Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 3, Issue 5, May-2016

Geostatistical Analysis of Groundwater Level Variability Using Geoinformatics in Mehsana District, Gujarat, India

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Abstract- *The water ecology of Mehsana district is fragile where most of the people are dependent on groundwater for their daily needs. The surface water sources are limited and with rapid growth in agriculture and dairy farming, the encumbrance on groundwater has increased exponentially. The present study has analysed the variability in depth to water level below ground level (bgl) from 2010 to 2014. Geostatistical analysis method, ordinary kriging has been used to depict the groundwater surface map of the last five years of the district to study and analyse the spatial variability of groundwater levels. Pre-monsoon and post-monsoon groundwater level fluctuations are used to generate groundwater surface maps and trend graphs in GIS environment. Over exploitation of ground water is the single major issue in the district resulting in the fast depletion of this resource. Piezometric heads of deep confined aquifer has also declined sharply owing to the huge withdrawal.*

Keywords- *Geostatistical analysis, ordinary kriging, groundwater level fluctuations, spatial variability*

I. INTRODUCTION

Semi-arid Mehsana district is one of the severely-threatened groundwater socio-ecologies in India. While surface water supplies are limited, irrigation has intensified with rapid energisation of wells and growth in tube wells for intensive cropping and dairy farming [1]. Abstraction of groundwater exceeding natural replenishment generates stress in the aquifers causing depletion of water table, changes in the direction and velocity of groundwater flow, increased cost of abstraction and ecological damage[2]. Rivers Rupen and Khari drain part of the Mehsana district, both these rivers are ephemeral in nature and flow only during good monsoon years. The river Sabarmati forms the eastern boundary of the district with very limited catchment area in the district. Major part of the area in the district is devoid of any drainage network and does not fall in any catchment. The surface water resources of the district are very limited. Groundwater is the main source of irrigation, about 93% of the area is irrigated by groundwater [3]. Since groundwater is one of the main water resources in this region, it needs to be managed much more efficiently than other water resorces. The recently large variations of groundwater levels over years in many parts of Mehsana, suggest a study to be undertaken to have a better understanding of the variability of groundwater.

II. STUDY AREA

The study area is Mehsana district which is situated in north part of the Gujarat and is one of the 33 districts of the state. The district falls between the latitude 23°1’12” to 24°5’24” N and longitude 71°12’36” to 75°31’12” E. The geographical area of the Mehsana district is 4393.74 sq.kms and it has 10 Talukas. The taluka map of the study area and locations of observation wells (confined & unconfined) is as shown in figure 1.

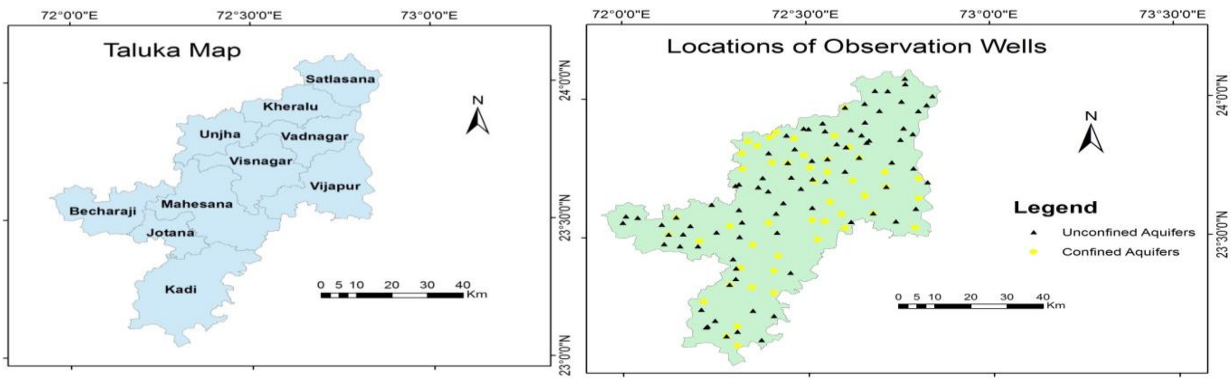

Fig. 1: Taluka map and locations of observation wells

III. METHODOLOGY

Ordinary kriging has been used under Geostatistical analyst tool in ArcMap software, which gives most appropriate results when compared to other interpolation techniques [4]. 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 figure 2.

