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GROUNDWATER EXTRACTION IN THE UNITED ARAB EMIRATES UNDER THE CONSTRAINT OF SALINE WATER INTRUSION

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The United Arab Emirates is predominantly desert adjacent to the sea where saline water intrusion into coastal aquifers takes place, and there is very little or no rainfall to supply freshwater recharge. This paper presents a mathematical analysis to investigate the phenomenon of upconing below wells, concludes that the upconing increases as the depth of the well, and the discharge increases. We suggest construction of horizontal infiltration galleries to obtain groundwater of satisfactory quality and quantity.

INTRODUCTION

The United Arab Emirates (UAE) is situated in the northeastern part of the Arabian peninsula (Figure 1). The UAE has about 600 km of coast line with the Persian Gulf, also called Arabian Gulf, and about 100 km of coast line with the Gulf of Oman. Abu Dhabi and Dubai are important cities of the UAE on the Persian Gulf coast, Fujairah is on the Gulf of Oman coast, while Al Ain lies inland. The country is predominantly desert with a stratigraphy consisting of eolian sand. The characteristic feature of eolian deposits is that the particles are well rounded in shape, stratification in the vertical direction is not present, and high hydraulic conductivity exists in the horizontal direction. Owing to saline water intrusion in the coastal aquifers, quality of groundwater is often unsatisfactory as upconing of saline water below the wells occurs in the coastal region, and therefore, a different method of extracting groundwater so as to cause a minimum disturbance to the natural system has to be devised.

Figure 1. Map of the United Arab Emirates.

MATHEMATICAL ANALYSIS

Saline Water Intrusion

Saline water intrusion takes place in all coastal aquifers and pumping of fresh water increases the saline water intrusion. The boundary between saline and fresh water is known as the interface.

When equilibrium between saline water and fresh water in a coastal aquifers is reached, the depth of the interface below mean sea level is given by the Ghyben-Herzberg relation (Drabbe and Ghyben, 1888; Herzberg, 1901) under the following assumptions :

a. The aquifer is homogeneous and unconfined.

b. Saline water-fresh water is separated by a sharp interface.

c. There is no direct flow of fresh groundwater to the sea.

d. There is no mixing zone between the saline water and the fresh water

The pressure of fresh water from the water table is equal to the pressure of saline water from mean sea level at the same point of the interface.

$$\rho_s g h_s = \rho_f g \left(h_f + h_s \right) \tag{1}$$

which gives,

$$h_s = \rho_f \,/ \left(\rho_s - \rho_f \right) \tag{2}$$

where

ρ_s = density of saline water = 1.025 kg/m3

ρ_f = density of fresh water = kg/m^3

h_s = depth of the interface below sea level = 40 h_f

h_f = elevation of the phreatic level above sea level

g = acceleration due to gravity.

Theory of upconing

In coastal aquifers, where the fresh water lies above saline water, and is pumped by a well, the interface rises below the well due to drawdown of the groundwater table around the well. The pressure on the interface is reduced and saline water rises as a conical mound beneath the well. This phenomenon is known as upconing. If the top of the conical mound reaches the well, saline water will begin to mix with fresh water, and degrade the quality of the well water.

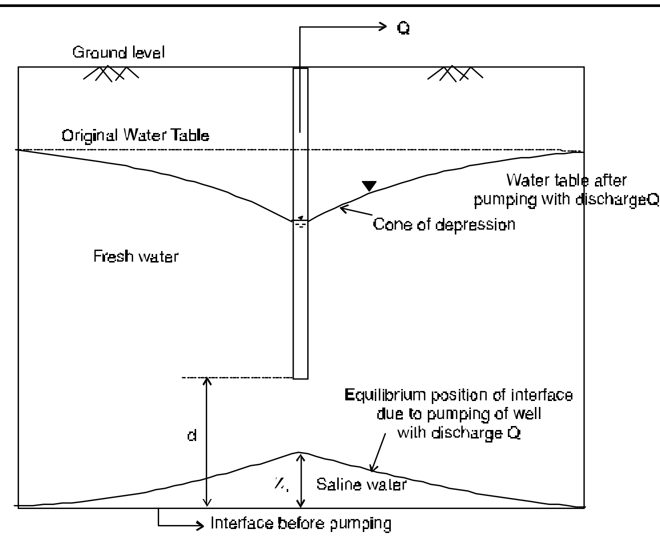

Figure 2. Upconing of salt water beneath a pumped well.

