Evaluation of Groundwater Quality in Karbala City

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Abstract

The aim of the paper is determine the groundwater quality depending on mathematical method for chemical analysis of groundwater to confining the suitability to multiple uses.

The chemical analysis of groundwater for Karbala city depending on mathematical method is evaluated. Then used to find groundwater quality and suitability for multiple uses based on different chemical indices. The characterization of laboratory data has been contoured for the hydrogen ion concentration (PH), and the electrical conductivity (EC), and they are compared with WHO and Iraqi standards. Also, the contaminants parameters distributions of GW in the Karbala city have been evaluate the suitability of water. The evaluation based on the observed GW data of 91 unconfined wells represented the study area. Then, described the treatment of water based on Lewa Plus package gives details for the specific pump, motor power consumption as well as system power consumption. The estimated system capacity is about 96 $\frac{m^3}{day}$ with a recovery of 80%.

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1. Introduction

In the last years, the water quality concept has been evaluated to understanding of water mineralization process [1]. The quality of groundwater (GW) supply is required depends on its purposes of use such as drinking, irrigation and industry.

The quality properties of GW determined by analysis a sample of GW chemically, biologically and physically that include the concentrations as well as the PH and EC measurements. The physical analysis includes turbidity, color, temperature, taste and odor. The biological analysis includes tests to detect the presence of Coliform bacteria, which indicate the sanitary quality of water for human consumption [2]. Chemical analysis means determine the concentrations of different ions by weight or by chemical equivalence [3]. Also, determine the concentrations of heavy metals in GW. The movement of GW through the soiltends to develop a chemicalequilibrium by chemicalreactions with its environment, such as movement of pollutants, artificialrecharge and clogging of wells [4, 5].

The contour maps are useful to illustrate the above contaminants with physical parameters which help to determine the regions of high and low chemical concentrations of GW [6]. Practically, can indicate the position of better wells that have low contaminated. These expedient will reduce the high costs of refreshing the GW for different uses.

This research employs mathematical method studied in [7-10] to determine rate of contaminants in GW of Karbala city with illustration by contour maps.

2. Contamination of Groundwater

In this section we estimate the chemical contamination of GW for Karbala city. Karbala is an Iraqi governorate that locates about 100 km south-west of Baghdad, the capital of Iraq [11-12]. It locates between latitude 32°06´ to 32°46´ and longitude 43°10´ to 44°19´. It covers an area of 5034 km^2 with a population of 1.151 million people in 2015 [13]. There are many reasons exhortation authors to study this region, such [14-16]:

1. Absence of surface water resources in the region since it is far from Tigris and Euphrates rivers.
2. Its characterized by arid to semi-arid climate, having little rain, limited recharge.
3. Having a free water table, making it unconfined pelvis aquifer type, this facilitates the measuring process.
4. Shallow ground water, which produces an effective and quick recharge process.
5. Information about hydrological and geo-hydrological of the region is available.

The soil of Karbala is generally in type sandy loam soil. The data of chemical contaminants concentrations for 91 wells were officially collecting and done by X- Ray Fluorescence analysis (XRF) [17, 18]. By using Google Earth program, the map of wells locations are drawn as illustrated in Figure (1). The depths of these wells range from 30m to 290m. The data include the concentrations of chemical ions like Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, NO_3^{-} and the total dissolved solids (T.D.S) all these concentrations are measured in (mg/l) and PH with electrical conductivity (EC) (μmhos/cm). Also, the data contain the natural ground level of wells, the groundwater level of wells with respect to mean see level and the geographical coordinates of latitude and longitude lines for wells locations.

