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Network Design For Groundwater Monitoring – A Case Study From Amritsar District, Punjab

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ABSTRACT : Monitoring of groundwater regime is the backbone of the any groundwater resource evaluation or management project. Uncertainties become large if the number of observation points is less and the network is not able to represent the actual groundwater conditions. Collection of data is both time consuming and expensive exercise. Beyond certain number of observation points, the improvement in monitored variable is not much as compared to the cost involved in monitoring. Therefore, there is a need to develop an optimal groundwater observation well network to minimize the uncertainty of groundwater monitoring and minimize the time and cost of monitoring.

Present paper evaluates the existing network of groundwater monitoring in Amritsar District of Punjab. The study indicates that the existing network of 81 observation wells is not adequate to represent the groundwater table in the Amritsar District, due to presence of number of canals and rivers. Based on the network design, 104 observation points are required to monitor groundwater table accurately.

INTRODUCTION

Water is essential for sustenance of life next only to air, and one of the principal elements that influences economy, industrial and agricultural growth of mankind. Although the ancient civilization had flourished mainly along surface water recourses, both surface water and ground water are of crucial importance to mankind. The continuing and ever accelerating depletion of water recourses in India and elsewhere in the world is matter of great concern.

All groundwater flow and transport models are dependent on the inputs (forcing functions and boundary and initial conditions) and coefficients (hydraulic conductivity, porosity and dispersivity etc.). Model predictions are function of the model parameters which are numerical approximations of the continuous inputs and coefficients of the governing equations. Lack of knowledge about the model parameters can result from spatial variability of aquifer flow and transport properties (e.g., hydraulic conductivity and hydraulic head) which may exhibit large fluctuations over relatively short distances. Commonly, there are few measurements of a property with which to develop a detailed estimate of the distribution of the property throughout the area of the aquifer to be modelled. Considerable estimation error in the model parameters results from interpolating model inputs and coefficients at numerous points over a large area on the basis of measurement at only a few locations.

For optimum and economic utilization of water resources, a determination of the extent and availability of surface and ground water is the first requisite. In the initial stages of investigation, there is little or no information available about groundwater table and aquifer properties. At this stage, the uncertainty of estimation in the aquifer is large. On the basis of this preliminary information, a more detailed study of the aquifer is usually made. Groundwater models are used to determine the ground water resources and its dynamics. If the data is sparse, the uncertainty of the model prediction is large. To minimize the uncertainty large amount of field data need to be collected.

Everett (1980) has defined monitoring network can be defined as "a scientifically designed surveillance system of continuous measurement and observation, including evaluation procedures". Monitoring of ground water regime is an effort to obtain information on ground water levels and chemical quality through representative sampling. Monitoring of groundwater regime is the first step for any programme of groundwater resource evaluation and its rational development. It is imperative to adopt a scientific methodology to precisely determine the change in ground water storage from time to time both natural and manmade. For achieving this goal estimation of vital parameters like specific yield, return seepage, from irrigation water and long term water level fluctuation through a Network of Observation wells are to be determined.

The various magnitudes that are important in hydrology (e.g., hydraulic head, transmissivity, permeability, thickness of a layer, storage coefficient, rainfall, effective recharge, etc.) are all functions of space and are very often highly variable. However, this spatial variability is, in, general, not purely random: if measurement are made at two different location, the closer the measurement points are to each other, the closure the measured values. In other words there is some kind of correlation in the spatial distribution of these magnitudes. Matheron (1983) has given the name of "Regionalized Variable" to these types of quantities: they are variables typical of a phenomenon developing in space (and/or time) and possessing a certain structure.

The present study throws a light on the existing network of Amritsar Dist. of Punjab. If the number of monitoring wells goes high in an area, the monitoring cost, time and data becomes high(Upadhyay, 2002). Vice versa, with less number of observation points it is difficult to get an exact picture of the area. Recognizing the need for guidance on the planning and implementation of a ground water monitoring network, it was decided to check the adequacy of the existing groundwater monitoring network in Amritsar district of Punjab.

