Using groundwater levels and Specific Yield to Estimate the Recharge, South of Erbil, Kurdistan Region, Iraq

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ABSTRACT

Recharge estimation accurately is crucial to proper groundwater resource management, for the groundwater is dynamic and replenished natural resource. Usually recharge estimation depends on the; the water balance, water levels, and precipitation. This paper is studying the south-middle part of Erbil basin, with the majority of Quaternary sediments, the unconfined aquifer system is dominant, and the unsaturated zone is ranging from 15 to 50 meters, which groundwater levels response is moderate. The purpose of this study is quantification the natural recharge from precipitation. The water table fluctuation method is applied; using groundwater levels data of selected monitoring wells, neighboring meteorological station of the wells, and the specific yield of the aquifers. This method is widely used for its simplicity, scientific, realistic, and direct measurement. The accuracy depends on the how much the determination of specific yield is accurate, accuracy of the data, and the extrapolations of recession of groundwater levels curves of no rain periods. The normal annual precipitation there is 420 mm, the average recharge is 89 mm, and the average specific yield is around 0.03. The data of one water year of 2009 and 2010 has taken for some technical and accuracy reasons.

KEYWORDS : Recharge, Groundwater, Precipitation, Water table, Specific yield.

1. INTRODUCTION

Climate change and more human activities, especially; extra groundwater pumping, expanding urbanisation lands, and the change in land use during the last few decades caused the climate elements to show clear and dramatic changes. The rainfall pattern including both time and intensities of precipitations, also the degrees and ranges of temperature in most of the seasons has changed Naqishbandi (2008). High number of formal and informal wells has been drilled in the area; most are pumping for agricultural activities; they are pumping enormous volumes of the groundwater in the area. High number of new houses, roads, and infrastructure constructions have built in the area, that has minimized the infiltration ratios and increased both surface runoff and also increase evapotranspiration. Large areas have been converted from agricultural and arable land to urbanized areas. In result the water balance in the area has negatively deformed and all these factors together are decreasing the amount of the recharged water to the groundwater and increasing the discharge amount from groundwater, especially during the summer and autumn seasons, when the recharge from precipitation is very limited, but discharge rates relatively are high for the mentioned activities, which they also affecting the groundwater levels depletion. Recharge definition that comes with this research paper is the downward flow of water to reach the saturated zone, adding to groundwater storage. (Healy, 2018). Estimation of groundwater recharge in an accurate way has the key role in the proper groundwater resources management, also it is imperative in any estimation of groundwater flow or pollution transport. Recharge can be defined, as the downward flow of water reaching the saturation zone and the water table, adding to groundwater storage (Healy and Scanlon, 2010). The dynamic of groundwater recharge and discharge is highly dependent on many factors, they are; climate, land cover, land use, sedimentology, and the thickness of the unsaturation zone (vadose zone) (Healy & Scanlon, 2010; Aish & de Smedt, 2005; Dandekar, Singh, Sarangi, & Singh, 2018; Hashemi, Berndtsson, Kompani-Zare, & Persson, 2013; Healy & Cook, 2002; Li, Li, Liu, Ma, &

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Wu, 2014; Varni, Comas, Weinzettel, & Dietrich, 2013). The precipitation hyetographs and the water tables are plotted on the same base time to discover the effect of infiltrated water of the rainstorms on the recharge of the aquifers of the area. Determination of specific yield and evaluation of water levels fluctuation per time acurately is extremely difficult, this make the results to be not completely acurate (Healy and Cook, 2002), which it requires using more than one method to estimate the recharge. Quaternary deposits are formin the most study area and its aquifers (Fig. 2). The deposits are of different source, type, and structures of unconsolidated clastic sediments (Buday, 1980; GEOSURV, 1997; Adnan Aqrawi, et al., 2006). The unsaturated zone roughly is ranging between 10 to 50 meters. The present research is depending of the water levels, using water table fluctuation method (WTFM) according to the lag time of precipitation water to reach the saturation storage and rise the water level in the area. This method is widely used for estimation of groundwater recharge from precipitation, especially in unconfined aquifers and shallow unsaturated (Vadose) zone, to show the relativly fast response of water levels. The specific yeald is another vital factor to control the recharge and discharge process, it depends on the structure and the texture of the sediments of the aquifer.