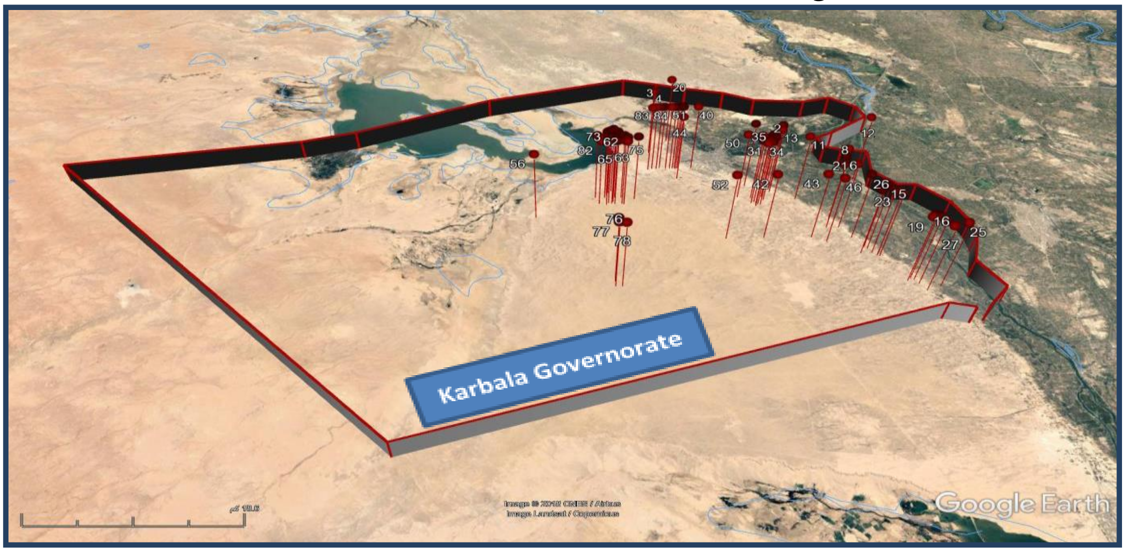

Figure 1: Google Earth map of Karbala wells locations

3. Mathematical Model of Groundwater

The equation that govern GW flow depending in [19, 20] is

$$\left(T_x \frac{\partial^2 h}{\partial x^2}\right) + \left(T_y \frac{\partial^2 h}{\partial y^2}\right) + \left(T_z \frac{\partial^2 h}{\partial z^2}\right) + Q = S \frac{\partial h}{\partial t} \qquad (1)$$

IC:	$h(x,y,z,0)=f(x,y,z)$
BC:	$h(0,y,z,t)=h(l_x,y,z,t)=0$ $h(x,0,z,t)=h(x,l_y,z,t)=0$ $h(x,y,0,t)=h(x,y,l_z,t)=0$

$t > 0$, $0<x<l_x$, $0<y<l_y$, $0<z<l_z$

Where;

T_i : transmissivity in the i-direction (L^2/T)

S : storage coefficient (-)

h : hydraulic head or simply "head" or pressure head (also known as piezometric head) (L)

Q : the volumetric source per unit volume (discharge rate) (L^3/T).

To simplify the solution we chose the following assumptions

Let $\bar{x} = \frac{x}{\sqrt{T_x}} \rightarrow \frac{d\bar{x}}{dx} = \frac{1}{\sqrt{T_x}}$,

$\bar{y} = \frac{y}{\sqrt{T_y}} \rightarrow \frac{d\bar{y}}{dy} = \frac{1}{\sqrt{T_y}}$

$\bar{z} = \frac{z}{\sqrt{T_z}} \rightarrow \frac{d\bar{z}}{dz} = \frac{1}{\sqrt{T_z}}$

$\bar{t} = \frac{t}{S} \rightarrow \frac{d\bar{t}}{dt} = \frac{1}{S}$

And the boundaries are

$$\bar{t} > 0 \ , \quad \overline{a_x} < \bar{x} < \overline{b_x} \ , \quad \overline{a_y} < \bar{y} < \overline{b_y} \ , \quad \overline{a_z} < \bar{z} < \overline{b_z}$$

$$where\ \overline{a_x} = \frac{a_x}{\sqrt{T_x}}\ , \overline{b_x} = \frac{b_x}{\sqrt{T_x}}\ , \overline{a_y} = \frac{a_y}{\sqrt{T_y}}\ , \overline{b_y} = \frac{b_y}{\sqrt{T_y}}\ , \overline{a_z} = \frac{a_z}{\sqrt{T_z}}, \overline{b_z} = \frac{b_z}{\sqrt{T_z}}$$

Then equation (1) is become

$$\left(\frac{\partial^2 h}{\partial \bar{x}^2}\right) + \left(\frac{\partial^2 h}{\partial \bar{y}^2}\right) + \left(\frac{\partial^2 h}{\partial \bar{z}^2}\right) + Q = \frac{\partial h}{\partial \bar{t}} \qquad (2a)$$

Suppose Q=0, and we will use the original symbols i.e.

$$\left(\frac{\partial^2 h}{\partial x^2}\right) + \left(\frac{\partial^2 h}{\partial y^2}\right) + \left(\frac{\partial^2 h}{\partial z^2}\right) = \frac{\partial h}{\partial t} \qquad (2b)$$

We will use the technique of separation of variables, which involves looking for a solution of the form:

$$h(x,y,z,t) = X(x)*Y(y)*Z(z)*T(t)$$

For functions *X*, *Y*, *Z* and *T* to be determined.

