# 3-D Map Producing for Groundwater Level using Kriging Interpolation Method

**Alaa Soud Mahdi**
Assistant prof.at Remote sensing Unit
College of Sciences - Baghdad University
Email_dralaa_smahdi@yahoo.com.

**Hussein Alwan Mahdi**
Lect.at Surveying Dept.
College of Engineering Baghdad Univ.
Email_husaln@yahoo.com.

**Rusul Khalid Tahir**
Msc. Student at Surveying Dept
Email_rusul2000_kh@yahoo.com

## ABSTRACT:

Groundwater is one of the main water resources in the arid and semi arid areas. Due to increasing demand for water in different purposes these resource management is very important. Prediction of groundwater depth and elevation is useful for management of the scarce water resources.The application of the spatial statistical technique (kriging) is used in this study as estimation method, The data set consists of groundwater levels measured at about 43 wells were selected in the studied area in May 2010, in an area (1350) $km^2$ a part of Baghdad City. With the use of measured elevations of the water table, experimental semivariograms were fitted into many models as linear, spherical, exponential and Gaussian semivariogram. The finally selected models were used to estimate groundwater levels and estimation variance (which express the accuracy of the estimated groundwater levels) to develop corresponding contour maps.

**KEY WORDS:** Kriging – Groundwater – Contour map – Cross-validation – semivariance – Variogram models.

# إنتاج خارطة ثلاثية الابعاد لمناسيب المياه الجوفية بأستخدام تقنية التخمين الإحصائي (الكريكنك)

**علاء سعود مهدي ، حسين علوان مهدي و رسل خالد طاهر**

## المستخلص:

تعتبرالمياه الجوفية من أهم موارد المياه البديلة في المناطق الجافة وشبه الجافة، ونظرا للطلب المتزايد على المياه في أغراض مختلفة فإن إدارة هذه الموارد مهمة جدا لكافة الاستخدامات المدنية والزراعية. وعليه فإن التنبؤ بعمق المياه الجوفية وارتفاعها عن السطح مفيد لإدارة تلك الموارد. تم في هذا البحث تطبيق تقنية التخمين الاحصائي الكريكنك (kriging) في التخمين المكاني لمنسوب المياه الجوفية. اخذت مجموعة بيانات لمنسوب المياه الجوفية المقاسة حقليا من 43 بئر مختارة في شهر الخامس 2010 في منطقة الدراسة لمساحة 1350 كم مربع لجزء من مدينة بغداد. تم عمل تقريب ملائم (fitted) لعدة نماذج من (semivariograms) منها (Linear, Spherical, Gaussian and Exponential) وبعد إجراء الاختبارات لعدة نماذج تم أختيار النموذج النهائي من هذه النماذج لتخمبن مستوي المياه الجوفية في المنطقة وكذلك مقدار التباين ( الذي يعبر عن دقة التخمين في منسوب المياه الجوفية ) ورسم خارطة كنتورية لمنسوب المياه الجوفية.

**الكلمات الرئيسية: طريقة التخمين الاحصائي (الكريكنك) – المياه الجوفية – الخرائط الكنتورية – طريقة Cross validation – شبه التباين – نماذج** Variogram

## AIM OF THE STUDY

Using a kriging technique to estimate the groundwater levels within the study area (a part of Baghdad City), as well as study and create the hydrological map of ground water table in Baghdad city and finally producing 3-D map of groundwater levels.

## 1. INTRODUCTION

Groundwater is one of the major sources of water. Management of this resource is very important to meet the increasing demand of water for domestic, agricultural and industrial use. Baghdad is the largest and most heavily populated city in Iraq. The nature of its groundwater is complex , because the water table is fluctuating among the year. In the recent years, there is a rapid growth of population, increasing municipal, industrial and agricultural activities, as well as the seepage from raw or treated water distribution network, in addition to the natural climate changes led to significant changes in ground water elevation periodically. Due to the above factors, it was difficult to create specific and accurate maps for groundwater, also collect the various data measured in one time was hard, beside the limited studies on this topic (absence of specific studies and maps) on the Baghdad water table. A part of Baghdad city was chosen with data of groundwater collected from observation wells which is the most important information sources for groundwater resources studying. Therefore, prediction of groundwater elevation, to create specific maps is useful to manage the groundwater in the study area.

## 2. GROUNDWATER ELEVATION MAP

Maps of water table elevation are a basic element of regional hydro geological investigations , they are used to identify the direction of groundwater flow and zones of recharge or discharge, to evaluate surface water, groundwater interactions and to assess the effect of natural or anthropogenic stresses on the groundwater system, **[**Desbarats et al., 2002**].**

Each water level measurement from a well or location of a surface water feature that was deemed to represent the water table at land surface was represented by a point (or set of points for some surface water features). These points represent the water table at these locations and can be used to interpolate the position of the water table between these points, **[**Snyder, 2008**]**.

Geostatistical techniques play a vital role in sustainable management of groundwater system by estimating the model of regular grid points derived from random locations of measured points. Geostatistics is a collection of techniques that solved estimation problems involving spatial variables. It offers a variety of tools including interpolation, integration and differentiation of hydro geologic parameters to produce the prediction surface and other derived characteristics from measurements at random locations. Geostatistical techniques (such as kriging, co-kriging and universal kriging) have the capability of producing a prediction surface, and also provide some measure of capability of these predictions, **[**Kambhammettu et al., 2011**]**.

The accuracy of the water table elevation maps depends on various factors: pertaining to the data, the method of interpolation, and the hydro geologic conditions of the surficial aquifers in the study area. The following assumptions are made with regard to the well data used for interpolation, **[**Snyder, 2008**] :**

- Water levels in wells are representative of water table conditions in unconfined aquifers;
- The median value of all water level measurements for each well is representative of the long-term position of the water table;
- Spatial positions of the **wells** are accurately known;
- Land surface elevations of the **wells** are assessed accurately;
- The surface water features that were used for interpolation were assumed to be the features that represent the long-term position of the water table as being present at land surface; spatial positions of the **features** are known accurately; and land surface elevations of the **features** are assessed accurately.

## 3. THE CASE STUDY

The study area lies in Baghdad city , restricted to latitudes between (33º 10′ - 33º 29′ N), and longitudes of (44º 09′- 44º33′ E), which located in the (UTM) lines follows: Latitude ( 3670300 – 3704442) and Longitude (420555 – 458534), with an area of about (1350 $km^2$) approximately, The Tigris River passes through the city dividing it into two parts; Karkh and Rusafa. The area is bounded from the east by Diyala River which joins the Tigris River southeast of Baghdad. The Army Canal, 24 km long, recharges from the Tigris River in the northern part of the city and terminates in the southern part of Diyala River, **[**Al-Hiti, 1985**]**.