2. MATERIAL AND METHODS

STUDY AREA

The study area is located in the south Erbil city. It is between longitude (43^o 52′ 09″ to 44^o 06′ 50″) East, and latitude (35^o 58′ 27″ to 36^o 08′ 30) North including three sub-districts of; Daratu, Qushtapa, and Shamamik (Fig. 1. The study area is about (402.35) km^2. The highest and the lowest elevations in the studied area are 277m and 524m respectively). The shape of the area is rectangular, formed of Quaternary deposits of different origins, sources, and structures (Fig. 2). The center of the area is (43^o 59′ 28″ E and 36^o 03′ 28″N).

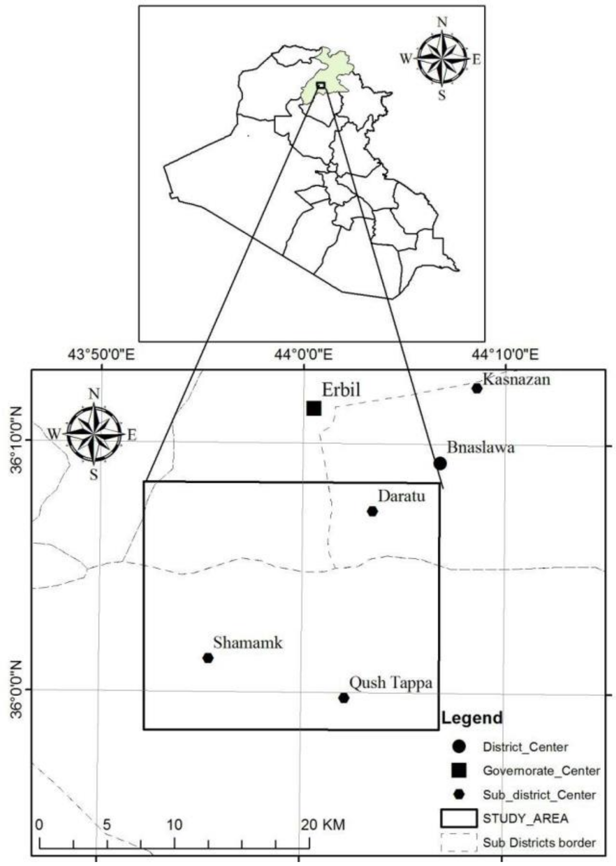

Fig (1) : The study area

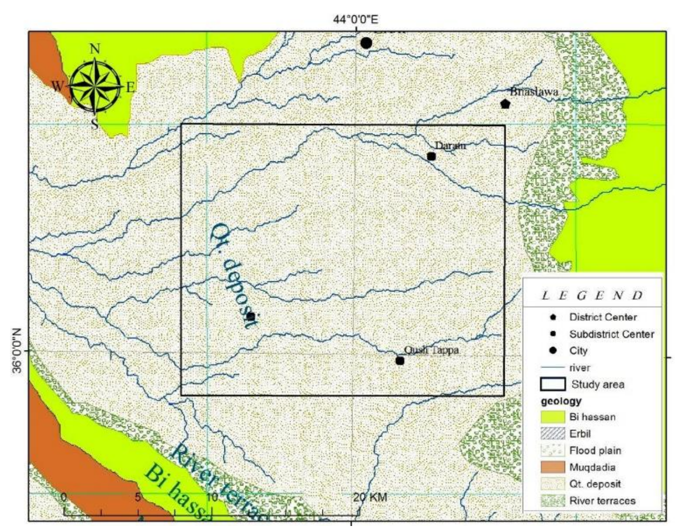

Fig (2) : Geology of the study area

WATER TABLE AND PRECIPITATION DATA

Precipitation data are of 5 meteorological stations, which 2 are located in the study area (Shamamik and Qushtapa), the other three (Erbil 1, Erbil 2, and Binaslawa) are close to the study area in north and northeast. These meteorological stations are monitoring by the ministry of Agriculture and water resources, and the ministry of communication of Kurdistan regional government (KRG). The water level data and their long pumping tests of 9 monitoring wells are used inside the

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study area (Fig. 3). These wells are belonging to the Directorate of Groundwater in Erbil. The monitoring wells are not used for agricultural or commercial uses, but they have limited discharge for supply for drinking and other home needs of the habitants.

