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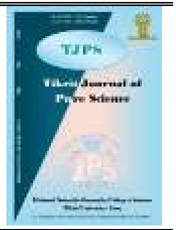

# Estimation of Groundwater Recharge Using Chloride Mass Balance (CMB) Unconfined Aquifer in Kirkuk Sub-Basin/ NE Iraq

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## Abstract

An estimation of groundwater recharge for the unconfined aquifer in Kirkuk - Iraq sub-basin, has been conducted using chloride mass balance method by measuring the monthly chloride concentration in monthly basis for rainy (wet) season 2015-2016 , samples have been selected from 44 water wells scattered in the region of interest ,the results shown that the groundwater recharge is about 15.6% from the total annual precipitation (304.3 mm) where the total recharge reached ~ 47.5 mm, moreover an additional source of fresh water is feeding the region of interest represented by Kirkuk irrigation channel ,the discharge is nearly 7 $m^3$/sec for 360 days ( 218 MCM/Year). the total amout of recharge to Kirkuk sub-basin is equal to 411 MCM/Year. The discharges of Al-Khassa river which crossed the central parts of ROI, were neglected because the river became controlled by Al-Khassa dam which was recently constructed at the northern border of the ROI which represented by Kirkuk structure. The present study is recommended to use this source of renewal water through strategic plan where additional comprehnsive hydrologic studies and aquifer modeling are needed to prevent the groundwater depleting in the region.

## Introduction

Groundwater recharge may be defined as 'the downward flow of water reaching the water table, forming an addition to the groundwater reservoir[1]. Four main ways of recharge can be distinguished [2]: a) Downward flow of water through the unsaturated zone reaching the water table. b) Lateral and vertical inter-aquifer flow. c) Induced recharge from nearby surface water bodies resulting from groundwater abstraction. d) Artificial recharge such as from borehole injection or man-made infiltration ponds. In arid and semi-arid areas, assessment of groundwater recharge is one of the key challenges in determining the sustainable yield of aquifers as recharge rates are low in comparison with average annual rainfall or evapotranspiration, and thus difficult to determine precisely [2]. The factors that influence the amount and type of recharge include 1) Precipitation (volume, intensity, duration). 2) Topography. 3) Vegetation Cover (cropping pattern, rooting depth) and evapotranspiration. 4) Soil and subsoil types. 5) Flow mechanisms in the unsaturated zone. 6) Bedrock geology. 7) Available groundwater storage. 8) The presence of influent rivers. 9) The presence of karst features. Some of these – most notably, the thickness and permeability of subsoil– also control groundwater vulnerability, and hence recharge studies can assist in the assessment of groundwater vulnerability [3].

There are two main types of recharge: direct (vertical infiltration of precipitation where it falls on the ground) and indirect (infiltration the following runoff) [4]. Also, there are two main methods for determining recharge flux, namely, direct method and indirect method [5]. The **direct method** Although there are lysimeter instruments for direct recharge measurements, their construction and management are difficult to control, and they are costly. Recharge rates are difficult to measure directly because the measurement must be at depth, and it requires the construction of lysimeters, which is expensive. The direct method is not suitable for arid regions because of low average rainfall [5].

The **indirect method** may not be as reliable as direct methods but due to their simplicity, economy, and quick result finding they are preferable in practical studies with reliable estimations. Among such techniques are various balance approaches such as surface water balance, measurement of saturation and water potential within the vadose zone, groundwater budget analysis, water table response to rainfall, groundwater discharge within well-defined groundwater basin, numerical groundwater flow model, measurement of environmental isotopes, and use of chemical mass balance methods such as with chloride [5].

The Chloride Mass Balance (CMB) method is one of the important methods use to estimate the groundwater recharge. The CMB method was used first by Eriksson and Khunaksem (1969), Later Allison and Hughes (1983), the CBM method used for groundwater recharge estimation in arid and semi-arid zones. The method assumes that in the groundwater the principal chloride source is from the atmosphere, and there is no chloride contribution from host rocks [5]. The CMB method can yield regional rates of recharge under certain conditions and assumptions [6]. The application of the CMB method is simple with no dependence on sophisticated instruments [5]. This paper aimed to estimate recharge rates of the main aquifer in the Kirkuk Sub-basin, (Shallow Aquifer) northern Iraq using Classical CMB and Refined CMB.