For this study, groundwater level data pertaining to 43 wells in May 2010 (**fig. 1**) were selected, in addition to 14 monitoring wells (this wells within the 43 wells) were used to study the fluctuation of the water table during the period starting in (May 2010) to (April 2011), **Table 1** shows the monitoring wells, [ALI, 2010]. The fluctuation of the water table at Rasafa side ranged from( 0.05 to 1.95) meter, whereas at Karkh the fluctuation ranged from (0.02 to 2.03) meter, The descriptive statistics of the observed groundwater levels for monitoring wells are shown in **Table 2** and **fig. 2**

## 4. DERIVED DATA

It is obvious, the Tigers river divides the region into two parts. Therefore, the groundwater table estimation of the river was considered as boundary data. Tigris River elevation was calculated for each one kilometre based on elevation data on Sarai station ,the slope of the river in this region drops to about (7 *cm/km*), **[**AL-ANSARI, 1979**]**.

Because the lack of data for Diyala River and Army Canal , the slope of them calculated by using mathematical operations. Their slopes were 10 *cm/km* , 11 *cm/km* respectively. The elevations of Diyala River and Army Canal was calculated for each one kilometer based on elevation of the Tigris River. The total number of points becomes 157 points (43 wells and 114 points of the surface water feature). The Universal Transverse Mercator (UTM) is the coordinate system used in locating the observation wells. The datum of this system is World Geodetic System of 1984 (WGS 1984). The primary results indicated that the observed data set were normal. Statistical specifications of the water table elevation of Baghdad city are presented in **Table 3**.

## 5. KRIGING METHOD

Kriging is a group of geostatistical techniques to interpolate the value of a random field (e.g., the elevation, *z*, of the landscape as a function of the geographic location) at an unobserved location from observations of its value at nearby locations, the distance of every point pair is quantified to provide information on the spatial autocorrelation of the sample point set, **[**Muhsin, 2010**]**.

In this study, ordinary kriging was evaluated as a procedure for interpolation water table elevation. Ordinary kriging is a linear estimator by which an estimated value of water table elevation in a particular site can be calculated, from water table elevation measured at other sites, according to the linear combination , eq. (5-1):

$$z(x_o) = \sum_{i=1}^{n} w_i\, z(x_i) \qquad (1)$$

Where $Z$ is water table elevation, $z(x_o)$ is the estimated value of $Z$ at point $x_o$, $z(x_i)$ is the measured value of $Z$ at point $x_i$ , $w_i$ is the weight given to observed value $z(x_i)$. These weights are allowed to change as estimates are computed at different locations), $x_o$ is the coordinates [Universal Transverse Mercator (UTM)] of an estimated point, $x_i$ is the coordinates (UTM) of a measured value, and $n$ is the number of measured values used in the estimation. The weights $w_i$ are calculated using the ordinary kriging system of equations.

A common approach when solving the kriging system of equations is to employ what is called a semivariogram function $\gamma^*(h)$. The experimental semivariance $\gamma^*(h)$ is estimated as, **[**Al-Mussawi, 2008**]** :

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \qquad (2)$$

Where, $N(h)$ = the number of pairs separated by lag distance h; $z(x_i)$ = measured variable value at point i ; and $z(x_i + h)$ = measured variable value at point i+h.

Therefore, to use above equation to estimate semivariograms, data must be grouped into pairs with similar separation distances of about *h* (distance lags). Each lag contains *N*(*h*) number of pairs. **Table 4** illustrated Semivariance values (experimental). Experimental semivariograms were calculated for 43 wells and 114 elevation point for surface water feature using the computer software (Geostatistics for the environmental sciences) Ver. (5.1).

There are two reasons for not using the experimental semivariogram directly in the ordinary kriging system. First, the kriging system of equations may need semivariogram values for distances that are not present in the sample data; this requirement will depend on the location at which $Z$ is being estimated. Second, the use of the experimental semivariogram does not guarantee the existence and uniqueness of the solution to the ordinary kriging system of equations.

Once the semivariogram function has been computed from the sampled values of $Z$ at different locations, the next step is to fit a parametric semivariogram model to the experimental semivariogram $\gamma^*(h)$. The most common semivariogram models used to fit experimental semivariograms and therefore used to describe the spatial variability of the variable under study are Gaussian, spherical, exponential, and linear. Four commonly used variogram models are, **[**Robertson, 2008**]:**

- **Spherical Model**

$$\gamma(h) = C_o + C\left[1.5\left(\frac{h}{a}\right) - 0.5\left(\frac{h}{a}\right)^3\right] \qquad (3)$$

- **Exponential Model**

$$\gamma(h) = C_o + C\left[1 - exp\left(\frac{-h}{a}\right)\right] \qquad (4)$$

- **Linear Model**

$$\gamma(h) = C_o + \left[h\left(\frac{C}{a}\right)\right] \qquad (5)$$

- **Gaussian Model**

$$\gamma(h) = C_o + C\left[1 - exp\left(\frac{-h^2}{a^2}\right)\right] \qquad (6)$$

The parameters that characterize these models are the nugget, sill, and range and are calculated through the fitting process. **Fig. 3** illustrated semivariogram models and **Table 5** indicate the properties of fitted semivariograms. The best semivariogram model was generated by observing the coefficient of determination ($r^2$) and residual sum square (RSS) values. The coefficient of determination ($r^2$) provides an indication of how well the model fits the variogram data ; highest $r^2$ value ,the better the model fits. Residual Sum of Square (RSS) , provide an exact measure of how well the model fits the variogram data , the lower RSS ,the better the model fits.

The results in **Table 5** indicate that best fitted semivariogram has spherical for the optimum model parameters (sill, nugget, and range) corresponding to the highest $r^2$ and lowest RSS value were noted. Then from the best fit model **fig. 3** (d), The theoretical fitted Spherical semivariogram for May 2010 data is of the form:

$$\gamma(h) = o.5 + 14.11\left[1.5\left(\frac{h}{57810}\right) - 0.5\left(\frac{h}{57810}\right)^3\right]$$

The covariance function is given by:

$$C(h) = C(0) - \gamma(h) = o.5 + 14.11\left[1.5\left(\frac{h}{57810}\right) - 0.5\left(\frac{h}{57810}\right)^3\right]$$

The implementation of the ordinary Kriging method requires solving a huge number of equations, **[**Muhsin, 2010**]**.

