EVALUATION OF GROUNDWATER VULNERABILITY TO SEEPAGE FROM OPEN DRAINS CONSIDERING DIFFERENT PUMPING SCHEMES IN UNCONFINED AQUIFERS

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ABSTRACT

Groundwater is considered the main source of water supply in many regions all over the world. One-third of the world's drinking water is provided by groundwater. Groundwater aquifers are recharged from rainfall and seepage from canals and drains. Drains as source of groundwater recharge are also source of pollution. The existing water in drains comes from agricultural land which contains chemicals, fertilizer and pesticides. Also, drains receive industrial wastes which contain chemicals and heavy metals in addition to sewage water from residential areas. This study aims to evaluate the impact of different pumping schemes on the groundwater quality due to seepage from open drains including different abstraction rates, depths and locations of wells. Numerical model MODFLOW is used to simulate groundwater flow and contaminant transport in unconfined aquifer. The domain considered in the study of depth 100m, length2000 m, width 2000m and abstraction rate Q depends on the number of wells. Different scenarios were considered including; different abstraction rates (Q_w), depths of wells (D_w) and locations of wells from the drain (L_w). Sensitivity analysis were done to investigate the effect of changing these parameters (Q_w, D_w ,L_w) on the extension of contaminate (X_T) into the aquifer. The results indicated that pollution from open drains is very sensitive to increasing abstraction rate from wells. Also well depths and the distance between wells and the drain have clear effect on contamination extension. This reveals that, the abstraction rate of wells and distance from the drain and well depth should be considered in management of aquifers to reduce contamination extension and protect pumping wells.

Keywords: Groundwater quality, pumping wells, open drains, MODFLOW, confined aquifers.

1 INTRODUCTION

Groundwater is an important source of water supply for domestic, agriculture and industry. Therefore predicting the behavior of contaminates in flowing groundwater is of vital importance to make the necessary decisions to protect groundwater aquifers. One of the most important factors that help to pollutants extension are wells with all the factors affecting them, such as abstraction rates, locations of wells from the drain andwell depth. Astutiet al. (2017)studied the effect of drainage channel type on seepage to groundwater. The study showed that some parameters could be addressed to assist water conservation such as construction of channel, groundwater level, slope, soil characteristics and channel layout.Islam et al. (2016) presented the safe distances between groundwater-based water wells and pit latrines at different hydrogeological conditions in the Ganges Atrai floodplains of Bangladesh. The results showed that the safe distance from the tubewell to the pit latrine varied from site to site depending on the horizontal and vertical distances of the tubewell as well as hydrogeological conditions of a particular area**.**Orlikowskiet al. (2015) presented assessment of river water impact on groundwater quality in an urban flood plain area at Lobau, Vienna. The results showed that the main processes being responsible for groundwater quality in the Lobau is the character of the aquifer itself because nearly half of the variation in groundwater quality (45%) is dependent on the ionic strength in the aquifer. A smaller amount depends on redox activity represented by manganese and iron (12%) and organic and nutrient concentration of infiltrating surface water (9%). A number of researchers studied the seepage from rivers on groundwater (e.g. Hoehn and Scholtis (2010) andOrlikowskiet al. (2015)). Someother researchers studied on the ground water–surface water interaction (e.g. Anderson (2005), Asnachinda et al. (2005) andZhang et al. (2015))

In this study a numerical model MODFLOW is used to investigate groundwater flow and contaminant transport in unconfined aquifer considering different scenarios of abstraction rates, locations of wells from the drain and depths of wells.The study includes assessment to the impact of leakage from drains on the quality and quantity of groundwater.

2 METHOD AND MATERIALS

2.1 Area Description and Flow Domain

Extension of contaminate (X_T) in unconfined aquifer is investigated considering different scenarios. In this study, a hypothetical case study is considered of domain 2000 m length, 2000 m width and 100m depth. Main drain was allocated in the middle of the case study and two canals parallel to the drain with distance of 1000m as shown in Figure 1. Three wells were allocated on each side with equal distance of 500m. Figure1presents plan and cross section of the study area.