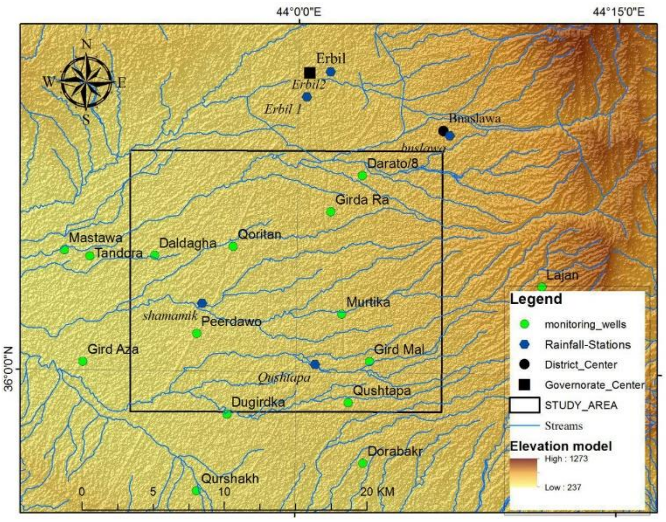

Fig (3) : Monitoring wells, and meteorological stations in the study area

THEORIES BEHIND THE MODEL

The regional water balance equation, which is the law of mass conservation to a drainage area or any area (Serano, 1997), is considered as the base for groundwater budget to this method (Varni et al., 2013). WTFM is estimation of groundwater budget, recharge from precipitation and discharge when the water table is intersecting the ground surface (Xu and Beekman, 2003).

$$P + G_i + Q - ET - G_o = \Delta S \text{ ………. (1)}$$

Where P is precipitaion, G_i is regional groundwater inflow, Q is streamflow, ET is evapotranspiraion, G_o is regional groundwater outflow, and ΔS is change in the sorage of water. The direct recharge R is that volume of water reaching the water table from the surface (Wendland, 2015). The base of WTFM is the measurements of water levels in monitoring wells for a arranged time period (Healy and Cook 2002, Scanlon et al. 2002). Simply the recharge amount can be calculated as follows :

$$R = S_y \, {}^{\Delta h}/_{\Delta t} \text{ ………. (2)}$$

Where R is recharge, S_y is specific yield, Δh is change in water table, and Δt is change in time. The Method of WTFM is depending on thy hypothesis that water table is rising when the unconfined aquifer is receiving more water by recharging (Fig. 4), the antecedent recession curve is the trace that the well hydrograph would have followed in the case of absence of the recharging precipitation. Because WTFM is applying to unconfined aquifers, and when the time of aquifer storage recharging from precipitation and the water level response is in short period of time (few hours to few days) then we can neglect all the other componets of the water budget (equation 1). But if the time lag is long the redistribution of water is taking more time, then all the components of (equation 1) are considred, and this method will not be accurate. The well hydrographs are superimposed to the groundwater levels against same base-time (Fig. 5). When groundwater table is rising in any rainstorm we can apply the equation (1) to estimate recharge, but, we can also estime use this method for seasonal or longer time to estimate groundwater storage changes as a total recharge. In order to calculate the total recharge for a certain month, a season, or longer time, we should make a table including **Δh** which it represents the difference between the highest water lavel after precipitation and the acurate extrapolated antacedent recession curve of the same time of the highest point (Dingman, 2002).

