Optimization of Ground Water Level Network Using Geostatistical Method

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Abstract

Groundwater management and optimized monitoring has become more significant to satisfy the need and demand of rapidly ever-increasing population. In most of the developing countries, optimized networks for monitoring groundwater are rarely designed. This study presents optimization of existing network using geostatistical method for 42 observation wells in Warangal district, Telangana state. From 42 observation wells, average ground water level fluctuation is evaluated with geology, lineament, geomorphology, recharge map and ground water level fluctuation map of Warangal district. These variables are evaluated stochastically with ordinary and universal kriging methods in Geographic Information System (GIS). Further, Semi variogram has been performed to fit suitable theoretical model compared to experimental model. Results of experimental models are compared from groundwater level data with theoretical models (gaussian, circular, exponential and spherical). This study resulted that ordinary kriging method is suitable optimal model and five observation wells were removed using error variance of monitoring networks. It is also explaining that prediction of groundwater level and upgrading of monitoring networks from randomly distributed wells using multiple variables considered in the study. The geostatistical method proposed in the study is detected as effective method for selecting suitable observation wells in complicated geological setup. It also concludes that 37 observation wells are required for proper monitoring in the study region.

Key Words: geostatistical method, Semi variogram, kriging

1. Introduction

Observation well networks are useful for quantitative and qualitative monitoring of groundwater resources. A properly designed groundwater monitoring system helps in understanding the state of region with respect to space and time. The optimal design of observation well network mainly depends on geographical location, spatial and temporal distribution of water levels. For the effective management of groundwater, it is essential to know the status of the groundwater levels (GWLs) in the monitored zone so that addition of new observation wells to the network or removal of existing wells from the network can be done. Installation of new observation wells is based on the place, demand of groundwater, local circumstances and socioeconomic factors of specific area (IGRAC, 2006). Removal of groundwater wells from the network is based on increase in population, over exploitation and contamination of groundwater.

Statistical approach is the commonly used method for the network optimization. This is subdivided into classical statistics, geostatistics and time series analysis (Uil et al.1999). Geostatistics approach is the extensively used method among three for the network optimization. The main benefit of this approach is to estimate the variance associated with a particular sampling pattern. This method examines the correlation among the variables using variograms. Many researches have successfully applied these methods for optimal design of network. Prakash and Singh (2000) used geostatistical tool for the optimal location of sites for groundwater level monitoring for upper Kongal basin, Andhra Pradesh. Chao et al. (2011) used overlay tools for the demonstration of optimal design of groundwater level network. Fahimeh et al. 2017 applied NSGA-II algorithm for the minimizing the error as well as observation wells for the optimization of existing network. Fisher 2013 used kriging-based genetic algorithm method for the optimization where forty wells are removed from the monitoring network. Chandan and Yashwanth 2017 used GIS based geostatistical tool and multi parameter analysis for the optimization of monitoring network, concluded that 82 number of observation wells are required for the site for better monitoring of observation wells.

The objective of this study is to optimize the current observation well network over Warangal District of Telangana State. As the groundwater levels are decreasing due to over exploitation and varying geological properties, observation wells are to be removed from the network for better utilization and management of groundwater. In this study 42 observation well data is used as input for the optimization of monitoring network using geostatistical (kriging) methods and standard error prediction map. Network optimization using only observation well data will not be enough. So, several parameters such as geology, geomorphology, lineaments, land use land cover and precipitation-recharge are considered for effective design of groundwater monitoring network. To optimize the network, few observation wells are removed from the network in such a way that error should be within the limits. To prioritize the suitable site for the removal of observation wells, additional parameters such as geology, lineaments, recharge etc. are used along with groundwater level fluctuation map.

2. Study area

Warangal district of Telangana State falls in the drainage basins of both Krishna and Godavari rivers with a geographical area of 12,846 km^2. The district is bounded by longitude 78^0 49′ E - 80^0 43′ E and latitude 17^0 19′ N -18^0 36′ N with a total population of 35,12,576. Piezometric level data from 30 observation wells for the period 1996 to 2017 obtained from Groundwater department, Warangal District are used for the analysis. The groundwater level data is considered for Monsoon (June to September) season only.

3. Methodology

In the present study, optimization of existing network is performed using geostatistical approach in consideration with multiparameter using GIS (Zhou et al. 2013). In geostatistical approach, ordinary and universal kriging interpolation methods are used. Using these methods one can estimate the values at unsampled sites along with the error i.e., uncertainty of prediction within the area under consideration. this uncertainty of prediction acts as the base for the upgradation of the existing network. Multi-Parameters are used in association with the geostatistical method for the optimization of existing observation well network.