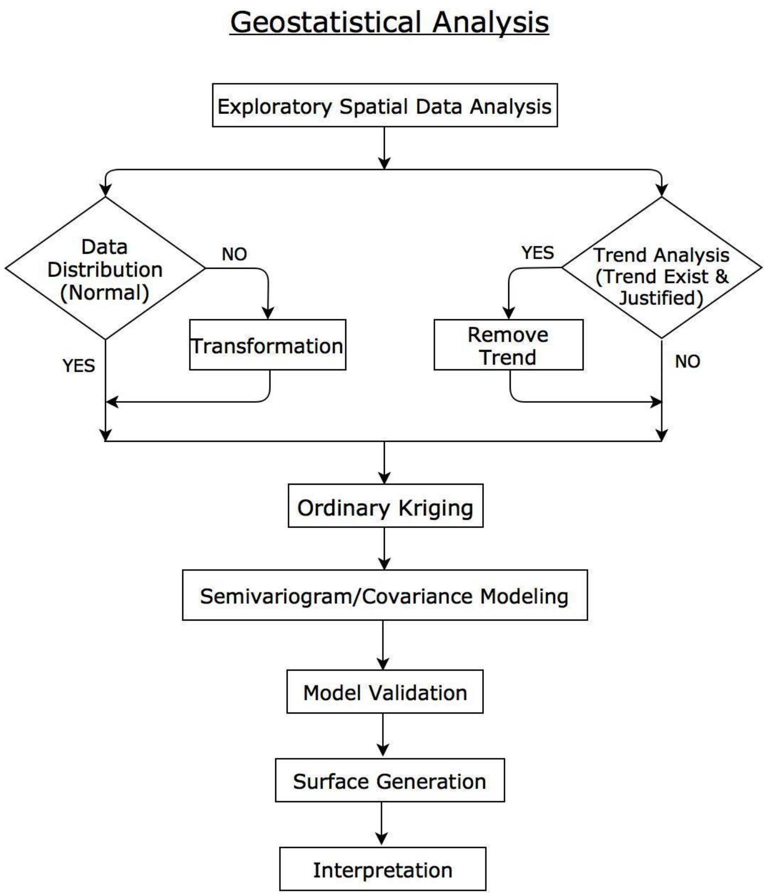

Fig. 2: Flow chart of Geostatistical analysis

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, SWDC. The data of pre-monsoon & post-monsoon water levels were taken for both confined & unconfined aquifers.

B. Histogram Tool

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 [5]. Figure 3 shows the histogram (frequency distribution) of the ground water level of confined aquifers post-monsoon 2014. 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 (figure 3), it can be seen that the plot is very close to being a straight line and thus no transformation is required in this case.

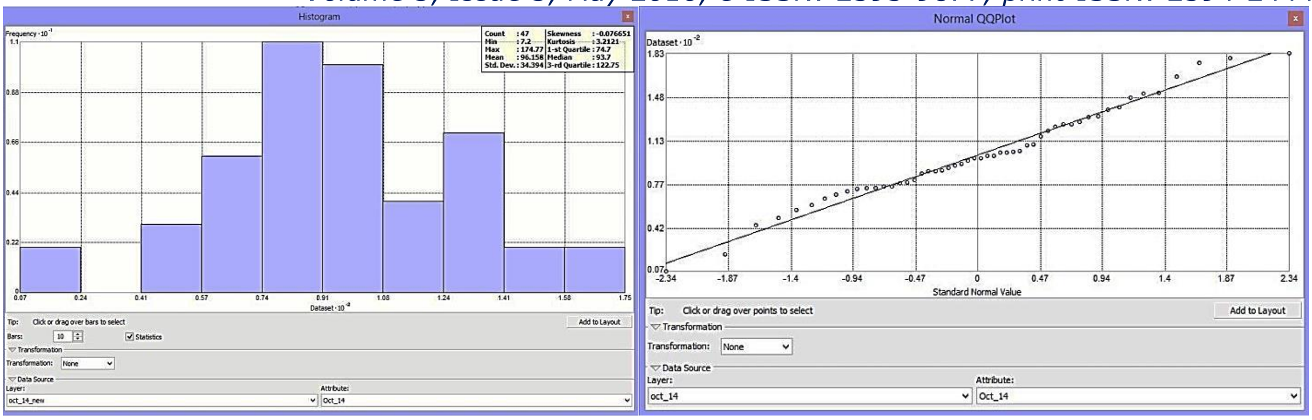

Fig. 3: Histogram and normal QQ plot of the data

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 [5]. In the figure 4, ground water level values of confined aquifers post-monsoon 2014 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.

