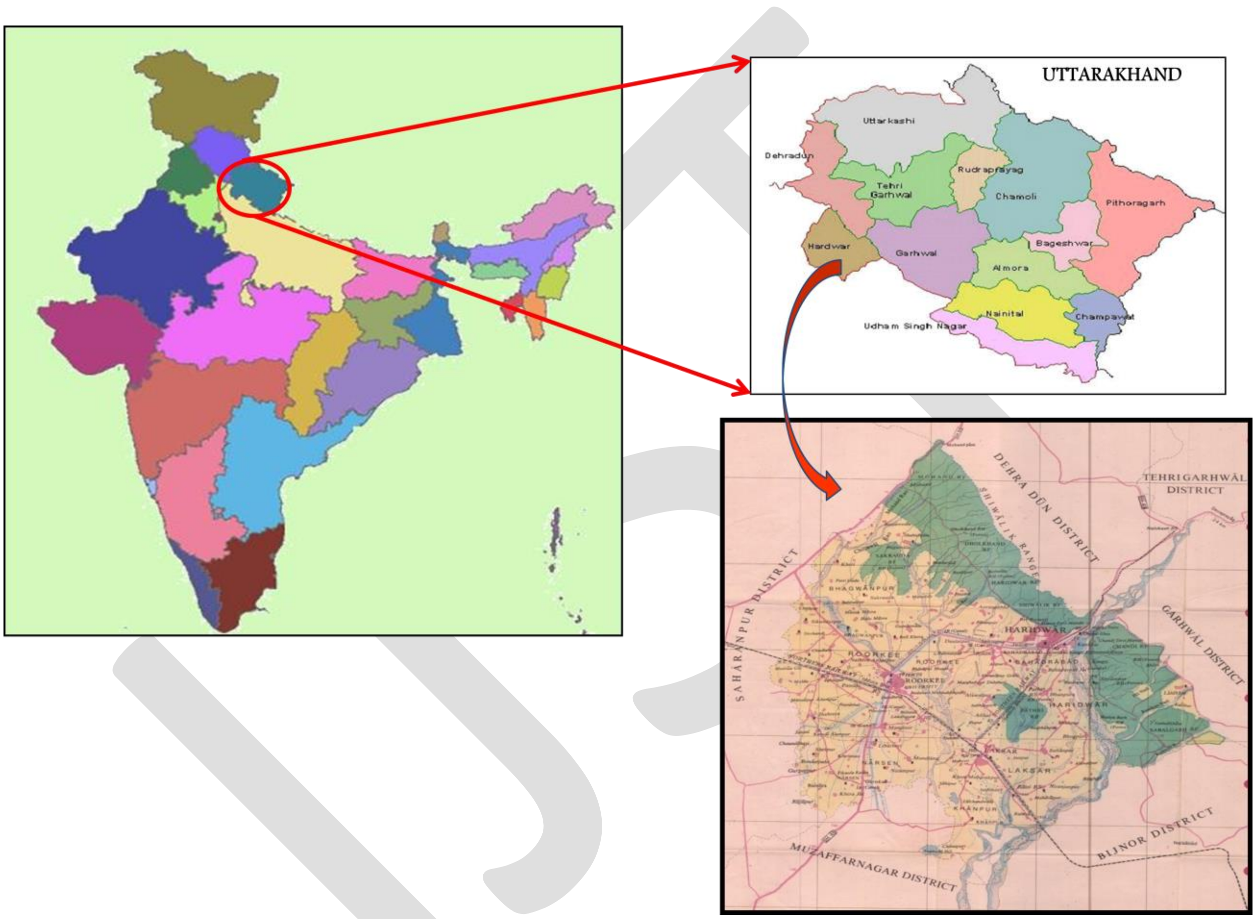
Use of geostatistics for mapping groundwater for mapping groundwater quality and groundwater depth has been analyzed in several studies. Mouser, 2004 used geostatistics for analyzing Ground water quality. Nazari Zade et.al, 2006 used geostatistics method to study spatial variability of Ground water quality in Balarood plain. Their results showed spherical model is the best model for fitting experimental variogram of EC, Cl and SO4 variables. In other similar studies spatial distribution of groundwater quality by using geostatistics was carried out by Mehrjardi et.al, 2008 using IDW, kriging and cokriging which showed that for interpolation of groundwater quality, kriging and cokriging methods are Superior than IDW method. Other similar studies has been done by P. Goovaerts et.al, 2005 they compare the performances of multi-Gaussian and indicator kriging for modeling probabilistically the spatial distribution of arsenic concentrations in groundwater. Various studies investigate that kriging is a beneficial and capable tool for detecting those critical regions which need more attention for sustainable use of groundwater. One more study done by Partha Pratim Adhikary et.al, 2010 is used as geostatistical approach for preparation of thematic maps of the groundwater quality parameters such as bicarbonate, calcium, chloride, electrical conductivity (EC), magnesium, nitrate, sodium, and sulphate with concentrations equal or greater than their respective groundwater pollution cut-off value. Their study showed spherical model as the best fitted model for groundwater quality assessment.