3.1 Geostatistical method

This method helps in understanding the spatial/temporal occurrences and get most on spatial relationships to model parameters at unsampled and unobserved locations (Caers, 2005).

Ordinary kriging method

For analyzing ordinary kriging method, an average of regionalized parameter is assumed to be same all over the region of interest.

$$\hat{X}(y_o)=\sum_{k=1}^{z}\lambda_k X(y_k) \tag{1}$$

$$\sum_{k=1}^{z}\lambda_k \text{ and } \sum_{k=1}^{z}\lambda_k\gamma(y_k, y_l)-\mu=\gamma(y_k, y) \tag{2}$$

$\hat{X}(y_o)$ is measured variable at y_o location; $y_o$is kriging weight and $X(y_k)$ is observed variable at y_k at location; z are samples in dataset; $\gamma(y_k, y_l)$ are the modeled semi variogram at location y_k and y_l; μ is Lagrange multiplier; $\gamma(y_k, y)$ are modeled semi variogram at y_k location and y is predicted location.

Universal kriging method

This method is a complex form in mathematics. Spatial distribution of parameter is sum of deterministic trend modelled by linear regression on covariates, and random component or function

$$\hat{X}(y_0)=n(y_k)+X(y_k)=\sum_{l=0}^{L}a_l f_l(y_k)+X(y_k) \tag{3}$$

$n(y_k)$ is deterministic trend; $X(y_k)$ is random component; a_l is lth drift coefficient; f_l spatial coordinates; L samples in dataset.

3.2 Cross validation

Cross validation test is performed to know the unbiasedness prediction and to select suitable kriging interpolation and semi-variogram model. 42 observation ground water level fluctuations were considered as an input to cross validation and further used for interpolating using kriging methods. For prediction stage, four semi variogram models (gaussian, exponential, circular and spherical) were used to select suitable fitted one among the kriging methods. To verify the performance of model means square error (MSE), Root mean square error (RMSE), average standard error (ASE) are measured. These procedures were repeated to ordinary and universal methods of kriging.

$$ME = \frac{1}{z}\sum_{k=1}^{z}[x^*(y_k) - x(y_k)] \quad (4)$$

$$MSE = \frac{1}{z}\sum_{k=1}^{z}\left[\frac{x^*(y_k)-x(y_k)}{\sigma_v^2(y_k)}\right] \quad (5)$$

$$RMSE = \sqrt{\frac{1}{z}\sum_{k=1}^{z}[x^*(y_k) - x(y_k)]^2} \quad (6)$$

$$ASE = \sqrt{\frac{1}{k}\sum_{k=1}^{z}\sigma_v^2(y_k)} \quad (7)$$

$\sigma_v^2(y_k)$ is variance for the location y_k, $x^*(y_k)$ and $x(y_k)$ are observed and estimated values of variable at that location respectively.

3.3 Thematic maps preparation

ArcGIS 10.2 software is used for the processing, analysis and development of thematic maps. Groundwater level fluctuation (GLF) map is created seasonally using observation well data. GLF maps are analyzed seasonally and are developed for each season. Using GIS environment observation well data is processed and interpolated using geostatistical methods for the development of GLF map.

Geology, lineament and geomorphology are considered as important parameter for groundwater storage, recharge and discharge. Lineament property is directly related to the geological structures (Nag and Ghosh, 2012). These data sets are collected from Telangana State Remote Sensing Applications Centre, Telangana. These maps are analyzed in the GIS environment.

Groundwater recharge map is developed for only pre-monsoon season using rainfall data as input. Thomas et al. 2009 proposed a relationship between rainfall and recharge as shown below

$$R = 5.732(P - 89.7)^{0.51} \quad (8)$$

Where, $R =$ groundwater recharge and $P =$ mean precipitation.

3.4 Estimating optimum observation wells

Using the groundwater level fluctuations from 2003-2016, standard error map was prepared for the study region. Standard error (S_{error}) measures the accuracy and bias of the predicted sample and is calculated by equations 9 & 10.

$$S_{error} = \frac{\sigma}{\sqrt{n}} \quad (9)$$

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{n}} \quad (10)$$

Where, σ is the standard deviation, n is the number of samples, x observed GWL, $\bar{x}$ is the mean GWL of the dataset. Standard error map obtained from GLFs and the multi-parameters were compared and are separately analyzed with GLF map. From the standard error obtained from GLF map in association with influencing parameters, minimization of observation wells from the network is performed. Initially few observation wells were removed from the network and standard error was computed until the error was bounded within the limits (not exceeding 1). The selection of observation wells that are to be removed will be based on the GLF at that observation well and its influence on multi-parameters.