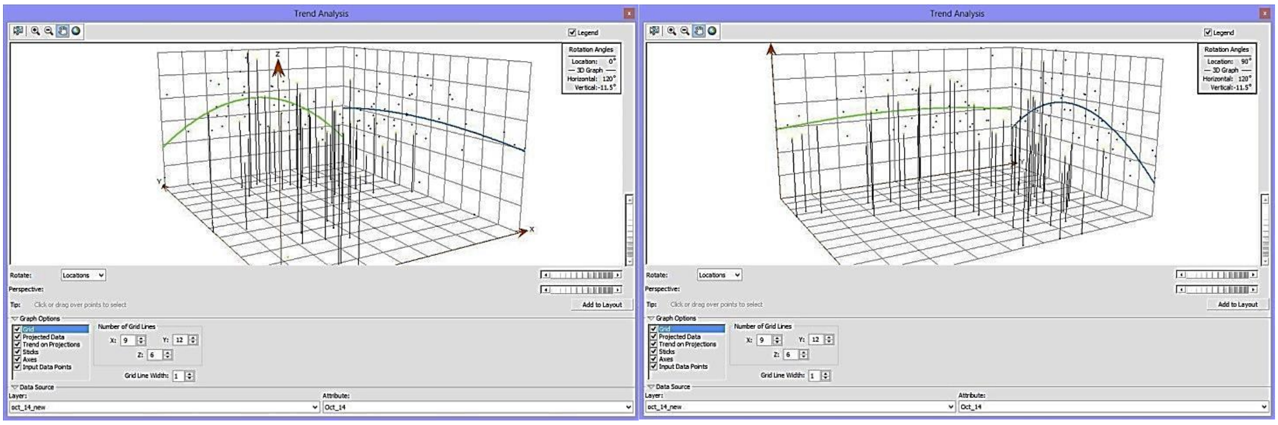

Fig. 4: Trend analysis of data in different directions

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 figure 5 for confined aquifers post-monsoon 2014 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 (figure 5), 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.

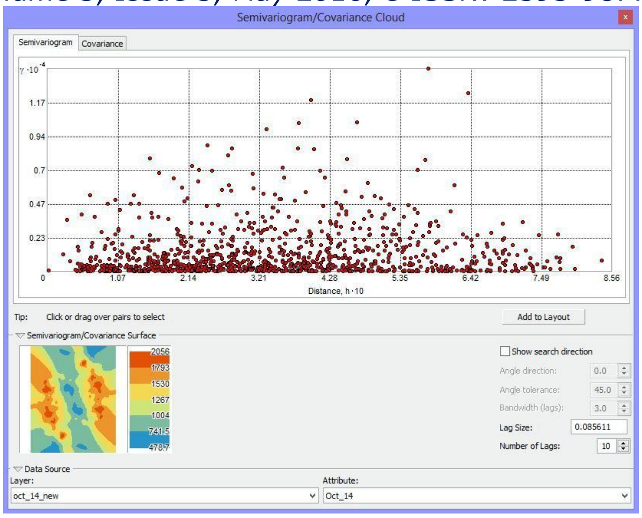

Fig. 5: Semivariogram cloud

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 (figure 6), 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 figure 3.12). 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 45^0 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 (figure 6) are:

- The predictions are unbiased, indicated by a mean standardized error close to 0.
- The standard errors are accurate, indicated by a root-mean-square standardized prediction error close to 1.
- 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.

The Cross Validation dialog box also allows you to display scatterplots that show the error, standardized error, and QQ plot for each data point.

IV. GROUNDWATER SURFACE MAPS

Although unconfined aquifers data shows fairly good groundwater levels but this is due to the local presence of discontinuous clayey layers. The unconfined data is largely showing the perched water table which is above the clay lenses. Water table in perched aquifers fluctuates depending upon the recharge and use of groundwater locally in unsaturated zone. The actual water table in the area has gone down well below the confined aquifers [6]. By analysing the lithologs of the area and due to presence of basalt, it is observed that the hydraulic conductivity and specific yield of the unconfined wells are very low, extracting this water is practically fruitless which forces the users to go for deep tube wells [7]. Thus, an analysis of unconfined aquifers is pointless as currently the area is utilising the water stored in deep confined aquifers only.

