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Assessment of Hydraulic Performance of Groundwater Recharge Techniques

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Abstract: The limited availability of fresh water and its acute scarcity has led to the greater emphasis on water resources management. Rainfall is the primary source of natural water replenishment. Part of the rainfall flows as surface runoff and part infiltrates to the ground after the initial losses. Changes in the climatic condition have increased the rainfall frequency and intensity even in the Arab gulf region. Recharge is a critical parameter for understanding, modelling and protecting groundwater systems from overexploitation and contamination. Adopting the concept of sustainability and conservation of water resources using artificial recharge techniques can help to cope with the global water shortage. This study discusses the effect of hydraulic and geotechnical parameters on the different groundwater recharge methods with reference to three methods frequently used in KSA (surface spreading, injection wells into Vadose zone and direct injection wells into the aquifer. In each method, recharge capacity is evaluated at different geotechnical parameters. Also, the effect of geotechnical parameters on wetted front and infiltration rate of surface spreading methods are studied. Moreover, the effect of deposition of suspended fines i.e. clogging on the recharge rate is studied.

Key words: Recharge · Injection well · Vadose zone · Permeability

INTRODUCTION

Flow through porous medium was the subject of many investigations in both saturated and unsaturated phases [1, 2, 3]. Al-Wagdany [4] utilized a drainage lysimeter to estimate direct evaporation from surface soil of Namman basin, Western Saudi Arabia. The study results indicated that evaporation rate was high during the first few days immediately after supplying the soil with water. Mean daily evaporation depth from the soil was estimated to be about 0.5 cm/day. AlShaikh *et al.* [5] gave a comprehensive review on artificial recharge techniques, factors to be considered for artificial recharge and shed some light on the Saudi experience. They concluded that artificial recharge techniques can be used to store excess storm water runoff and treated sewage effluent. Al-Wagdany and Kiwan [6] investigated groundwater recharge at various soil depths of Namman basin in Western Saudi Arabia using a one dimensional model for simulating water movement in soil layers. Results indicated that values of infiltration rate were very high in most of the surface soil in the basin and their average was about 98% of rainfall volume.

Asano and Cotruve [7] made a review for groundwater recharge and its management with special reference to health and regulatory aspects of groundwater recharge with reclaimed municipal wastewater. They mentioned that there are some uncertainties with respect to health risk considerations have limited expanding use of reclaimed municipal wastewater for groundwater recharge, especially when a large portion of the groundwater contains reclaimed wastewater. Manghi *et al.* [8] proposed hydrological budget method for regional groundwater recharge. It utilizes matched pairs of groundwater level measurements, groundwater extraction data and distributed specific yield information for estimating groundwater recharge. Patel *et al.* [9] have derived general analytical equations for evaluation of recharging capacity of well with predominant geotechnical parameters like permeability of aquifer soil, depth of water table, depth of pervious strata, porosity and particle size distribution of soil. Patel and Desai [10] and Patel *et al.* [11] have highlighted from numerical equations, analytical approach, computer algorithm and field test that hydraulic conductivity is a prime and predominant geometrical design governing parameter for any recharging technique.

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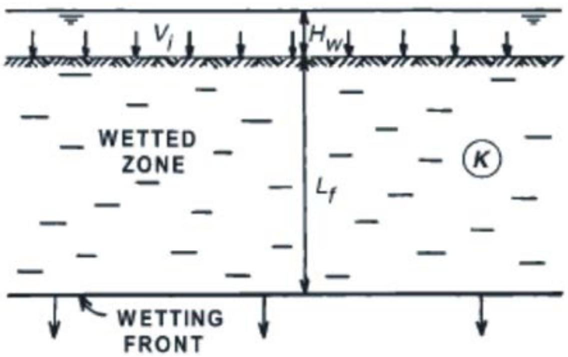

Fig. 1: Schematic diagram for the variables used in Eqn.(1)

According to the aforementioned literature review, there are many subjects concerning ground water recharge need further research. So, in the following investigation, evaluation for the different recharge methods and the parameters which affect on its efficiency are studied.

Theoretical Basis

Surface Basin Infiltration: A common form of the equation used to predict infiltration rates [12] is:

$$V_i = K\frac{H_w + L_f - H_{cr}}{L_f} \quad (1)$$

where V_i = infiltration rate (m/day), K= hydraulic conductivity of the wetted zone (m/day), H_w = depth of water above the soil (m), L_f= depth of wetting front (m) and H_{cr} = critical pressure head of soil for wetting (m of water). Figure (1) shows schematic diagram for the variables used in Eqn. (1).

