Evaluating the Recharge of Ground Water within Al-Wand River Basin.

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ABSTRACT

The estimation of recharge to ground water is the important basics to improve the use of ground water with other available resources, and to save ground water resource from depletion, especially when using large quantity of ground water during a long time such as for agricultural purposes. Al-Wand River Basin in Iraq suffers from water shortage of its requirement of Blajo–Al-Wand Project, and to cover this shortage, the ground water plays a good role to overcome this problem. In this study, three methods were used to estimate the recharge and ground water storage for Al-Wand Basin, these methods are: Water Table Fluctuation (WTF), Water Balance of Climatic for Basin, and Water Table Balance for Basin. The results showed differences between the methods used to estimate recharging and ground storage for this basin. The approximated values between drawl water from production wells and water balance of climate for basin method make it better the other methods, which the difference percentage was large with drawls water. Also, classifying the methods by assumptions found make (WTF) better method, because it contains less assumptions compared to the other methods.

Key words: ground water, recharge of ground water, WTF method, water balance of climate basin method, water balance of basin.

تقييم تغذية المياه الجوفية لحوض نهر الوند

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الخلاصة

تعد عملية تقدير تغذية المياه الجوفية من الاساسيات المهمة لتحسين استخدام الماء الجوفي مع المصادر المائية الاخرى ولحفظ مصادر المياه الجوفية من الاستنفاذ ، خصوصاً عند استخدام مياهها بكميات كبيرة ولوقت طويل مثل استخدامها للاغراض الزراعية. ان حوض نهر الوند يعاني من انخفاض في كميات المياه التي تمر به لذا تستعمل المياه الجوفية لغرض سد هذا النقص. تم استخدام ثلاث طرق في هذه الدراسة لتخمين تغذية المياه الجوفية والخزين الجوفي لهذا الحوض وهذه الطرق هي : تذبذب مناسيب المياه الجوفية ، الموازنة المائية المناخية للحوض والموازنة المائية للحوض. اظهرت النتائج اختلاف كبير في قيم تغذية المياه الجوفية لهذا الحوض. التقارب بين قيم الماء المسحوب من الابار المنتجة بطريقة الموازنة المناخية للحوض يجعلها افضل من الطرق الاخرى التي تكون نسبة الفرق واضحة فيها مع الماء المسحوب من الابار ، كذلك تصنيف الطرق حسب الافتراضات المستخدمة في الطرق يجعل طريقة تذبذب المناسيب افضل من الطرق الاخرى، لانها تحتوي على اقل عدد من الافتراضات.

الكلمات الرئيسية : المياه الجوفية ، تغذية المياه الجوفية ، نظرية تذبذب مناسيب المياه الجوفية ، نظرية الموازنة المناخية للحوض ، نظرية الموازنة المائية للحوض .

1. INTRODUCTION

The important factors when using ground water are the limited recharge and the strategy of drawls the water from aquifer. This is especially when there is a high need for ground water due to water increase for agricultural purpose, and when there is a shortage in the surface water recourse. The method to define the recharge resources is the main objective for Al-Wand Basin. This basin is located in Iraq and Iran. Most part of the basin lies within the Iranian borders. So, the estimation of recharging and ground storage is for Iraqi part, because the information of the Iranian part is limited for the same basin.

1.1 Recharging Ground Water

The fundamental components of the water balance of any basin is the recharge of water to ground water reservoir, many methods are used to estimate the recharge of ground water, one of these methods is direct measurement, which is widely used with complexity and costly, **Risser, 2005**. The rate of recharge and volume of recharge are connected with rainfall quantity, the conditions of geology in the ground water basin such as surface and subsurface condition affect the availability and distribution from supply surface water to the ground water basin, all these points are very important to indicate the aquifer recharge, **Dudley, and Fulton, 2005**. There are many methods of recharging water to ground. Selecting the proper method depends on the type of aquifer and if the surface water in basin is available. These methods as presented by **Dedley, and fulton, 2005** are:

1- Natural recharge: This is considered as simple methods of replenish ground water reservoir in almost all basins by percolating the water to aquifer from available surface water sources as a stream, lakes, rivers and applied irrigation water in fields. Natural recharge does not need to infrastructure or surface water supply because the water already exists through the aquifer in natural conduction, because that this method consider slowest of replenishing the water to aquifer system, and relatively unmanaged from human.
2- In-lieu recharge: This method can be applied when using the ground water in any basin and this basin does not include as a natural surface water resources, so it is recommend providing the aquifer with water from application of surface irrigation water and seepage water due to low of conveyance facilities. The advantages of this method are leaving more ground water in aquifer storage for later use, reducing the demands on aquifer system from ground water extraction, and can be implemented under virtually any soil and geologic conditions, but the disadvantages are when using recharge by this method because it is very complex and expensive to implement especially when the area of basin need to construct a special irrigation networking system to recharge water for aquifer basin.
3- Aquifer injection: The recharge of ground water by using method of injection water to aquifer system by operating wells in backwards. The use of this method is limited because of geological condition, and when the other methods of recharge are not suitable for the aquifer. At large scale area this method is very expensive, and includes the costs of well construction, pump operation, cost necessary to treat the water prior to injection, and mechanical maintenance existing with aquifer injection. In artificial recharge method such aquifer injection must be available with good quality and when supplied to aquifer with free of turbidity, bacteria, bio-matter, and viruses.