## The Region og interest (ROI)

The region of interest is located in the northern east of Iraq between 44° 26' 20" - 44° 19' 8" E and 35° 30' 42" - 35° 23' 13" N, The topography ranged from 110 in the SW parts to 590 m.a.s.l in the NE, bounded by Kirkuk structure from N and NE and surface water divide between lesser zab river basin and alkhassa watershed from NW and surface water divide with Taweq Su river from SE, and by himreen structure from SWS, Figure (1), the ROI is covered about 3740 $km^2$, this area composed of Quaternary deposits. Tectonically, the ROI lies within the Foothill zone (Chamchamal - Butmah) subzone. Geomorphologically, the ROI can be divided into two main parts. The first part consists of flat terrain including some hilly and undulating plains, whereas the second part consists of mountains area, the maximum and minimum heights are 150 – 350 m.a.s.l. respectively. the highest spot is located in the NE, whereas the lowest one is in the SW. From Hydrogeological perspective, the depth of the ground water varies due to the topography, structure, and type of the aquifer, it ranges from less than 100m up to 250m above sea level. The aquifers are mainly of clastic rocks. The exposed formations in the area under consideration have wide stratigraphic range extending from Tertiary up to Quaternary deposits, the exposed formations according to [7], Figure (2): are

1) **Fatha Formation**: Middle Miocene, the formation is widely exposed within the area under consideration and well developed representing the cyclic evaporite deposits, but towards northeast, it changes its nature and becomes less evaporitic in nature, it consists of cyclic deposits of marl, limestone, gypsum.

2) **Injana formation**: Upper Miocene, the formation is exposed in all structures. It consists of gray and brown sandstone interbedding with brown claystone and reddish brown siltstone in cyclic nature.

3) **Mukdadiyah Formation**: upper most Miocene – Pliocene, the formation is exposed in all structures. It consists of an alternation of yellowish gray to dull brown, soft, claystone with gray, coarse grained, friable, cross-bedded sandstone, and brown and gray siltstone. Some of the sandstone horizons are a pebble, pebbles are increasing in abundance upwards in the formation. In the upper most parts thin lenses of conglomerate (with fine pebbles) may occur.

4) **Bai-Hassan Formation**: Pliocene, the formation is exposed widely in all structures. It covers large areas south east, east and north of Kirkuk forming typical bad land terrain. The formation consists of thick and coarse conglomerates (up to 50 -80 m) alternating with thick brown claystone and thin sandstones. The upper part is formed by thick claystone with rare conglomerates and is usually highly weathered and eroded, covered by Quaternary deposits of different types.

5) **Quaternary deposits**: Different type of Quaternary deposits developed in the study area, although many types are developed in small restricted areas because to their different genetic origin. There are nine different types of Quaternary deposits are Pliocene to Holocene in age they are: River terraces, Polygenetic deposits, Slope deposits, Gypcrete, Residual gravels, Sabkha deposits, Depression fill deposits.