Calculating the rate of advance of the wetting front dL_f/dt is important to estimate when the wetting front will reach the aquifer and begin to influence mounding. The rate of movement of the wetting front is equal to V_i/f, where f is the fillable porosity (difference between volumetric water content before and after wetting). Eqn. (1) may be rearranged and integrated to solve for *t* as follows:

$$t = \frac{f}{K}\left\{L_f - \left(H_w - H_{cr}\right)\left[\ln\left(\frac{H_w + L_f - H_{cr}}{H_w - H_{cr}}\right)\right]\right\} \quad (2)$$

where *t* is the time since the start of infiltration and other terms are as defined previously.

Vadose Zone Injection Well: Vadose zone injection wells are analogous to recharge pits or recharge shafts that have been used for the recharge of groundwater. The vadose zone injection wells should penetrate permeable

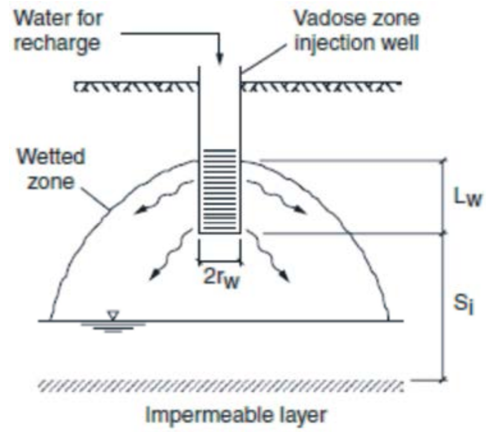

Fig. 2: Schematic of vadose zone injection well wetted zone

layers to enhance infiltration rates. Equation, developed by Zangar [12], can be used to estimate recharge rates as a function of the hydraulic conductivity of vadose zone soils. For a typical vadose-zone well geometry, with groundwater levels significantly below the bottom of the well and a water depth in the well of at least five times well diameter, this equation can be simplified to:

$$Q = \frac{2\pi k {L_w}^2}{\ln\left(2L_w / r_w\right) - 1} \quad (3)$$

where *Q* is the recharge rate, *K* is the hydraulic conductivity of the soil material, L_w is the water depth in the well and r_w is the radius of the well as shown in Figure (2).

Recharge Injection Well: A recharge injection well may be defined as a well which admits water from the surface to underground formation. Its flow is the reverse of a pumping well, but its construction may or may not be the same. If water is passed into a recharge well, a cone of recharge will be formed which is reverse of a cone of depression for a pumping well, Figure (3). Steady state equation for recharge rate *Q* into a completely penetrating well for unconfined aquifer is;

$$Q = \frac{\pi K(h_w^2 - h_o^2)}{\ln(r_o / r_w)} \quad (4)$$

Though the equation is similar to discharge equation but the recharge rate are seldom equal to pumping rates. The water is fed into recharge wells by gravity or may be pumped under pressure to increase recharge rate.

Dong *et al.* [13] show that hydraulic conductivity of artificial aquifer recharge attenuated due to clogging with time power function and the relation is as follows:

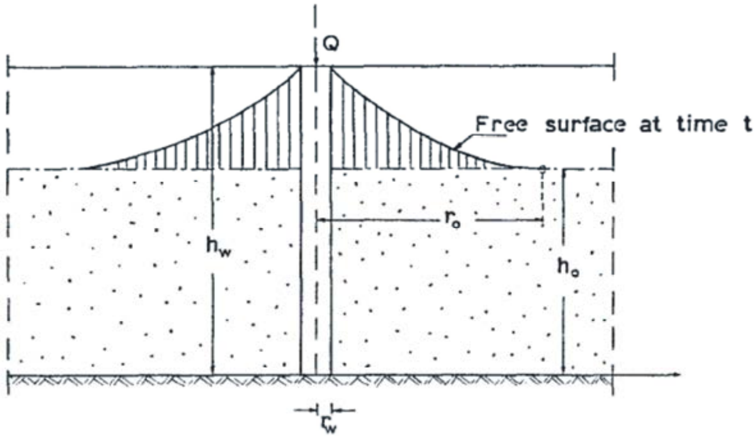

Fig. 3: Schematic sketch of recharge well

$$K = K_o t^{-\lambda} \quad (5)$$

where K_o is the initial value of hydraulic conductivity; ë is the attenuation coefficient and is taken as the average values of Dong *et al.* [13] as 0.135.

RESULTS AND DISCUSSIONS

Figure (4) shows the advance wetting depth with time for water infiltrating from recharge basin at different saturated hydraulic conductivity (Ksat). The advance time is calculated using Eqn. (2) at different values of wetting depth for three types of soils with hydraulic conductivity (K) equals to 0.2, 0.5 and 1.0 m/day i.e. loams, loamy sands and fine sands, respectively. Two cases were studied, the first is one layer soil and the second is two layers soil with different thickness and K . Table (1) shows the variables used in this study. It is shown from this figure that the time required for the wetting front to arrive the original groundwater level increases by decreasing the K and this means that more water will be evaporate before infiltrating into the soil. The time required for recharged water to arrive the saturated zone is varied from less than 2 days at *K=1.0* m/day to more than 12 days at *K=0.2* m/day.