$$\begin{bmatrix} w_{n*1} \\ \lambda \end{bmatrix} = \begin{bmatrix} C\{z(x_i),z(x_j)\} & K \\ K^T & 0 \end{bmatrix}^{-1}_{(n+1)*(n+1)} \begin{bmatrix} C\{Z(x_i),Z(x_o)\} \\ K^T \end{bmatrix}_{(n+1)*1} \qquad (7)$$

$$C\{z(x_i), z(x_j)\}_{(n+1)\times(n+1)} =$$

$$\begin{bmatrix} C\{0\} & C\{d12\} & C\{d13\} & \cdots & C\{d1n\} & 1 \\ C\{d21\} & C\{0\} & C\{d23\} & \cdots & C\{d2n\} & 1 \\ C\{d31\} & C\{d32\} & C\{0\} & \cdots & C\{d3n\} & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C\{dn1\} & C\{dn2\} & C\{dn3\} & \cdots & C\{0\} & 1 \\ 1 & 1 & 1 & \cdots & 1 & 0 \end{bmatrix}$$

$$C\{z(x_i), z(x_o)\}_{(n+1)\times 1} = \begin{bmatrix} C\{d1o\} \\ C\{d2o\} \\ C\{d3o\} \\ \vdots \\ C\{dno\} \\ 1 \end{bmatrix}$$

*Note:* $C\{d_{ij}\} = C\{d_{ji}\} \Rightarrow C\{z(x_i), z(x_j)\}$ *is symmetric*

$Z(x)$: vector, its height value of Ground Control Point (GCP);
$C\{z(x_i), z(x_j)\}$: Covariance between ground control points with each other;
$C\{z(x_i), z(x_o)\}$: Covariance between ground control points with unknown point;
And it is named $C\{z(x_i), z(x_j)\}$ and $C\{z(x_i), z(x_o)\}$ semi-variance.
$W$ : weighted value of the control points.

The minimum squared error estimation is also a measure for the accuracy of estimates, which is known as estimation variance, or kriging variance, and is given by,**[** Al-Mussawi, 2008**]**:

$$\sigma_k^2(x_o) = \sum_{i=1}^{n} w_i \ \gamma(x_i, x_o) + \lambda \qquad (8)$$

Application this method have been used by GS+ software. Based on the obtained data values for study area from this method, the 3D-map of water table elevation was created, **fig. 4**.

## 6. CROSS VALIDATION

The accuracy of the estimation was evaluated by cross-validation method (i.e. without additional data). In cross-validation analysis each measured point in the spatial domain is individually removed from the domain and its value estimated as though it were never there. The point is replaced and the next point is removed and estimated, and so on. In this way a graph can be constructed of estimated vs. actual values for each sample location in the domain, **[**Robertson, 2008**]**. In this case the transformed data were used for the calculation and the differences between estimated and sample values were expressed in two-dimensional diagrams **fig. 5**, with calculation of the regression coefficient, standard deviation and correlation coefficient ($R^2$), the regression coefficient represents a measure of the goodness of fit , a perfect 1:1 fit would have a regression coefficient of 1.00. While the correlation coefficient ($R^2$), which can summarize the correlation between the observed and estimated values.

The distribution of errors was analysed using many of summary statistics: the mean error (ME), the mean absolute error (MAE), kriged reduced mean error (KRME) and kriged reduced mean square error (KRMSE), the error should satisfy the following criteria **[**MERINO et al., 2001**]**:

$$ME = \frac{\sum_{i=1}^{N}[z^*(x_i) - z(x_i)]}{N} \cong 0 \qquad (9)$$

$$MAE = \frac{\sum_{i=1}^{N} |z^*(x_i) - z(x_i)|}{N} \cong 0 \qquad (10)$$

$$KRME = \frac{1}{N}\sum_{i=1}^{N}\left[\left(z^*(x_i) - z(x_i)\right)/\sigma_k\right] \cong 0 \qquad (11)$$

$$KRMSE = \frac{1}{N}\sum_{i=1}^{N}\left[\left(z^*(x_i) - z(x_i)\right)^2/\sigma_k^2\right] \cong 1 \qquad (12)$$

Where, $z^*(x_i)$, $z(x_i)$ and $\sigma_k^2$ are the estimated value, observed value and estimation variance, respectively, at points $x_i$ . N is the sample size. As a practical rule, the MSE should be less than the variance of the sample values and KRMSE should be in the range 1±2√2/N.

Results of cross validation for may 2010 data with the fitted Spherical model resulted in a mean error (ME) of 0.11, (which is near to zero), mean square error (MSE) of 1.88, (which is very low as compared to the variance of the data ), kriged reduced mean error (KRME) of 0.0817, (which is very near to zero) and a kriged reduced mean square error (KRMSE) of 1.0002, (which is very near to 1 and within the range 1±2√2/N). The above cross validation results show that the chosen model and its parameters are adequate.

Groundwater levels and estimation variances were calculated by kriging for May of 2010. These estimated level values are used to draw the contour maps of groundwater levels and estimation variance. **Fig. 6** and **7** are shown the contour maps of the groundwater levels and estimation variance obtained for May 2010 respectively. **Fig. 7** can be interpreted as the map of the reliability of the kriged ground water level in Fig. 6. As seen from the Fig. 7, the estimation variance is low at 1.5 $m^2$ in the middle and southeast of the study area (where most of the observation points are located) and increase rapidly towards the boundaries, where no observation well is located.

## 7. CONCLUSIONS

In this study, kriging, a type of geostatistical techniques, is applied to the groundwater level data of May 2010, The Spherical model is found to the best model was generated by observing the coefficient of correlation (highest $r^2$) and residual sum square (lowest RSS). Groundwaterer levels in the part northeast of Baghdad city are highest results of high population density as well as the seepage from raw or treated water distribution network. The result of the groundwater level maps showed that groundwater level has declined in central (toward the surface water feature) of the study area. The estimation variance is low at 1.5 $m^2$ in the middle and southeast of the study area. The correlation between estimation and actual values was strong (R=0.81).

## REFERENCES

Al-Hiti B.M., (1985) , “Ground water quality within Baghdad area”, M.Sc. Thesis, University of Baghdad.

ALI S. M., (2012), “ Hydrogeological Environmental Assessment Of Baghdad Area”, Ph.D. Thesis presented to the University of Baghdad, College of Science, .

Al-Mussawi W. H. , (2008) “ Kriging of Groundwater Level - A Case Study of Dibdiba Aquifer in Area of Karballa-Najaf” , Journal of Kerbala University , Vol. 6 No.1 Scientific .

AL-ANSARI N. A., ALI S. H. and TAQA A. S., (1979), “Sediment discharge of the River Tigris at Baghdad (Iraq)”, The hydrology of areas of low precipitation, Proceedings of the Canberra Symposium, no. 128 December.

Desbarats A. J., Logan C. E., Hinton M. J. and Sharpe D. R., (2002), “On the kriging of water table elevations using collateral information from a digital elevation model”, Journal of Hydrology vol. 255.