Need for Ground Water Regime Monitoring Network

The primary objective of establishing the groundwater monitoring network stations is to record the response of groundwater regime to the natural and artificial conditions of recharge and discharge with reference to geology, climate, physiography, land use pattern and hydrologic characteristics. The natural conditions affecting the regime involve climatic parameters like rainfall, evapotranspiration etc. and the artificial conditions include pumpage from the aquifer, recharge due to irrigation system and other manmade causes like waste disposal etc. The database generated can form the basis for groundwater development and management programme. The ground water level and quality monitoring assume particular importance in coastal as well as inland saline environment to assess the changes in salt water/ fresh water interface, as also the gradual quality changes in the fresh ground water regime.

In the present study, it is proposed to optimize the existing network for observation of groundwater table. Optimization is to be aimed at for maximizing the reliability of monitoring network with the minimum measuring effort. To know about the ground water regime of an area it is sufficient to monitor a few selected sample wells, which can collectively represent the whole area. Statistical techniques are increasingly used to decide the optimum number of wells that may be sufficient to represent an area. The present work is carried out with following objectives:

- To check the adequacy of the existing monitoring network,
- To suggest improvement in the monitoring network, if the existing network is not optimal.

STUDY AREA

The Amritsar district, of Punjab has been selected for the present study (*Figure 1*). The district lies between latitude 31⁰ 6' to 32⁰ 6' North and longitude 74⁰ 30' to 75⁰ 30' East and covers an area of about 5087 km^2. Amritsar district is largely underlain by the Indus alluvium with Siwalik Hills bordering the north eastern fringe of Gurdaspur district and eastern fringe of Hoshiarpur and Ropar district. The depth of alluvium in major parts of the plains is 1000- 2000 m.b.g.l.

Climate of the area is semi-arid monsoon type; owing to a long distance from the Ocean / Sea, the region fails to get the full benefit from monsoon currents. It is characterized by a deficiency of rainfall over its greater part, high summer temperature and evaporation more especially in the southern parts. The average annual rainfall in the area is 1015.26 mm.

Though the region is apparently rich in rivers, its greater part suffers from a lack of perennial rivers and a very inequitable distribution of the drainage channels –a direct result of its topography and climate. The cultivation is very dense in the entire area of central Punjab. The area is surplus in food grains especially wheat and rice. Other main food grains are maize, gram, and pulses. Major cash crops are oilseeds, sugarcane, cotton, and potato