Then we have

$$\begin{cases} \left(\frac{\partial^2 h}{\partial x^2}\right) = (YZT)X''(x) \\ \left(\frac{\partial^2 h}{\partial y^2}\right) = (XZT)Y''(y) \\ \left(\frac{\partial^2 h}{\partial x^2}\right) = (XYT)Z''(z) \\ \left(\frac{\partial h}{\partial t}\right) = (XYZ)T'(t) \end{cases} \qquad (3)$$

Substitute (3) in (2) this implies

$$T_x(YZT)X''(x) + T_y(XZT)Y''(y) + T_z(XYT)Z''(z) = S(XYZ)T'(t) \quad (4)$$

Dividing (4) by XYZT we have

$$T_x\frac{X''(x)}{X(x)} + T_y\frac{Y''(y)}{Y(y)} + T_z\frac{Z''(z)}{Z(z)} = S\frac{T'(t)}{T(t)} \qquad (5)$$

The right hand side (r.h.s.) depends only on t and the left hand side (l.h.s.) depends on x, y, and z. Hence if t varies and x, y, and z are held fixed, the l.h.s. is constant, and hence T'/T must also be constant and vice versa, i.e. there is a constant -λ s.t

$$T_x\frac{X''(x)}{X(x)} + T_y\frac{Y''(y)}{Y(y)} + T_z\frac{Z''(z)}{Z(z)} = -\lambda \ \ \& \ \ S\frac{T'(t)}{T(t)} = -\lambda \quad (6)$$

From (6)

$$T_x\frac{X''(x)}{X(x)} + T_y\frac{Y''(y)}{Y(y)} = -\lambda - T_z\frac{Z''(z)}{Z(z)}$$

By the same above reason, there is a constant ξ s.t.

$$T_x\frac{X''(x)}{X(x)} + T_y\frac{Y''(y)}{Y(y)} = \xi \qquad \& \qquad -\lambda - T_z\frac{Z''(z)}{Z(z)} = \xi$$

Let α=λ+ξ then we have

$$T_x\frac{X''(x)}{X(x)} + T_y\frac{Y''(y)}{Y(y)} = \xi \qquad \& \qquad T_z\frac{Z''(z)}{Z(z)} = -\alpha \quad (7)$$

Now from (7)

$$T_x\frac{X''(x)}{X(x)} = \xi - T_y\frac{Y''(y)}{Y(y)}$$

By the same above reason, there is a constant -β such that:

$$T_x\frac{X''(x)}{X(x)} = -\beta \qquad \& \qquad \xi - T_y\frac{Y''(y)}{Y(y)} = -\beta$$

Let $\delta=-\beta-\xi$ then we have

$$T_x\frac{X''(x)}{X(x)} = -\beta \qquad \& \qquad T_y\frac{Y''(y)}{Y(y)} = -\delta \qquad (8)$$

Then from (6), (7) and (8) we have

$$S\frac{T'(t)}{T(t)} = -\lambda$$

$$T_x\frac{X''(x)}{X(x)} = -\beta$$

$$T_y\frac{Y''(y)}{Y(y)} = -\delta$$

$$T_z\frac{Z''(z)}{Z(z)} = -\alpha$$

Where λ=β+δ+α

The solution on x variable

$$T_x\frac{X''(x)}{X(x)} = -\beta$$

From BC in (1)

$h(0,y,z,t)$=X(0)$Y(y)$Z(z)$T(t)$=0

$h(l_x,y,z,t)$=X(l_x)$Y(y)$Z(z)$T(t)$=0

If $Y(y)$= 0 & Z(z)=0 & T(t)=0 for all y,z,t in the domain then $h(x,y,z,t)$=0 i.e. the trivial solution, then there exists y_0, z_0 and t_0 s.t. $Y(y_0)\neq 0$ & $Z(z_0)\neq 0$ & $T(t_0)\neq 0$ and hence $h(0,y_0,z_0,t_0)$=

$X(0)Y(y_0)Z(z_0)T(t_0)=0$ this implies that $X(0)=0$ and similarly $X(l_x)=0$.