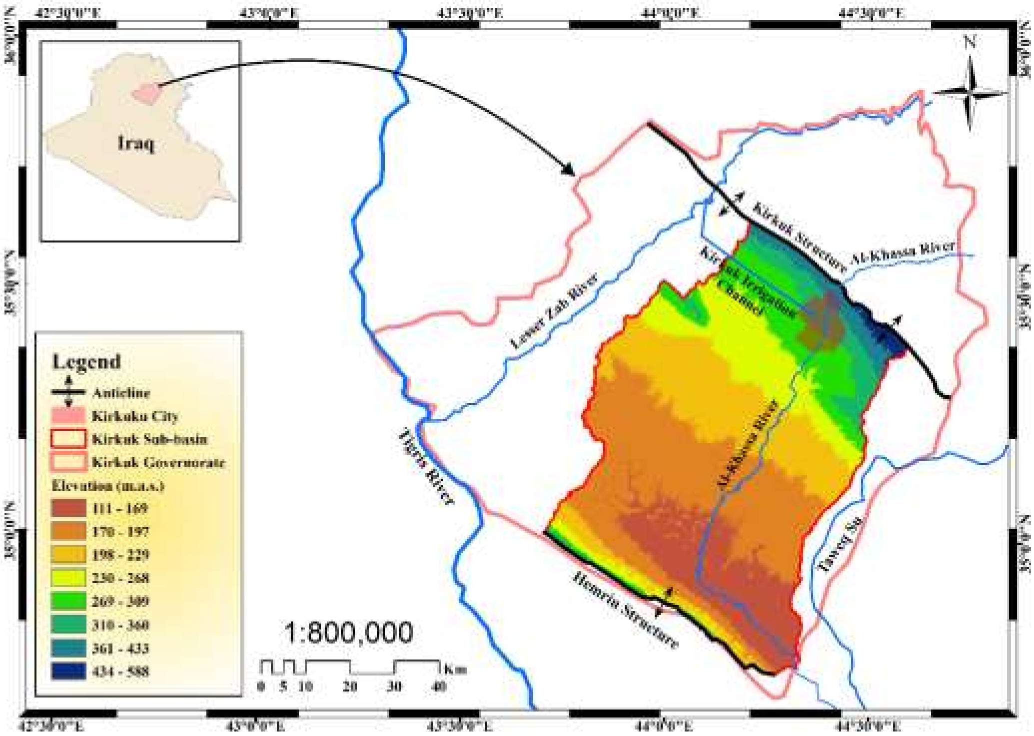


Figure (1): Location and geological map of study are.

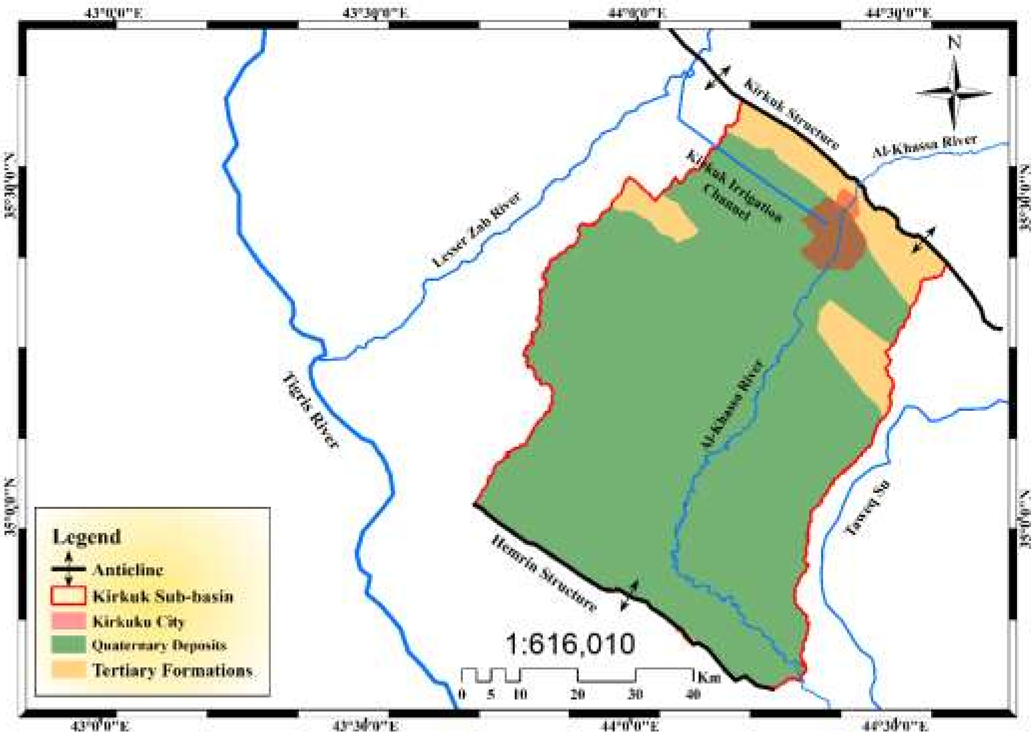


Figure (2): Geological Map of Study Area.

## The Hydrogeological Setting to ROI

The hydrogeological setting represented by two main aquifers, the first is unconfined aquifer of Quaternary deposits and the second is semi-confined aquifer of Bai-Hassan and Mukdadiyah formations Figure (2), [8; 9]. The Flownet of shallow groundwater of study area has been drawn depending on the data of [8] and Table (1) that clearly shown the groundwater movement direction is relatively similar to the drainage patterns of surface water Figure (3) [7; 8].

