Estimation of Groundwater Recharge for the Main Aquifer in the Northeastern Missan Governorate, South of Iraq Using Chloride Mass Balance Technique

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Abstract

The groundwater recharge from rainfall for the main shallow aquifer in the northeastern Missan governorate south of Iraq is investigated via classical and refined chloride mass balance techniques. Application of both techniques reveals that the mean annual groundwater recharge is 0.82 mm/y. The annual recharge received by the aquifer approximately reaches to three million cubic meters after multiply this figure by the area of the study area (about 1856 km^2). This figure represents a renewable storage from which a sustainable management of the groundwater reserve could be implemented. The techniques applied are robust, costly-effective, and could be used with other methods such as groundwater table fluctuation method to give a more realistic value for this very important parameter.

Key words: Groundwater recharge, mass chloride balance, Iraq, Missan governorate

تقييم تغذية المياه الجوفية للخزان الجوفي الرئيس في منطقة شمال شرق ميسان باستخدام طريقة موازنة كتلة الكلور

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الخلاصة:

لتقييم تغذية المياه الجوفية للخزان الرئيس في منطقة شرق ميسان تم استخدام طريقة موازنة كتلة الكلور . بينت نتائج تطبيق الطريقة بان مقدار التغذية السنوية لمكمن المياه الجوفية الرئيس في المنطقة هي بحدود ثلاثة ملايين متر مكعب . وهذه الكمية تمثل خزيناً متجدداً يمكن من خلاله وضع خطط لاستثمار المياه الجوفية في المنطقة وفق الاستخدام المستدام لهذا المورد المائي المهم . حيث ان كميات ضخ المياه الجوفية في المنطقة يجب ان لا تتعدى هذه الكمية او تتعداها بقليل لكي لا يحصل استنزاف للخزين الاستترا تيجي (خزين المياه الجوفية غير المتجدد). خرج البحث بتوصية مفادها امكانية تطبيق هذه الطريقة لخزانات جوفية اخرى لانها بسيطة وغير مكلفة وتعطي نتيجة سريعة اذا ما قورنت بغيرها من الطرائق الاخرى خاصة الطرق المباشرة في تقييم تغذية خزانات المياه الجوفية من الامطار .

Introduction:

Groundwater recharge can be defined simply as the downward flow of water reaching the groundwater reservoir via the soil and unsaturated zone [1]. The amount of precipitation that reaches

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the groundwater reservoir depends upon several factors. Among these are the character and thickness of the soil and other deposits above and below the water table, the topography, vegetal cover, land use, soil moisture content, the depth to the water table, intensity and distribution of the rainfall, the occurrence of precipitation as rain or snow, and the air temperature and other meteorological factors (humidity, wind, …etc) [2]. Recharge must be estimated before groundwater resources can be evaluated and before the consequences of the utilization of aquifer can be forecast. The quantity of vertical leakage varies from place to place and is controlled by the permeability and thickness of the deposits through which leakage occurs, the head differential between sources of water and the aquifer and the area through which leakage takes place. At places, deeply buried aquifers are recharges in part by the vertical leakage of water through thick unconsolidated deposits, including clay materials [2].
Various techniques are available to quantity recharge; however, choosing appropriate techniques is often difficult. These techniques produce estimates over various time and space scales and encompass a wide range of complexity and expense. Information of different methods is contained in references such as [3-7]. Generally, there are two main methods for estimating recharge rate: direct and indirect. In direct method a suitable instrument such as lysimeter is used for direct recharge measurements. Generally, in the semiarid and arid regions installation and maintenance of lysimeter are expensive and difficult and is not suitable because of low average rainfall. The indirect methods are not accurate than direct methods but they are preferable in practical applications due to their simplicity, economy, and quick finding-results. Among such techniques are various balance approaches such as surface water balance and groundwater budget analysis, water table fluctuation method, numerical groundwater flow model, measurements of environmental isotopes, and use of chemical mass balance method such as with chloride.

Because of the variability of rainfall in many semiarid and arid regions physical methods which rely on direct measurements of hydrological parameters are problematic, because the recharge rates are low and changes in these parameters will be small and difficult to detect. Thus for estimating recharge rate, chemical and isotopic methods show more promise than physical methods [3]. It has been shown by [8] and [9] that the Chloride Mass Balance (CMB) method can yield regional rate of recharge under certain conditions and assumptions. Various applications of the CMB method have been presented for different parts of the world [7-18]). The application of the CMB method is simple with no independence on sophisticated instruments. Due to simplicity, the classical CMB and refined one by Subyani and Sen (2006) were used to estimate lumped recharge rates of main aquifer in the northeastern Missan governorate, south of Iraq, which is one of the most important agricultural and industrial areas in south of Iraq.

