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Analysis of groundwater level differences in Ganges basin using geostatistical modeling

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■ **ABSTRACT :** India is a developing country, with the increase in the industrialization and urbanization burden on the water resources increasing day by day. The most common source for the water extraction is the groundwater. With the increasing demand of water, groundwater exploitation increases. As Ganges basin have many large industrial towns the problem of groundwater exploitation is more widen and the extent of groundwater exploitation varies considerably from one place to other place within basin. Thus, this studies is mainly focused towards the analysis of the spatial variation and mapping of groundwater level differences. Ganges basin is largest basin in India, thus Geostatistical methods are used to assess the depletion of groundwater level. This study is carried out to get the spatial information on extent of groundwater exploitation, it can help to make the policy for the use of water groundwater resources in a more judicial way to avoid more depletion of water level.

■ **KEY WORDS :** Geostatistical modeling, Groundwater fluctuation, Ganges basin, GIS

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The Ganges basin is the largest river basin in India, having catchment area of 86.2 million ha (CWC, 2010) (Fig.A). Its geographical location is spread between longitudes 73°30 and 89°0 East and latitudes 22°30 and 31°30 North. Dropping of groundwater levels has been serious issue in many parts of the Ganges basin. The decline rate is about 0.15 m/yr in the western Ganges plains and in some places as high as 0.35–0.4 m/yr over the period 1994–2005 (Samadder *et al.*, 2011). Increasing agricultural demand for a rising population and industrial development in an area had severely impacted on the groundwater resources in Ganges basin.

Groundwater level values of nearby areas are needed for prediction of groundwater level values which cannot be observed directly. Prediction of those unsampled values with any statistical method is growing concern. Geostatistics method is primarily used in the prediction of groundwater level. In this method surface map for required parameter are developed to predict the value of that particular parameter at unsampled location. In Geostatistics method, the most widely used technique for interpolation is the kriging interpolation. Using this technique unknown points can be predicted using known points.

Where it predicts an unknown point by using known point. During the use of Kriging technique for interpolation if the data is normally distribued then the results obtained are most efficient. If the data is not normally distributed it can be modified by using natural logarithmic transform.

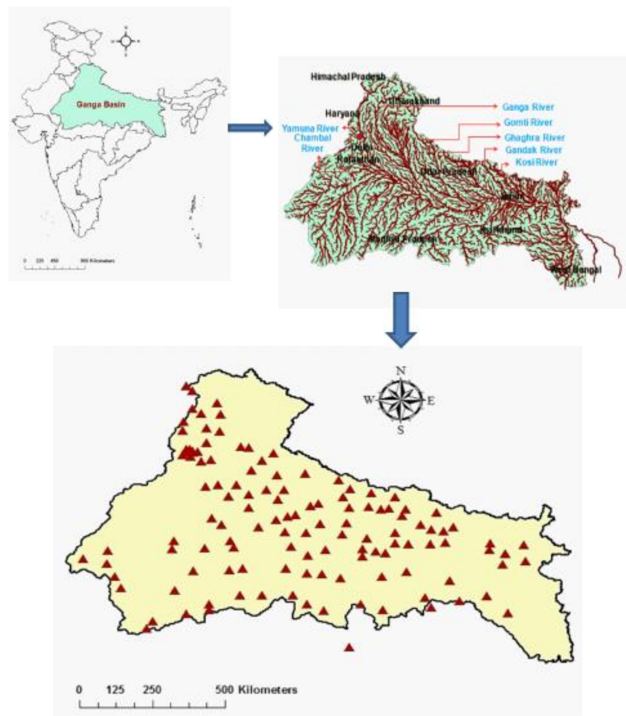

Fig. A : Geographical location of the Ganges basin and observation wells located in the catchment area

METHODOLOGY

Geostatistic is based on a stochastic process concept and is closely connected to the theory of random functions. It is used for predicting optimal number of random points in a given region. A geostatistical analysis can be divided into three parts namely modelling, estimation and simulation. It can be used for quantitative measures of spatial correlation. The empirical semivariogram [γ (h)] is defined as half the average quadratic difference between two observations of a variable separated by a distance vector h.

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2 \quad ....(1)$$

were,

γ (h) is semivariogram at distance h

N (h) is the total number of the variable pairs separated this distance

Z(x) is the value of the variable.