**Table (1) Data of Groundwater table in the Study Area [8].**

| Well No. | Wt (m.a.s.) | Well No. | Wt (m.a.s.) | Well No. | Wt (m.a.s.) |
|---|---|---|---|---|---|
| 1 | 278 | 16 | 186 | 31 | 166 |
| 2 | 277 | 17 | 198 | 32 | 167 |
| 3 | 235 | 18 | 194 | 33 | 172 |
| 4 | 255 | 19 | 194 | 34 | 133 |
| 5 | 239 | 20 | 175 | 35 | 183 |
| 6 | 200 | 21 | 180 | 36 | 184 |
| 7 | 188 | 22 | 170 | 37 | 197 |
| 8 | 192 | 23 | 177 | 38 | 189 |
| 9 | 205 | 24 | 180 | 39 | 232 |
| 10 | 226 | 25 | 198 | 40 | 314 |
| 11 | 232 | 26 | 195 | 41 | 313 |
| 12 | 235 | 27 | 174 | 42 | 313 |
| 13 | 228 | 28 | 166 | 43 | 295 |
| 14 | 188 | 29 | 160 | 44 | 319 |
| 15 | 191 | 30 | 162 | | |

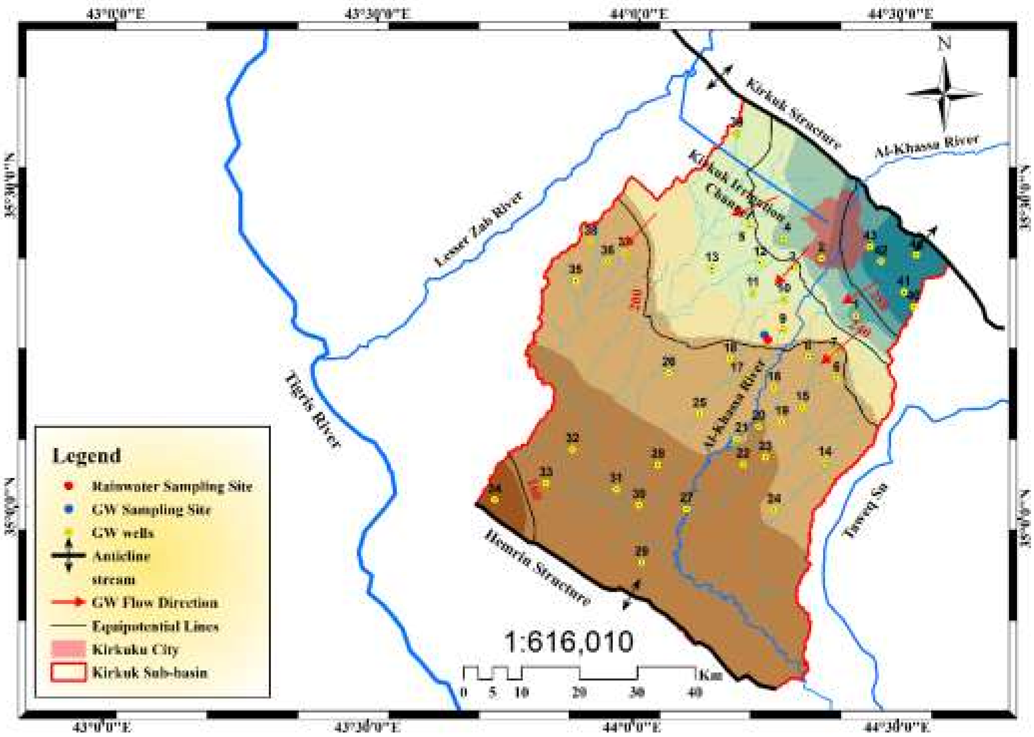


**Figure (3): Flownet Map of Study Area.**

## Methodology

The chloride mass balance method determines recharge by calculating the ratio of chloride concentration in precipitation to that in groundwater [10]. The chloride ion is used in chemical recharge studies because of its conservative nature, the ion neither leached nor absorbed by sediments particles. This is based on the assumption that the chloride concentrations in the rainfall and the recharge areas are in steady-state balance, the input is equal to output without chloride storage change during a specific time period, often one month or year [5]. Several underlying assumptions are outlined for the method to be applicable [11]: 1) The chloride is a conservative tracer, i.e., its concentration is neither diminished nor increased through chemical reactions in the soil, vegetative uptake or increased evaporative action among other things. 2) There are no other sources of chloride to the groundwater other than precipitation. 3) The losses through leaching are minimal, i.e., there is no incremental change in chloride concentration in the vertical direction. The Chloride concentrations in regional, single, and consecutive rain events significantly differ according to [12]: 1) The distance from the source area of chlorides. 2) Weather trajectories. 3) Re-evaporation. 4)The regional condensation altitude. 5) Rain intensities. There is two Chloride Mass Balance methods, the **first** method is Classic CMB: In the classical CMB equation, only averages are used without taking into consideration spatial or temporal variations quantitatively by considering additional statistical variables in the calculations [5]. The fundamental equation applicable for recharge calculations is presented by [13] as follow:

$$R = P\frac{Cl_P}{Cl_{gw}} \qquad (1)$$

Where R: annual recharge amount (mm / y), $P$ : mean annual rainfall depth (mm), $Cl_P$ : is the mean chloride concentration in rainfall (ppm), and $Cl_{gw}$ : is the mean chloride concentration in the groundwater (ppm), Table (2).

The **second** method is Refined CMB: is the method was used to recharge calculations, refined CMB equation was written as [6]:

$$q = \frac{P*Cl_P+\rho_{RCl_r}\sigma_R\sigma_{Cl_r}}{Cl_{gw}} \qquad (2)$$

Where $q$ : annual recharge amount (mm / y), $P$ : mean annual rainfall depth (mm), $\rho_{RCl_r}$ : correlation coefficient between the rainfall and its $Cl^-$ concentration, $\sigma_R$ and $\sigma_{Cl_r}$ : the standard deviation of rainfall and its $Cl^-$ concentration, $Cl_P$ : is the mean chloride concentration in rainfall (ppm), and $Cl_{gw}$ : is the mean chloride concentration in the groundwater (ppm), Table (2).

The annual groundwater recharge quantity ($m^3$/y) in the unconfined aquifer calculated according to [14]:

*Annual GW recharge quantity (Renewal Groundwater Recharge) ($m^3$/y) = Area of recharge region ($m^2$) * Annual GW recharge amount (m/y)* (3).

**Table (2) Basic Data for Calculation Amount of Groundwater Recharge Calculation.**

| Period | Month | (Cl) Conc. in Rainfall (ppm) | (Cl) Conc. in GW (ppm) | Monthly Average of Rainfall (mm)* | Annual Rainfall Depth (P) (mm) | Area of Recharge Region (Km²) |
|---|---|---|---|---|---|---|
| 2015 - 2016 | Oct. | 9.5 | 44 | 13.29 | 304.3 | 4061.436 |
| | Nov. | 8.5 | 48 | 37.24 | | |
| | Dec. | 8 | 47 | 49.42 | | |
| | Jan. | 7.3 | 55 | 69.84 | | |
| | Feb. | 7.2 | 48 | 46.76 | | |
| | Mar. | 7.6 | 67 | 41.73 | | |
| Mean | | 8.02 | 51.5 | - | | |
| *[15] | | | | | | |

The rainfall water samples are collected for the rainy period of wet year 2015 – 2016 from Oct - Mar, while groundwater samples are collected from water wells, are collected in pre-cleaned bottles from groundwater well, where six rainfall samples and six groundwater samples are collected Figure (3), Then the samples kept in the refrigerator. The samples analysis using (Photolab S6 WTW) Photometer, where 1 ml of sample mix with reaction of chloride kit, then put the kit in photometer and measure chloride concentration. The chloride analysis has performed in the Environmental Research Unit, College of Sciences, Kirkuk University, Kirkuk / Iraq.