The alluvial aquifers are deep in Mehsana district, also there is evidence of substantial horizontal zones of more permeable sands between 100 and 250 m below ground level [8]. These aquifers have very high transmissivity and storage coefficients, the geo-hydrological parameters determining the yield of the confined aquifers. In this region, groundwater from the deep aquifers is being tapped using deep tube wells and high capacity pumps.

Using geostatistical method (ordinary kriging), groundwater level maps are generated for 5 years (2010, 11, 12, 13 & 14). In total, 10 maps are produced i.e 2 maps for every year, one for the pre-monsoon and other for the post-monsoon (Confined aquifers).

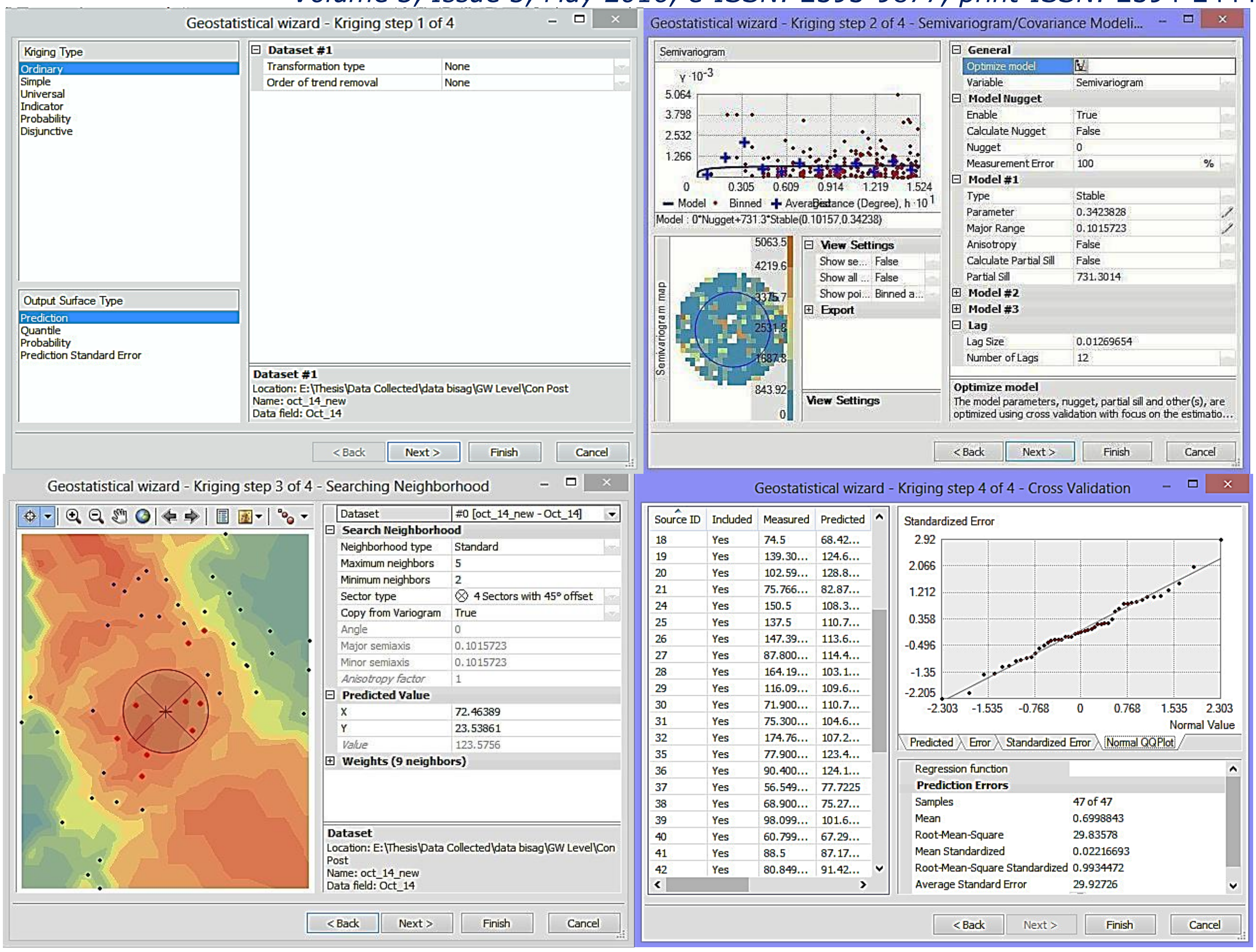