Limiting of the methods that are used to estimate the recharge of ground water reservoir is difficult to apply since it must be available in the primary measurement for evaporation and deep percolation or other parameter input that affect balance of hydrologic cycle, and these methods are:

1. Physical or natural method: this method can be applied by considering the properties of soil and the measurements of the water quantity which inflows under root zone.
2. Chemical method: Can be used by following the relative presence of solution tendency material in water such as chloride and matches through the soil during deep percolation.

The methods that are used to estimate the recharge of ground water in Al-Wand Basin (the part of Iraq) in this research are:

1.1.1 Water table fluctuations

Water table fluctuation method may be the most widely used as a technique for estimating the recharge, the specific yield and change in water level must be available during a period of time as a requirements of this only. There are many methods that use water level to estimate the recharge of ground water, but these methods are based on Darcy equation, instead of that (WTF) method depends on knowing the specific yield that can be determined, in addition to that the water levels change method will give the accuracy than the other method. The simple and insensitivity of mechanics in (WTF) method makes it useful especially when water moves through the unsaturated zone, **Healy, and Cook, 2002**.

Ramadhan, et al., 2013, presented the evaluation of ground water recharge for arid and semiarid regions by using four methods (fluctuating water table, water balance of the basin, numerical modeling and balance of chloride ion mass in unsaturated zone). The result of these methods showed the there is a difference in value of recharge, but it was closer to real result when comparing with volume of water in inventories renewed when using chloride ion method in unsaturated zone.

The (WTF) is based on the rises of ground water levels in unconfined aquifer, and the recharge of water that will arrive to the water table is calculated as:

$$R = Sy\,\Delta h / \Delta t \tag{1}$$

where:

Sy = specific yield,
Δh = difference of water table, m, and
Δt = the time of recharge calculating.

And the ground storage of ground water is given as:

$$\Delta S = R * A_t * C \tag{2}$$

where:

ΔS = ground storage, m^3,
A_t = total area of basin, ha, and
C = conversation unit.

1.1.2 Recharge from water balance of climate for basin method

The recharges from water balance of climate for basin method is a widely used in world to evaluate the recharge of ground water for any basin. The main parameters of this method depend on the theoretical balance basin parameters which the other methods depend on too, especially the data of surface water and ground water system at unsaturated and saturated zone, **Ibrahim, et al., 2011**. The water balance for hydrologic system must be equal to input and output parameter which is contained in this system, otherwise the change of ground storage will appear if these parameter increase or decrease one to other, the water balance is as follows:

$$Input - output = change\ in\ storage \tag{3}$$

The rainfalls or snow are the only input in water balance budge, and the output parameters which can be limited are:

- Evapotranspiration: the evaporation process is the loss of water from water surface or the soil, while the transpiration is the process of loss water from the plants, and the two processes are called evapotranspiration. Many methods are used to estimate evapotranspiration for any study area especially the cultivated area.
- Soil moisture content: is the second parameter of the balance climate for basin method and depends on the type, texture and depth of soil. The soil moisture content (SMC) affects the amount runoff and recharge of ground water and this cannot be satisfactory except when soil reaches the saturated state, or the average of soil filtration of water reaches low level, and when the capacity of filtration at high level, **Famiglitti, et al., 1998**. Run off of water occurs when the average of filtration decreases and rainfall intensity is higher than average of filtration rate and before the soil reaches to saturation level, **Domenico, and Schwartz, 1998**.

The water surplus is a result of the difference between the rainfall and evapotranspiration average which is formulated as:

$$WS = P - Et \tag{4}$$

where:

WS = monthly water surplus, *mm*,
P = monthly average rainfall, *mm*, and
Et = monthly potential evapotranspiration, *mm*.

The recharge of ground water is not considered the only affecting factor in water surplus (*WS*), but the surface runoff and soil moisture content are main factors affecting water surplus which is equal to:

$$WS = Gr + SR + SM \tag{5}$$

where:

Gr = recharge of ground water, (*mm*),
SR = surface runoff, (*mm*), and
SM = soil moisture content.

The surface runoff equation can be used in the upper soils of Adhime basin to estimate the annual runoff of Al-Wand basin, **SOGREA, 1983**.

$$SR = 0.168\ (P - 180) \tag{6}$$

where:

P = annual rainfall in, *mm*.

The water balance of climate to estimate the ground storage can be formulated as:

$$P - (Et + SM + SR) = \pm \Delta S \tag{7}$$

where:

ΔS = change of ground storage in month, (*mm*).

Ibrahiem, et al., 2012 used the climatic water balance for evaluating the recharge of ground water for Tikrit sub basin. In his study, he depends on the climate parameters such as rainfall, temperature and evapotranspiration which are estimated using**, Thornthwait formula, 1948**. He also used other parameters for the balance which are surface runoff, soil moisture content as a recharge for ground water. The climate balance illustrated the increasing of average evapotranspiration on the average of rainfall which causes the decreasing in water surplus that affect the recharge of ground water.

1.1.3 Water balance for basin method

Water balance method illustrated the natural parameters which are used as input in water balance of basin method to evaluate the recharge of ground water, which is recharged from rainfall, base flow from rivers, seepage from surface, and from irrigation water application. The discharge parameters from water balance system can be indicated by drag wells which are draw water out for any purpose, and evapotranspiration from ground water.

Sethi, et al., 2002 used the ground water balance model as a way to connect it with conjunctive use for agricultural purposes in a Coastal river basin. The linear program of optimization is applied with ground water balance to maximize the economic returns for optimal cropping pattern.