Now we obtain the boundary value problem

$$X''(x)+\frac{\beta}{T_x}X(x)=0 \quad 0<x<l_x$$
$$X(0)=X(l_x)=0 \quad (9)$$

Then (9) is an eigen value problem and we want to find the solutions to this problem.

There are three cases of the constant β:

i) If $\beta=0$ then (9) is become $X''(x)=0$ and the solution of this equation is $X(x)=Ax+B$, A and B the constants of integration.
From BC in (9)
$X(0)=A(0)+B=0$ then $B=0$.
Also from BC in (9)
$X(l_x)=A\,l_x=0$ then $A=0$.
Then $X(x)=0$ and this impossible.

ii) If $\beta<0$ then the solution of (9) is
$X(x)=Ae^{\sqrt{\frac{\beta}{T_x}}x}+Be^{-\sqrt{\frac{\beta}{T_x}}x}$
From BC in (9)
$X(0)=A+B=0$ then $B=-A$
Also from BC in (9)
$X(l_x)=Ae^{\sqrt{\frac{\beta}{T_x}}l_x}-Ae^{-\sqrt{\frac{\beta}{T_x}}l_x}=0 \rightarrow$
$e^{2\sqrt{\frac{\beta}{T_x}}l_x}=1 \rightarrow 2\sqrt{\frac{\beta}{T_x}}l_x=0 \rightarrow l_x=0$
and this impossible.

iii) If $\beta>0$ then (9) is the harmonic equation and its solution is
$X(x)=A\cos\left(\sqrt{\frac{\beta}{T_x}}x\right)+B\sin\left(\sqrt{\frac{\beta}{T_x}}x\right)$
From BC in (9)
$X(0)=A(1)+B(0)=0$ then $A=0$
Also from BC in (9)
$X(l_x)=B\sin\left(\sqrt{\frac{\beta}{T_x}}l_x\right)=0$ then
$\sin\left(\sqrt{\frac{\beta}{T_x}}l_x\right)=0$

Then

$$\sqrt{\frac{\beta}{T_x}}l_x=n\pi \rightarrow \sqrt{\beta}=\frac{n\pi\sqrt{T_x}}{l_x} \quad n=1,2,3,\ldots$$

Then there are infinite number of solutions of (9)

$$X_n(x)=B_n\sin\left(\frac{n\pi}{l_x}x\right) \quad , n=1,2,3,\ldots$$

Then the final solution of (9) is

$$X(x)=\sum_{n=1}^{\infty}B_n\sin\left(\frac{n\pi}{l_x}x\right)$$

Similarly the solutions on y and z variables we have

$$Y(y)=\sum_{m=1}^{\infty}C_m\sin\left(\frac{m\pi}{l_y}y\right)$$
$$Z(z)=\sum_{k=1}^{\infty}D_k\sin\left(\frac{k\pi}{l_z}z\right)$$

The solutions on t variable

$$S\frac{T'(t)}{T(t)}=-\lambda$$

Then we have

$$T'(t)+(\lambda/S)T(t)=0 \quad (10)$$

The solution of the ordinary differential equation (10) is

$$T(t)=Ae^{-\frac{\lambda}{S}t}$$

But $\lambda=\beta+\delta+\alpha=T_x\left(\frac{n\pi}{l_x}\right)^2+T_y\left(\frac{m\pi}{l_y}\right)^2+T_z\left(\frac{k\pi}{l_z}\right)^2$

where $n,m,k=1,2,3,\ldots$

Therefore, there are infinite number of values of λ and then by the principle of superposition we have the general solution of (1)

$$h(x,y,z,t)=X(x)Y(y)Z(z)T(t)$$
$$=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\sum_{k=1}^{\infty}A_{nmk}\sin\left(\frac{n\pi}{l_x}x\right)\sin\left(\frac{m\pi}{l_y}y\right)\sin\left(\frac{k\pi}{l_z}z\right)e^{-\frac{\lambda}{S}t}$$

For any choice of constants A_{nmk}.