## 2. Study area and materials

District Haridwar is a famous holy place in India where millions of pilgrims came every year. It is located in the western part of the Uttarakhand. The district headquarter is situated at Haridwar. Haridwar district is covering a total area of about 2360 sq km. The district is located in the western part of Uttarakhand, situated at $29^0$ 30’ to $30^0$ 15’ N latitude and $77^0$ 45’ to $78^0$ 15’ E longitude. Average elevation of the district from the sea level is around 249.7 meters. Haridwar District is bounded by Saharanpur in the west, Dehradun in the north and east, Pauri Garhwal in the east, Muzaffarnagar and Bijnor in the south. The study area shows three distinct seasons’ winters, summers, and monsoon. Temperature during summers: 15 °C - 42 °C and Winters: 6 °C – 16.6 °C. Haridwar receives Monsoon rains, mostly during the summer. As of 2011 Indian census, Haridwar district has a population of 19, 27,029, millions of pilgrims visiting every year contribute towards moving population of the district. It is located besides the Shiwalik Mountain in north which makes water hard. In addition to this, "the increase of industrialization, garbage disposal, septic tanks, cementaries, oil spills, agricultural and domestic activities are also alarming problems of groundwater contamination and decreasing groundwater level".

*Figure 1: location of study area Haridwar district, India*

*Groundwater Depth and Quality (electrical conductivity) Data Acquisition*




Data related to groundwater depth and quality (electrical conductivity) was acquired from Central Ground Water Board (CGWB). data is given by Central Ground Water Board (CGWB), Dehradun for the year 2008 covering 55 sample points. In this study in order to analyze the data determining groundwater depth and quality (electrical conductivity), a GIS software package ArcGIS 9.3, ArcGIS Geostatistical Analyst extension and ERDAS imagine were used. An interpolation technique called ordinary kriging was used to produce the spatial distribution of groundwater depth and quality (electrical conductivity) in Haridwar district of Uttrakhand, India.

# 3. Methods

## 3.1 Geostatistical Approach

### 3.1.1. Semvariogram modeling

"Geostatistics is a technique for estimating the values of properties (at unsampled places) that vary in space from more or less sparse sample data" (Oliver and Webster, 1991). Geostatistics is based on the regionalized variable theory, which states that variables in an area exhibit both random and spatially structured properties. The spatial structure is quantified using a semivariogram (Burgess and Webster, 1980). The experimental semivariogram is a graphical representation of the mean square variability between two neighboring points of distance h as shown in eq.1.

$$\gamma(h) = \frac{1}{2}\sum_{i=1}^{N}(\mathrm{Z}(\mathrm{x}+\mathrm{h}) - \mathrm{Z}(\mathrm{x}))^2 \quad (1)$$

Where, function γ(h) is semivariogram and Z(x) is random variable.

The experimental semivariogram γ(h) can be fitted to different theoretical models such as spherical, exponential, linear, or Gaussian to determine three semivariogram parameters, i.e., as the nugget ($C_0$), the sill ($C_0$ + C), and the range ($A_0$) (Isaaks and Srivastava, 1989). Semivariograms can be computed in different directions to detect any anisotropy of the spatial variability. Here only isotopic variation was considered.