Kambhammettu B., Allena P. and King J. P., (2011), “Application and evaluation of universal kriging for optimal contouring of groundwater levels”, Indian Academy of Sciences, Journal of Earth Syst. Sci. vol. 120, No. 3 .

Muhsin I. J. , (2010), “ High Resolution Digital Elevation Model (DEM) for University of Baghdad Campus”, PhD. Thesis, University of Baghdad, College of science.

MERINO G. G. , JONES D. , STOOKSBURY D. E. and HUBBARD K. G. , (2001), “Determination of Semivariogram Models to Krige Hourly and Daily Solar Irradiance in Western Nebraska”, Journal of the Nebraska Agricultural Experiment Station, American Meteorological Society, No. 12746.

Robertson, G. P., (2008), “ GS+: Geostatistics for the Environmental Sciences”, Gamma Design Software, Plainwell, Michigan USA.

Snyder D. T., (2008), “Estimated Depth to Ground Water and Configuration of the Water Table in the Portland, Oregon Area”**,** U.S. Geological Survey Scientific Investigations Report 5059.

**Table (1):** Groundwater level fluctuation of the monitoring wells

| Well No. | May. (5) | Jun. (6) | Jul. (7) | Aug. (8) | Sept. (9) | Oct. (10) | Nov. (11) | Dec. (12) | Jan. (1) | Feb. (2) | Mar. (3) | Apr. (4) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W7 | 35.61 | 35.68 | 34.71 | 35.28 | 35.21 | 35.63 | 35.73 | 35.83 | 35.88 | 35.83 | 35.88 | 35.88 |
| W16 | 31.94 | 31.74 | 31.49 | 31.49 | 31.59 | 31.59 | 31.84 | 31.94 | 31.99 | 31.94 | 31.79 | 31.89 |
| W17 | 28.64 | 28.59 | 28.44 | 28.64 | 28.54 | 28.24 | 28.84 | 28.44 | 28.64 | 28.34 | 28.49 | 28.64 |
| W19 | 32.20 | 31.60 | 31.15 | 31.60 | 30.62 | 30.25 | 31.55 | 31.35 | 31.55 | 31.30 | 31.80 | 31.90 |
| W21 | 32.80 | 32.52 | 32.60 | 32.60 | 32.70 | 32.61 | 32.91 | 33.25 | 33.40 | 33.55 | 33.60 | 33.50 |
| W24 | 33.36 | 33.15 | 33.05 | 33.40 | 33.40 | 33.30 | 32.97 | 33.20 | 32.75 | 32.50 | 33.30 | 33.40 |
| W25 | 33.12 | 31.79 | 31.09 | 31.19 | 31.24 | 31.29 | 31.41 | 31.98 | 32.34 | 32.31 | 32.49 | 32.49 |
| W28 | 30.75 | 30.42 | 29.92 | 30.52 | 30.57 | 30.47 | 30.57 | 30.95 | 30.97 | 30.92 | 30.87 | 30.82 |
| W29 | 29.94 | 29.22 | 28.87 | 28.54 | 29.02 | 29.12 | 29.52 | 29.42 | 29.62 | 29.67 | 29.92 | 30.12 |
| W32 | 32.37 | 32.22 | 32.17 | 32.02 | 32.07 | 31.97 | 32.07 | 32.42 | 32.47 | 32.52 | 32.42 | 32.42 |
| W34 | 29.57 | 29.55 | 29.47 | 29.47 | 29.37 | 29.17 | 29.27 | 29.47 | 29.37 | 29.37 | 29.27 | 29.32 |
| W35 | 31.00 | 29.60 | 29.66 | 29.70 | 29.90 | 29.80 | 29.65 | 29.57 | 29.40 | 29.75 | 29.95 | 30.75 |
| W39 | 31.47 | 31.57 | 31.32 | 31.47 | 31.62 | 31.67 | 31.72 | 31.97 | 31.86 | 31.57 | 31.27 | 31.62 |
| W41 | 30.59 | 30.44 | 30.19 | 29.49 | 29.84 | 29.89 | 30.09 | 30.49 | 30.64 | 30.74 | 30.79 | 30.79 |

**Table (2):** Descriptive statistics of the Monitoring wells

| Well No. | Max. G.W. | | Min. G.W. | | Diff Elv. In (m.) | Remarks |
|---|---|---|---|---|---|---|
| | Elv. | Date | Elv. | Date | | |
| W7 | 35.88 | (1) Jan. | 34.71 | (7) Jul. | 1.17 | Max. In (1),(2),(3),(4) |
| W16 | 31.99 | (1) Jan. | 31.49 | (7) Jul. | 0.50 | Max. In (1),(2),(3),(4) |
| W17 | 28.84 | (11) Nov. | 28.24 | (10) Oct. | 0.60 | |
| W19 | 32.20 | (5) May. | 30.25 | (10) Oct. | 1.95 | |
| W21 | 33.60 | (3) Mar. | 32.52 | (6) Jun. | 1.08 | |
| W24 | 33.40 | (4) Apr. | 32.50 | (2) Feb. | 0.90 | Max. In (8),(9),(4) |
| W25 | 33.12 | (5) May. | 31.09 | (7) Jul. | 2.03 | |
| W28 | 30.97 | (1) Jan. | 29.92 | (7) Jul. | 1.05 | Max. In (1),(2),(3),(4) |
| W29 | 30.12 | (4) Apr. | 28.54 | (8) Aug. | 1.58 | |
| W32 | 32.52 | (2) Feb. | 31.97 | (10) Oct. | 0.55 | Max. In (1),(2),(3),(4) |
| W34 | 29.57 | (5) May. | 29.17 | (10) Oct. | 0.40 | |
| W35 | 31.00 | (5) May. | 29.40 | (1) Jan. | 1.60 | |
| W39 | 31.97 | (12) Dec. | 31.27 | (3) Mar. | 0.70 | |
| W41 | 30.79 | (4) Apr. | 29.49 | (8) Aug. | 1.30 | Max. In (1),(2),(3),(4) |

**Table (3)**: Statistical parameters of data set in May 2010.

| Date | | No. of W.T.E points | Mean (m) | Variance $(m^2)$ | Max G.W.L (m. a.s.l) | Min G.W.L (m. a.s.l) |
|---|---|---|---|---|---|---|
| Year | Month | | | | | |
| 2010 | May | 157 | 28.58 | 5.39 | 36.50 | 25.40 |