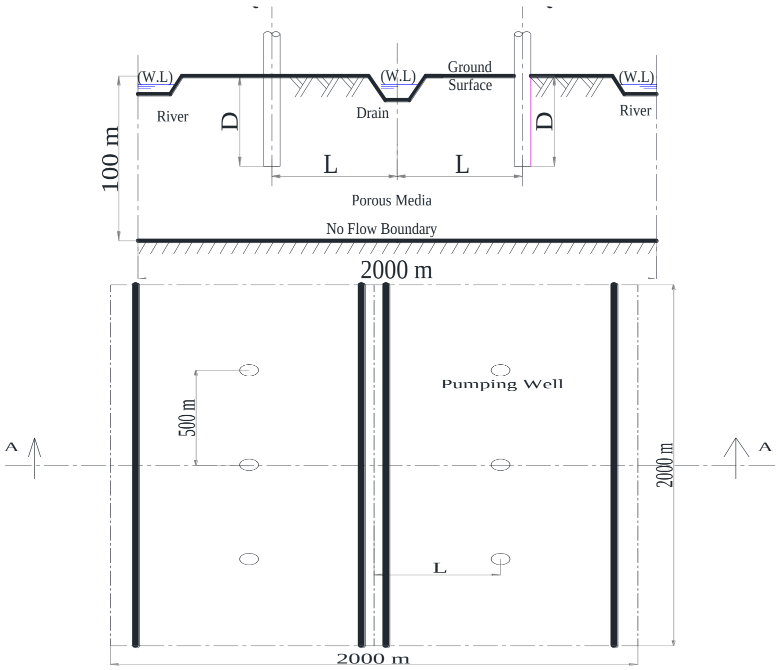

Figure 1. Plan and vertical cross section of the case study

2.2 Numerical Model

Numerical models can help to investigate water flow and contaminant transport in aquifers. In this studyVisual MODFLOW is used to investigate seepage from polluted drains into groundwater. The model input parameters and results can be visualized in 2D (cross-section and plan view) or 3D at any time during the development of the model or the displaying of the results The governing equation of groundwater flow solved by MODFLOW can be defined as (McDonald and Harbaugh, 1988)

$$\frac{\partial}{\partial t}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \quad (1)$$

Where; K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes (L/T), h is the potentiometric head (L), W is volumetric flux per unit volume representing sources and/or sink of water in (T^{-1}), S_S is specific storage of the porous material (L^{-1}), and t is time (T).

2.3 Boundary Conditions

The drain was assigned with elevation levels range between 2.50 m to 2.80 m below the ground surface. The tworivers on both sides of the study area was assigned with average stage range between 0.50 to 0.80 m and bed range between 3.00 to 3.30m below the ground surface. The annual recharge rate was assigned in the first layer equals to 365 mm/year. Constant concentration of contaminant has been assigned in the drain equals to 2000 mg/L.

2.4 Hydraulic Parameters

The hydraulic parameters of the study area were assigned based on previous studies and mathematical calculations. Based on previous studies of homogenous aquifer was assigned using horizontal and vertical hydraulic conductivities of 50 m/day and 5 m/day respectively.The storage parameters are $27*10^{-7}$for specific storage (S_s), 0.2 for specific yield (S_y),20% effective porosity and 35% total porosity.

3 SIMULATION OF GROUNDWATER FLOW AND CONTAMINANT TRANSPORT IN THE AQUIFER.

MODFLOW is used for the simulation of groundwater flow and contaminant transport in the aquifer. For model calibration a mathematical equation based on Darcy's low is used to calculate the head between the drain and the river as following

$$K(h^2 - h_0^2) - N * x(L - x) + \frac{K * x}{L(h_0^2 - h_l^2)} = 0 \qquad (2)$$

