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IMPACT ASSESSEMENT OF SEWERAGE DRAIN ON TUBEWELL WATER QUALITY USING MT3D MODEL

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ABSTRACT

In last few decades, the demand of fresh water is rising magnificently due to rapid increase in population and food demand. A large quantity of groundwater is being used for irrigation due to shortage of surface water. In Pakistan the availability and quality of groundwater has been affected due to rapid urbanization and over exploitation. This research was conducted to assess the impact of sewerage drain at Jaranwala Drain on groundwater quality and evaluate the rate at which drain is deteriorating the groundwater quality. MODFLOW and MT3D models were used to calculate concentrations for different time intervals in aquifer at the end of year 2014. The results showed that the concentration of 723 mg/l was travelled 320 m towards pumping well for simulation time of 35 days in all three layers. After 1096 days of simulation, the travelled distance towards the pumping well was 1000, 970 and 920 m with concentration of 7020, 5630 and 5120 mg/l in the first, second and third layer, respectively. It was concluded that the horizontal movement of the concentration was very high as compared to the vertical movement. It was also concluded that if sewerage drain is passing near agricultural land then tubewell installation on two kilometers or away from drain is safe to avoid the contamination of tubewell water.

Keywords: Groundwater, MODFLOW and MT3D models, sewerage drain.

INTRODUCTION

The groundwater resources are being utilized for drinking, irrigation and industrial purposes. However, due to rapid growth of population, urbanization, industrialization and agricultural activities, groundwater resources are under stress. The use of groundwater resources is increasing because of limited surface water availability and its utilization will further expand in future. Groundwater is one of the major sources of irrigation in arid and semi-arid

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regions. Climatic conditions affect the quality of groundwater that also affects the percolation of water during the inputs from soil (Ashok *et al.,* 2011).

In Pakistan for more than two decades, the main source of progress in agriculture production is groundwater and more than one million tubewells deliver approximately 50% of total irrigation water (Shah, 2007b). In Punjab, 73% of groundwater is of good to marginal quality but at some locations, it is becoming difficult to maintain purity of groundwater (Ashfaq *et al.,* 2009). Groundwater assessment for irrigation has become a necessary and important task for present and future groundwater quality management. Thus, for protecting groundwater quality, data of water quality parameters on spatial and temporal distribution are important (Taghizadeh *et al.,* 2008). Saltwater intrusion is one of the major sources which pollute the groundwater. Other include seepage from sewerage drains, underground storage tanks, oil wells, septic tanks, landfills and agricultural leaching. There is growing concern on the deterioration of groundwater quality and over exploitation of groundwater, which resulted in increase in salinity of groundwater. Saline intrusion into groundwater via aquifer penetration has become a major concern because it is the source of groundwater pollution. It was found that the groundwater quality is being deteriorated due to sewerage and solid wastes disposal (Sudharjarajini, 2005).

The most common source of groundwater pollution is from substances used in forestry, waste and agriculture such as insecticide, herbicide and fungicide. The constituents of many of the pesticides are highly toxic, even in minute amounts (Fetter, 1994). Fertilizers with nitrogen are the most identifiable pollutant in groundwater. Nitrate is non-toxic, it can cause certain condition, excess amount not consumed by plants and flush down which pollute the groundwater (Offodile, 2002). Zailin *et al.* (2010) found that groundwater quality was not upto the mark due to the sewerage drain in the region. Similarly, Ahmad *et al.* (2012) identified that most of the groundwater samples were much polluted by the intrusion of sewerage water, dumping of waste and percolation of domestic sewerage by inhabitants.

In Pakistan, untreated industrial and urban waste is directly exposed to open drain, which is one of the major sources of groundwater contamination. It is a temporary solution to transport wastewater in open drainage system. Open drains are not a suitable mechanism for conveying sewerage. Open drains produce a high health hazard as they are regularly used for the execution of domestic and/ or industrial wastewater, and solid waste. There is danger of interference and interruption of saline water into fresh water aquifers due to the reason of extreme expansion of groundwater (Chaudhry and Shah, 2003).

Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. PMWIN is one of the powerful groundwater modeling software, which is able to simulate groundwater flow in a wide range of natural systems. The programs can combine extension, such as MODFLOW and MT3D. PMWIN is used widely throughout the world and it can be applied to many modeling applications extensively (Qureshi *et al.,* 2011 and Shakoor, 2015). This research study was carried to evaluate the rate at which sewerage drain deteriorating the groundwater quality and to assess the impact of sewerage drain on tube well water quality.

MATERIALS AND METHODS

Study area

The research was conducted at Jaranwala Drain, which is passing near Chak No.53GB tehsil Jaranwala district Faisalabad, Punjab, Pakistan. The drain starts at the latitude $31^{o}19^{'}46^{''}$ N and longitude $73^{o}24^{'}35^{''}$ E and outfall in River Ravi at latitude $31^{o}17^{'}54^{''}$ N and longitude $73^{o}55^{'}23^{''}$ E. The drain is 385 km long at the altitude of 182.58 m above mean sea level, having maximum discharge capacity of 70.85 m^3/s. The location of study area is shown in Figure 1.