To satisfy the IC in (1), we need to find A_{nmk} such that $h(x,y,z,0)=f(x,y,z)$ i.e.

$$f(x,y,z)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\sum_{k=1}^{\infty}A_{nmk}\sin\left(\frac{n\pi}{l_x}x\right)\sin\left(\frac{m\pi}{l_y}y\right)\sin\left(\frac{k\pi}{l_z}z\right) \quad (11)$$

Now to solve for the A_{nmk} we use the orthogonality property for the function $\sin(\frac{n\pi}{L}u)$ in general i.e. we want to calculate

$$\int_0^L \sin\left(\frac{n\pi}{L}u\right)\sin\left(\frac{m\pi}{L}u\right)du$$

Now if $n=m$ we have

$$\int_0^L \sin^2\left(\frac{n\pi}{L}u\right)du = \int_0^L \frac{1}{2}\left(1-\cos\left(\frac{2n\pi}{L}u\right)\right)du$$

$$= \frac{1}{2}\left[u - \frac{L}{2\pi}\sin\left(\frac{2n\pi}{L}u\right)\right]\Big|_0^L = \frac{L}{2}$$

If $n \neq m$ we have

$$\int_0^L \sin\left(\frac{n\pi}{L}u\right)\sin\left(\frac{m\pi}{L}u\right)du$$

$$= -\frac{1}{2}\int_0^L \left[\cos\left(\frac{n\pi}{L}u - \frac{m\pi}{L}u\right) - \cos\left(\frac{n\pi}{L}u + \frac{m\pi}{L}u\right)\right]du$$

$$-\frac{1}{2}\left[\frac{L}{(n-m)\pi}\sin\left(\frac{(n-m)\pi}{L}u\right) - \frac{L}{(n+m)\pi}\sin\left(\frac{(n+m)\pi}{L}u\right)\right]\Big|_0^L = 0$$

Then the orthogonality property [21] gives us the following result

$$\int_0^L \sin\left(\frac{n\pi}{L}u\right)\sin\left(\frac{m\pi}{L}u\right)du = \begin{cases} L/2 & n=m \\ 0 & n\neq m \end{cases}$$

Now apply this result in the variables *x*,*y* and *z* and fixed *n*,*m* and *k* on the equation (11) we have

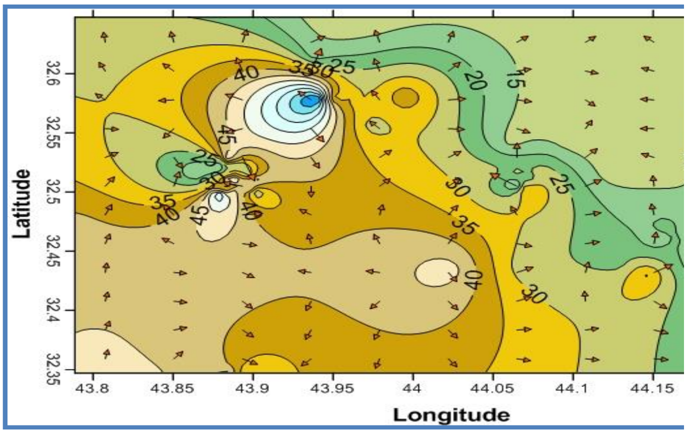

Figure 2: Contour map of GW level

$$\int_0^{l_z}\int_0^{l_y}\int_0^{l_x} f(x,y,z)\sin\left(\frac{n\pi}{l_x}x\right)\sin\left(\frac{m\pi}{l_y}y\right)\sin\left(\frac{k\pi}{l_z}z\right)dxdydz = \frac{l_x l_y l_z}{8}A_{nmk}$$

Then

$$A_{nmk} = \frac{8}{l_x l_y l_z}\int_0^{l_z}\int_0^{l_y}\int_0^{l_x} f(x,y,z)\sin\left(\frac{n\pi}{l_x}x\right)\sin\left(\frac{m\pi}{l_y}y\right)\sin\left(\frac{k\pi}{l_z}z\right)dxdydz \quad (12)$$