**Table (4)**: Semivariance values

| Lag class | Average Distance (m) | Average Semivariance | Pairs |
|---|---|---|---|
| 1 | 2044.71 | 1.27 | 738 |
| 2 | 5066.36 | 2.41 | 1459 |
| 3 | 8131.15 | 3.06 | 1885 |
| 4 | 11434.83 | 4.35 | 2047 |
| 5 | 14556.60 | 6.15 | 1941 |
| 6 | 17811.53 | 7.54 | 1479 |
| 7 | 21061.47 | 7.72 | 1112 |
| 8 | 24286.40 | 8.23 | 771 |
| 9 | 27612.35 | 10.07 | 455 |
| 10 | 30693.62 | 10.64 | 228 |

**Table (5)**: Properties of semivariogram models

| Model | Nugget $C_o$ | Sill $C_o + C$ | Range (m) Parameter a | $r^2$ | RSS |
|---|---|---|---|---|---|
| Spherical | 0.500 | 14.610 | 57810 | 0.985 | 1.44 |
| Exponential | 0.050 | 21.090 | 44850 | 0.984 | 1.51 |
| Linear | 0.752 | 10.924 | 30693 | 0.981 | 1.76 |
| Gaussian | 1.530 | 10.970 | 19030 | 0.980 | 1.85 |