4 Results and discussions

4.1 Cross validation of groundwater level fluctuations

Ordinary and universal kriging interpolation methods were analyzed and computed separately for four semi-variogram models like exponential, gaussian, circular and spherical in GIS environment. Among these, best interpolation technique was finalized using ASE, ME, RMSE and MSE and cross validation results were represented in Table1. To ensure that the predicted values are unbiased, mean error values should be equal to zero.

Table 1: Ordinary and Universal kriging cross validation

Kriging	Semi-variogram model	ME	RMSE	ASE	MSE
Ordinary	exponential	0.091	1.321	0.03	1.251
	gaussian	0.098	1.492	0.031	1.352
	circular	0.125	1.398	0.036	1.299
	spherical	0.103	1.499	0.045	1.458
Universal	exponential	0.109	1.368	0.03	1.239
	gaussian	0.132	1.476	0.035	1.372
	circular	0.118	1.654	0.052	1.568
	spherical	0.112	1.624	0.046	1.503

From Table 1, ordinary and universal kriging methods were compared using four semi-variogram models by ME, RMSE, ASE and MSE. By using exponential model, ordinary kriging (0.091, 1.321) was performed better than universal kriging (0.109, 1.368) based on ME and RMSE. Among four semi-variograms, exponential model performed well with least mean errors followed by gaussian model. From Table 1 the cross-validation results suggested that Ordinary kriging with exponential model provided accurate estimation of ME (0.091), RMSE (1.321), ASE (0.03) and MSE (1.251) which are least among the kriging methods. Therefore, for further analysis ordinary kriging with exponential semi-variogram model was selected for optimization process. Using ordinary kriging GLF map, groundwater recharge map was developed.

4.2 Multi-parameter impact on GLFs

Many researches have used geostatistical method for selection of observation well locations either for adding or removal of wells from the network (Prakash and Singh 2000, Ibtissem et al., 2013). In this method, Standard error map was generated for only monsoon season using observation well data and their geographical locations in GIS environment. Using average ground water level, standard error values were measured. If the error values are within the limits (> 1) then the site was considered suitable for additional observation wells. If the error is < 1, then, removal of existing observation wells from the network can be done. Practically, standard error map obtained from observation well data is insufficient for the site selection. Other than groundwater level fluctuations there are several other parameters which can be considered in geostatistical analysis for this purpose such as groundwater recharge, geology and lineaments etc.

From observation well data groundwater level fluctuation map was generated for Monsoon season using ordinary kriging (exponential model) method in the GIS environment as shown in Figure 1. The GLF map was divided into five classes with lowest groundwater levels at southwest corner and highest levels in the middle of Warangal. The groundwater levels were varying from 3.82 meters below groundwater level (mbgl) to 18.07 mbgl. Other than GLFs, the parameters which influence the selection process directly or indirectly are explained in subsequent sections.

4.3 GLFs with reference to Geological features

The study region consists of six classes of geological features as shown in Figure 2. Most of the area was covered by Gneiss-Granitoid Complex (52.56%) followed by Semi-consolidated sediment groups (28.24%). Standard error for the study region exists within the limits ($S_{error} < 1$) as shown in Figure 5. So, site selection for the removal of observation wells was performed using geological features. Gneiss-Granitoid rocks are impervious compared to semi-consolidated group. As the GWFs (13-18 mbgl) are decreasing in west part of the region(Gneiss-Granitoid Complex), the site was considered for the removal of observation wells. In the central part of the region groundwater levels (3-6 mbgl) were more and was correlated with rock type (Metamorphic rock), no observation wells were selected from central part of the region. GLFs (11-14 mbgl) were decreasing in Northeast part, where the rock types were Semi-consolidated groups. So, observation wells were selected for the removal from this site of the study region.

4.4 GLFs with reference to Lineaments

Lineament specifies potential of permeable zone for ground water exploitation. It helps in understanding existence and movement of groundwater. The study region comprises of major and minor lineaments varying from meters to kilometers. Although the lineament density is high in west and Northeast part of the region the groundwater fluctuation is less difference due to vegetation. The site and removal observation wells were decided by including the difference in GLF and lineament density. Thus, more removal observation wells were included in the site. Removal of wells were located in the place with low GLF and low lineament density.