Methodology

The CMB method for estimating groundwater recharge is economic and effective, provided that the hydrological conditions for its applications are met and the modeling parameters are known. In the CMB, measurements of chloride concentration Cl^- in pore water and precipitation are used to estimate the recharge rate. The Cl^- is used in groundwater recharge studies because of its conservative nature and its relative abundance in precipitation. The ion neither leaches from nor is absorbed by the sediment particles. Also, it does not participate in any chemical reaction. The assumptions in the CMB approach for estimating recharge are that [1]: (1) There is no Cl^- source in groundwater storage prior to the rainfall. (2) There are no additional sources or sinks for Cl^- concentration in the area of the application. (3) The rainfall either evaporates or infiltrates in the region without any runoff. (3) Long – term rainfall and its Cl^- concentration amounts have a balanced situation, i.e they are in a steady – steady condition. Chloride concentration in single and consecutive rain events may differ significantly due to: [19] (1) The origin and the trajectory of air masses. (2) The storage of chloride in the atmosphere. (3) The distance from the coast. (4) The regional condensation altitude, above which interception deposition is favored. (5) The velocity of rain-out. Therefore, most precipitation starts with high and continuous with low chloride concentration. Thus, to avoid the variation of chloride concentration, the rainfall depth-weighted average of chloride Cl_{wav} was used. It is calculated based on the following equation: [18]

$$Cl_{wav} = \frac{\sum Cl_i h_i}{h_i} \quad \textbf{(1)}$$

where Cl_{wav}: rainfall depth-weighted average of Cl^- concentration(mg/l), Cl_i: chloride concentration in a considered rainfall event (mg/l), and h : depth of a considered rainfall event (mm).

On the basis of these assumption, the conservative of mass leads to the following relation between rainfall and recharge ([8], [19], and [13]:

$$R = \frac{P \times Cl_{wav}}{Cl_{gw}} \qquad \textbf{(2)}$$

Where *P*: mean annual precipitation in the study area (mm), Cl_{wav}: rainfall depth-weighted mean of chloride concentration (mg/l), Cl_{gw}: average chloride concentration of the groundwater (mg/l), and R : annual recharge amount (mm).

The classical CMB method was modified by **[17]** by taking into account some perceived deficiencies in the classic CMB method. The perturbation methodology was used to derive the refined CMB equation with homogeneity in 'averages'. It takes into consideration, in addition to the averages of variables, the correlation coefficient between the rainfall, its Cl^- concentration and the standard deviation. The refined equation was written as:

$$\bar{q} = \frac{\bar{R}Cl_{wav} + \hat{\rho}_{RCl_r}\hat{\sigma}_R\hat{\sigma}_{Cl_r}}{Cl_{gw}} \qquad \textbf{(3)}$$

where $\bar{q}$: recharge rate, $\bar{R}$: average of annual rainfall depth, $\hat{\rho}_{RCl_r}$: correlation coefficient between the rainfall and its Cl^- concentration, $\hat{\sigma}_R$ and $\hat{\sigma}_{Cl_r}$: the standard deviation of rainfall and its Cl^- concentration.

The study area

The study area is located in the northeastern of Missan governorate, south of Iraq between (32°03′25.52″– 32°30′30″) latitude and (47°05′21.16″–47°40′53.52″) longitude, figure-1, where It encompasses an area of (1856 km^2). The topography elevation ranges from (7 – 230 m), figure-2. The land surface is relatively flat in the central part of the area and it is bounded by Hemrin hills in the northeastern part and Band hill in the north close to the Al-Teeb. The surface elevations of the study area decrease from northeast to southwest. From the geomorphological point of view, the study area is flat and featureless surface bounded by the foothill zone in the northeast along the Iraqi-Iranian border. The most common landforms within the interested area were valleys network, alluvial fans, flood plain, sebkhahs, Ahwar (marshs), and sand dunes. Tectonically, the largest part of the study area lies in the Mesopotamian structure zone. The small part along the Iranian boundary belong the folded zone. Geologically, most part of the study area covers with fluviatile, lacustrine, aeloian sediments of recent age. The Quaternary deposits encompass about 72% from the study area whereas Tertiary sediments occupy 28%. The stratigraphic column consists of the following Formations (from oldest to newest): Euphrates, Fatha, Injana, Mukdadiyah and Bai Hassan, and Quaternary deposits.