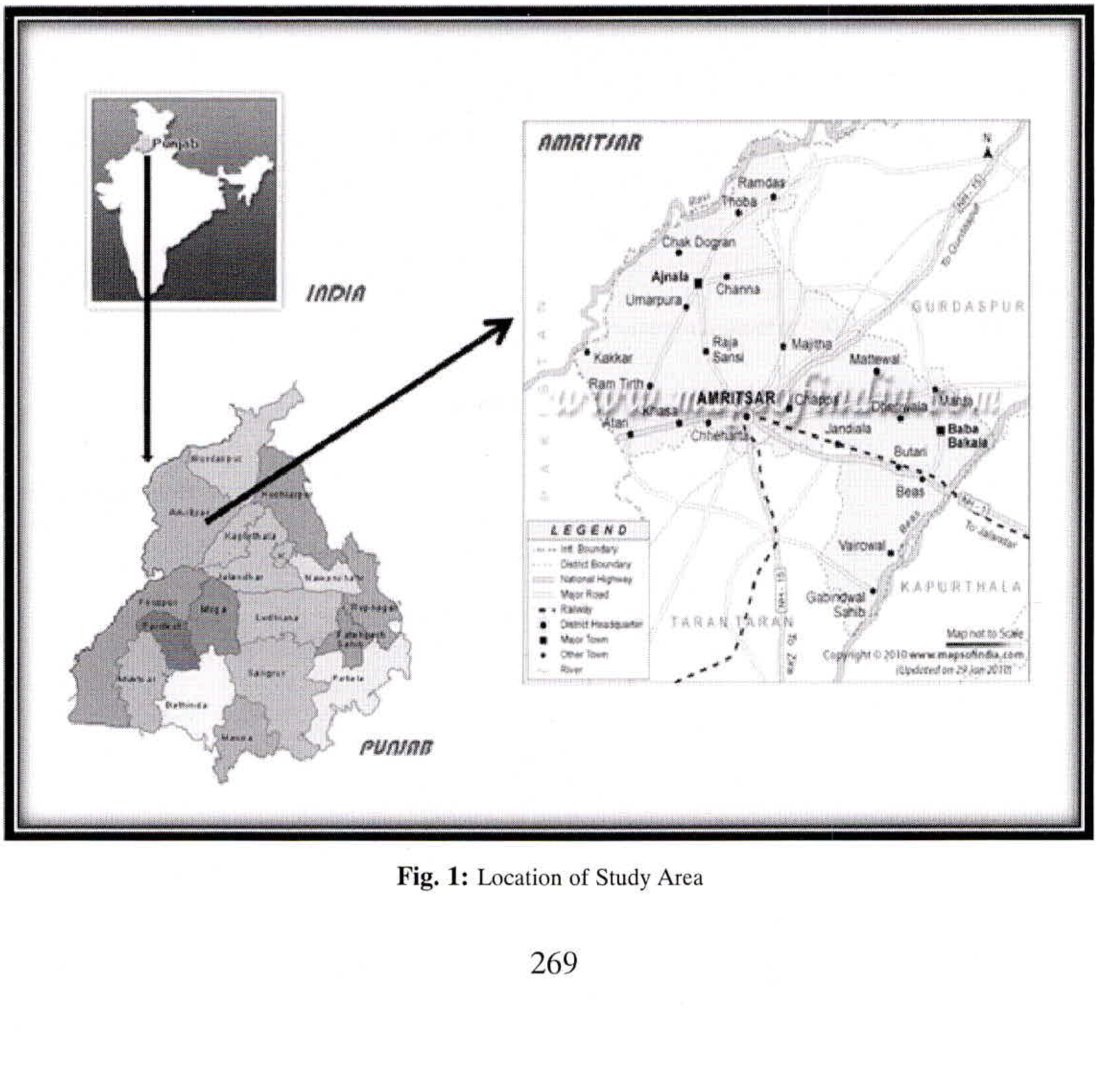

Fig. 1: Location of Study Area

Geologically, the area is of a very recent age and its surface has been built up by the silting action of its wayward streams. The Siwaliks bordering it in the north are composed entirely of Tertiary and principally of Upper Tertiary sedimentary river deposits. The alluvial deposits generally have a rich ground water potential. In the south western tract, the ground water is saline at deeper levels.

The elevation of the water table in the district varies from 197 to 237 m amsl. The gradient of the water table is gentle being of the order of 0.6 m/km (0.0006) and the direction of groundwater flow is generally from north east to south west. The disposition of the contours indicates that both Ravi and Beas rivers are effluent in nature.

The pre-monsoon water table in the area varies from 198.26 to 238.64, while in the case of post-monsoon; the water table varies between 199.45m to 237.82 m.

METHODOLOGY

A ground water observation network consists of a group of observation wells more or less randomly located over an area that may provide a sufficiently accurate data for various parameters over a period of time.

In the monitoring network design, there are no definite criteria established to determine the optimum solutions for 'what variables to measure, where, when, how frequently, and how long?' Therefore, a major difficulty underlying both the design and the evaluation of the monitoring systems is to assess the efficiency and the cost-effectiveness of networks (Mogheir & Singh 2003).

According to the design purpose of groundwater monitoring, the monitoring of groundwater can be separated into the groundwater quality-monitoring network and groundwater level-monitoring network (Loaiciga 1989; Loaiciga *et. al.,* 1992; Wu, 1992; Zidek *et. al.,* 2000). Based on the algorithm, Wu *et. al. (2004)* categorized the hydrological monitoring network design methods into three categories: (i) which includes the time series analysis and regression methods (Crawford 1979); (ii) the Kriging method (Carrera *et. al.,* 1984; Bogardi *et. al.,* 1985; Knopman and Voss 1989; Loaiciga 1989); and, (iii) the Kalman filtering method (Van Geer 1982; Wu and Bian 2003).

In the present study, krigging method has been used. The commercially available GEOPACK software has been used to arrive at the optimal groundwater monitoring network.

Krigging is a geostatistical interpolation technique based on the theory of regionalized variables. It is a method for optimizing the estimation of a magnitude, which is distributed in space and is measured at a network of points. Let $x_1, x_2 \ldots \ldots x_n$ be the location of n points of measurement and x_i denote simultaneously the one two or three coordinates of the point i, and let $Z_i = Z(x_i)$ be the value measured at the point i.