The conceptual for this method can be formulated as the recharge of ground water, discharge of ground water, and the change of ground storage which are effected by recharge and discharge, of all these parameter that will illustrated below:-

- Recharge of ground water

This parameter is input parameter which plays a role in recharge of ground water and it changes according to the nature of study area and properties such as type of soil, cropping pattern, and the networking of irrigation system and the last one can be indicated by estimated conveyance and irrigation efficiency, all these parameter are illustrated below:

$$GR = R_r + RC + RBF + RSF \tag{8}$$

where:

GR = ground water recharge, m^3,
R_r = recharge from rainfall, m^3,
RC = recharge from irrigation area and conveyance system,
RBF = recharge from base flow, m^3, and
RSF = recharge from seepage from drain, m^3.

1- Recharge from rainfall (R_r)

Chandra, and Saxena, 1975 presented an equation to calculate the recharge from rainfall, depended on the average annual of rainfall, and is illustrated below:

$$R_{r1} = 3.984\,(R_{av} - 40.64)^{0.5} \quad (9)$$

where:

R_{r1} = recharge from rainfall as, *cm*, and

R_{av} = average annual rainfall, *cm*.

Than the volume of recharge measured as (m^3):

$$R_r = R_{r1} * A_t * C \quad (10)$$

where:

R_r = volume of rainfall recharge,(m^3).

2- Recharge from irrigation area

Recharge from irrigated area depends on the irrigation efficiency, which is estimated amount from, **Ground Estimaation Committee, 1984**.

3- Recharge from base flow

Recharge from base flow as rivers, lakes or any resources of surface water. Many methods are used to estimate the percolation from rivers as annual average to ground water which flows with gradient from both sides of rivers, and from cross-sectional area such as in the application of Darcy law. Also, the direct measurement methodology is used to estimate the base flow by using the available information for hydraulic conductivity of river beds soil when it is estimated by using Falling Head parameter method in the laboratory, the curve tangent method, the chemical, isotope and the basin area method, all these methods are used to determine the recharge from base flow of rivers, **Delleur, 1998**.

4- Recharge from seepage flow of drains

The amount of seepage from open drains is affected by the dimensions of wetted perimeter, and length of drains. Many researchers assumed a percentage of runoff as a recharge to ground water and this percentage equals 40% rainfall from total run off goes to drains, **Sarma, et al., 1983**, and 8% of total run off goes directly to drains, **Chandra, and Saxena, 1975**.

- Discharge from ground water

The discharge from ground water can be defined as the quantity of water draft from ground water, which includes the discharge from wells, evapotranspiration from ground water, and discharge out way to another aquifer. The total discharge for this method is as below:

$$GD = GDW + GDE \quad (11)$$

where:

GD = ground water discharge, m^3,

GDW = ground water discharge from wells, m^3, and

GDE = ground water evapotranspiration discharge, m^3.

1. Discharge from draft well

The discharge production from the wells depends on the number of draft wells that draws water from the aquifer, and the time of wells operation during the year. The other important factor that effects on the well yield is depth of these wells.

2. Discharge due to evapotranspiration

When the aquifer is unconfined, and the water table is close to ground surfaces the water table level may be changed due to the evaporation and transpiration. The two processes play a role as discharge from ground water due to temperature atmosphere, and this phenomenon can occur in the region that has a high temperature, **Todd, 2005**.

Evaporation from ground water is influenced also by soil structure and texture which control the capillary tension above the water table. Field measurements to determine the evaporation can be done by using Lysimeters. The evaporation is largely controlled by atmospheric condition and the evaporation value rate decrease with water table depth. Transpiration from ground water can be estimated when water table approaches to ground surface and the region cultivated with vegetation, and when crops roots depths reach the saturated stratum, **Todd, 2005**.

- Ground-reservoir storage

The storage of ground water is the volume of water existing in the effective voids of geological layers in unconfined aquifer, and the storage in confined aquifer is the volume of water stored in pores under the artesian layers. In the type of two aquifers, the storage of ground water differs from aquifer to another due to quantity and percentage of their volumes. There are two types of storage one called Renewed Storage and the other is Fixed Storage. Renewed storage has a dynamic objective and a function of time, and affected by natural and boundaries of layers. Fixed storage has volumetric satirical quantity and a function of properties of geological layers dimensions (pressure and pores), **Al-Jawid, 1999**.

To avoid the overdraft which is defined as a condition of ground water basin which is the amount of water drawn by pumping that exceeds the amount of water that is recharged to the basin during a period of years. So that was important condition on using conjunctive use management as located in California State – USA, the storage ground water to prevent the overdraft case that might be happen, and to be at safe side, **California water plane, 2009**.

2. STUDY AREA PROPERTIES

This research have been carried out in Al-Wand Basin and the following paragraph describes the properties of this study area which includes, the geography, climates, investigation of soil, and the geology.

2.1 Geography

The Iraqi part of Al-Wand River Basin is located in the eastern part of Iraq, in Diyala Governorate. It is located in middle of Iraq with border crossings with Iran (Monthiriah and Mandali). It lies near the Iranian border and north–west of town Khanaqin. Specifically, the project study is located between (34° 18'), (34° 30') north latitude, and (45° 12'), (45° 24') east longitude **Fig. 1**.