### 3.1.2. Ordinary kriging and indicator kriging

Kriging is the estimation procedure using known values and semivariogram to determine unknown values. Ordinary Kriging (OK) is a standardized version of kriging. "Ordinary kriging is an estimation technique known as the Best Linear Unbaised Estimator (BLUE) that has the great advantage of using the semivariogram information" (Cressie, 1993). Here the predictions are based on the model:

$$Z(s) = \mu + \varepsilon'(s) \quad (2)$$

Where μ is an unknown constant and ε′(s) is the spatially correlated stochastic part of variation. Indicator kriging is a non parametric geostatistical method. Indicator kriging makes no assumptions about the underlying invariant distribution, and 0 to 1 indicator transformation of data makes the predictor robust to outliers (Cressie, 1993). Indicator kriging assumes the model

$$I(s) = \mu + \varepsilon'(s) \quad (3)$$

Where, μ is an unknown constant and I(s) is a binary variable.

### 3.1.3. Selection of Theoretical Model, Semivariogram Parameters and Cross Validation

Groundwater depth and quality (electrical conductivity) data were used for exploring the dataset for closely examining the data and its trend through histogram and QQ plot. Through QQ plot we compare the distribution of the data with standard normal distribution. Histogram shows and helps us to understand the whether the data is having normal distribution. Subsequently semivariogram parameters for each theoretical model such as spherical, exponential, linear, and Gaussian were generated. A theoretical variogram model is then fitted to the experimental semivariogram by adjusting the three key parameters namely sill, nugget and range and goodness of fit calculated. The objective of cross validation is to make an informed decision about which model provides the most accurate predictions. For a model that provides accurate predictions, the standardized mean error should be close to zero, the root–mean-square error and average standard error should be as small as possible. The error in the root-mean-square standardized error should be close to 1. When the average estimated prediction standard errors are close to the root-mean-square prediction errors from cross-validation, then we can be confident that the prediction standard errors are appropriate (ESRI, 2001). After selection of the suitable theoretical model and the corresponding semivariogram parameters, spatial variability maps were generated for groundwater depth and groundwater quality parameter using ordinary kriging. The ordinary kriging method with the point kriging option was used. Further indicator kriging was used to generate the probability of exceedence maps for the groundwater quality parameter based on the threshold values of the pollutant in drinking water.

## 4. Result and Discussion

The statistical evaluation of groundwater depth and quality (electrical conductivity) are given below in Table.1.

*Table 1. Statistical evaluation of groundwater depth and electrical conductivity for the Haridwar district*

| Variable Names | No. of points | Min | Max | Mean | Median | Std.Dev |
|---|---|---|---|---|---|---|
| Depth to water (DTW) | 55 | 1.9 | 21.44 | 7.3689 | 6.26 | 4.4921 |
| Electrical Conductivity (EC) | 55 | 149 | 1450 | 529.18 | 410 | 283.88 |

Spatial interpolation of groundwater depth and quality parameter (electrical conductivity)

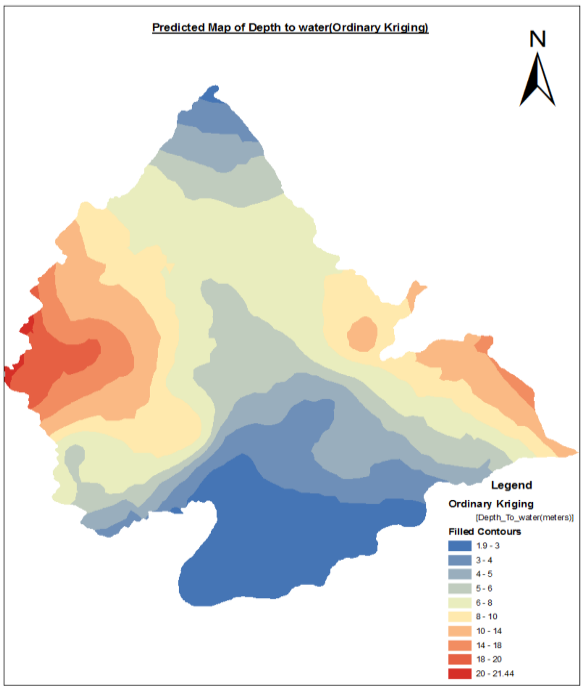
Ordinary kriging was used for obtaining the spatial distribution of groundwater depth and quality parameter electrical conductivity. In ArcGIS Geostatistical Analyst, the histogram and QQ Plots were used to see what transformation it has. Dataset showed log-normal transformation.