Figure (5) shows the infiltration rate (IR) calculated using Eqn. (1) at different values of K. It is noticeable that the initial IR at the case of one layer soil is high for higher K and decreases with time to arrive nearly a value equal to the K. For two layers soil, IR depends on the thickness of each layer and its hydraulic conductivity.

Figure (6) depicts the variation of recharge rate computed using Eqn. (3) with different screened length of vadose zone recharge well at different values of K and well radius. The screened length of the well is changed three times, 4, 6 and 8 m, respectively.

Table 1: Variables used in recharge basin experiments.

Run No.	Strata layers	L_f (m)	H_{cr} (cm)	H_w (m)	K (m/day)	Porosity (f)
1	One layer	10	-35	1.0	0.2	0.35
2	One layer	10	-25	1.0	0.5	0.35
3	One layer	10	-15	1.0	1.0	0.25
4	Upper layer	2	-35	1.0	0.2	0.35
	Lower layer	8	-25		0.5	0.35
5	Upper layer	2	-35	1.0	0.2	0.35
	Lower layer	8	-15		1.0	0.25
6	Upper layer	2	-25	1.0	0.5	0.35
	Lower layer	8	-15		0.2	0.35
7	Upper layer	2	-15	1.0	1.0	0.25
	Lower layer	8	-35		0.2	0.35

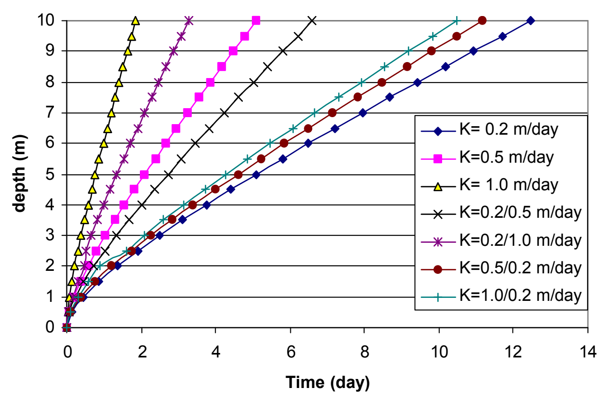

Fig. 4: Advance wetting depth versus time at different saturated hydraulic conductivity

For each screened length, the value of K is changed three times, 0.2, 0.5 and 1.0 m/day for three wells radius as 0.2, 0.3 and 0.4 m respectively. It is shown that the recharge rate increases dramatically by increasing of well screened length at the same value of K and well radius. Also, it can be shown from this figure that the recharge rate increases by increasing of K and well radius but the increase due to well radius is not so much.

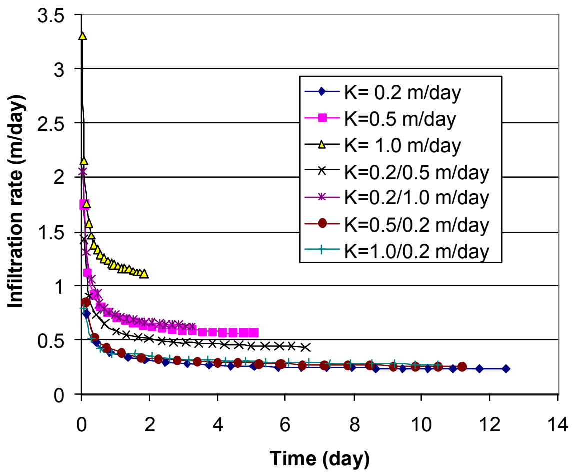

Fig. 5: Variation of infiltration rate with time at different values of saturated hydraulic conductivity

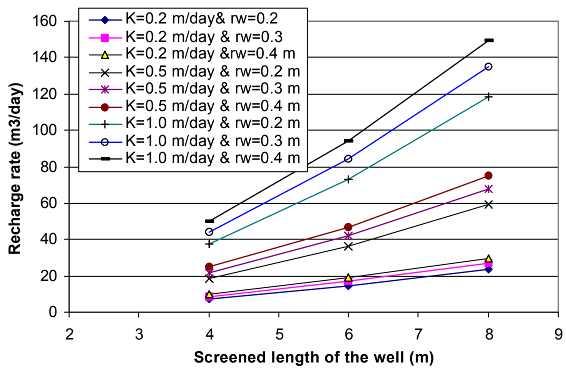

Fig. 6: Variation of recharge rate will screened length of Vadose zone recharge well at different values of hydraulic conductivity and well radius