Al-Wand River passes through the study area, and it is one of the most important rivers shared between Iraq and Iran. It is also one of the most important tributaries of Diyala River in the southern part. It flows from the mountains of Iran and joins with the Diyala River in Iraq. The length of river from its source to its mouth in Jalula is about (152*km*) of which (63*km*) is inside the Iraq land. The area of basin which is feeding Al- Wand river is about (3340 km^2), in Iran the basin area is about (2780km^2), and about (560km^2) inside Iraq.

2.2 Climates

The main climatic features of the region of the project is long and hot summer (from May to October), and the precipitations of annual average is of 282mm, falling only during the winter (from December to February). The climatic features of the Al-Wand region irrigation project are assessed on the basis of the climatic data recorded in Khanaqin Meteorological Station, which is located quite near to the irrigated area on (34° 18') latitude and (45° 26') longitude. The parameters of climate can be illustrated as annual average for 20 years. The annual rainfall average during this period is (282.16*mm*) only, and the humidity is equal to (48.52%) as an average for the period (1981-2000), and the averages of temperature in winter is (12C°), and (33C°) in summer and during the same interval. The average wind speed is (2.18 *m/s*), and the annual average of evaporation for interval (1988-2008) is (260*mm*), **National Center of Water Resource, 2014**.

2.3 Soils

According to the soil survey which was conducted in 1978 by an Iraqi team of experts from (State Organization of Soils and Land Reclamation) the soils in the project area are divided in three groups of soil depending on their permeability properties, **Alamdar, et al., 1978**.

a) First group – one layer soil.
b) Second group – two – layers soil with permeability decreasing in depth.
c) Third group – two – layers soil with permeability increasing in depth.

The main properties of these soils are:

- Alluvial soil, suitable for irrigation and cultivation with good depth.
- Texture is fine – moderate (permeability with average (0.5 *m/d*)).
- Gravel deposits in the depths of 200 cm in some areas.
- No salinity and gypsum problems.
- Infiltration rate ranging between (3.7 - 6) *cm/hr*.
- Low percentage of organic matter ranging between (0.2 - 2%).
- Soil pH ranging between (7.1 – 8.4).
- Land capability (USDA System): class II and class III are the dominate in the area which means that the area classified as productive land.

2.4 Geology

Al-Wand River valley basin is created due to the erosion, it consists of deposits of Quaternary Age almiosin which is a type of (almarl) and sandstones, most of the rock layers tend towards the North and North-East of angle (10 - 20) degree. Most of these rocks are covered by alluvial deposits. The most tracts Al -Wand river basin is an alluvial deposits, ranging from depths of (1.5 – 10*m*) which resulted from the historical phases of the age of the river and the transmission of these materials through runoff and floods on the river. Gypsum is found in almarl stones and sandy stones at ground bases in the form of small isolated pools and tests have shown that these stones were not self-executing and zaoian for gypsum or access filter. Due to the investigation of ground water from the wells which are excavated in area, the aquifer is unconfined aquifer.

3. RESULTS AND DISCUSSION

The properties of study area of Al-Wand River Basin were clarified as the input data which have been applied and which is available at many information offices. These data were applied in the recharge equation and the estimation of ground water storage. The results of recharge for three methods are illustrated below:

3.1 Water Table Fluctuation Method

Three observation wells are disturbed in study area to record the variation of water table of ground water due to draft and recharge process, the geographical locations with details for Binmel well, Mekhis well and Ahmed Taher well listed in **Table. 1**. The monthly variation of water levels during the period (2010-2013) for these wells are listed in, **Table. 2**, **Table. 3** and **Table. 4**. The monthly average for each observation well was shown in **Fig. 2, 3 and 4**. From these figures the maximum level due to recharge and minimum level due to drawls from well were noticed, which is increasing to cover the agricultural needed. The difference between April and October for Binmel well, Mekhis and Ahmed Taher are (0.81, -0.876 and 0.105 *m*) respectively, **General Commission of Ground Water, 2014,** which make the average difference of water table (fluctuation Δh_{av}) was used in **Eq.1**

The data for specific yield in study area are not available due to the data form pumping test were not practiced when excavated the production wells. So, the specific yield was assumed by depending on the last studies for the same basins as equal to (0.05). **Table. 5** presents the values of recharge to ground water and the amount of ground storage (ΔS_{ava}) for each well, and by knowing the total area of the project which is about 10181*ha*, the recharge to the ground water 28.85*mm* and the grand average of ground storage is about 3039028.5m^3.

3.2 Recharge from Water Balance of Climate for Basin Method

- Rainfall is the important input data to estimate the recharge of Al-Wand River Basin. **Table. 6** showed value of rainfall with average during (1988-2008). The annual rainfall average during this period is 282.16 *mm*.
- **Table. 7** shows monthly the evapotranspiration with other parameters of this method, **National Center of Water Resource, 2014**.
- The value of soil moisture content can be measured by many methods such as experimental measurements by calculating the saturation percentage of soil, field measurements by using the Lysimeters in study area and based on the last studies for same soil properties especially for the same Iraqi soil in (Adhime, Diayla and Lower Zap) basins as estimation for the saturation quantity, **Al-Furat Center for Designs of Irrigation project, 2000**. Because there is no available data for soil moisture content and there is no accuracy data for soil depth layers in soil properties report of this basin, it is assume that there is no

possibility that the soil moisture content will recharge to ground water. **Table. 7** shows the monthly water surplus, and annual water surplus is 31.45*mm*. Annual surface Runoff calculated using **Eq. 6** is 17.16*mm* so the annual recharge of ground water (Gr) is 14.29 *mm*. By applying **Eq. 7** the change of ground storage is + 14.29 *mm* and volume of ground storage is 1454864.9 m^3.