Semivariogram models: In this study, the semivariogram models (Circular, spherical, Gaussian, exponential, tetra spherical, pent spherical) were tested for both groundwater variables. Prediction performances were assessed by cross validation. Cross validation allows determination of which model provides the best predictions.

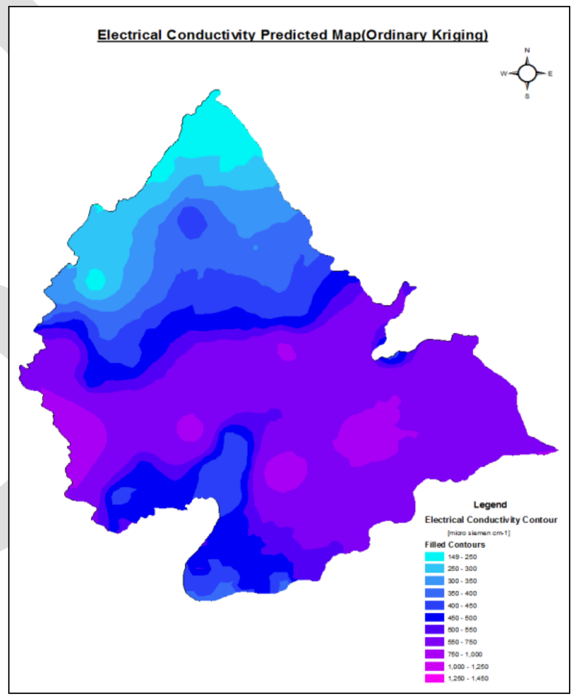
After applying different models for each variable examined in this study, the error was calculated using cross validation and models giving best results were determined. Table 2 shows most suitable models and their prediction error values for groundwater depth and quality parameter (electrical conductivity). For groundwater depth and electrical conductivity, RMSS values are 1.266 and 1.028 respectively.

*Table 2. Best-fit model of groundwater depth and quality parameter (electrical conductivity)*

| Groundwater variables | Model | Nugget | Sill | Range | Mean | Root-Mean-Square | Average Standard Error | Mean Standardized | Root Mean Square Standardized |
|---|---|---|---|---|---|---|---|---|---|
| Depth to water | Spherical | 0.05346 | 0.10095 | 0.093832 | 0.0730 | 3.379 | 3.232 | -0.06976 | 1.266 |
| Electrical conductivity | Exponential | 0 | 0.18434 | 0.079719 | 0.8797 | 282.4 | 273.4 | -0.04338 | 1.028 |




*(a)*




*(b)*

*Figure 2. Spatial distribution of groundwater depth (a) and quality (electrical conductivity)(b).*

Figure 2 (a) depict that small patches that are dark red (ranges in between 15 to 21.44 meters) in colour shows highest value of groundwater depth. On the other hand some patches in the south and in north part of the region is showing the lowest value (1.9 to 3 meters), these regions are safe zones as compared to others.

Figure 2(b) the above given figure depicts that small patches in the north in cyan (149 to 250 micro seimen/cm) shows least value of electrical conductivity of groundwater. On the other hand some patches in the east central and west part of the region is showing the highest value (1250 to 1450 micro seimen/cm).

## 5. CONCLUSIONS

In Hridwar district the measured sample point taken is 55. In those points we have collected the data of depth to water and electrical conductivity to show the areas of risk due to high total dissolved salt contents. It is increasing near the river since the wastes from industrial area like Haridwar and Roorkee get dissolved into the river water and get settled in the low line area and also in the areas where the slope of area is less and the river carry fewer loads. The distribution of electrical conductivity of groundwater is mainly concentrated in patches in southern part of the study area.

Kriging gives best result for depth to water. The best suitable model is spherical model for depth to water and for electrical conductivity exponential model is the best–fit model. Model fitting is based on the semivariogram parameters that are sill, nugget and range. From the above study, it can be concluded that geostatistical technique can explain spatial distribution of depth to water and electrical conductivity of groundwater. It helps us to predict the location of unknown points from the given measured sample points. In addition, the accuracy can be checked by cross validation giving us a clear picture of the entire area.

## 6. Acknowledgement

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