Then the final solution of (1) and satisfy IC and BC in (1) is

$$h(x,y,z,t) = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\sum_{k=1}^{\infty} A_{nmk}\sin\left(\frac{n\pi}{l_x}x\right)\sin\left(\frac{m\pi}{l_y}y\right)\sin\left(\frac{k\pi}{l_z}z\right)e^{-\frac{\lambda}{S}t} \quad (13)$$

where

$$A_{nmk} = \frac{8}{l_x l_y l_z}\int_0^{l_z}\int_0^{l_y}\int_0^{l_x} f(x,y,z)\sin\left(\frac{n\pi}{l_x}x\right)\sin\left(\frac{m\pi}{l_y}y\right)\sin\left(\frac{k\pi}{l_z}z\right)dxdydz$$

and

$$\lambda = T_x\left(\frac{n\pi}{l_x}\right)^2 + T_y\left(\frac{m\pi}{l_y}\right)^2 + T_z\left(\frac{k\pi}{l_z}\right)^2$$

4. Chemical Analysis of Groundwater

Understanding chemical composition of GW is necessary to estimating the suitable GW for different purposes. The contour map of GW level of all wells are plotted depending on inspected collected data and illustrated in Figure (2). The contour map of PH is illustrated in Figure (3). But the Contour map which illustrate the concentration of Ca, Mg, Na, K, HCO_3, Cl, NO_3, and EC are given in Figures (4-11) respectively.