A comparison between the infiltration time for recharge basin method and vadose zone recharge well method which gives the same recharge volume of water is shown in Figure (7). For K equal to 0.2 m/day, two wells are used to drain the same area of recharge basin while for hydraulic K equal to 0.5 and 1.0 m/day, one well is used. It is noticeable that two recharge wells with radius equal to 0.4 m and screened length of 8.0 m is better than recharge basin method for K equal to 0.2 m/day. However, for K equal to 0.5 and 1.0 m/day, one recharge well take the same time for recharge basin method to infiltrate the same volume of water.

The direct injection is mostly applied in drought regions where the geological and hydrological conditions do not enable either surface spreading or vadose zone wells. Equation (3) is used for computing the recharge capacity of deep injection well. Values of h_w and h_o are take as 20 and 10 m, respectively and radius of influence,

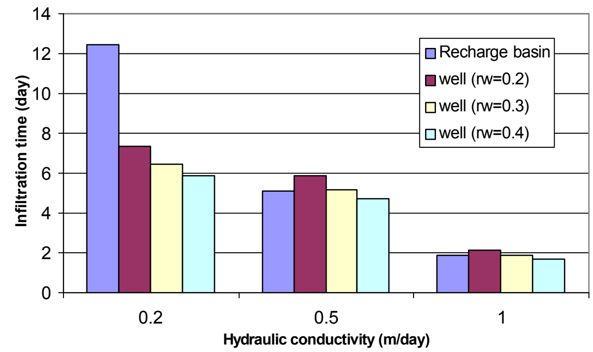

Fig. 7: Comparison between the infiltration time for recharge basin and vadose zone well

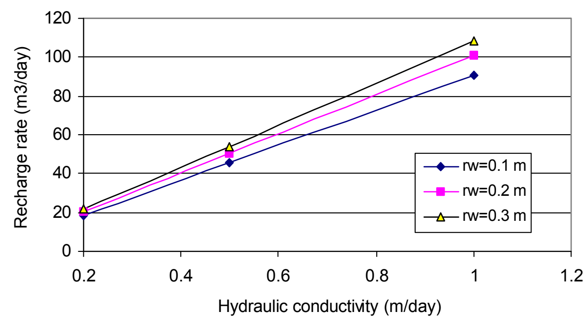

Fig. 8: Variation of recharge rate with hydraulic conductivity for injection recharge wells at different wells radius

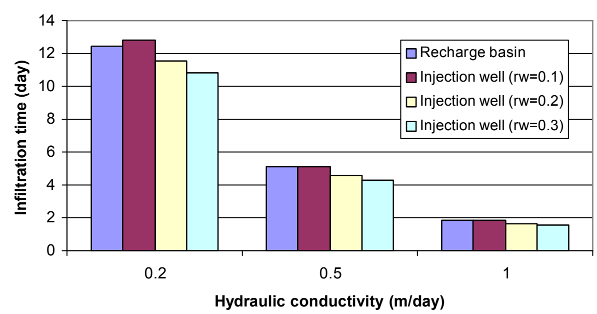

Fig. 9: Comparison between the infiltration time for recharge basin and injection recharge well

r_o, is taken equal to 100 m. Figure (8) shows recharging capacity of well increases by increasing of K of aquifer for the same radius of the well. Also, it can be shown that the recharge capacity increases by increasing of well radius.

Another comparison between the infiltration time for recharge basin method and injection recharge well method which gives the same recharge volume of water is shown in Figure (9). For the three values of K, one well is used to drain the same area of recharge basin. It is noticeable that one recharge well with radius equal to 0.2 m and screened length of 10.0 m is better than recharge basin method for the three values K. However, from the economic view point may be more costly than recharge basin and vadose zone injection well.

To indicate the effect of attenuation in K due to clogging, the recharge value is calculated using K computed by Eqn. (5) for vadose zone well of radius 0.3 m. It was found that the reduction in recharge volume is 12% and the reduction in recharge of deep injection well is 11%.

CONCLUSIONS

Evaluation of three methods of groundwater recharge is carried out aiming at better understanding of the effect of hydraulic and geotechnical parameters on the different groundwater recharge methods. It is found that geotechnical, hydraulic and geometrical parameters have large effect on all methods. The using of vadose zone injection well method and deep injection well recharge method may be effective when the upper layer of soil has a small hydraulic conductivity. The effects of suspended sediments, air trapper in the soil, bacteriological and chemical growths and accretions and other phenomena should be considered in detail. The methods presented are intended to provide guide lines for design of efficient ground-water replenishment schemes.

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