According to the hydrogeological conceptual model of the study area, the aquifer system within the area is subdivided into three aquifers: shallow, main, and artesian. These aquifers are separated by two less permeable aquitards the hydraulic characteristics of them are unknown. The hydraulic connection between aquifer units is possible and the confined portion of aquifer system is not fully separated. The most important aquifer in the study area is the main aquifer where most of the operated wells penetrate it to some extent. The maximum thickness of aquifer may reaches to 40 m while minimum thickness is of about 20 m. The spatial distribution of thickness of this aquifer is shown in figure-3.The main aquifer is semi-confined aquifer where the confined and unconfined occupy 72% and 18% of the whole study area, respectively. The two aquitard system consists of silt and silt clay with little amount of sand. The hydraulic characteristics of these confining units are unknown and no evidence available against hydraulic connection between aquifer units across these confining units.

Hydraulic conductivities values of Quaternary deposits range (0.5 – 15.5 m/d) and less than that for Tertiary (2 – 25 m/d) may be due to the fact the main sediments of the last is gravel and sand, while the sediments of Quaternary is gravel and sand with significant amount of silt and clay which decreases values of this parameter significantly. Values of Transmissivity parameter are also increase from south to north, indication capability of aquifer to get and transmit water through it in this direction. This also means that the Tertiary part of aquifer is more important than Quaternary one. The maximum, minimum, and mean of the storativity thematic map were 0.00012, 6.10×10^{-5}, 8.1×10^{-5}, respectively. The central and northern parts of the area especially in the Teeb area have high values of storativity resulting in most promising zone for extracting water. The storage capacity zones of the study area are classified into three classes: low, medium, and high. The area encompasses by these classes are: 60%, 38%, 2%, respectively. Approximately (60%) of the study area classify as low production zone implies that evaluation of this aquifer need more rigorous plans and extraction controls.