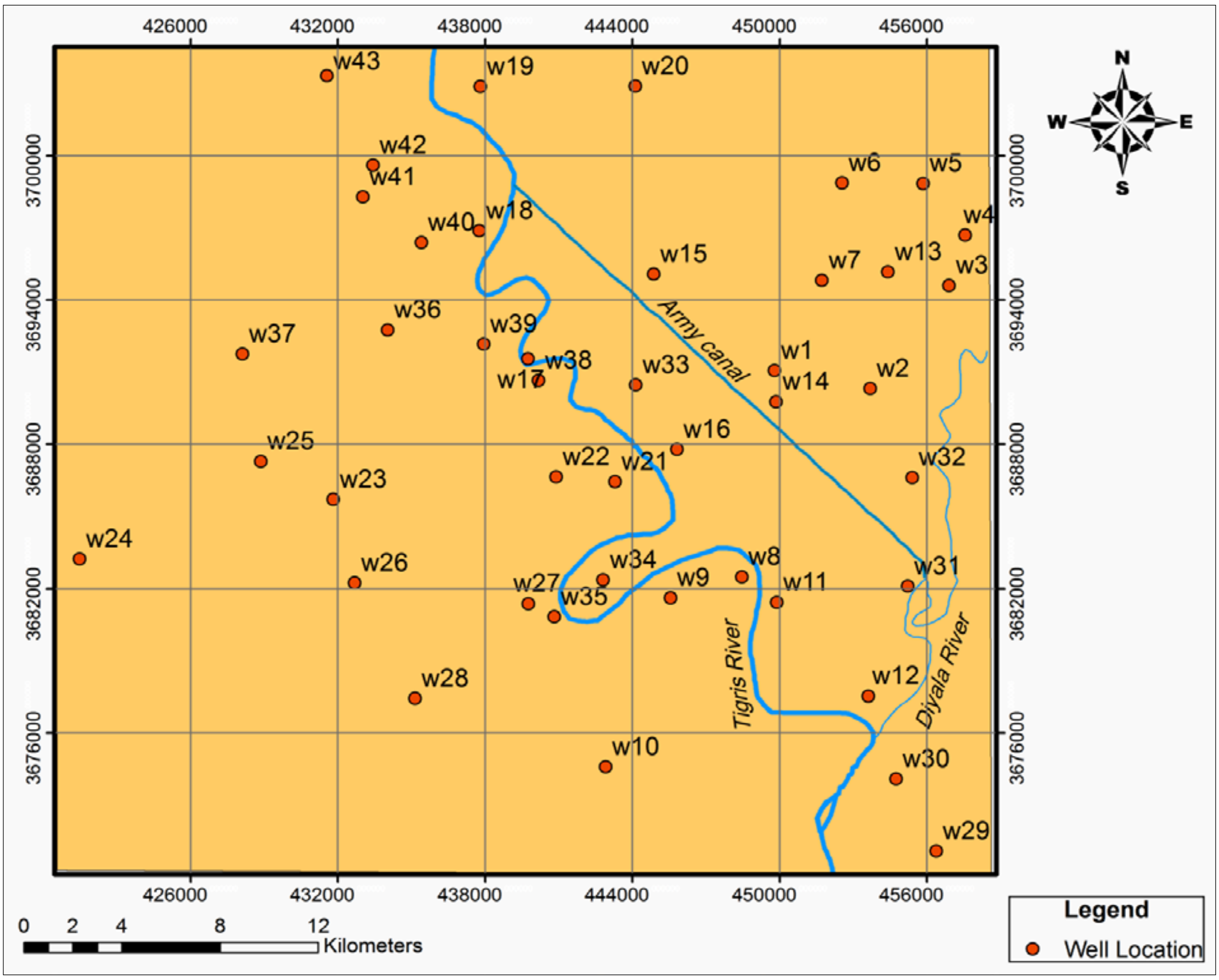

**Figure ( 1 )**: Digital map of the study area and location of observation wells.

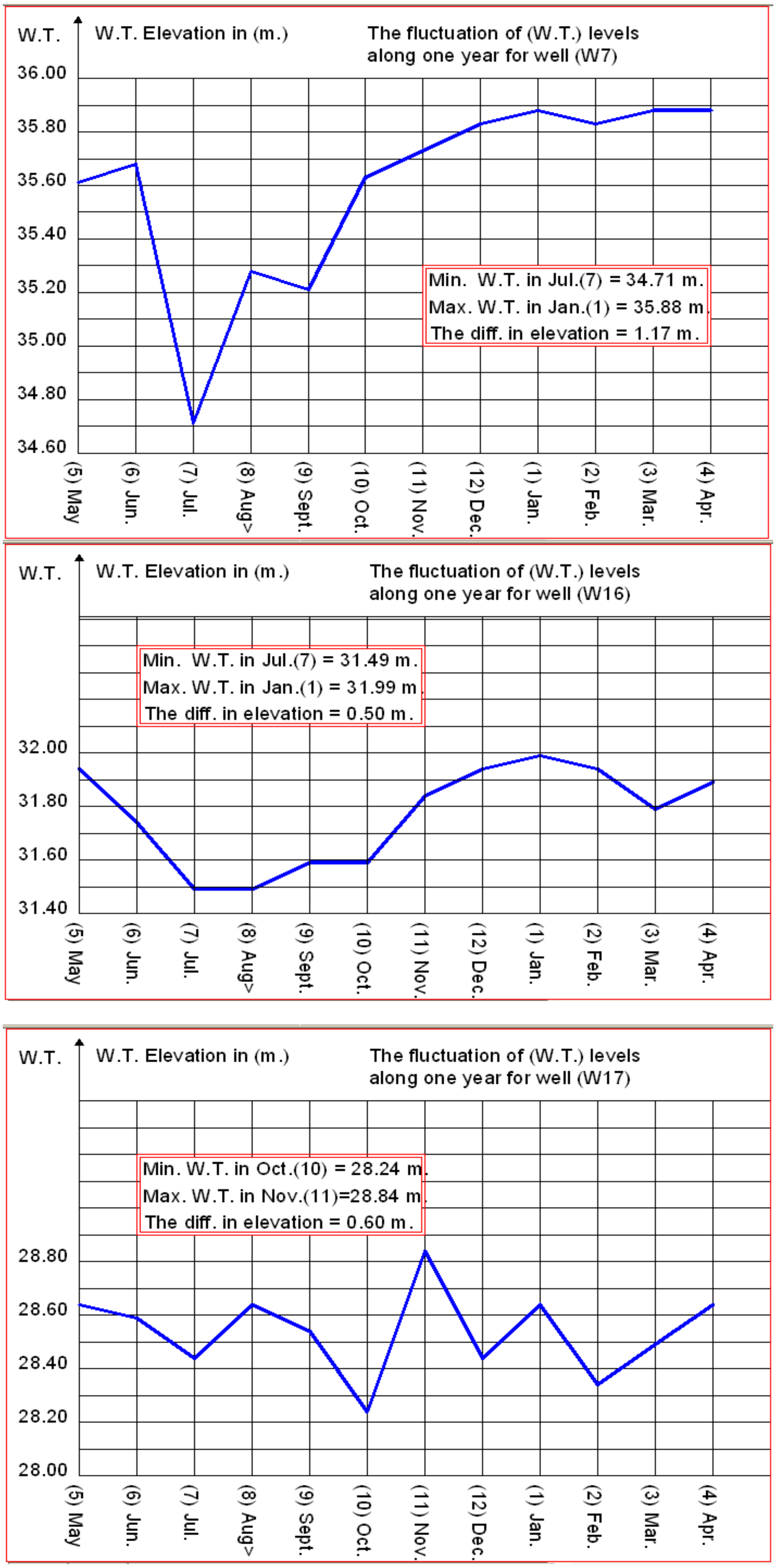

**Figure (2):** The fluctuation of (W.T.) levels

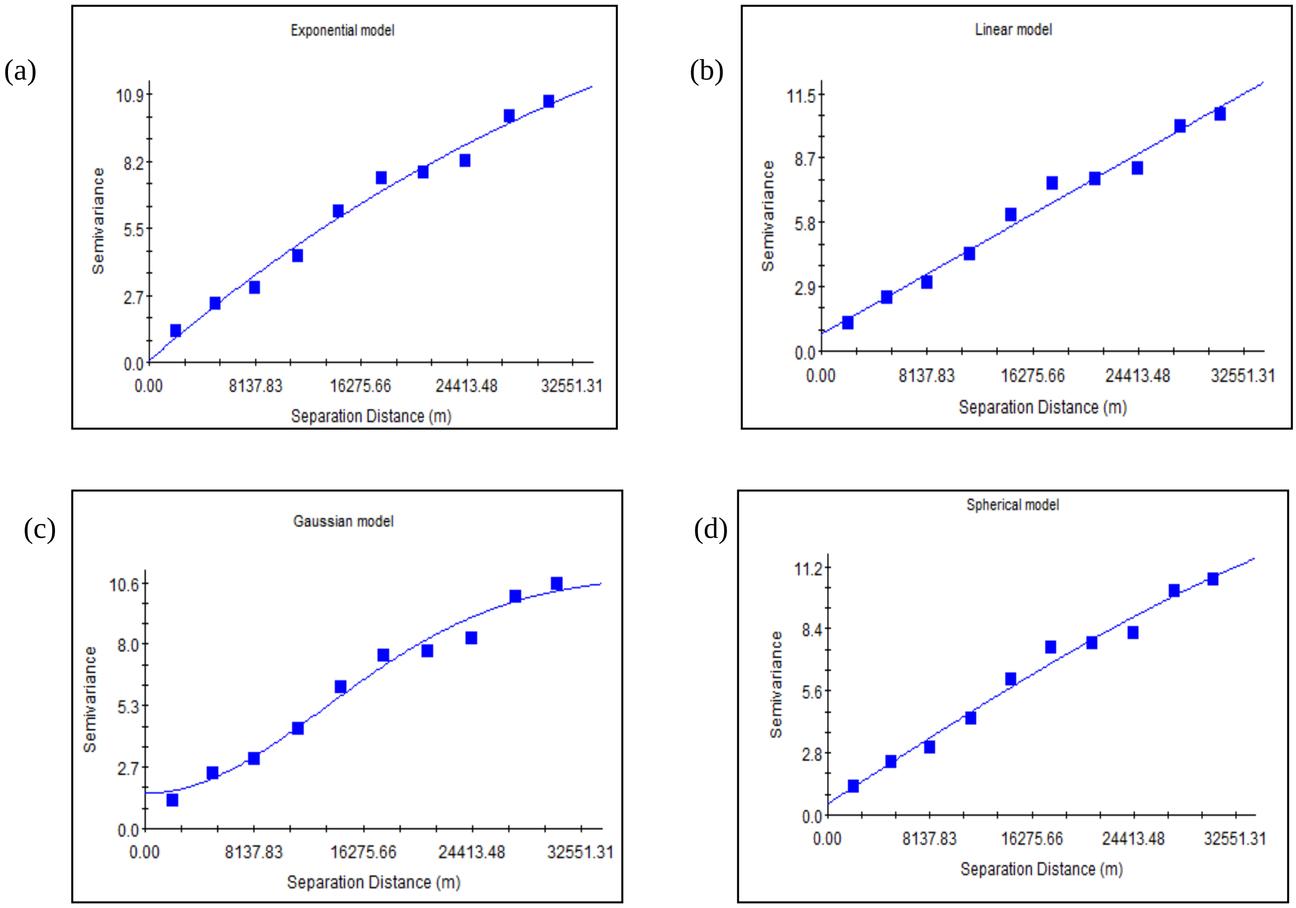