Fig. 6: Ordinary kriging steps

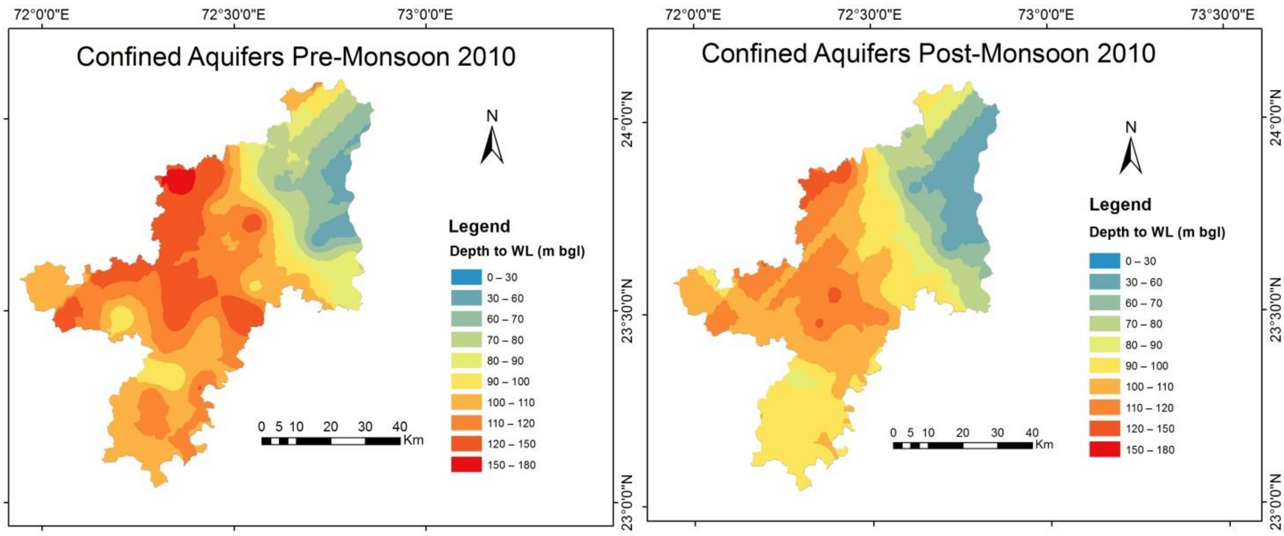

Fig. 7: Groundwater surface maps 2010

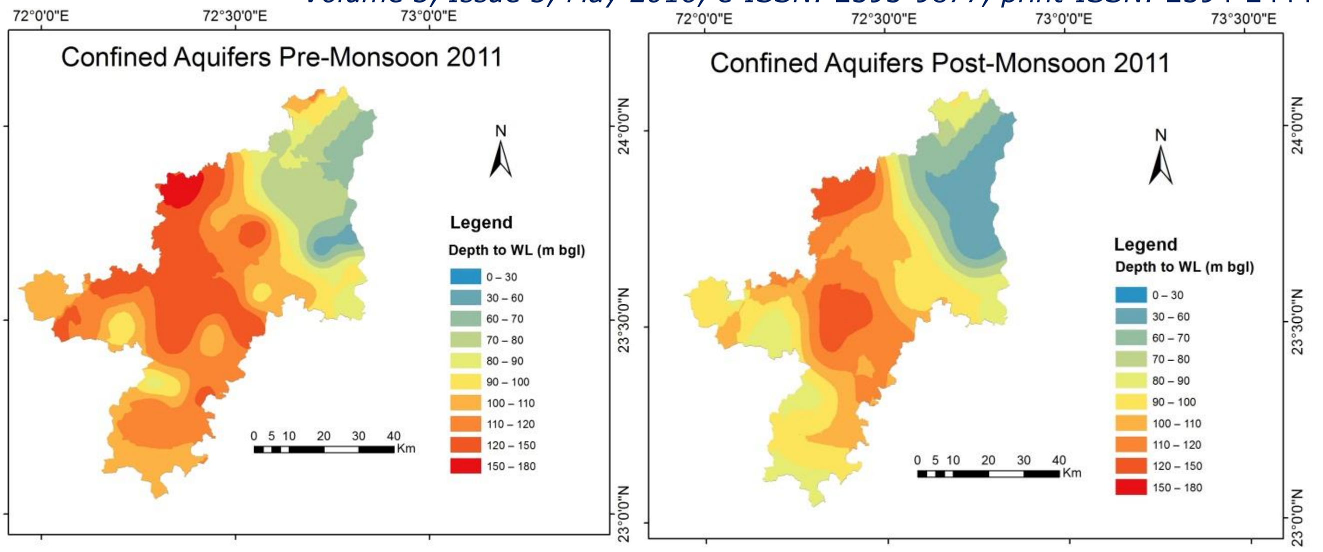

Fig. 8: Groundwater surface maps 2011

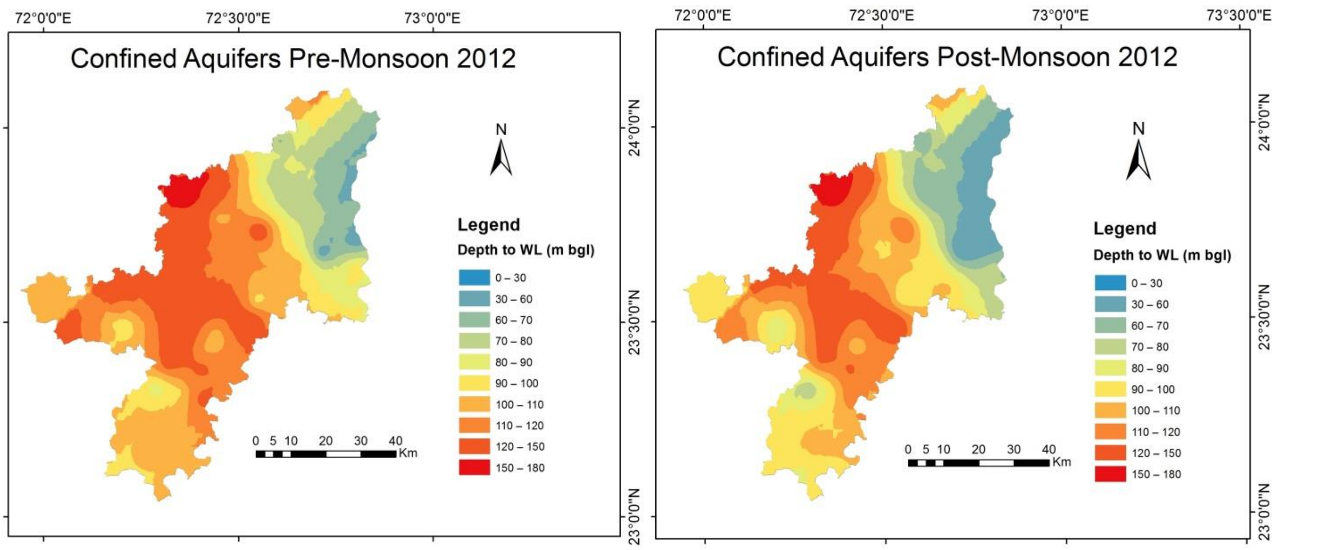

Fig. 9: Groundwater surface maps 2012

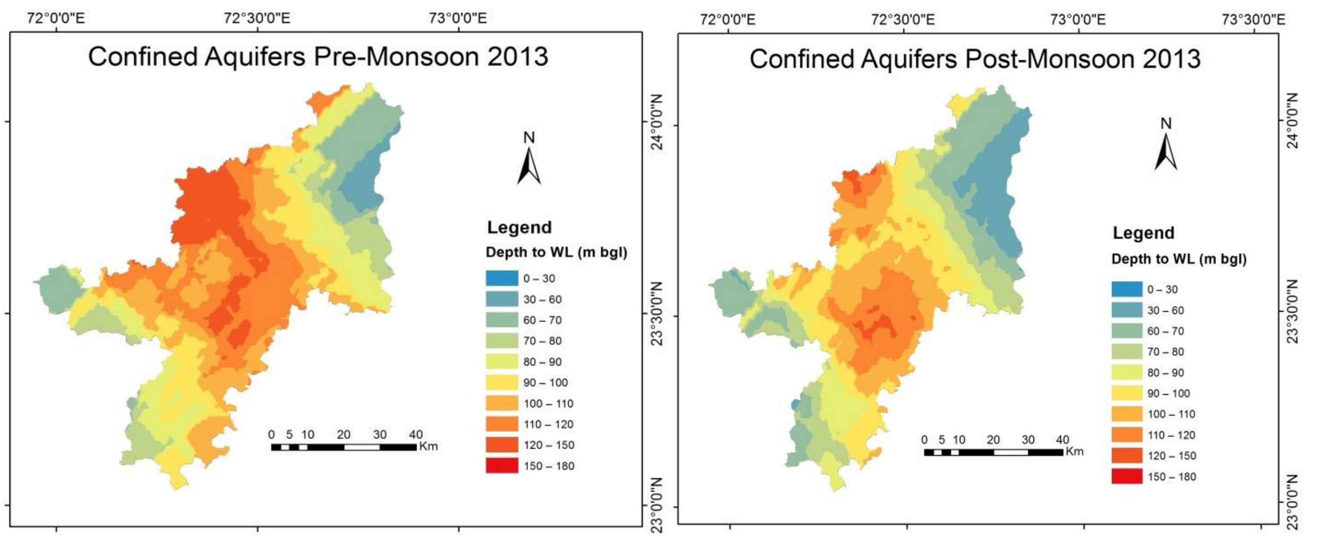

Fig. 10: Groundwater surface maps 2013