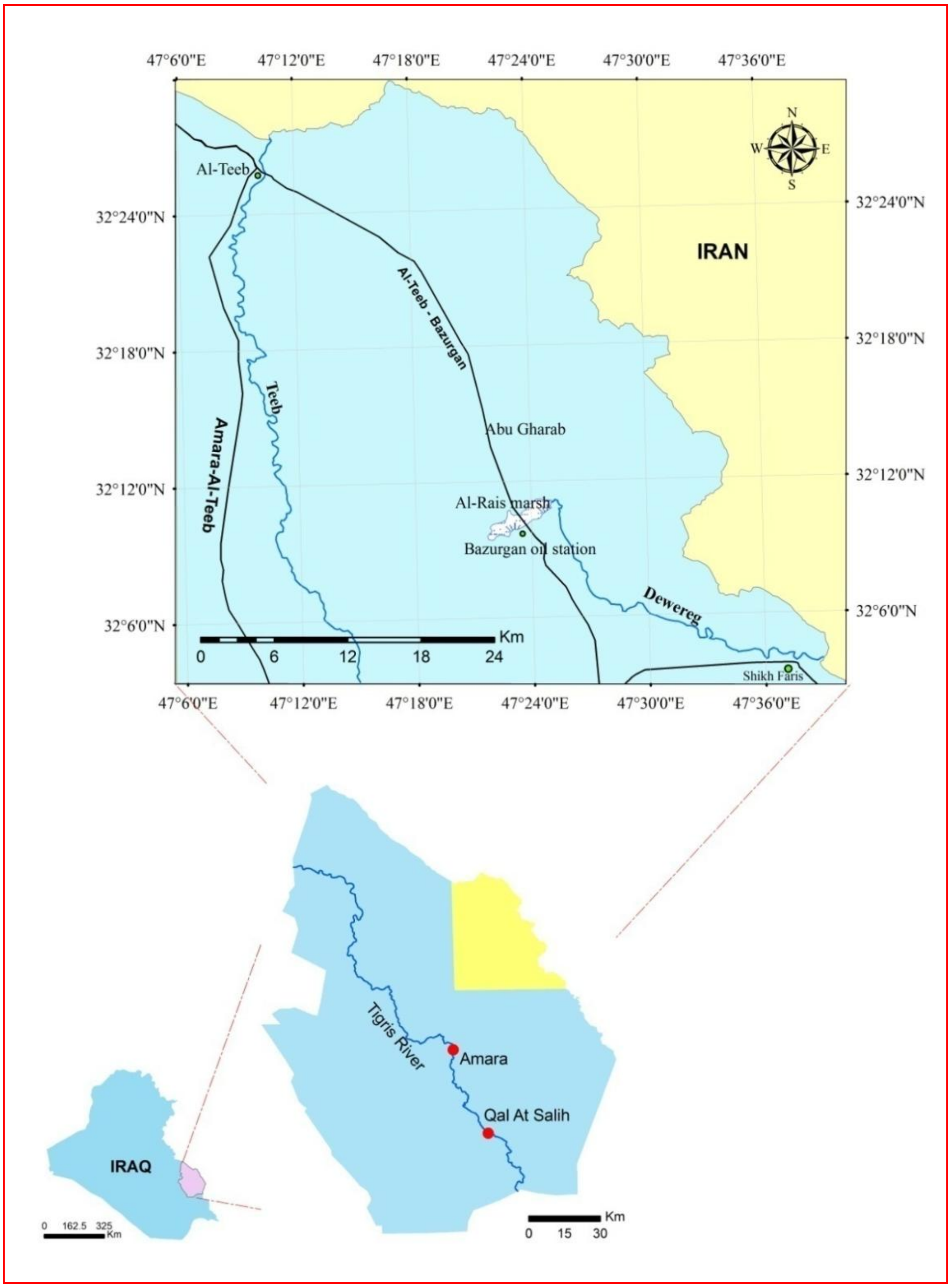

Figure 1- Location of the study area.