Most variograms are defined through the nugget effect, sill and range. In this effect the micro scale variation or measurement error are represented. It is estimated from empirical variogram as the value of γ (h) for h=0. Sill- the $\lim_{h \to \infty} \gamma$ (h) representing the variance of the random field. Range is defined as the distance at which data are no longer auto correlated. For the stochastic simulation, need to replace the empirical semivariogram with an acceptable semivariogram model. When there is clear range and sill and variance is not too large then Spherical model is preferred. When there is clear nugget and sill, but only a gradual approach to the range then exponential model can be used. In case the nugget variance is very small as compared to the spatially dependent random variation, then the Gaussian model can be used.

Cross validation was used to check the sufficiency of developed variogram. The least square error was calculated by comparing the real values and interpolated values.

Kringing is a method used for linear optimum unbiased interpolation with a minimum mean interpolation error. The method which is most commonly used for spatial analyses is Universal kriging method. Universal kriging method also consider local trends during minimizing the estimation error.

The following equation is used in kriging method:

$$Z^*(x_p) = \sum_{i=1}^{n} \lambda_i Z(x_i) \quad ....(2)$$

The following equations are solved simultaneously to get the unbiased estimation in ordinary kriging method.

$$\begin{cases} \sum_{i=1}^{n} \lambda_i \gamma(x_i, x_j) - \mu(x_i, x_j) \\ \sum_{i=1}^{n} \lambda_i = 1 \end{cases} \quad ....(3)$$

where, Z* (x_p) is the kriged value at location x_p, Z(x_i) is the known value at location x_i, λ_i is the weight associated with the data, μ is the lagrange multiplier, and γ (x_i,x_j) is the value of variogram corresponding to a vector with origin in x_i and extremity in x_j. The following equations of unbiased universal kriging which must be solved simultaneously are as follows.

$$\begin{cases} \sum_{i=1}^{n} \lambda_i \gamma(x_i, x_j) - \sum_{i=1}^{n} \mu f(x_i) = \mu(x_i, x) \\ \sum_{i=1}^{n} \lambda_i = 1 \\ \sum_{i=1}^{n} \lambda_i \gamma f(x_j) = f(x) \end{cases} \quad ....(4)$$

where, f (x) the type of function is used to model the trend and is directly suggested by the physics of the problem (Ahmadi and Sedghamiz, 2007).

RESULTS AND DISCUSSION

The groundwater level analysis carried out the eight years and water table fluctuation represented by the average decrease in the water table from 2005 to 2013. As the data is normally distributed, interpolation method is used to generate the groundwater level difference at the unknown points in the area. The data was tested for normal distribution by plotting histogram of groundwater level differences with normal distribution curve as shown in Fig. 1. Basic statistics parameters observed are summarized in Table 1. The Q–Q plot was also plotted to check the data for normal distribution and found that the data is groundwater level differences follows the straight normal distribution line as shown in Fig 2.

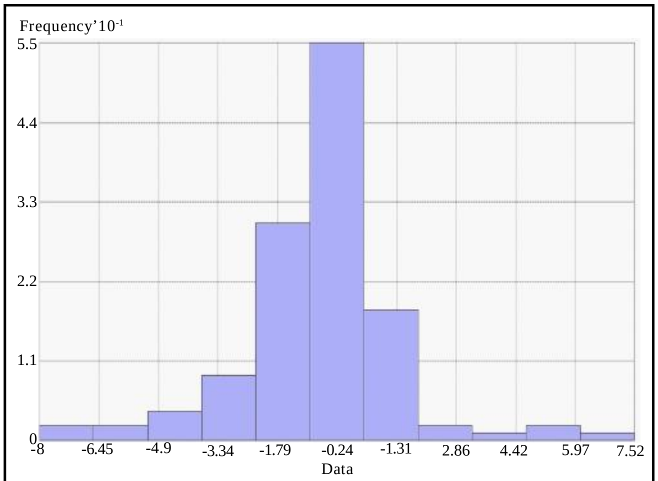

Fig. 1 : Histogram of groundwater level differences between the years 2005 and 2013

Table 1: Statistics of the difference between the groundwater levels in 2005 and 2013

Statistics	Values
Count	126
Min	-8
Max	7.52
Mean	-0.69048
Standard deviation	2.0377
Skewness	-0.036588
Kurtosis	6.7837
1st Quartile	1.61
Median	-0.435
3rd Quartile	0.28

Spherical model was fitted to experimental variogram and its cross validation results are shown in Fig. 3. The value of different model parameters are shown in the Table 2.

