Geostatistical Analysis of Spatial Variations of Groundwater Level using GIS in Banaskantha District, Gujarat, India

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Abstract—Groundwater is the main resource of water in Banaskantha district, which fulfills the daily needs of the people. The surface water resources of Banaskantha district are very limited. Economy of the district is basically dependent on agriculture and dairy farming, which has increased the exploitation of groundwater. The Geostatistical analysis shows the variation in water level below ground level (bgl) from 2010 to 2016. Ordinary kriging, the most widely used geostatistical method has been used to depict the groundwater surface map of the last seven years of the district to study and analyse the spatial variability of groundwater levels. Groundwater levels recorded in pre-monsoon and post-monsoon seasons has been used to generate groundwater surface maps and trend graphs in GIS environment. The district has semi-arid climate which has the characteristic features of extreme temperature and erratic rainfall. Ephemeral nature of the rivers flowing through the district and the economy dependency of the district on agriculture and dairy farming are the major factors of over exploitation of ground water which results in the fast depletion of this resource.

Key words: Geostatistical Analysis, Ordinary Kriging, Groundwater Level Fluctuations, Spatial Variability

I. INTRODUCTION

The district has semi-arid climate. Extreme temperatures, erratic rainfall and high evaporation are the characteristic features of this type of climate. Since the district experiences a semi-arid type of climate, the rivers flowing through it are of ephemeral nature i.e. have water during monsoon only and dry up after monsoon. The drainage network in the district is constituted mainly by the Banas and Sarashwati rivers and their tributaries. The surface water resources of the district are very limited. Groundwater is the main source of irrigation. Important Irrigation schemes of the districts are Dantiwada, Mukteshvar Irrigation Project, Sipu Reservoir Project and Hadmatiya Irrigation Scheme. Economy of the district is basically dependent on agriculture and dairy farming, which has increased the exploitation of groundwater. Apart from agriculture groundwater is extensively used for drinking water in most parts of the district through tube wells and also through hand pumps. Since groundwater is the main source of water in the district, it requires to be managed much more efficiently than other water resources.

II. STUDY AREA

The Banaskantha district takes its name from the river Banas, which flows through it. The district is situated in the north western part of the state and lies between north latitudes 23°33’ & 24°25’, and east longitude 71°07’ & 73°02’. It has an area of 10,303 sq. km and is bounded by state of Rajasthan in north, Rann of Kutch in west, by Sabarkantha, Mahesana and Patan districts in east, south and south west respectively. The district with its headquarter at Palanpur is consists of 12 taluks and 1249 villages. The taluks are Palanpur, Danta, Vadgam, Amirgadh, Dantiwada, Deesa, Dhanera, Kankrej, Deodar, Bhabhar, Vav, Tharad.

Ordinary kriging has been used under Geostatistical analyst tool in ArcMap software, which gives most appropriate results when compared to other interpolation techniques. Exploratory Spatial Data Analysis (ESDA) tools have been used to examine and gain a better understanding of the data. The data is first checked for normal distribution under histogram tool and QQ plot, and then trend analysis is carried out to explore the existence of any trend in the data and its justification. Semivariogram/ covariance modeling is then carried out, the best variogram model is chosen based on different types of prediction errors. Before producing the final surface, cross validation is carried out to have some idea of how well the model predicts the values at unknown locations and is model chosen is appropriate or not. The flow chart of methodology is shown in Fig. 1.

A. Data Collection

The rainfall data for the last five years was collected from the state water data centre (SWDC), Gandhinagar and it was found that the temporal variation in rainfall was fairly acceptable with no deviation in any particular year. The groundwater observation well data has been collected from groundwater investigation unit-2, GWRDC. The data of pre-monsoon & post-monsoon water levels were taken.
The interpolation methods used to generate a surface gives the best result if the data is normally distributed. The histogram tool in ESDA provides a univariate (one variable) description of the data and one can examine the shape of the distribution by direct observation. Fig. 4 shows the histogram of the ground water level of post-monsoon 2016. The plot shows that the data is fairly normally distributed with mean and median close to each other and thus no transformation is required. In some cases, transformation was required and it is done through log or box-cox transformation as suitable.

The quantile-quantile (QQ) plot is used to compare the distribution of the data to a standard normal distribution, providing another measure of the normality of the data. The closer the points are to the straight (45 degree) line in the graph, the closer the sample data follows a normal distribution. From the normal QQ plot (Fig. 5), it can be seen that the plot is very close to being a straight line and thus no transformation is required in this case.