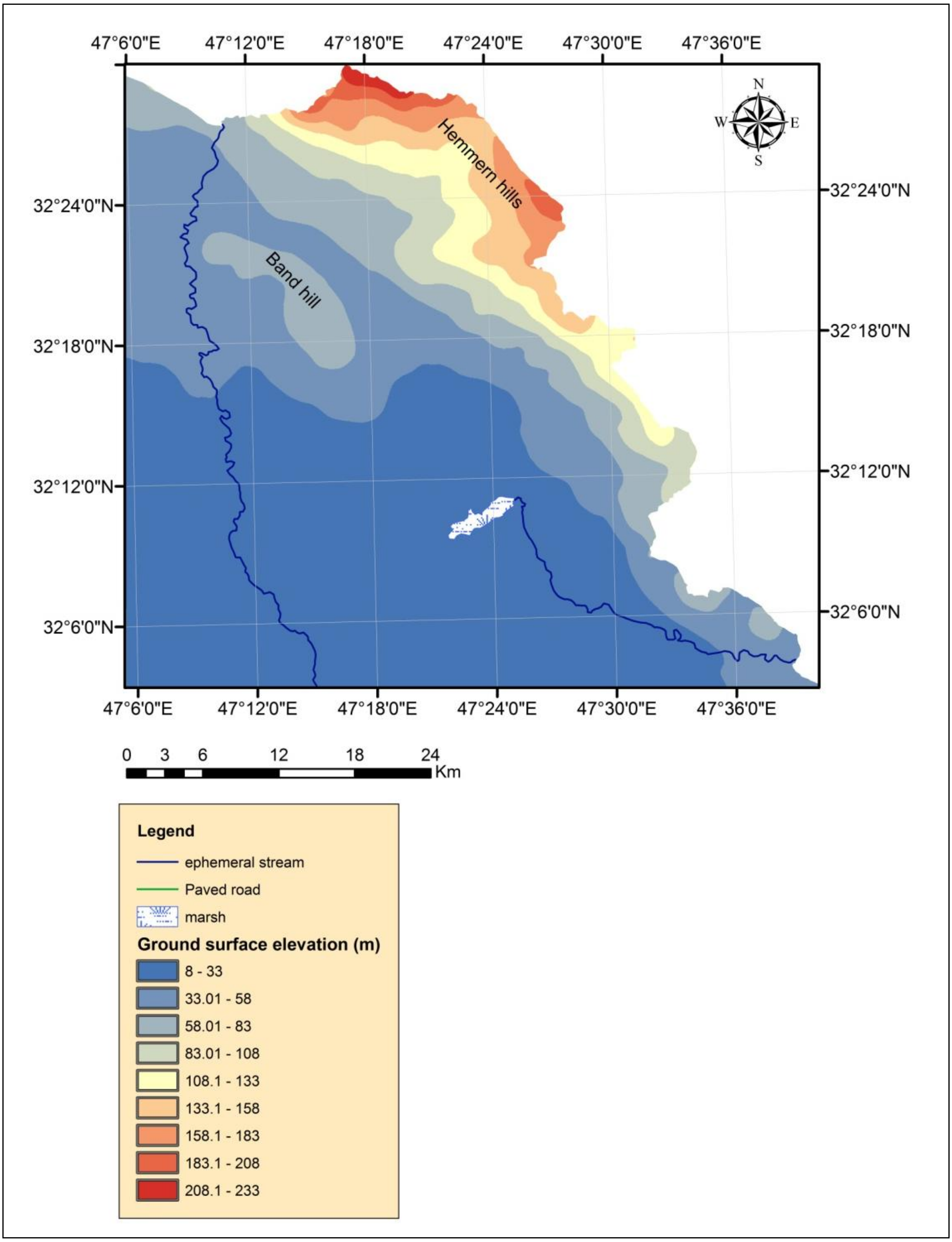

Figure 2- Topography of the study area.