The problem of the point estimation lies in determining the value of the quantity Z_0 for any point x_0 that has not been measured. By continually modifying the position of the point x_0 it is thus possible to estimate the whole field of the parameter Z.

Groundwater table in an area is a function of space and is often highly variable. However, this spatial variability in groundwater table is, in general, not purely random and shows some kind of correlation in space, i.e., it possesses a certain structure. A semi variogram defines the structure of the groundwater table in an area and can be developed if the intrinsic hypothesis can be made on the observed data. A semi variogram may be estimated for values of h which are multiples of the unit lag with

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

where Z(x) are experimental values at point x such that data are available at both x and x+h , N(h) is the number of pairs of data points , separated by a gap equal to h.

The semi-variogram is approximated initially from the given set of measured values of the regionalised variables.

Statistically a certain number of observation wells are necessary to find the average water table with a certain percentage of error .The steps involved in the estimation of the optimum number of observation wells is given below.

- For the existing network consisting of n wells, located at points u_i, i =1... n compute the kriging variance $\sigma^2_{k,n}$
- Consider an additional point u_{n+1}, without making any assumption for the value at the additional point.
- Develop the kriging system corresponding to the set of (n+1) data points i =1...(n+1).
- Compute the corresponding kriging variance
- Compute the relative variance reduction by the equation
- Locate the fictitious point successively on all the candidate points within the catchment and compute the variance reduction each time (i.e. repeat steps two to five). The candidate points will be determined by geographic, economic or climatic constraints. In the absence of such constraint, the fictitious point can be arbitrarily introduced in the high variance on the nodes of an arbitrary grid constructed on the catchment area and then plotting a contour map from the point values.
- The location giving the maximum reduction in variance identifies the optimal site for the additional wells. If variance reduction is marginal, then the reinforcement of the network is not called for. Optimal site location may also be done by contouring the variance reduction over the entire catchment and selecting the location with the highest contour values.

ANALYSIS AND RESULTS

Two basic scientific problems in network design are to determine how many data acquisition points are required and where to locate them. During recent years, most of the approaches of network design have seemed to fall into one of the following categories viz. the regionalization and system analysis. Regionalization deals with the distributed rather than point values and with treated data rather than in their original form.

In the present study an attempt has been made to optimally design the network of observation wells for ground water in the Amritsar district of Punjab. For this purpose water table data of the existing observation wells for the years 1991 to 1995 was collected. Only groundwater monitoring network of state government was considered for the analysis. Though Central Ground Water Board is also maintaining some observation wells, these were not included in the present study.

State Groundwater Department, Punjab has monitored 73-81 observation wells during 1991-95 in Amritsar District. Location of certain observation wells changed from year to year because some of the wells were abandoned and few new wells were selected during this period. Groundwater table maps based on available data are given in *Figure 2*. The water table map shows that the groundwater flow in general is from north east to south west. There is a small area in the west, which shows a groundwater mound, which is due to high recharge at this position due to the presence of an artificial lake created by the Hari-ke-barrage.