Where: h is the water elevation (m) between the drain and the river, h_0 is the elevation of thedrainon the west (m), h_L is the elevation of the river to the east (m), N is porosity, K is hydraulic conductivity (m/day), x is the distance along the aquifer from the drain on the west(m). The calculated heads by equation 2 assigned at the observation wells shown in Figure 3a. Figure 2a shows the zone budget calculated by the model and Figure 2b shows the calibration results as comparison between calculated head by the model versus the heads calculated by equation 2. The results shows good match between the model results and the calculated heads by equation. Figure 3a shows the head contours in the study area and Figure 3b shows the extension of contaminant in the study area without abstraction from the aquifer (base case). A number of scenarios were conducted to study the effect of wells location, depths and abstraction rates on contaminant extension in the aquifer. The different values of abstraction rates (Q_w), depths of wells (D_w) and locations of wells from the drain (L_w) are shown in Table (1).

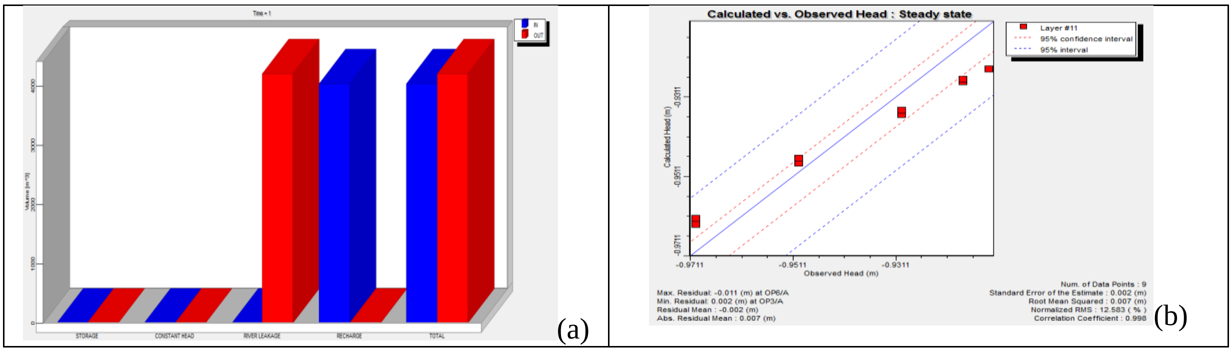

Figure 2. Zone budget and model calibration

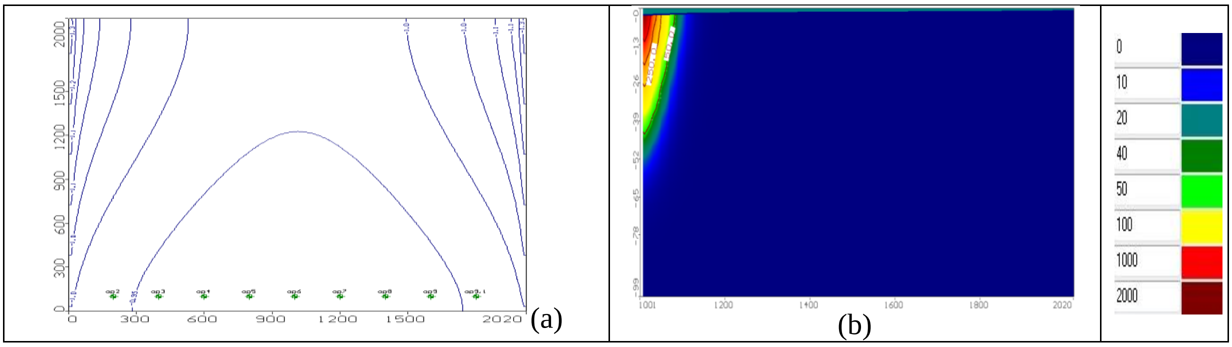

Figure 3. Head contour and Extension of contaminant in the study area (Base case)

Table1. Different values of (Q_w,D_w,L_w)

Scenario type	Scenario no	$Q_w(m^3/h)$	$L_w(m)$	$D_w(m)$
Q_w	1	60	600	60
	2	90	600	60
	3	120	600	60
	4	150	600	60
L_w	5	90	600	60
	6	90	700	60
	7	90	800	60
	8	90	900	60
D_w	9	90	600	30
	10	90	600	40
	11	90	600	50
	12	90	600	60