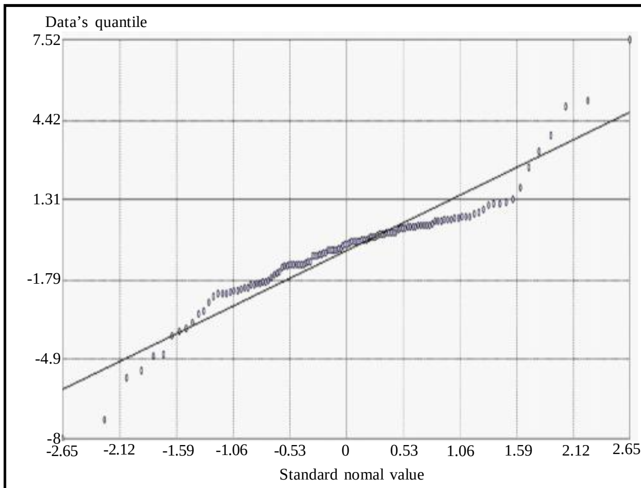

Fig. 2 : Q–Q plots of groundwater level differences

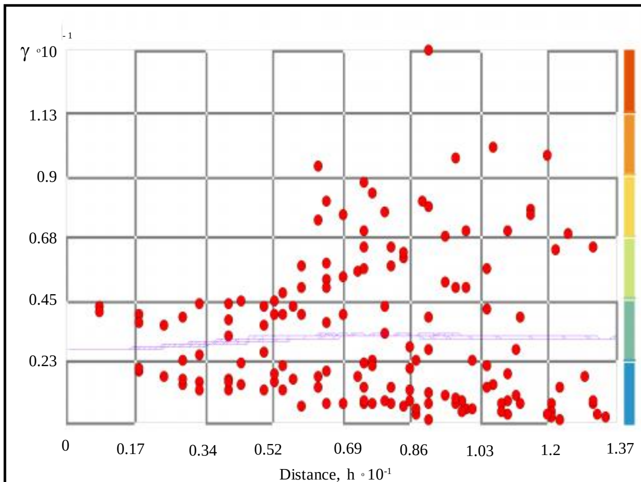

Fig. 3 : Multi-dimensional variogram

Table 2: Model parameters for the spherical model

Model parameter	Value
Nugget	2.59
Partial sill	0.481
Lag size	1.146
Range	13.47

The trend analysis was performed to analyze the trend. While rotating the points, the trends always exhibit down side-up U shapes in the west- east direction and upside down in the north south direction hence no specific trends were observed in the data sets as shown in Fig.4. Hence, we chose order of trend constant in the universal

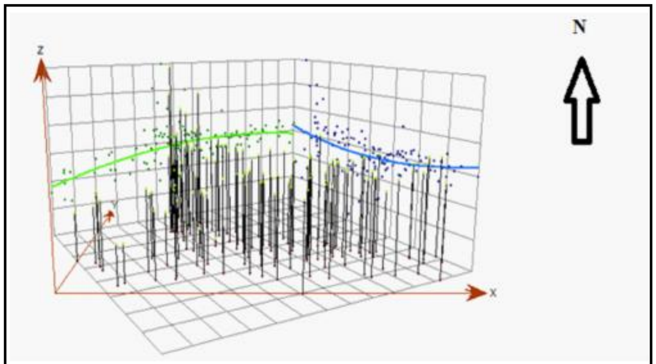

Fig. 4 : Trend analysis

kriging model.

Fig.5 shows the map of the values of kriged differences of the groundwater level between the years 2005 and 2013. There is a trend of increasing the depletion of groundwater level from the northern areas to the southern areas as well as from eastern area to western areas. Places where maximum groundwater abstraction and least groundwater abstraction are shown in Table 3.