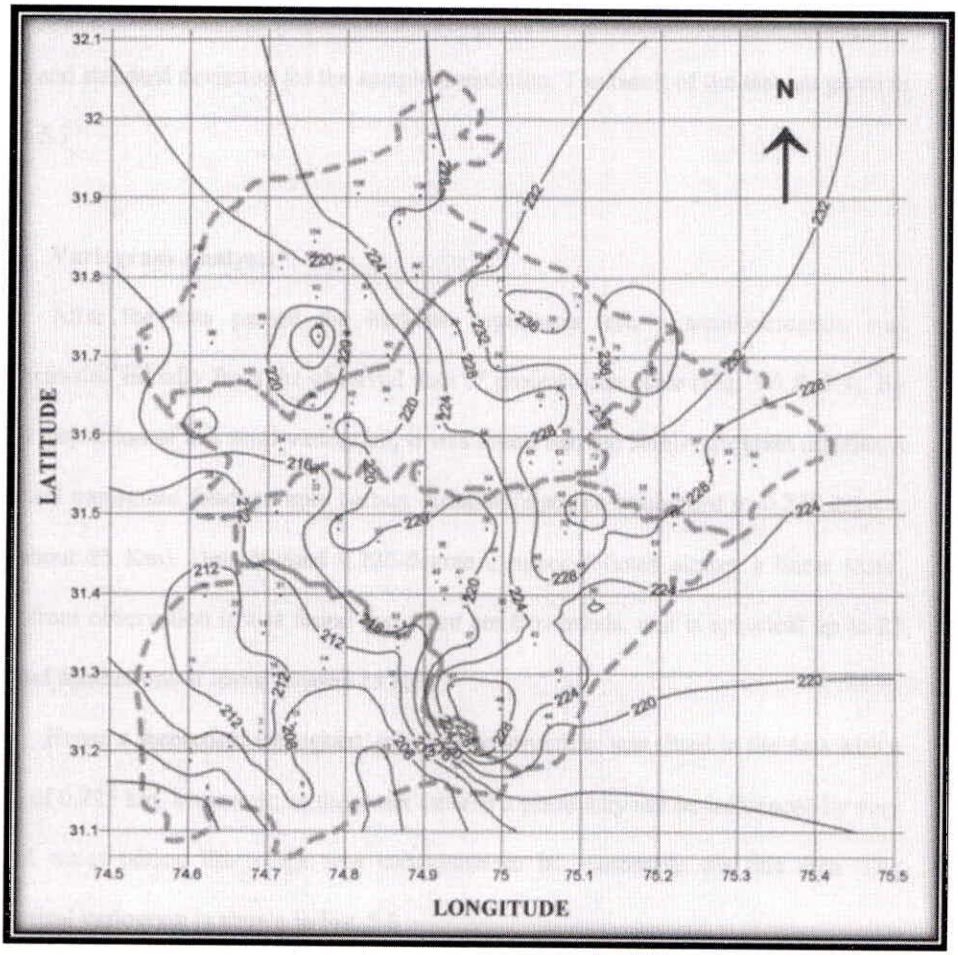

Fig. 2: Water table map of district Amritsar, Punjab (Pre-monsoon – 1995)

Intrinsic hypothesis was checked by the Kolomogorov-Smirnov Critical Test for distribution. The test was performed using the GEOPACK statistical software and it was found that the data uses the intrinsic hypothesis, i.e., the theoretical distribution uses the mean and standard deviation for the sample population.

A semi-variogram was approximated initially from the observed data of groundwater table after passing the intrinsic hypothesis test. By visual inspection of this semi-variogram, it was found that the semi-variogram matches a spherical variogram function upto certain distance (distance equivalent to 0.225 degree, i.e., about 25 Km). Data beyond 0.225-degree distance follows almost a linear trend. Thus from observation it was found that there are two trends, one is spherical up to 25 Km and another one is linear beyond 25 Km.

Hence a theoretical variogram (Figure 3), spherical in structure, was fitted in the data with a range of 0.225 degree. Moreover, as the water table at a place may not be influenced by very distant water tables, this range was considered to be reasonable for this area.

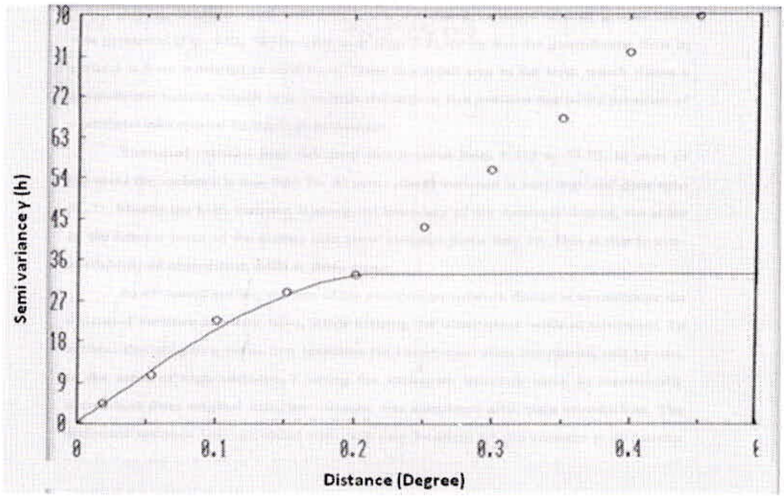

Fig. 3 : Theoretical semivariogram from the observed data

An estimated water table map and estimated variance map was generated using this theoretical semi variogram (*Figure 4*). Estimated variance map indicated that it varies from 5.315 to 33.75. In most of the areas the variance is less than 10. At some places variance is very high and goes up to 33.75. Mostly the high variance is along the boundary of the Amritsar district, but some interior areas of the district also show variance more than 10. This is due to non availability of observation wells in these areas.