Dagan and Bear (1968) gave a mathematical expression for determining the height of the cone, Z_t ,below the well. The formula is:

$$Z_t \frac{\rho_f Q}{2\pi \left(\rho_s - \rho_f \right) k_x d} \left[1 - \frac{2 \rho_f \theta h_f}{2 \rho_f \theta d + \left(\rho_s - \rho_f \right) k_x t} \right] \tag{3}$$

where

Z_t = rise of cone at time t

Q = discharge of well

d = depth of inter face below the bottom of the well, before pumping

K_x = hydraulic conductivity of aquifer in horizontal direction

K_z = hydraulic conductivity of aquifer in vertical direction

θ = porosity of aquifer

t = time since start of pumping

For $t = \infty$, the equilibrium height, z_∞ ,of the cone is given by

$$Z\infty = \frac{\rho_f Q}{2\pi(\rho_s - \rho_f)k_x d} \tag{4}$$

If z_∞ is to equal d, i.e. if the well is to discharge saline water, putting the value of $z_\infty = d$ in Equation (4),

$$d = \frac{\rho_f Q}{2\pi(\rho_s - \rho_f)k_x d} \tag{5}$$

From the Ghyben-Herzberg relation, the depth of interface below the well, before pumping is given by

$$d = h_f\left[1 + \left(\frac{\rho_f}{\rho_s - \rho_f}\right)\right] - d_w \tag{6}$$

where

d_w = depth of well from original undisturbed water table.

Equating the right-hand-sides of Equations (5) and (6),

$$\frac{\rho_f Q}{2\pi(\rho_s - \rho_f)k_x d} = h_f\left[1 + \left(\frac{\rho_f}{\rho_s - \rho_f}\right)\right] - d_w \tag{7}$$

Substituting ρ_f = 1 kg/m^3 and ρ_s = 1.025 kg/m^3 in Equation (7), Q can be expressed as

$$Q = 0.157 K_x (41 h_f - d_w)^2 m^3 \tag{8}$$

From Equation (8) it is seen that for a homogeneous aquifer, the safe discharge from the well is increased with increase in fresh water head, h_f, above mean sea level, and the safe discharge from the well is increased with decrease in the depth of the well, d_w, below the original undisturbed fresh water table.

In a desert country like the UAE, freshwater recharge is nil or very low because of extremely low rainfall and, as a result, h_f is small. If h_f is small and h_s is not very large, the interface is not far below mean sea level.

DISCUSSION

In coastal arid regions, deep tube wells are not preferable because of possibility of upconing of saline water. Shallow tube-wells or deep tube wells with low discharge may be used, but the discharge being low may not suffice to meet projected needs.

In this context, horizontal infiltration galleries can be constructed in the fresh water zone to avoid problems with upconing (Figure 3). The gallery may be a pipe of permeable material of 0.5 to 1.5 m diameter, set in a permeable aquifer at a depth of 3 to 5 m with gravel packing and wire nets at close intervals so that water can seep with low velocities into the gallery. This water can be pumped out and utilized while effectively preserving the quality of groundwater.

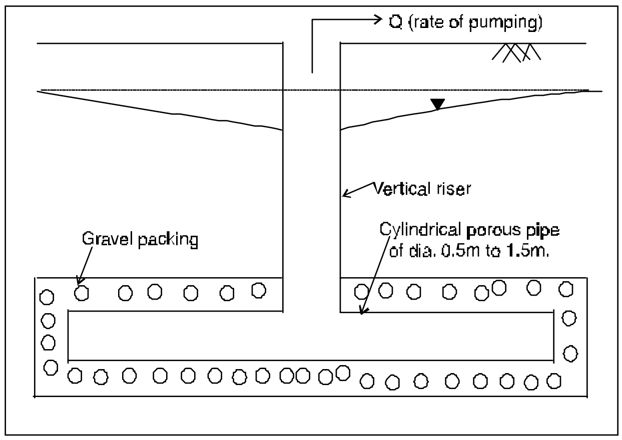

Figure 3. Schematic diagram of horizontal gallery at shallow depth below the water table.

CONCLUSION

Horizontal infiltration galleries are presented in this paper as a viable solution to upconing below vertical wells. As the analysis presented in this paper has shown, vertical wells may not be feasible in several situations and horizontal infiltration galleries can be successfully used in such cases**.**

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