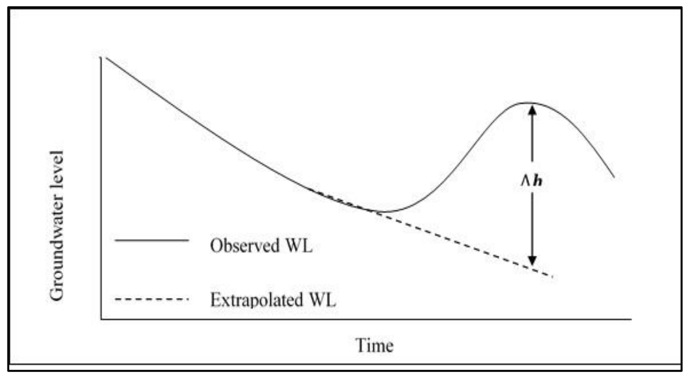

Fig (4) : The water-level rise in response to rainfall - recharge, and the dashed line is extrapolated antecedent recession curve at the time if there is no precipitation

The seasonal or annual hydrograph has many peaks of water levels, therefore many recession curves should be extrapolated to estimate Δh, which this tracing the extrapolation can be manually but very carefully. The net recharge is excluded from evapotranspiration from groundwater, the baseflow, and the subrface flow, then when these parameters of lossing groundwater are high, the estimation of recharge becames mor complicated and WTFM becomes less accurate for long periods. The time to reach the infiltrated water of precipitation to the groundwater storage is determining the applicability of WTF model in the area. If the water moving away from the groundwater storage faster than the recharging, then this method is not applicable. The lag time to travel rainfall water to the water table is depending on; the thickness of the unsaturated zone, the vertical unsaturated hydraulic conductivity (Fetter, 1994), the recharge rate, the soil water content, the depth to the water table (Cook et al.,1989), and increases with decreasing vertical air diffusivity of the unsaturated-zone sediments (Healy and Cook, 2002).

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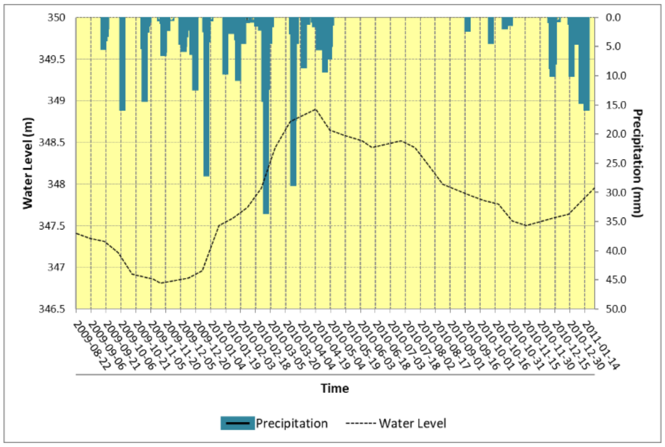

Fig (5) : Groundwater levels and the weekly average rainfall in the study area

THE SPECIFIC YIELD (S_y)

Specific Yield $\mathbf{S_y}$ is the ratio of the volume of water that drains from a saturated zone due to the attraction of gravity to the total volume (Zhu and Ren, 2018) or it is the volume of water that will drain by gravity per unit drop in the water table per unit volume of aquifer (Weight, 2008). For the unconfined aquifers the S_y values range from 0.01 to 0.30, which they are much greater than the values of storativities of confined aquifers (Kruseman & Ridder, 2000). Specific yield value depends on the rock type or the unconsolidated sediments, and the relationship between porosity and specific yield is complicated depending on the effect of certain deposit texture(Johnson and Morris, 1967), cementation and compaction (Brassington, 2007). (Childs, 1969) confirmed the fact that specific yield is not constant but varies as a function of depth to the water table, he described from the perspective of soil physics. Previous studies showed, from different deposit types and textures, using long pumping tests to determine the specific yields of the deposits and aquifers (Meixner, 2008). For this study area, the specific yield values (0.03 to 0.04), the (Clay, Silt, fine Sand), depending on the (Prickett, 1965) and the Specific yield of Geologic Materials (The unconsolidated Alluvial Deposits), after Johnson and Morris (1967) in (Dingman, 2002). The transmissivity and the specific yield can be determined from a single-well tests of the field data from an unconfined aquifer with the same procedure of aquifer test (Meixner, 2008) (Fig. 6). The long pumping well tests continuously have been taken for the monitoring wells in the study area, depth of the pumped boreholes, discharges, boreholes and screens diameters, and the drawdown data are accurately have taken for this purpose.