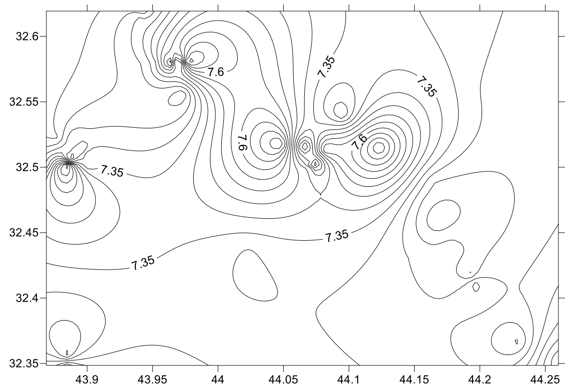

Figure 3: Contour map of PH

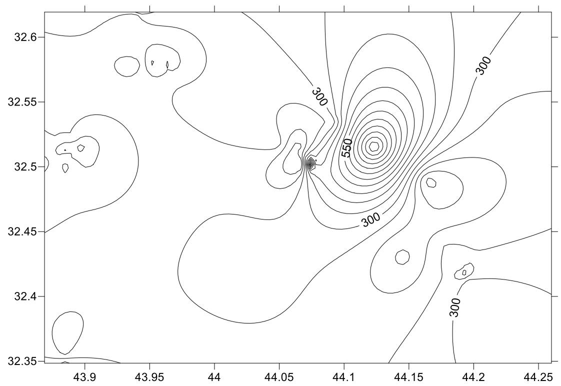

Figure 4: Contour map of Ca

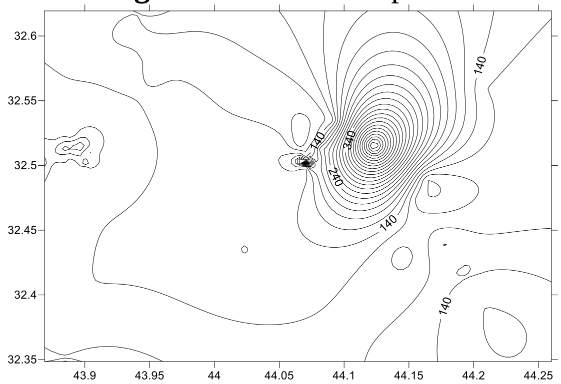

Figure 5: Contour map of Mg

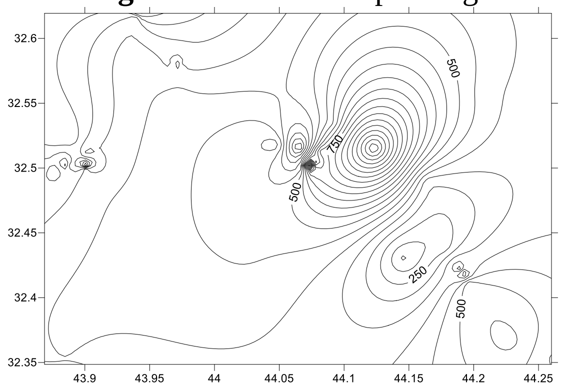

Figure 6: Contour map of Na

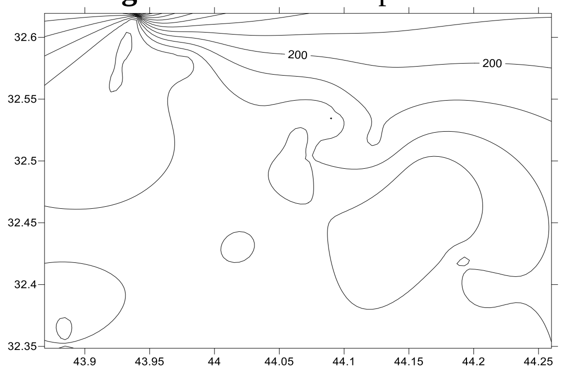

Figure 7: Contour map of K

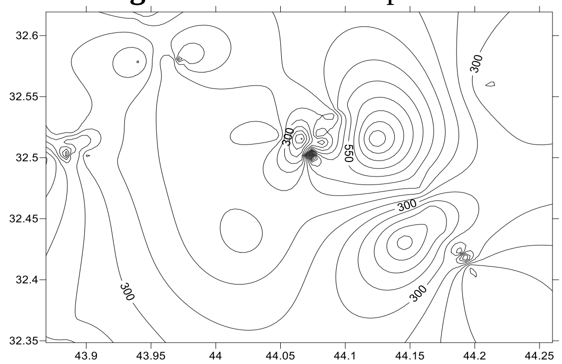

Figure 8: Contour map of HCO_3

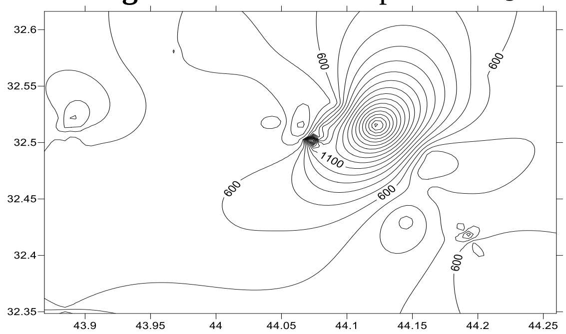

Figure 9: Contour map of Cl

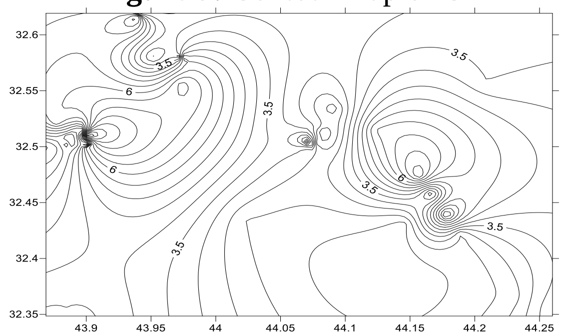

Figure 10: Contour map of NO_3

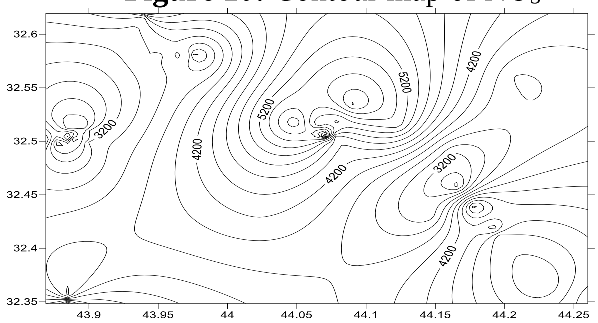

Figure 11: Contour map of EC

Moreover the mean, minimum, and maximum values of measured parameters for 54 wells inside the boundary of the study area are determined in Table (1) and compared with standards of the World Health Organization (WHO) in 2004 [22] and Iraqi standards (IS) in 2001 [23].