4 RESULTS AND DISCUSSION

Different scenarios of wells location, depths and abstraction rates (Q_w, D_w, L_w) were investigated.***The first scenario***, studied the impact of changing the abstraction rates(Q_w) on the extension of contaminant (X_T) in the study area. Four values of abstraction rate are examined, 60, 90, 120 and 150m^3/hour and the distance from drain and well depth were kept constant 600 and 60m respectively. Figure 3 shows the extension of contaminate (X_T) in the study area for the different values of abstraction rates and Figure 6a shows the relation between abstraction rate (Q_w) and contaminateextension(X_T). The results showed that increasing abstraction rate lead to increase the extension of contaminate (X_T) in the aquifer.

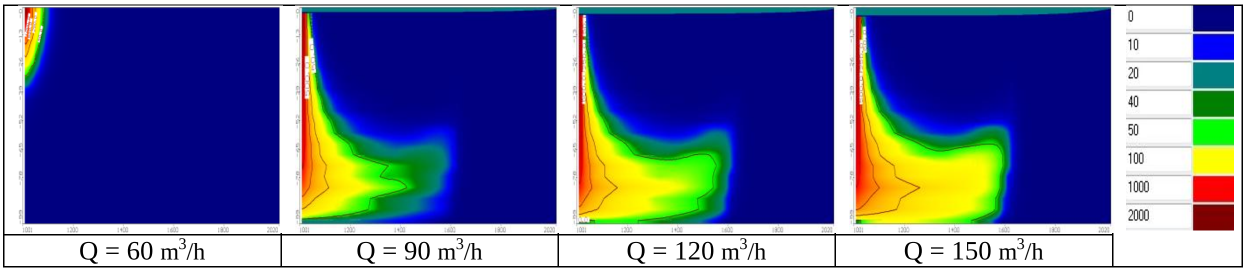

Figure 4. Impact of increasing abstraction rate on the extension of contaminant in the aquifer

In the second scenario, the impact of changing the location of wells(L_w) on the extension of contaminant (X_T) in the study area is studied. Four values of distances between the drain and wells are examined, 600, 700, 800 and 900 m and the abstraction rate and well depth were kept constant 90m^3/hour and 60m respectively. Figure 4 shows the extension of contaminate (X_T) in the study area for the different values of well distances from the drain and Figure 6b shows the relation between well location (L_w) and contaminateextension(X_T). The results showed that the extension of contaminate (X_T) in the aquifer is decreasing with increasing distance between the wells and the drain.

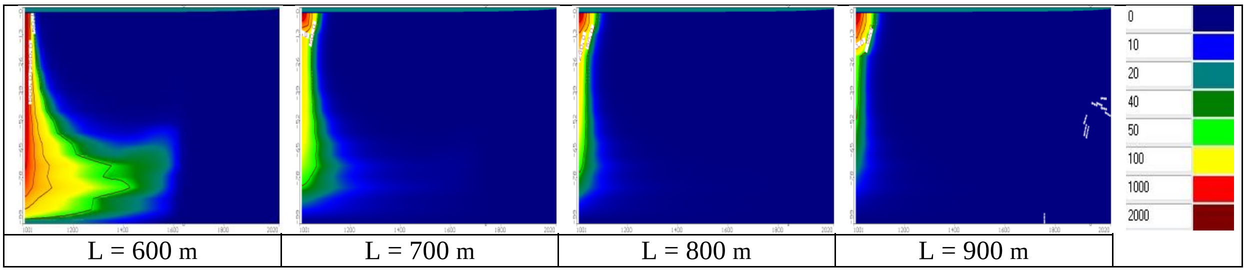

Figure 5. Impact of changing locationS of wells on the extension of contaminant in the aquifer

The third scenario, studied the impact of changing the well depths (D_w) on the extension of contaminant (X_T) in the study area. Four values of depths are examined, 30, 40, 50 and 60m and the abstraction rate and distance from drain were kept constant 90m^3/hour and 600 respectively. Figure 5shows that the extension of contaminate (X_T) in the study area for the different values of abstraction rates and Figure 6c shows the relation between well depths (D_w) and contaminate extension (X_T). The results showed that increasing well depths lead to increase the extension of contaminate (X_T) in the aquifer.