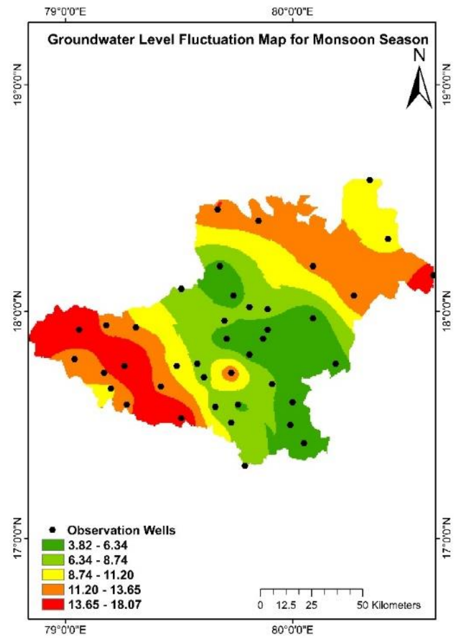

Figure 1: GLF map for monsoon season

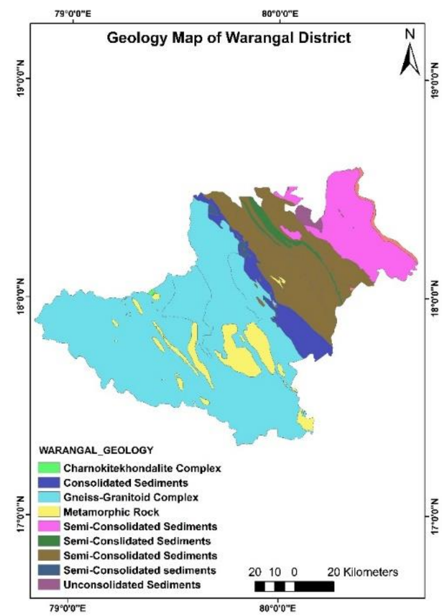

Figure 2: Geological Map of Warangal

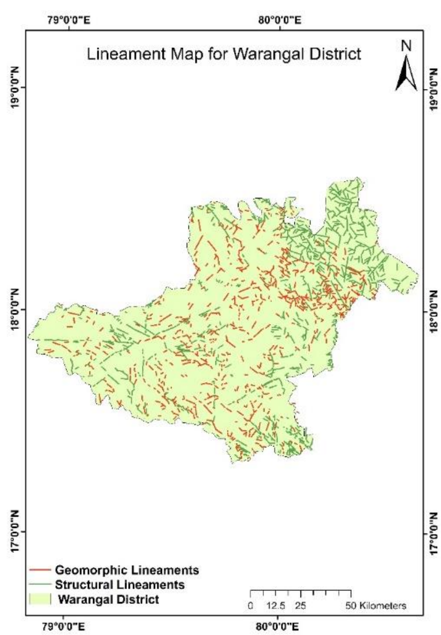

Figure 3: Lineament map of Warangal

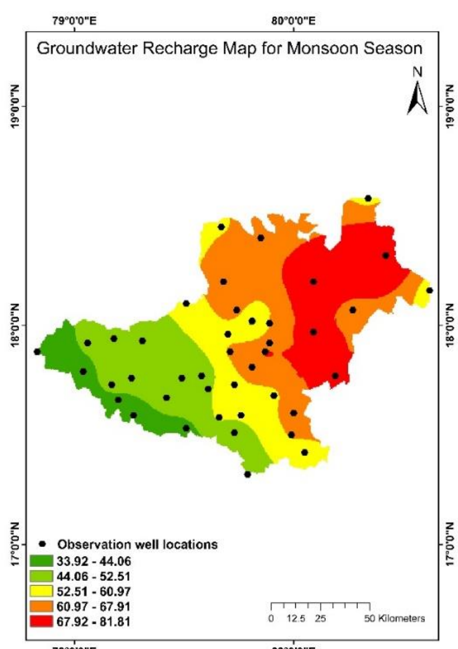

Figure 4: Groundwater recharge map of Warangal

4.5 GLFs with reference to Groundwater recharge

Average annual rainfall of the study region is 977mm. The relationship between annual and monsoon groundwater is analyzed for the period (2003-2016). Monsoon GWLs showed high correlation in the previous and current years rainfall respectively. Recharge from rainfall is affecting water level of the study area and therefore it is counted as one of the ways to select observation well location. It was detected that recharge of ground water was less in south east region and medium in central region and more in south west region. From the ground water recharge map it was detected that GLF were high at lowest recharge region. Site with high GLF and high recharge were chosen for removal of observational wells.