3.3 Water Balance for Basin Method

The recharging of ground water by using this method can be obtained by calculating each parameter used in **Eq. 8** of recharge and it can estimate the discharge of ground water to evaluate the ground storage of Al-Wand Basin.

- Recharge from rainfall is calculated by applying **Eq. 8** as an annual average recharge of ground water. (R_{r1}) is 61.91 mm depth, and for annual average volume recharge of ground water (R_r) is 6303195.56 m^3.
- The recharge from irrigation depends on the irrigation efficiency and conveyance efficiency and which were unknown in the project, in addition to that the depth of water table is deep from ground surface which make the recharge from irrigation fields neglected.
- The recharge from base flow which depends on the type of source of surface water as Al-Wand River which suffers from shortage of water and sometime has no flow during some months making this value negligible.
- The recharge from seepage of open drains depends on the network of drains and its dimension to estimate the recharge from it. But this network of drainage system was complete as a design and implement in Blajo-Al-Wand Project, so the recharge from seepage drains is also neglected.
- The discharge from ground water has been showed as a discharge from well, which is used for agricultural purposes, all details of these are well listed in **Table. 8**. The other source of discharge from ground water is the evapotranspiration, which depends on depth of reservoir from ground surface, if this depth is shallow the reservoir will be affected by the temperature atmospheric condition Blajo -Al-Wand Project which have ground water reservoir very deep .So, the effect of this parameter on the discharge phenomena can be neglected. If the operation of production wells was assumed by (12*hr/day*) in year, and as the average discharge for each well is (0.003m^3/s), the estimated discharge well (GDW) is 1418342.4 m^3.

The ground storage for Al-Wand basin was calculated using **Eq. 11** is 4884853.16 m^3. **Table. 9** shows the results of the three methods to estimate the recharge and ground storage of Al-Wand Basin.

4. CONCLUSIONS

Table. 9 represent the results of final calculation of recharging and the effects on ground water storage. The results showed difference between the three methods. To select the best method which is used to estimate recharging and ground storage by comparing with volume of water which drawls from production wells (it is explained by water balance for basin method as a volume 1418342.4m^3). The Percentage value between drawls volume and WTF method is 47%, percentage between drawls volume and water balance of climate for basin method is 97%, and last percentage between drawls volume and water balance for basin method is 29%. So, water balance of climate basin is better than method due to nearest with water drawls from production wells. Also, depending on assumptions in the methods make the estimated recharging not accuracy. WTF method less used the assumption than the other methods, which used many assumptions due to data of study area are not available.

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NOMENCLATURE

At	= total area, *ha*.
C	= conversation unit, dimensionless.
Et	= potential evapotranspiration, *mm*.
GD	= discharge of ground water, m^3.
GDE	= discharge from ground water, m^3.
GDW	= discharge of ground water, m^3.
GR	= recharge of ground water B, m^3.
G_r	= recharge of ground water, *mm*.
P	= average of rainfall, *mm*.
R	= recharge of ground water for (WTF), *mm*.
$R_{av.}$	= annual average rainfall, *mm*.
RBF	= recharge from base flow, m^3.
RC	= recharge from irrigation fields, m^3.
R_r	= recharge from rainfall, m^3.
R_{r1}	= recharge from rainfall, *mm*.
RSF	= recharge from seepage flow of drains, m^3.
SM	= soil moisture content, *mm*.
SR	= surface runoff, *mm*.
Sy	= specific yield.
WS	= water surplus, *mm*.
$\Delta h_{ava.}$	= average of water Fluctuation (WTF). *m*.
ΔS	= change of ground storage, m^3.
Δt	= period of recharge estimation, year.