C. Trend Analysis

A trend is an overriding process that affects all measurements in a deterministic manner. It is desired in Geostatistical analysis that attribute should be free of location and the mean of it should be independent of location. If there is a trend in the area then it shows that the attribute is not distributed appropriately and it will start to increase or decrease with their coordinates. In the Fig. 6 and Fig. 7, ground water level values of post-monsoon 2016 are given by the height of each stick in the Z direction. The X-axis denotes East-West direction and the Y-axis denotes North-South direction. A best-fit line (a polynomial) is drawn through the projected points, which shows model trend in that specific direction. The green line is the east-west trend line and the blue line is a north-south trend line. On rotating the points, the trend does not always exhibit the same shape as shown is subsequent figure, even rotating it by small angle changes the trend which means that the data does not exhibits any particular trend. It is best to keep the models as simple as possible. If one removes a trend surface, there are more parameters to estimate. Thus, it can be concluded that trend does not exist in the data and the scenario is same for all the years.
D. Semivariogram Cloud

To examine spatial correlation between the measured sample points semivariogram clouds are used. The semivariogram cloud value is obtained by the difference squared between values of each pair of location, plotting on y-axis and the distance separating each pair plotting on x-axis as shown in Fig. 8 for post-monsoon 2016 data. In the semivariogram plot the locations that are closest (on the far left on the x-axis) should have small semivariogram values (low values on the y-axis). As the distance between the pairs of locations increases (moving right on the x-axis), the semivariogram values should also increase (move up on the y-axis). Looking at the semivariogram of the data (Fig. 8), it can be concluded that it is fairly correlated within the permissible limits. If this is not the case then one should investigate the pairs of locations to see if there is a possibility that the data is inaccurate.

E. Ordinary Kriging

The ordinary kriging is started with the selection of the proper attribute. Trend is not removed in any data as clarified above (C). The next step is semivariogram/ covariance modelling (Fig. 8), its goal is to determine the best fit for a model that will pass through the points in the semivariogram (shown by the blue line in Fig. 9. (c)). The semivariogram is a graphic representation used to provide a picture of the spatial correlation in the dataset. There are several other types of semivariogram models that could be used (exponential, gaussian, spherical etc.), depending on how well they fit the data. Parameter values for the semivariogram model are the nugget, range, partial sill, and shape. One can manually adjust the parameters to achieve the best fit of variogram or click on ‘optimize model’ to let software decide the parameters to fit the best model. Maximum of five neighbours are included and 4 sectors with 45° offset are used for selecting neighbourhood for better cross validation.

F. Model Validation

Before producing the final surface, validation is carried out to have some idea of how well the model predicts the values at unknown locations. It removes each data location one at a time and predicts the associated data value. For all points, cross-validation compares the measured and predicted values. The parameters to judge if a model provides accurate predictions Fig. 9. (e) are:

1) The predictions are unbiased, indicated by a mean standardized error close to 0.
2) The standard errors are accurate, indicated by a root-mean-square standardized prediction error close to 1.
3) The predictions do not deviate much from the measured values, indicated by root-mean-square error and average standard error that are as small as possible.

IV. GROUNDWATER SURFACE MAPS

Using geostatistical method (ordinary kriging), groundwater level maps are generated for 5 years (2012, 13, 14, 15 & 16). In total, 10 maps are produced i.e 2 maps for every year, one for the pre-monsoon and other for the post-monsoon.
Fig. 12: GW Surface Map Pre-Monsoon (2013)

Fig. 13: GW Surface Map Post-Monsoon (2013)

Fig. 14: GW Surface Map Pre-Monsoon (2014)

Fig. 15: GW Surface Map Post-Monsoon (2014)
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V. GROUNDWATER LEVEL TREND

Graphs showing groundwater trend are generated from year 2012 to 2016, therefore the groundwater observation wells which have measured values in all five years are considered for the analysis. To separate those wells, ‘intersect’ overlay method in ArcMap is used and new attribute table is generated with year and ground water level as different fields. The graph is generated taluka wise and average level of water in well is considered in each taluka for analysis. Different types of graphs are available for data exploration. A line graph displays data as a line which is apt for showing
variation in groundwater level. New attribute table is created for each taluka using data management which includes year and groundwater level in fields as variables. The next step is to add each attribute table (different talukas) in ‘create graph wizard’. With the help of graph generated it can be easily analysed that how the groundwater level is varying in different years in different talukas. The variation is shown for each taluka in the district, there are total two graphs which are for pre-monsoon & post-monsoon as shown in Fig 21 and Fig. 22.

**VI. CONCLUSIONS**

Groundwater surface maps and trend graphs are found to be in tandem with each other, following conclusions can be drawn from the present study:

There is relatively deeper groundwater level in areas which are situated in geographically mid portion of the district i.e. in Deodar, Tharad, Bhabhar, Kankrej and portion of Vav taluka. The water level of Deodar, Bhabhar and Kankrej taluka is continuously going down in the last five years.

The talukas in the north eastern part of the district i.e. Palanpur, Amirgadh, Vadgam and parts of Deesa have relatively shallow depth of groundwater level as compared to other parts of the area.

The need of the hour is for management of resources for sustainable development. Taking up of artificial recharge on large scale through appropriate techniques on a local scale with active community participation is suggested. In the confined aquifers artificial recharge by indirect injection technique is suitable that is dual purpose connector wells.

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