Table 1: Observed data for 54 wells with standards comparison

Parameter	Min.	Max.	Mean.	WHO(2004)	IS(2001)
pH	7.11	7.81	7.3271	6.5-9.2	6.5-8.5
EC	2320	6680	3982.040	1500	1000
T.D.S	1460	32210	3500.898	1000	1000
Ca	70	924	244.8163	200	50
Mg	36	596	138.8163	150	50
Na	0.4	1390	414.2939	200	200
K	1	745	59.76327	200	
Cl	160	2931	616.8334	250	250
HCO3	59	1225	360.8163	240	
SO4	381	3270	947.7959	250	250
NO3	1	11	3.759184	50	50

5. Results and Discussion

In this work many important results are obtained and conforming the theoretical studies, we exhibit laconically here in two items:

1. Contour maps evaluation of GW parameters

Locally, different directions of flow may occur throughout the region, depending on the geological setting of water–bearing horizons and nature of structure and topography [22, 24]. Figure (2) illustrate the trending of GWF. The contour maps which illustrated in Figures (6–11) show that the high contaminants concentrations of Karbala GW are generally located between longitude (44°00´– 44°20´), (43°20´– 43°40´) N and latitude (32°10´– 32°40´) E. The verification of contour maps illustrated in Figures (4 – 11) gives good relation between observed and estimated data according to the correlation coefficient (R) ranged 0.82 to 0.97.

2. Evaluation of GW quality for drinking

- Estimating of PH: The mean value of PH is agreement with IS and WHO. Table (1) illustrate that the PH values vary from 7.1 to 7.81, this means that the GW has nature acidic to alkaline and at average value tending to alkaline activity.
- When the GW moves along its flow paths in the saturated zone, the major ions increases normally, this is actuality given in [10, 11]. In this work we got the same actuality, i.e., Figures (3 – 11) show this increasing of EC and the ions such: Ca^{+2}, Mg^{+2}, Na^{+}, $HCO3^{-}$, Cl^{-}, $NO3^{-}$, and Na^{+} was generally dominant, but the concentration of cation K^{+} decreased in flow direction. It is found that all the observed data for GW have values of PH between 6.5 –9.2, respectively.
- From Table (1), we see that in all cations, the Na^{+}, K^{+} represents 91.84%, 2% respectively. So, Na^{+} represents above the WHO and IS limits. While K^{+} is immensely below the WHO limit of 200 mg/l. The Cl^{-} and $HCO3^{-}$ have percentages 87.67%, and 73.47% respectively which represents above the WHO and Iraqi limits. While the concentration of $NO3^{-}$ varies from 1 to 11 mg/l, below the WHO and Iraqi limits of 50 mg/l.
- The distribution pattern of ions in the GW of Karbala city is as:

$Na^{+} > Ca^{+2} > Mg^{+2} >> K^{+}$ and $Cl^{-} > HCO3^{-} >> NO3^{-}$

Generally, the distribution pattern of all the major ions can be decreasingly arranged

$Cl^{-} > Na^{+} > HCO3^{-} > Ca^{+2} > Mg^{+2} >> K^{+} > NO3^{-}$

The EC gives a qualitative picture of the quality of GW the EC values of the observed GW data have 100% which is highly exceeds of both the WHO and IS.

6. Conclusion

The chemical analysis of groundwater for Karbala city by using mathematical method is evaluated to find groundwater quality and suitability for multiple uses of water for drinking and irrigation purposes.

The contour maps of concentrations of the ingredients groundwater gave admissible presentation of groundwater quality and contaminants. Therefore, these maps can be approximately used to estimate the locations of new suitable wells including minimum harmful contaminants.

According to the water quality index (WQI), 58.7% of the data is unsuitable and 41.3% is suitable for drinking purposes. About 94.8% of the groundwater in the study area is admissible for irrigation purposes.

The system R.O. is an effective water treatment if it is filtered, the water is suitable for drinking in case of adding ultraviolet unit for disinfection, but chlorine unit is important because UV dose not completely kill all types of bacteria and viruses. The R.O. output stream decreases conductivity to about 250 µS, TDS is decreased to about 150 ppm. R.O. System is an effective water treatment if it is filtered, the water is suitable for drinking in case of adding ultraviolet unit for disinfection, but chlorine unit is important because UV dose not completely kill all types of bacteria and viruses. The R.O. output stream decreases conductivity to about 250 µS, TDS is decreased to about 150 ppm.

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