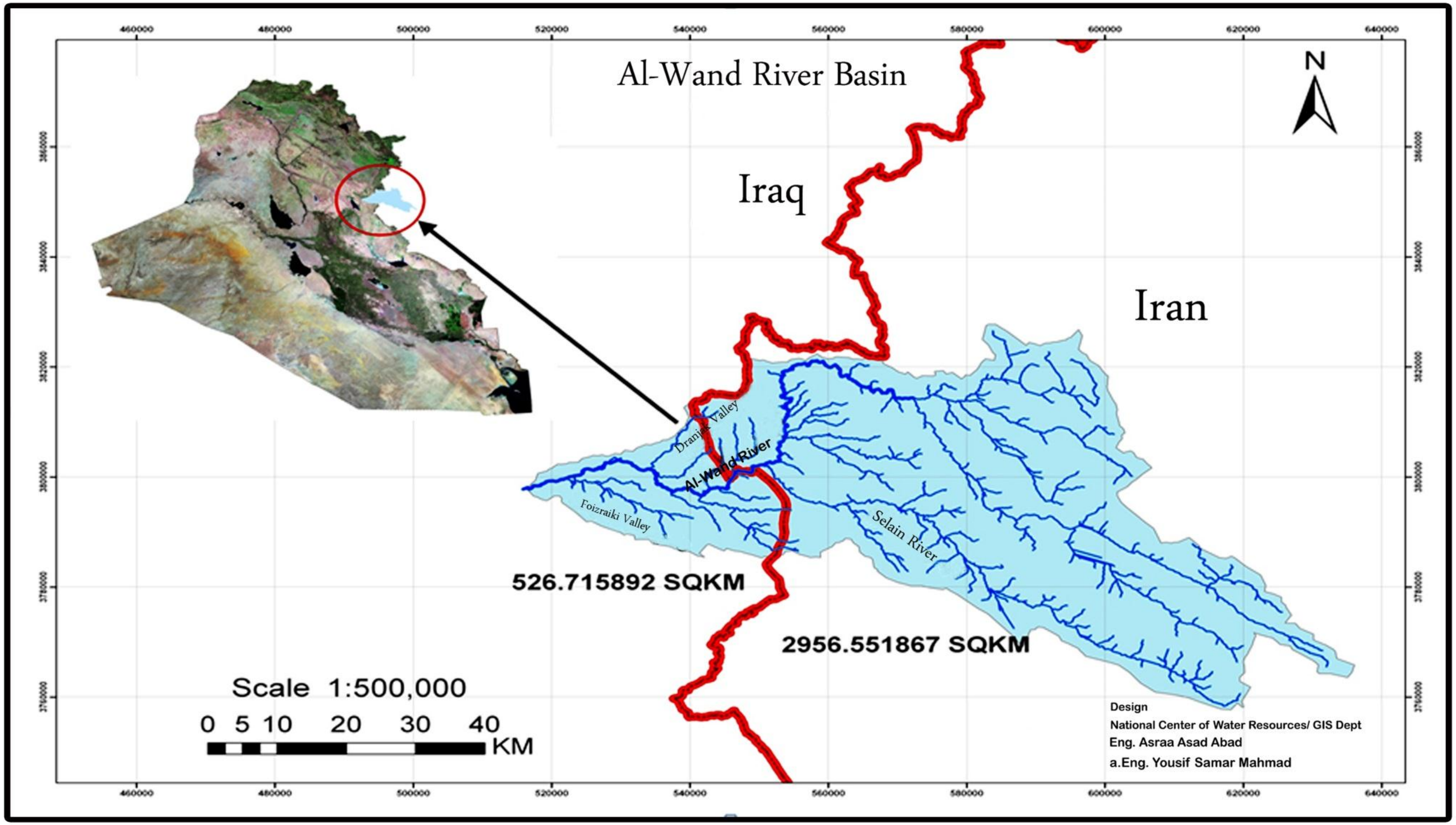

Figure 1. The geographic and basin of Al-Wand River, **National Center of Water Resource**.

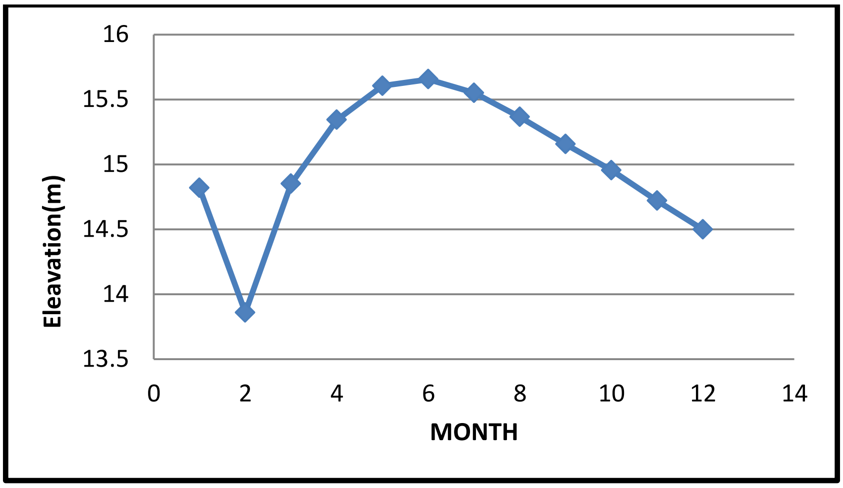

Figure 2. Average fluctuation of Binmel observation well.

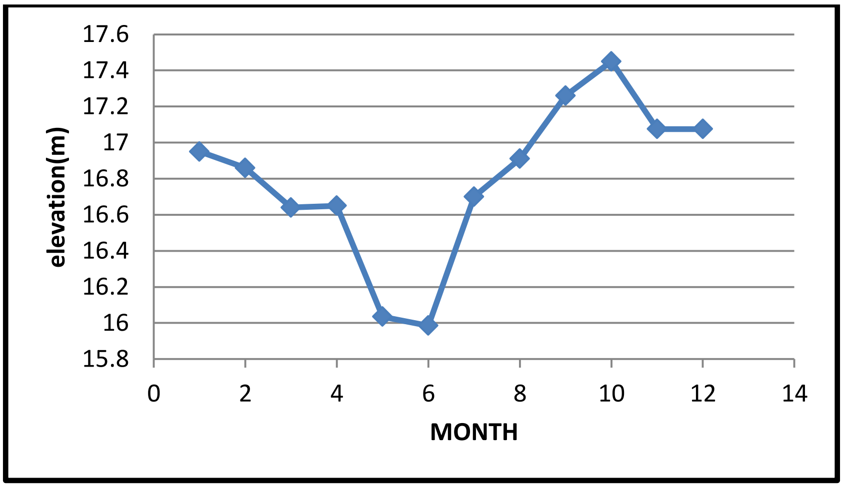

Figure 3. Average fluctuation of Mekhis observation well.