**Figure ( 3 ):** Semivariogram models: (a) exponential; (b) Linear; (c) Gaussian and (d) Spherical.

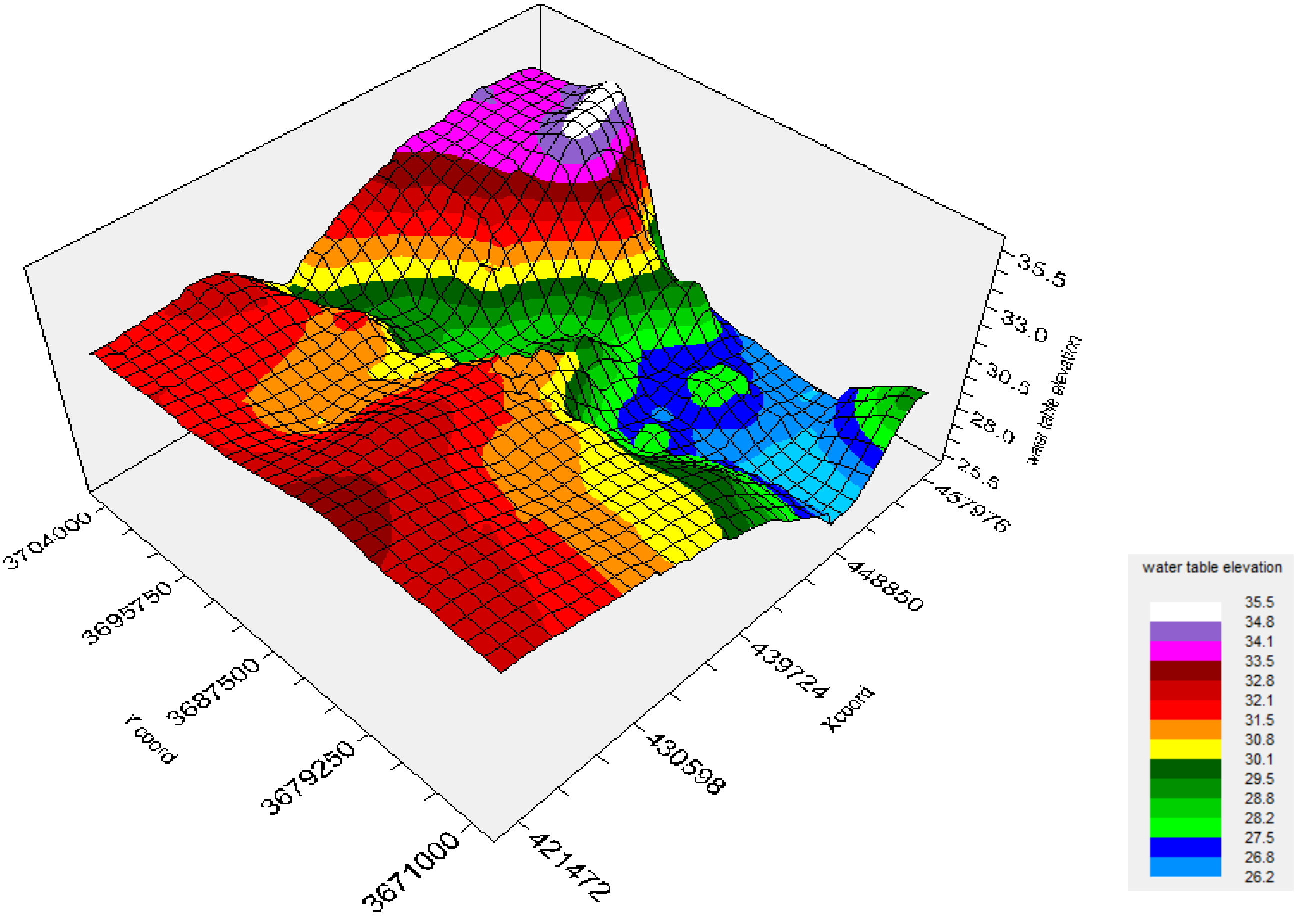

**Figure (4):** A 3-D map of G.W.T. visualizing the spatial distribution of the water table.

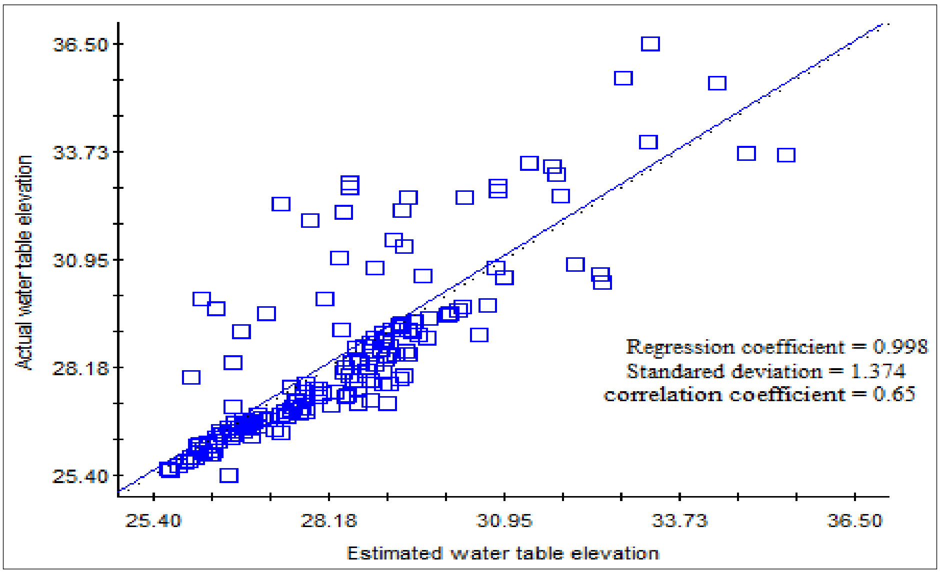