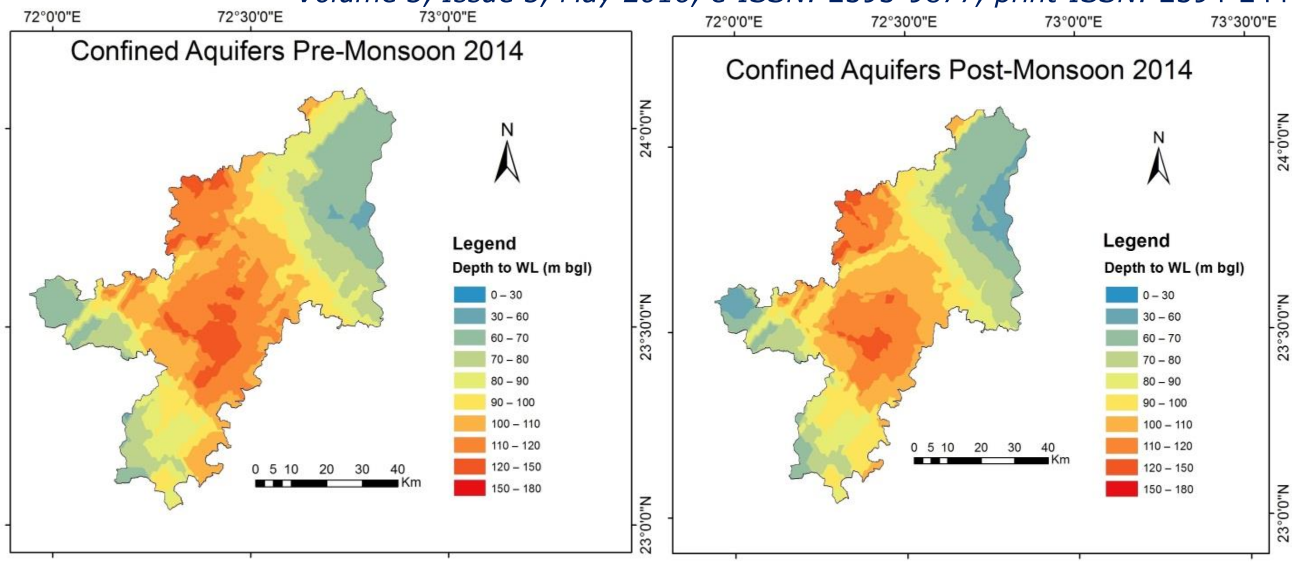

Fig. 11: Groundwater surface maps 2014

V. GROUNDWATER LEVEL TREND

Graphs showing groundwater trend are generated from year 2010 to 2014, 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 ground water 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 (confined aquifers) as shown in fig. 12.