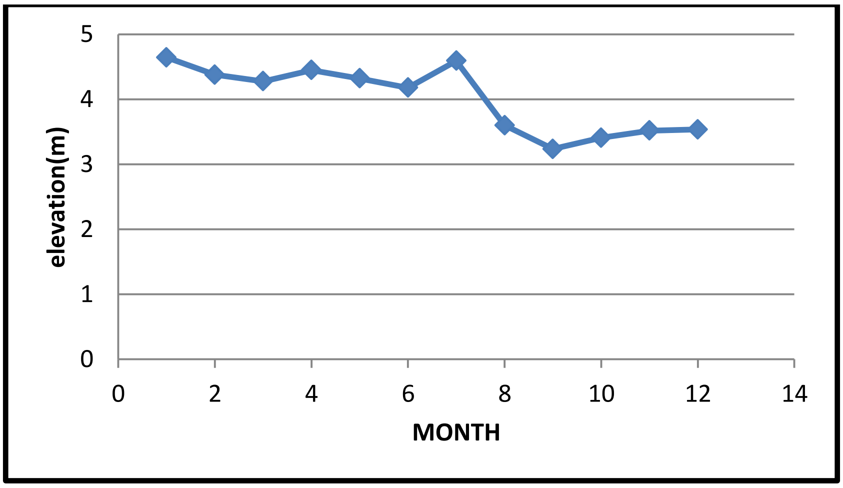

Figure 4. Average fluctuation of Ahmed Taher observation well.

Table 1. Observation wells details for Al-Wand River Basin.

No	well	Longitude	Latitude	Bed level *(m).* a.m. s.l	Depth (*m*)
1.	Binmel	45º 24' 19''	34º 18' 88''	190	60
2.	Mekhis	45º 21' 79''	34º 23' 23''	179	60
3.	Ahmed Tahar	45º 19' 13.1''	34º 19' 9.2''	171	60

Table 2. The elevations water of Binmel well (*m*), **General Commission of Ground Water, 2014**.

Month	1	2	3	4	5	6	7	8	9	10	11	12
2010	15	15	14.5	15	15.2	15.5	15.7	15.8	15.45	15.15	14.27	13.94
2011	14.5	13.07	14.07	14.57	14.97	15.03	15.04	15.06	14.63	14.33	13.91	13.01
2012	14.07	13	15.85	16	16.28	16.2	16.46	16.34	16.34	16.12	16.4	16.65
2013	15.7	14.37	14.98	15.8	15.97	15.89	15	14.26	14.2	14.22	14.3	14.4
average	14.817	13.86	14.85	15.342	15.605	15.655	15.55	15.365	15.155	14.955	14.72	14.5

Table 3. The elevations water of Mekhis well (*m*), **General Commission of Ground Water, 2014**.

Month	1	2	3	4	5	6	7	8	9	10	11	12
2010	17	17	16.5	16.5	16.25	16.15	16.2	16.3	16.7	17	17.08	17.06
2011	16.9	16.72	16.78	16.8	15.82	15.82	17.2	17.52	17.82	17.9	17.07	17.09
2012	-	-	-	-	-	-	-	-	-	-	-	-
2013	-	-	-	-	-	-	-	-	-	-	-	-
average	16.95	16.86	16.64	16.65	16.035	15.985	16.7	16.91	17.26	17.45	17.075	17.075

Table 4. The elevations water of Ahmed Taher well (*m*), **General Commission of Ground Water, 2014**.

Month	1	2	3	4	5	6	7	8	9	10	11	12
2010	4.5	4.5	4	4.4	4.35	4.3	4.38	3.75	3.7	4.26	4.31	4.32
2011	4.82	5.24	5.48	5.8	5.56	5.56	4.93	4.12	4.26	4.3	4.59	4.62
2012	4.65	4.18	4.28	4.36	4.25	3.87	5.8	4.1	2.95	2.94	2.93	2.95
2013	4.6	3.58	3.34	3.23	3.12	2.98	3.25	2.42	2.03	2.13	2.24	2.25
average	4.642	4.375	4.275	4.447	4.32	4.177	4.59	3.597	3.235	3.407	3.517	3.535

Table 5. The recharge and ground storage are for observation wells for (WTF) method.

No	well	Recharge(*mm*)	$\Delta S(m^3)$
1.	Binmel	40.5	4123305
2.	Mekhis	43.8	4459278
3.	Ahmed Tahar	5.25	534502.5

Table 6. Mean monthly rainfall (*mm*) for period (1988-2008), **National Center of Water Resource**.