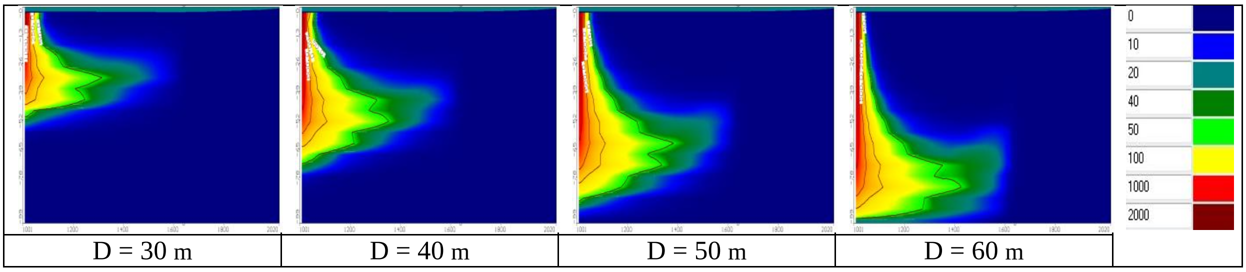

Figure 6. Impact of changing depths of wells on the extension of contaminant in the aquifer

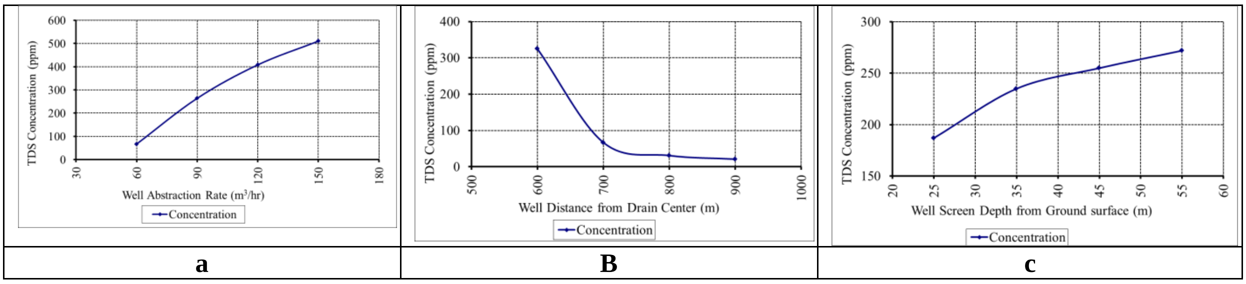

Figure 7. Relation between extension of contaminant in the aquifer and (a) abstraction rate, (b) well locations and (c) well depths

5 SUMMARY AND CONCULSION

Contamination of groundwater from polluted drains is avital issue in water resources management. Finite difference model (MODFLOW) is applied to a hypothetical case study to investigate seepage from open drains on groundwater quality inunconfined aquifer. The effect of three parameters, abstraction rates (Q_w), well depths (D_w) and well locations (L_w) on the extension of contaminate (X_T) were studied.The study showed that the extension of contaminate (X_T) into the aquifer was affected by changing these parameters. Increasing the abstraction rates has increased the extension of contaminate (X_T) inthe aquifer. Also, increasing the well depths has increased the extension of contaminate (X_T) inthe aquifer. However, increasing the distance between wells and the drain has decreased the extension of contaminate (X_T) inthe aquifer. Increasing the abstraction rates gave the highest impact on the extension of contaminant in the aquifer. The abstraction rates, well depths and well locations should be considered in the design and allocation of wells close to polluted drains to avoid abstraction of contaminated water that may effect on plants, animals and human.

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