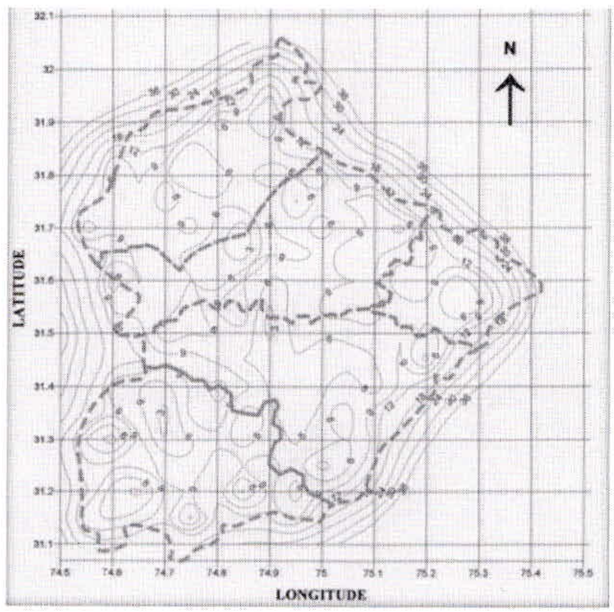

Fig. 4: Estimated Variance of groundwater Table, District Amritsar, Punjab

As discussed earlier, the aim of the observation network design is to minimize the estimated variance of water table, while keeping the observation wells at minimum. To achieve this objective, some new locations for observation were introduced, one by one, in the areas of high variance. Keeping the variogram structure same as theoretically determined from original data, the variance was calculated after each introduction. The estimated variance was calculated with each new location, till the variance at all interior points was reduced below 9. Newly introduced locations for observation and estimated variance map with these new locations are shown in *Figure 5*.