**Figure (5):** Cross-Validation for kriging.

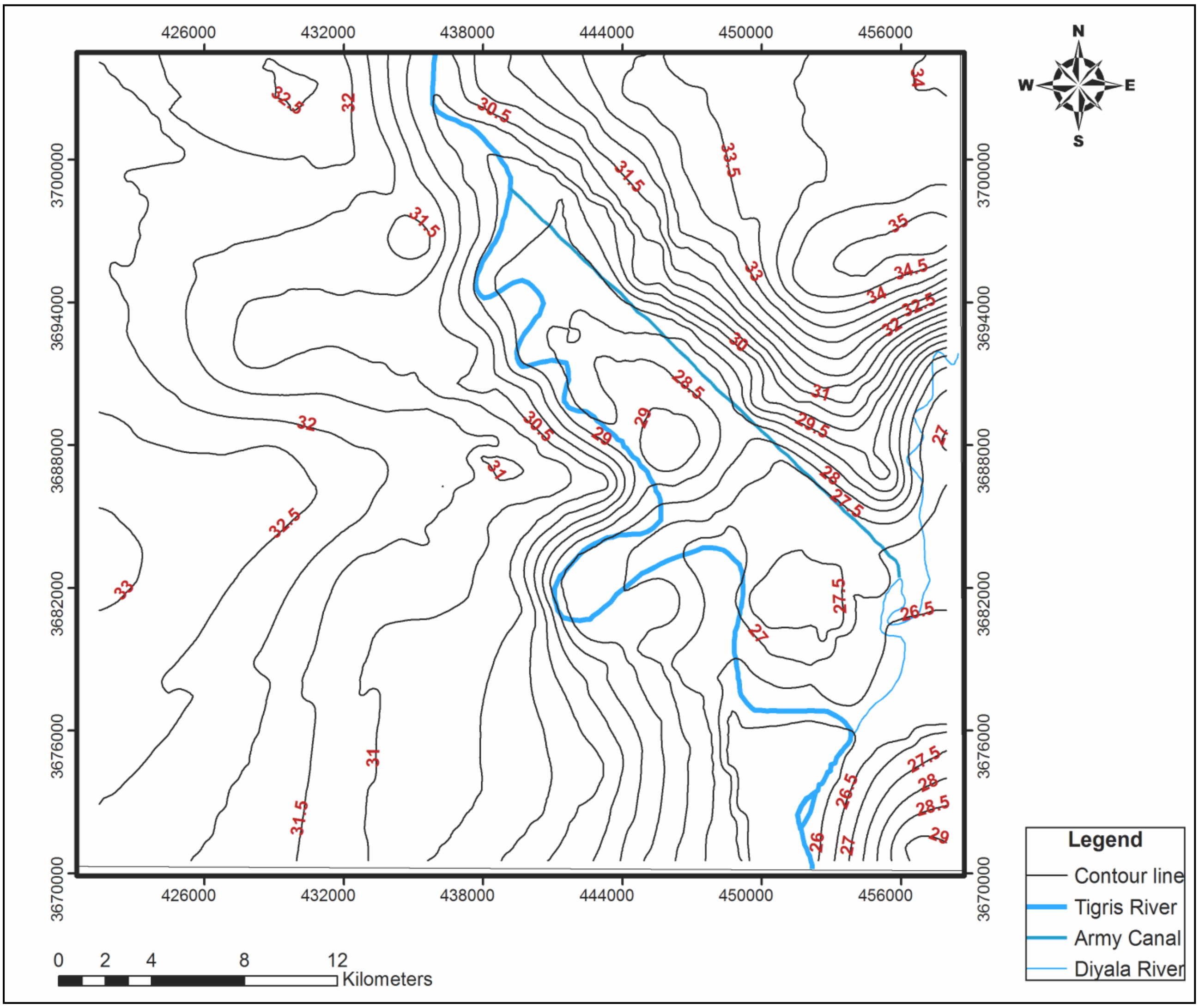

**Figure (6)**: Groundwater level contours maps of the study area (m) .

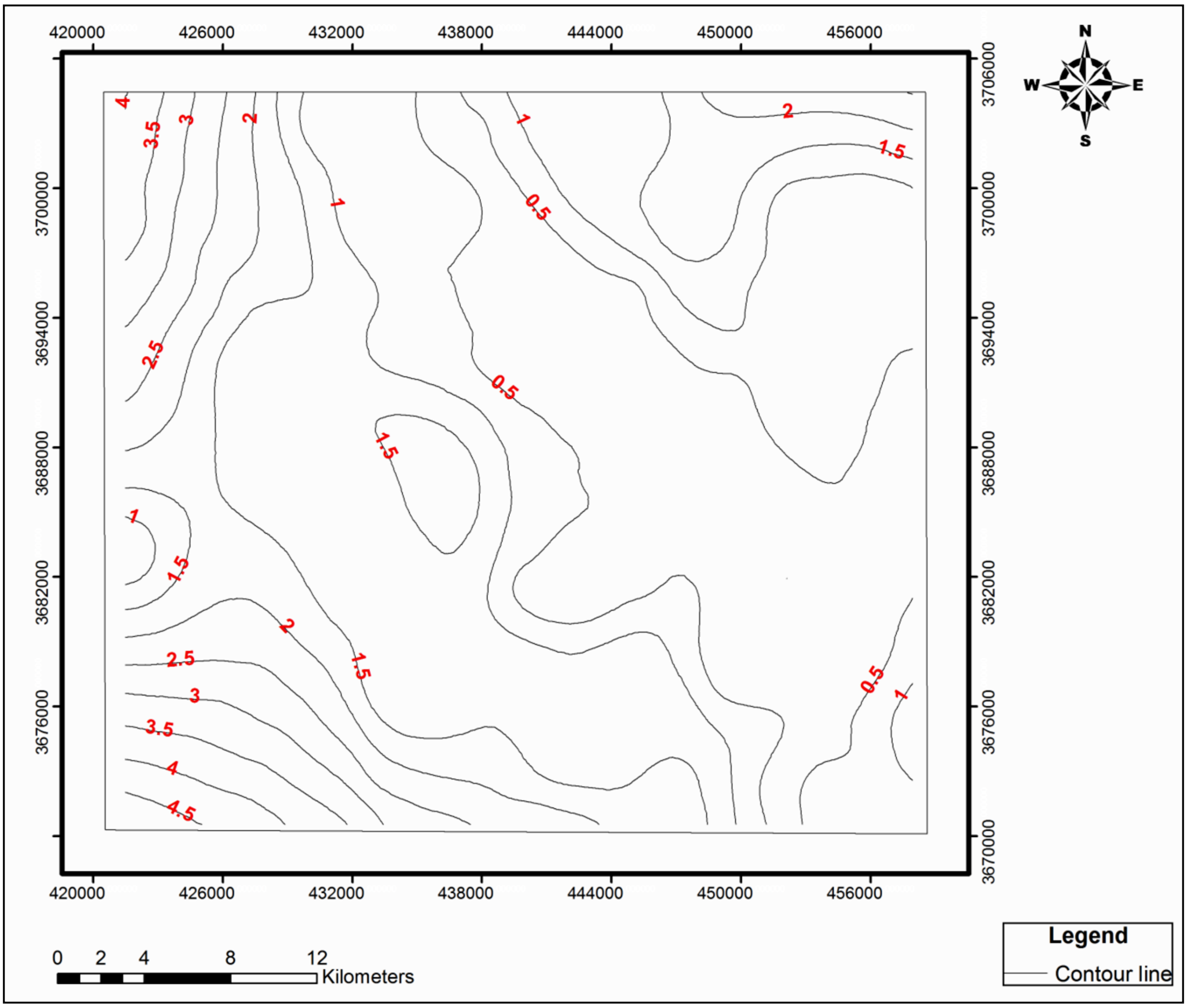

**Figure (7)**: Estimation variance $(m^2)$ by Kriging .