4.6 Optimization

Based on standard error map obtained from GLF including lineament, geology and recharge parameters, observational wells are located to remove from the region. The $Serror$ was created for 42 observation wells, the error was found less than 1. When observational were increased it is observed that an increase in error values, so removal of observational wells site in the region at south east and west part of the study region. To optimize the well network, five observation wells were removed as shown in Figure 5. After removal of wells, error is checked and observed that ASE, MSE and RMSE of the well values are minimum. The Standard error is decreased from 0.69 to 0.97 < 1. Absolute standard error (1.2812 to 1.6418) Mean error (0.0128 to 0.0408), Mean error (0.0264 to 0.072) and Root mean square error (1.1821 to 1.989). Therefore, from the study it is analyzed that five wells were removed from the 42 well network in the study region.

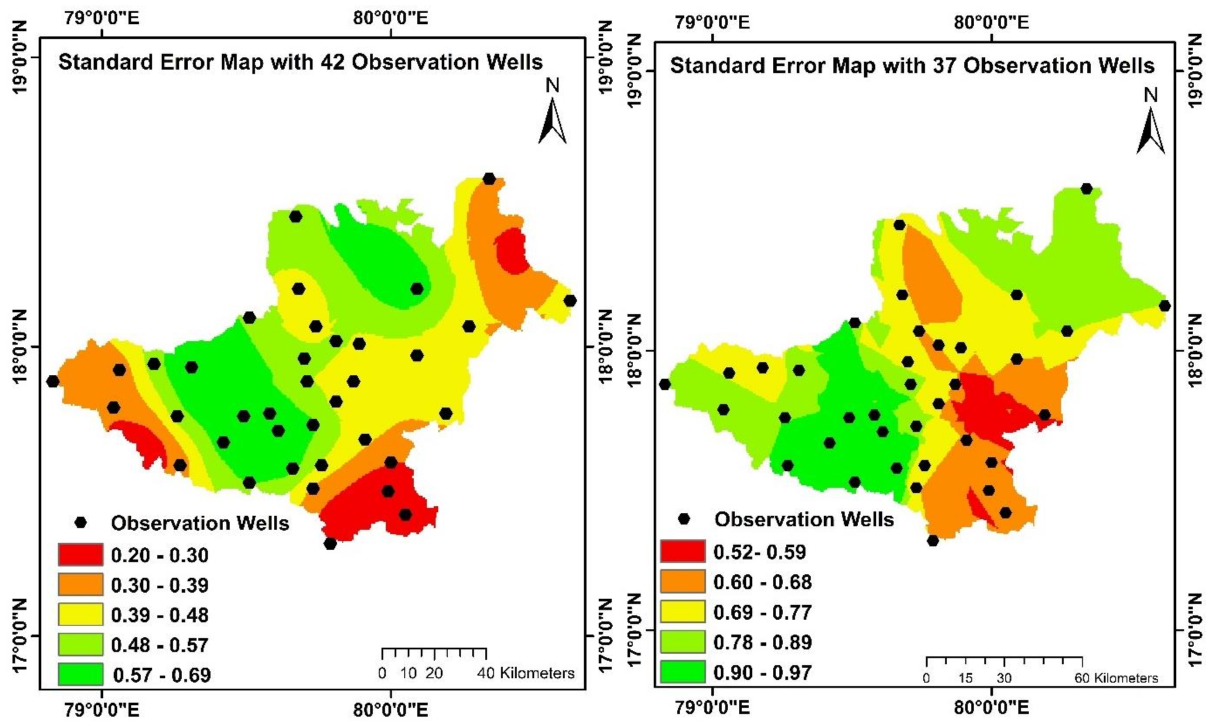

Figure 5: Standard error map before and after removal of observation wells

5 Conclusion

This study concludes that use of Geostatistical method in combination of different variables that shows impact for groundwater levels, to optimize the suitable network system in the region. Different variables analyzed with respective to lineament, recharge and geology shows good results. Forty-two observations wells were considered in the study, standard error map was prepared and checked for influence of different variables considered in the region using cross validation technique. Based on the measures of error indices it is suggested that five wells out of 42 should be removed were the Ground water level fluctuation is not showing much impact in exploitation for optimized network. Therefore, after the removal of wells performance of the network is checked and analyzed. From the study it is detected that

Geostatistical method is efficient in locating the observation wells for better understanding of recharge, availability of ground water level and movement of ground water level using other optimization methods.

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