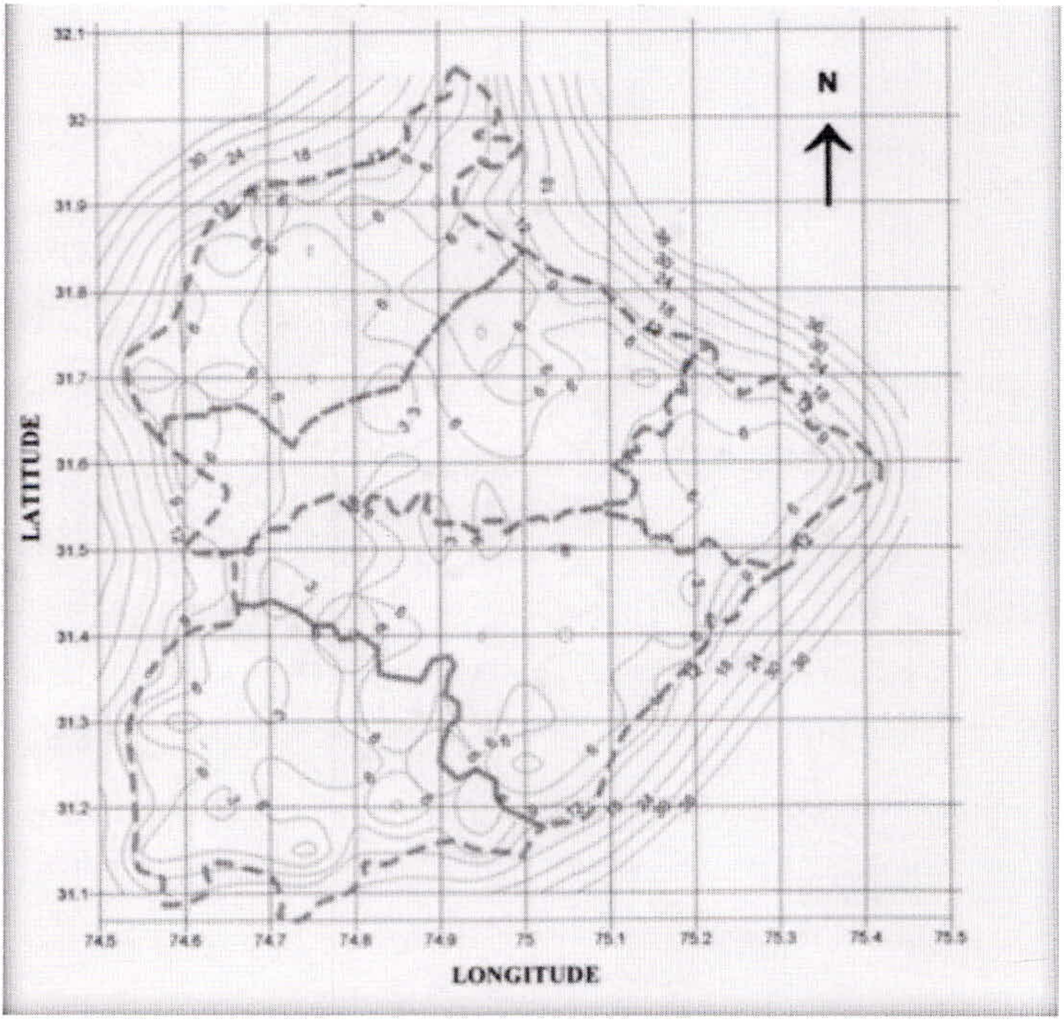

Fig 5: Estimated Variance of groundwater Table with additional observed wells, District Amritsar, Punjab

Now, to optimize the observation network, the observation wells which are very close to each other, were dropped one by one and the variance at 400 locations at a grid of 0.05 x 0.05 degree was calculated *(Figure 6)*. When the variance at these locations became acceptable (<6), reduction of observation points was stopped. This final configuration of observation points gave the optimal network for groundwater table monitoring. It has been found that 104 observation points are required to monitor the water table accurately in Amritsar District. This number may further reduce if the data of the observation wells of the nearby districts of Gurdaspur, Moga, Firozpur and Kaputhala are taken into account.