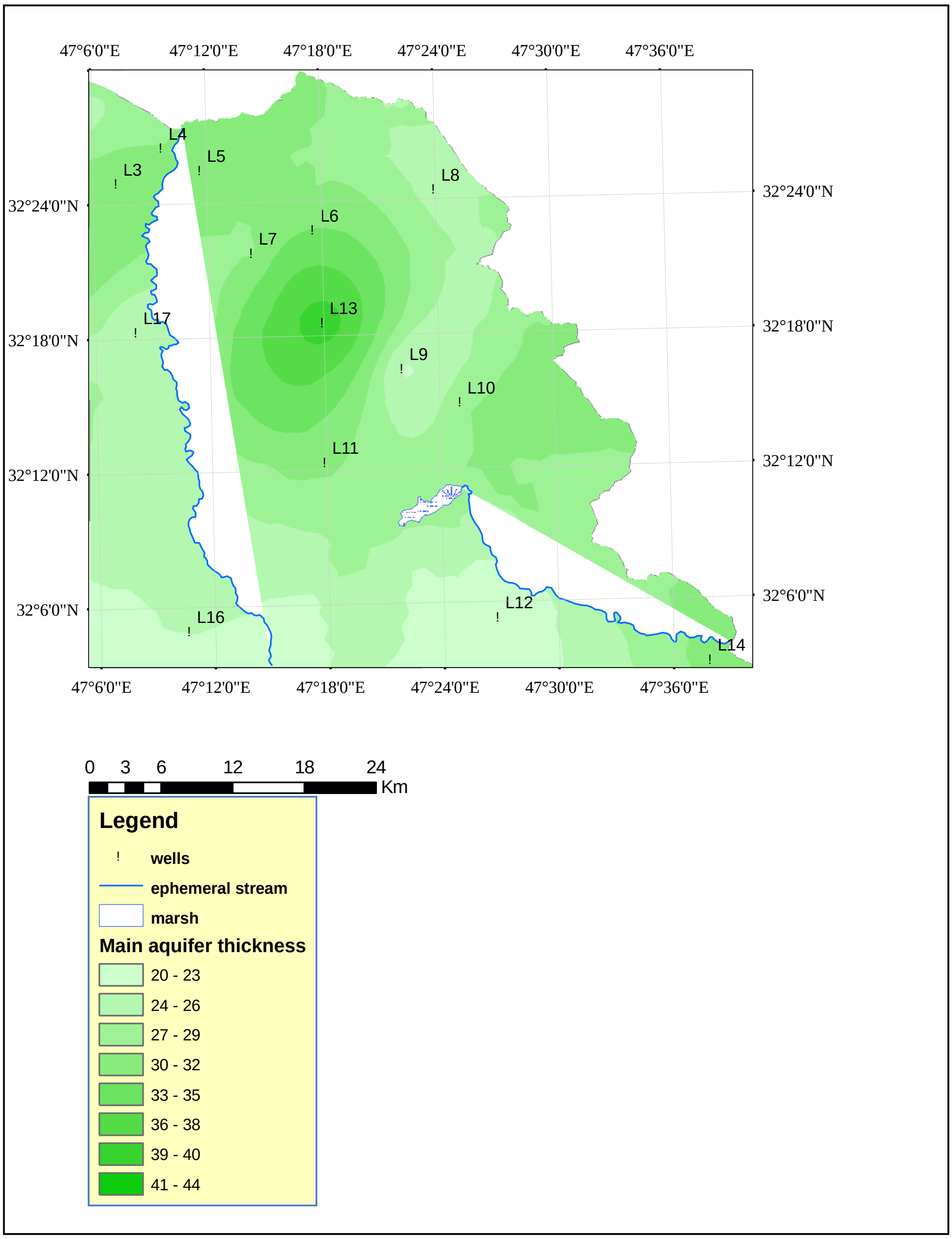

Figure 3- The spatial distribution of main aquifer thickness in the study area

Data set

In order to apply the classical and refined CMB in the study area for estimating annual lumped recharge rate, rainfall water samples were collected for the rainy period of water year (2010 – 2011) extending from October to April. Collecting rainfall water samples were very difficult and time-consuming. Before went to the field, weather in the study area were monitor in the weathering web pages such as yahoo weather services to expect the rainy day. Sometimes, two days and sometime four days spend in the field to collect significant amount of rainy samples. Sometimes, the Expected weather was wrong and the field trip was failed too. The collected samples were collected from a single sample point because of difficulty in movement in the study area during storm events especially heavy one. Other constituents such as cation and anion were measured in laboratory using standard procedures. A total of 23 samples of groundwater from tube wells are collected. Two bottles are used for each sample. Groundwater samples are collected in pre-cleaned bottles from each well location.

The water samples are kept in a refrigerator until all samples have been collected. The accuracy of these analyses was tested and the results were acceptable within 10% error. Temperature, electric conductivity, pH, and total dissolved solid (TDS) are measured in situ for both rain and groundwater samples.

Results and Discussion

All the data needed for the application of the classic and refined CMB were given in Table (1). The annual rainfall average for the period (1970 – 2009) is 174 mm. The standard deviations of rainfall chloride concentration and rainfall depth were 23 and 12.1, respectively. The correlation coefficient between monthly rainfall depth (height) and its chloride concentration was 0.87 referred to a strong relationship between these two variables. The average concentration of chloride in main groundwater reservoir is 1281.39 (mg/l). The depth weighted mean of chloride concentration is computed according to eq. (1), Table (1) as:

$$Cl_{wav} = \frac{1850.05}{137.94} = 13.41\ (mg/l)$$

Substitution of all the values into eq. (2) and eq.(3) give:

$$R = \frac{174 \times 13.41}{1281.39} = 1.82\ (\text{mm y}^{-1})$$ **Classic CMB**

$$\bar{q} = \frac{174 \times 13.41 + (0.89 \times 12.1 \times 3.47)}{1281.39} = 1.83\ (\text{mm y}^{-1})$$ **Refined CMB**

Table 1- depth of monthly rainfall and their chloride concentrations

Month	Mean monthly rainfall (mm)	Cl^{-1} concentration $(mg\ l^{-1})$
October	6.84	10
November	19.0	8
December	37.2	16
January	36.5	16.5
February	24.1	12
April	14.3	10
Arithmetic mean	22.99	12.08
Standard deviation	12.10	3.47
Correlation coefficient		0.87

The estimated recharge rate using refined CMB is very slightly higher than that obtained by classic CMB. The amount of annual recharge for main aquifer storage was computed by multiplying the value of 1.82 mm y^{-1} by the total area of the study area, i.e., 1856 $\times 10^6$ resulting in ~ 3× 10^6 m^3 y^{-1}. The recharge values calculated by two methods are similar because the correlation coefficient between mean monthly rainfall and chloride concentration is high. If these correlation weak it is expected to have two different values.

Conclusions

The procedure adapted for estimating annual recharge using chloride mass balance technique is robust and simple to implement. The annual recharge value estimated by using CMB method is a lumped value and does not takes into account the temporal and spatial variation of rainfall. More sophisticated methods such as water table fluctuation method or isotopic method could be used to validate the recharge rate computed by CMB method if observation bore holes established in the study area or if the suitable techniques are available in the country.

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