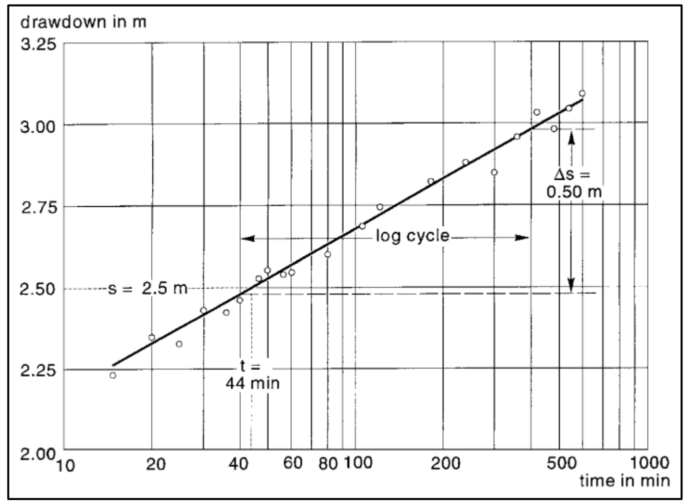

Fig (6) : Time-drawdown plot of field data of a single-well test in an unconfined aquifer (Delleur, 1999)

(Fig. 6) is the plot of time-drawdown of the observed drawdowns in the pumped well on semi-log paper. The data plot shows a straight line over the whole time range. A best fitting trend line was drawn to passes through all the points. One log cycle has taken to determine the slope (Δs), to substitute appropriate values into the equations to determine transmissivity and the specific yield, as follows (Cooper-Jacob, 1946) in (Todd, 2005) :

$$T = \frac{2.30Q}{4\pi\Delta s} \quad \ldots\ldots\ldots (3)$$

$$S_y = \frac{2.25 * Tt_0}{r^2} \quad \ldots\ldots\ldots (4)$$

The intersection of the straight line with the x-axis where s = 0 should be determined to determine $\mathbf{t_o}$. The above procedure has developed from (Jacob and Lohman, 1952) they derived an equation for pumping test under constant discharge and variable drawdown of a well including a straight line approximation solution to determine Transmissivity and Storativity. The equation is as follows:

$$S = 2.25T\left(\frac{t}{r_w^2}\right) \quad \ldots\ldots\ldots (4)$$

Where **S** is Storativity, **T** is Transmissivity, **t** is elapsed time since start of test, $\mathbf{r_w}$ is radius of the well. When $\mathbf{r_w}$ and **T** is known the straight line is extended to intercept the **s/Q** and **S** can be found using the above equation. (Fig. 6).

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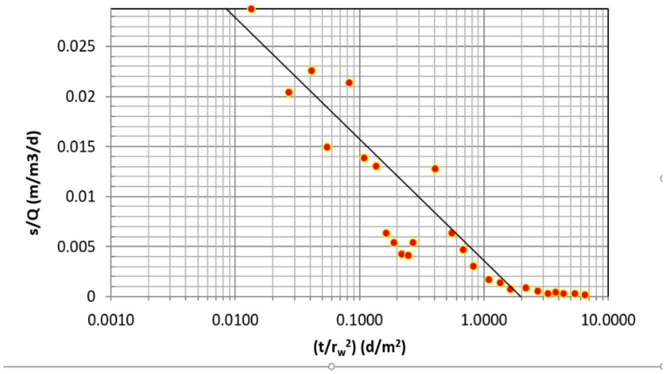

Fig (7) : The (Jacob and Lohman, 1952) Straight line solution for Transmissivity and Storativity. The Q = 414 m^3/d, T = 2 m^2/d, and the Well radius is 0.16m. The resulted Storativity is 0.036