Years	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep	Oct.	Nov.	Dec.
1988.00	68.00	62.30	51.80	39.90	0.00	0.00	0.00	0.00	0.00	9.90	6.70	57.20
1989.00	13.90	63.20	16.40	0.00	0.10	0.00	0.00	0.00	0.00	0.00	49.60	31.40
1990.00	33.70	109.10	90.30	26.30	0.00	0.00	0.00	0.00	0.00	0.40	12.50	15.10
1991.00	43.30	95.50	65.50	8.60	8.00	0.00	0.00	0.00	0.00	10.40	12.20	117.30
1992.00	62.20	69.20	11.20	81.60	81.60	0.00	0.00	0.00	0.00	0.00	18.00	55.90
1993.00	71.10	46.70	47.50	22.20	5.30	0.00	0.00	0.00	0.00	31.90	54.20	42.40
1994.00	71.30	13.80	64.40	78.20	78.20	0.80	0.00	0.00	0.00	52.00	132.30	50.80
1995.00	6.40	67.00	86.90	31.80	31.80	0.20	0.00	0.00	0.00	0.00	24.20	32.30
1996.00	103.80	11.90	94.70	34.80	4.90	0.00	0.00	0.00	0.00	1.90	0.50	38.80
1997.00	60.50	16.10	102.70	8.60	0.00	0.00	0.00	0.00	0.00	14.00	112.10	70.70
1998.00	118.30	10.50	0.50	5.50	0.00	0.00	0.00	0.00	0.00	0.00	28.80	0.00
1999.00	90.50	43.70	29.00	3.20	0.00	0.00	0.00	0.00	0.00	11.00	0.00	19.50
2000.00	38.70	2.70	59.70	7.70	1.70	0.00	0.00	0.00	0.00	1.40	59.30	154.40
2001.00	31.90	44.20	55.30	61.50	0.00	0.00	0.00	0.00	0.00	1.20	18.60	58.10
2002.00	105.80	41.60	24.60	24.60	0.00	0.00	0.00	0.00	0.00	7.60	39.50	55.30
2004.00	89.90	21.00	4.40	9.00	20.10	0.00	0.00	0.00	0.00	0.00	59.10	65.60
2005.00	57.40	34.00	0.80	19.90	0.80	0.00	0.00	0.00	0.00	0.80	73.70	21.70
2006.00	57.40	65.40	8.00	35.80	0.00	0.00	0.00	0.00	0.00	0.00	7.40	16.80
2007.00	89.40	57.30	10.80	59.10	4.00	0.00	0.00	0.00	0.00	16.90	17.70	4.00
2008.00	52.00	16.80	8.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.60
Average	62.45	44.60	41.64	27.92	11.83	0.00	0.00	0.00	0.00	11.33	36.39	46.00

Table 7. The monthly water surplus for Water Balance of Climate to Basin method.

No	Average rainfall(*mm*)	ET(*mm*)	WS
Jan.	62.45	38	24.45
Feb.	44.6	52	0
Mar.	41.64	89	0
Apr.	27.92	135	0
May	11.83	199	0
Jun.	0	237	0
Jul.	0	254	0
Aug.	0	236	0
Sep	0	178	0
Oct.	11.33	135	0
Nov.	36.39	69	0
Dec.	46	39	7

Table 8. The details of the productivity wells that situated in Al-Wand Basin, **General Commission of Ground Water, 2014**.

No	X	Y	Well depth (*m*)	Dynamic water depth* (*m*)	Static water depth* (*m*)	Discharge (*L/S*)
1.	45 23 18.6	34 18 15.8	54	22.5	25	3
2.	45 23 33.5	34 18 22.0	52	24	25.6	2
3.	45 21 08.1	34 21 04.2	42	18.29	21	5
4.	45 21 32.9	34 20 39.0	65	20.6	28.46	6
5.	45 21 31.2	34 20 24.1	60	19.32	23.67	2
6.	45 21 31.3	34 20 28.0	54	14	18.2	2
7.	45 15 25.0	34 23 15.9	17	5.5	7.5	2
8.	45 13 05.2	34 21 59.7	50	5	7.2	9
9.	45 21 16.7	34 23 52.9	9	4.15	5.5	3
10.	45 20 51.4	34 24 00.0	14	7	8.75	4
11.	45 21 05.2	34 24 00.2	12	3	4.5	2
12.	45 21 14.4	34 23 50.5	14	3.7	5.3	3
13.	45 21 06.3	34 23 40.7	12	3.65	5.4	3
14.	45 23 34.1	34 22 51.4	9	3.24	5	3
15.	45 23 34.4	34 22 47.7	72	4.5	25.25	5
16.	45 23 27.7	34 22 45.0	52	4.75	9	3
17.	45 23 31.6	34 22 53.7	54	5.5	13	3
18.	45 22 27.4	34 21 43.2	8	6.59	7.5	2
19.	45 23 07.6	34 22 34.5	45	20	35	3
20.	45 23 36.3	34 22 33.4	42	13.12	17.2	3

Table 8. continued

21.	45 23 20.2	34 22 40.5	52	15	45	2
22.	45 23 10.8	34 22 41.7	44	16	40	1
23.	45 22 38.9	34 21 49.1	30	9.65	12.5	4
24.	45 22 37.8	34 21 47.3	13	9.15	10.35	3
25.	45 22 00.3	34 21 29.4	12	7.3	9.2	3
26.	45 22 02.2	34 21 27.6	12	7.33	9.35	3
27.	45 22 05.9	34 21 29.8	12	7.71	9.75	3
28.	45 22 04.3	34 21 30.8	12	7.36	9.13	3
29.	45 22 08.1	34 21 30.6	16	7.37	9.47	3
30.	45 22 14.8	34 21 36.6	13	7.5	9.5	3
31.	45 22 16.8	34 21 39.3	30	7.3	8.95	4
32.	45 22 06.1	34 21 34.7	13	7.51	8.9	3
33.	45 22 04.5	34 21 36.0	12	7.25	8.85	3
34.	45 22 02.3	34 21 33.3	12	7.17	8.44	3
35.	45 20 59.9	34 21 40.0	12	6.5	9	3
36.	45 20 56.4	34 21 44.4	8	6.1	7.35	3
37.	45 20 53.1	34 21 45.7	7	7	8.9	3
38.	45 20 57.8	34 21 43.0	14	6.15	7.9	4

* The datum from ground surface.

Table 9. The recharge and ground storage for suggested methods.

No	Method	Recharge(mm)	$\Delta S(m^3)$
1.	Water Table Fluctuation	28.85	3039028.5
2.	Water Balance of Climates	14.29	1454864.9
3.	Water Balance of basin	61.91	4884853.16