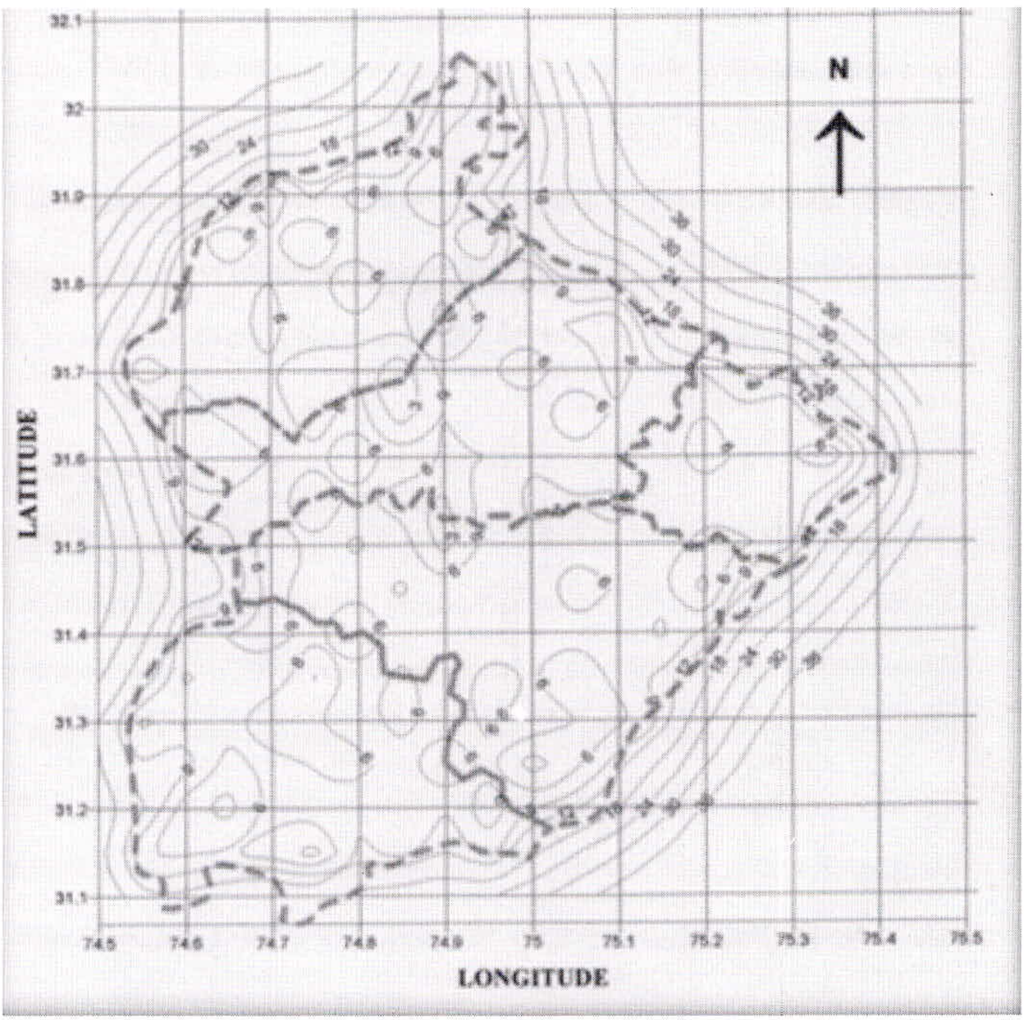

Fig. 6: Estimated Variance of groundwater Table after removing extra wells, District Amritsar, Punjab

Final network design for observation of groundwater table and water table maps from optimal groundwater observation well network are shown Figure 7.

CONCLUSION

As the aim of the observation network design is to minimize the estimated variance, while keeping the observation points at minimum. Water table was monitored at about 81 locations at one particular time and these observation points are not sufficient to monitor the groundwater table in the district, because the water table in the district is highly influenced by the presence of canals and rivers crossing the district. Based on the network design it has been concluded that 104 observation points are required to monitor the groundwater table accurately. Additionally, certain wells, which are very close to each other, may be removed and new wells (where there is no observation in a large area) need to be introduced. Thus, new observation points were introduced till the variance at all interior points was reduced significantly.

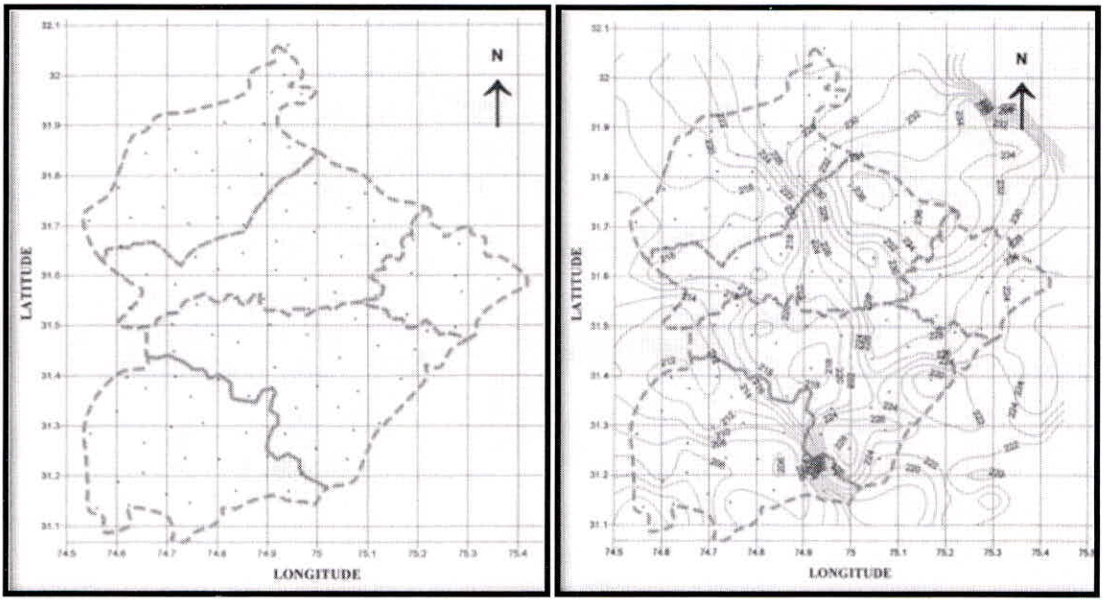

Fig. 7: Optimal network for groundwater table monitoring and water table from optimal groundwater observation well network

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