3. RESULTS AND DISCUSSION

The study area is almost of square shape, but, for more accuracy in estimation the recharge from precipitation the observation wells have taken in three groups of observation wells, this because to overcome the errors that may take place with neglecting the underground geology of the area. Average of water levels of each group of wells plotted against the average weekly rainfall amounts of the water year 2009 – 2010 with the same time base of graph paper. Exponentially the previous recession of the hydrograph has extrapolated in order to measure the change in the water tables (Δh) in case if no rainfall recharge occur. (Fig. 5). Specific yields of the sediments forming the aquifers have estimated and calculated taking three ways; first is the previous studies that used empirical and pumping tests, the second and the third methods were using the field pumping test data of the study area to plot on the semi-log papers, the methods were (Delleur, 1999) Time-drawdown plot of field data of a single-well test in an unconfined aquifer, and the (Jacob and Lohman, 1952) Straight line. In each of the above method the specific yields have estimated, the average of specific yield of any area of the grouped wells have conducted. The values of $\mathbf{S_y}$ according to the field pumping test methods were 0.039, 0.035, and 0.045 for Qushatapa, Daratu, and Pirdaud groups respectively. And according to the previous studies the Sy for the study area is estimated to range between 0.03 to 0.04 (Table – 1).

Table (1) : Rainfall and recharge to groundwater amounts in the study area, using WTF models, and S_y

Months	Qushtapa, Gird Mala, and Murtka		Daratou, and Girdarasha		Dugirtkan, Daldaghan and Pirdaud		Average Gw Recharge (mm)
	Change in WL (mm) ?s	GW Recharе (mm) R	Change in WL (mm) ?s	GW Recharе (mm) R	Change in WL (mm) ?s	GW Recharе (mm) R	
Sep. 2009	0	0	0	0	0	0	0
Oct. 2009	243	9	600	21	125	6	12
Nov. 2009	135	5	60	2	125	6	4
Dec. 2009	378	15	1680	59	375	17	30
Jan. 2010	189	7	180	6	325	15	9
Feb. 2010	1243	48	450	16	688	31	32
Mar. 2010	946	37	180	6	363	16	20
Apr. 2010	135	5	150	5	150	7	6
May -2010	54	2	90	3	0	0	2
Jun. 2010	27	1	180	6	0	0	2
Jul. 2010	0	0	0	0	0	0	0
Aug. 2010	0	0	0	0	0	0	0
Total	3351	131	3570	125	2150	97	
Estimated *Sy*		0.039		0.035		0.045	
Total precipitation recharged to Groundwater of The Year (2010) (mm) =							**117**
Total rainfall of the water year 2009 - 2010 **(mm) =**							**371**
Total precipitation recharged to Groundwater of The Year (2010) % =							**32**

The total average total precipitation of the all meteorological stations for the water year of 2009 -2010 (from Septemper – 2009 to August – 2010) was 371 mm. The amount of the precipitated rainfall that is reaching to the saturated zone to add the storage of groundwater has estimate through measuring the change (rising) of water level multiplying by the specific yield. Average monthly and the annual recharge from precipitation, and also the total average recharge from precipitation have estimated. The recharges were 131 mm, 125 mm, and 97 mm, for Qushatapa, Daratu, and Pirdaud groups respectively, these amounts are close to each other, due to similarity in deposits, geology, and aquifer type. Also there is somehow difference in the surface and ground water hydrology, in addition to the travel time of the flowing water in the area, which it gives more chance to water in the downstream to infiltrate into the underground. The total rainfall recharged to groundwater storage in the year was 117 mm, it is 32% of the total rainfall of the year. From the recharged depth of the rainfall and the recharging area we can conclude the volume of the recharging water to the groundwater storage. Roughly it can be calculating for the study area is about 47263 m^3 of water is adding to the storage of the groundwater in the study area (402.35 km^2). The relatively moderate thickness of the unsaturated zone, and the intermediate specific yield of the study area come to an end with the lag time of 2 to 3 weeks of the water levels to response to the rainfall recharging.

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