## Results and Discussion

The Groundwater recharge rate in the ROI estimated by using classic and refined CMB methods presented in Table (3):

**Table (3) Annual Groundwater Recharge Amount, and Renewal Storage**

| Period | R (mm/y) | q (mm/y) | Annual GW recharge amount (mm/ y) | Renewale GW Storage (MCM/ y) | Recharge Percent (%) |
|---|---|---|---|---|---|
| 2015 - 2016 | 47.388 | 47.627 | 47.507 | 192.95 | 15.6 |
| **R (mm/y):** annual recharge amount. **(Classic CMB)**<br>**q (mm/y):** annual recharge amount (recharge rate). **(Refined CMB)** | | | | | |

The annual portion of groundwater recharge from precipitation (P) in the study area is about 15.6%, as follow:

$$Gr = 0.156 * P \qquad (4)$$

Where: $Gr$ is Groundwater recharge amount (%), 0.156 is a constant, $P$ is annual rainfall depth (mm). However, depending on the equation above we can calculate the annual groundwater recharge amount in the future depends on annual rainfall depth (P) in this region. The estimated annual recharge amount by using classic and refined CMB method are rather similar (47.388 mm/y) and (47.627 m/y), respectively.

The ROI have two another sources of water which replenishes the groundwater storage, it is (Kirkuk Irrigation Chanel) to complete the deficit of water demand in Kirkuk city which discharges 7 $m^3$/sec for 360 days [16]. Which equivalent to (217.728 MCM/ y) annually, add this amount to what penetrates into the groundwater calculated previously and whose total imports of the Shallow Aquifer of rainfall and surface water, and the second is represented by Al-Khassa perennial river which has approaciate discharge value of water equal to 3.0 $m^3$/ sec during all water year days [16], especially after running Al-Khassa upstream dam, however no information is available about the infiltration amount of water from its valley to aquifer which flows through, where the discharges of Al-Khassa river which crossed the central parts of ROI, were neglected because the river became controlled by Al-Khassa dam which was recently constructed at the northern border of the ROI which represented by Kirkuk structure, The annual discharge of AlKhassa stream water equal to (93.33) MCM/Year where no information about how quantity from this value is going to replenish the ROI , so this amount is neglected from the total value of study area recharge .

The total quantity to the Shallow Aquifer of Kirkuk sub-basin is 192.95+217.728 = 410.678 MCM/Year.

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# تقدير كمية تغذية المياه الجوفية للخزان العلوي (المفتوح) باستخدام طريقة توازن كتلة الكلور(CMB) في حوض كركوك الثانوي / شمال شرقي العراق

**عمر صباح ابراهيم التميمي**

*وحدة البحوث البيئية ، كلية العلوم ، جامعة كركوك ، كركوك ، العراق*

**الملخص**

تم في هذا البحث إجراء تقديرًا لتغذية المياه الجوفية للمكمن العلوي غير المحصورة في حوض كركوك الثانوي، الواقع شمال شرقي العراق ، وذلك باستخدام طريقة توازن كتلة الكلور(CMB) بعد قياس معدل تركيز آيون الكلورايد شهرياً خلال موسم الرطب 2015–2016 وكذلك قياس تراكيزه في المياه الجوفية في المنطقة من خلال نمذجة مياه بئر موجود في نفس المنطقة ، وبعد تطبيق اسلوبين لتحليل النتائج للطريقة المذكورة تبين أن خزين المياه الجوفية المتجدد يبلغ حوالي 47.5 ملم أي (15.6 ٪) اي مايعادل (193) مليون متر مكعب / سنة من الساقط المطري السنوي والبالغ حوالي 304.3 ملم ، في سنة المراقبة ، وعلاوة على ذلك هناك مصدر آخر للمياه العذبة لمنطقة الدراسة، وهي قناة ري كركوك التي تصرف حوالي 7م$^3$ / ثانية لمدة 360 يوماً في السنة من المياه والتي تسحب مياها من نهر الزاب الاسفل اي مايعادل حوالي 218 مليون م$^3$ /سنة. عندئذ يكون إجمالي كمية المياه التي تغذي حوض كركوك الثانوي يساوي 411 مليون متر مكعب في السنة. وقد اهملت تصاريف نهر الخاصة الموسمي و الذي يمر عبر الاجزاء الوسطى من منطقة الدراسة وذلك بسبب حجز مياهه في خزان سد الخاصة الذي تم إنشائها مؤخراً قبل الحدود الشمالية للمنطقة و التي هي تركيب كركوك. وهنا نوصي باستخدام هذا القدر من الماء المتجدد من خلال اعتماد خطة ستراتيجية معتمدة على دراسات هيدرولوجية مفصلة تعتمد النمذجة العددية تنبؤية لمنع استنزاف خزين المياه الجوفية في المنطقة.