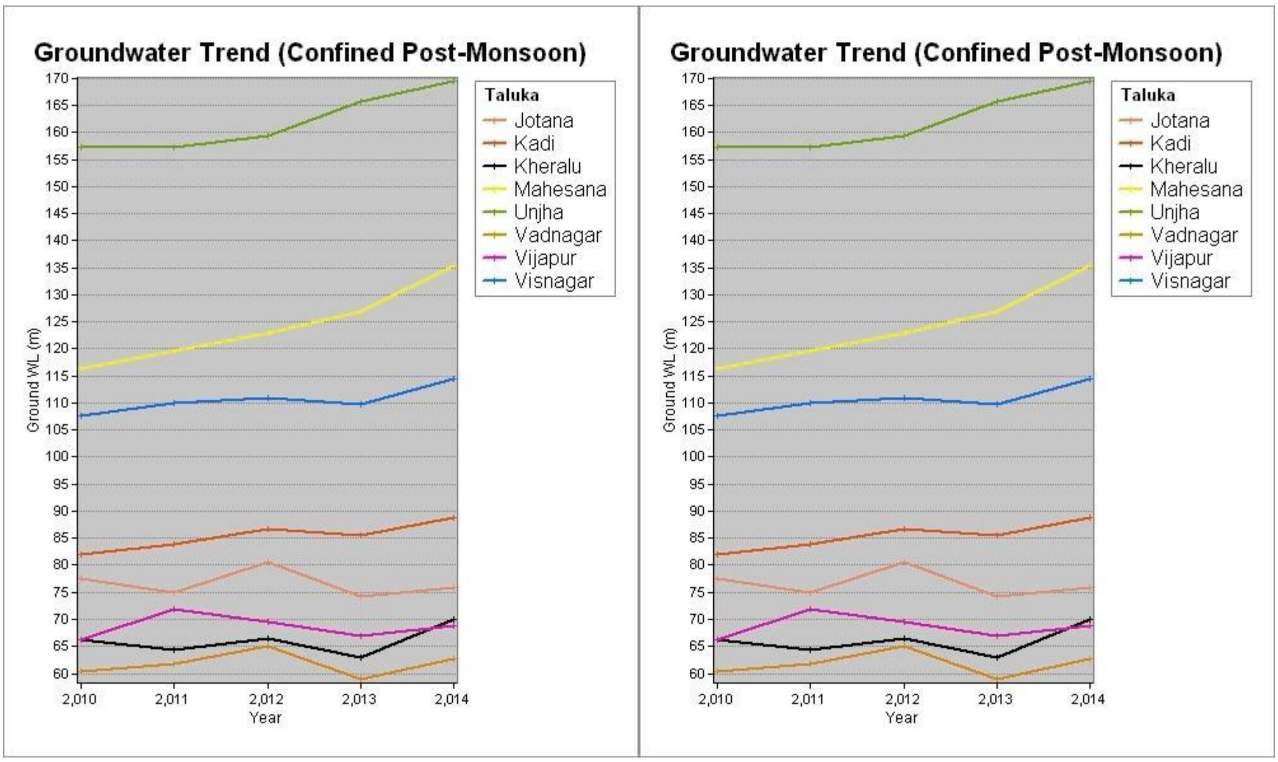

Fig. 12: Graphs showing groundwater trend

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 Mahesana, Unjha and Visnagar taluka. The level of Mahesana and Unjha taluka is continuously going down in the last five years.

The talukas in the north eastern part of the district i.e. Vadnagar, Kheralu and parts of Vijapur have relatively Shallow depth of groundwater level as compared to other parts of the area as these are less densely populated (census data [9]) and thus encumbrance on confined aquifers is less. The talukas Unjha and Kadi are showing the best recharge of confined aquifers which can also be validated by the trend graphs.

Ground water from the confined aquifer system is under exploitation in a major way for various uses in the district. These aquifers have very high transmissivity and storage coefficients, the piezometric surface of confined aquifer ranges from less than 60 m bgl to more than 150 m bgl. However, in major part, it is more than 90 m bgl. Because of excessive ground water development, consistent decline of piezometric surface is observed in the district.

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.

ACKNOWLEDGMENT

The authors would like to express their sincere thanks to the Director, Bhaskaracharya Institute for Space Applications and Geo-informatics (BISAG), State Water Data Centre (SWDC), and groundwater investigation unit-2, SWDC for providing necessary facilities and support during the study period.

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