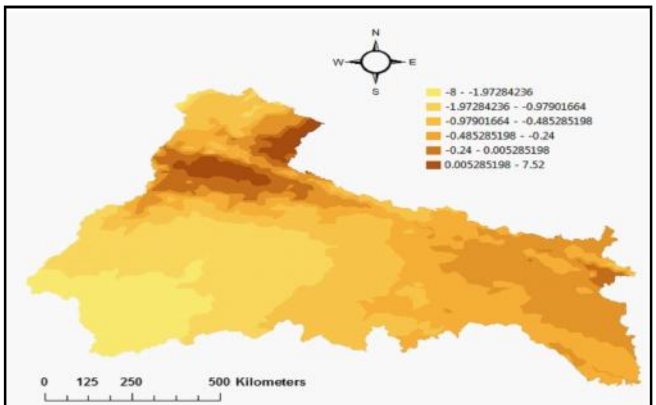

Fig. 5 : Map of the values of kriged differences of the groundwater level between the years 2005-2013

Table 3: Maximum groundwater abstraction and least groundwater abstraction

Maximum groundwater abstraction places in Ganges basin	North Delhi, South Delhi, East Delhi, Bulandshahr, Meerut, Budan, Bareilly, Moradabad, Rampur, Panipat
Least groundwater abstraction places in Ganges basin	Rajasmand, Chittaurgarh, Neemuch, Mandsaur, Rajgarh, Sehore, Dewas, Indore, Shivapuri

Fig.6 shows the regression line between the observed and estimated levels of groundwater. R^2 value is 0.70 which indicates that the estimation of the kriging is confident.

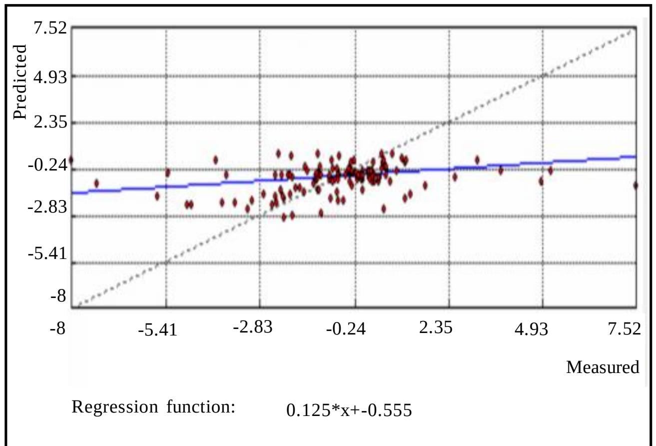

Fig. 6 : Least-squares regression line and the 1:1 (dashed) line between the observed and the estimated groundwater level

A map of prediction standard error was created using the kriging method as shown in Fig. 7. The bright yellow colours shows the areas of low standard error in prediction. Dark brown color are the areas of high standard error in prediction

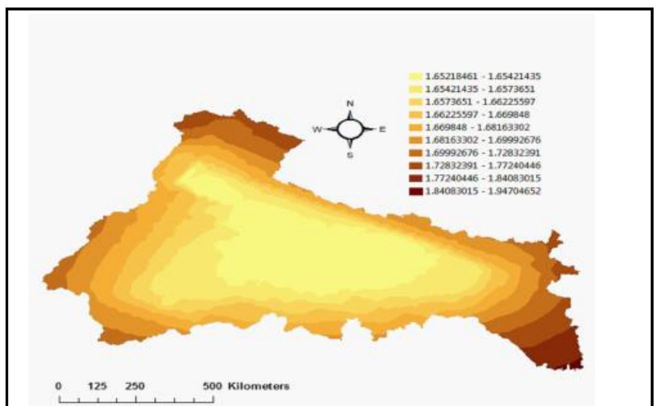

Fig. 7 : Prediction of standard error in the differences of the groundwater level between the years 2005 and 2013

Increasing agricultural demand for a rising population and industrial development in an area had severely impacted on the groundwater resources in the basin, hence modern Irrigation methods and precise use of water for the industries has been adopted. The use of micro irrigation method in the areas of high groundwater depletion can make the use of water more efficient as the agriculture is major practice in Ganges basin. Also, there must be a regulation on the exploitation of groundwater using tube wells operated by the industries in the area.

Conclusion:

It has been proved that for management and supervision of water resources the geostatistical method is an important method. The study was conducted to determine the change in groundwater level between the years 2005 and 2013. During the study kriging method was used to estimate the parameters at unknown points by using known points and to verify the accuracy of the method in estimating the parameters cross validation and universal kriging was used. By using this method we determined the areas where the depletion of water is at higher rate. The results obtained in the study could enhance the decision making of water authorities and also helps in determine most effective preservation and management practice for the available water resources. The Geostatistics and GIS are two for the study of water resources and integration of the two will explore the new approaches for water resource monitoring and management.

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