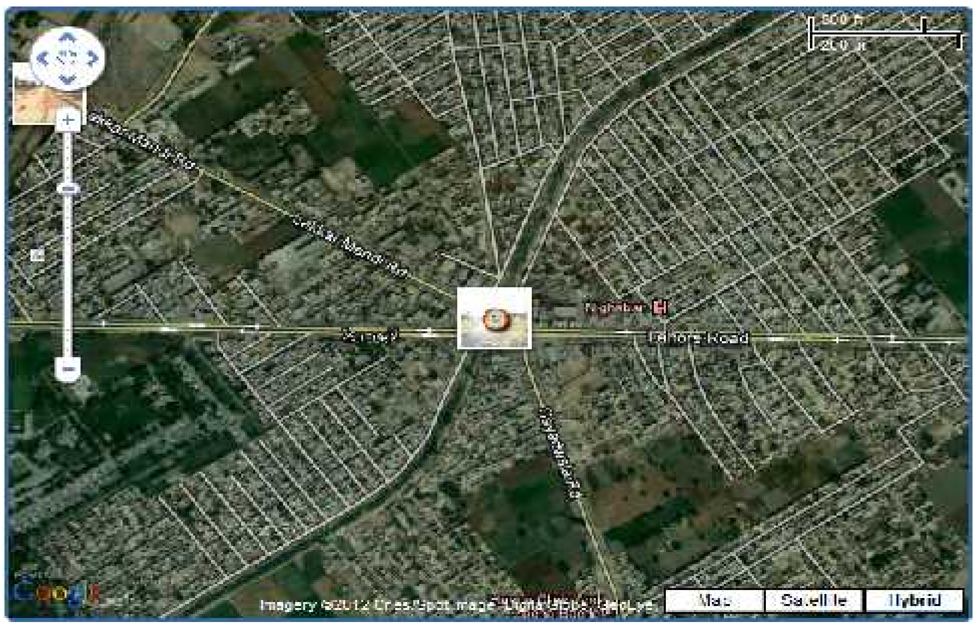

Figure 1. Map of Jaranwala Drain (Source: Google earth).

Data analysis

A tubewell was selected 3 km away from Jaranwala Drain and it is located at latitude $31°19^{'}19^{''}$ N and longitude $73°22^{'}44^{''}$ E. The drain data and tubewell water data for last ten years was taken from Irrigation Department, Faisalabad. The tubewell water samples were also collected and examined for pH, electrical conductivity (EC), Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC).

Groundwater Flow Model

To accomplish the objective the PMWIN (Processing Modflow for Window) was used in this research. PMWIN is the most broadly used mathematical groundwater flow model. The most commonly used extensions of the model are MODFLOW and MT3D (McDonald and Harbaugh, 1988). Many researchers used this model for groundwater modeling and found satisfactory results because of its wide variety of hydrologic features and processes (Kori *et al.,* 2013; Zailin *et al.,* 2011; Lalehzari *et al.,* 2010).

MODFLOW

The Modular Three- Dimensional Finite Difference Groundwater Flow Model (MODFLOW) was used to determine the behavior of groundwater flow along the sewerage drain. The domain of the model is shown in the Figure 1. The parameters and their values used in the MODFLOW model are shown in Table 1. The model domain has 3000 cells with 50 columns and 60 rows and each cell size was of 100m × 100m.

Table 1. MODFLOW input values.

Parameters	Layer 1	Layer 2	Layer 3
Thickness of Layers (m)*	7	23	60
Horizontal Hydraulic Conductivity (m/s)*	0.0004	0.0009	0.0011
Vertical Hydraulic Conductivity (m/s)*	0.00002	0.00004	0.00004
Recharge (m^3/s)*	8×10^{-9}	--	--
Well Discharge (m^3/s)	-0.028	-0.05	-0.028

* Uniformly distributed on domain

Groundwater recharge from rainfall in Rechna Doab was considered 20% of total rainfall. Arshad *et al.* (2005) conducted a field and modeling study in Rechna Doab, Punjab, Pakistan and reported that the contribution of recharge to groundwater was found from 17 to 22% of rainfall. To determine the sewerage effect on tubewell water quality, a tubewell of maximum discharge of (-0.05m^3/s), 3 km away from sewerage was selected, cell no. 30 and 20 as shown in Figure 2.

In MODFLOW model, the positive and negative sign indicate the recharging and pumping well, respectively. Discharge rate is high in second layer because pump strainer lied in this layer. The all values used in MODFLOW are in accordance with the reported by Khan *et al.* (2008), calibrated the MODFLOW for Rechna Doab, Pakistan.

MT3D model

MT3D is a comprehensive three-dimensional model for simulating solute transport in composite hydrogeological formation. MT3D is capable of modeling advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and nonlinear sorption. MT3D model was used to determine the rate of solute transport along sewerage drain towards pumping well. The parameters and their values used in the model as input for MT3D are presented in Table 2.

The values of recharge, horizontal and vertical hydraulic conductivity of three layers, well discharge, hydraulic head, boreholes and observations, and drain boundary conditions were used as input of the groundwater system. MT3D concentrations were computed as model's outputs. In advection package Method of Characteristics (MOC) for the solution scheme and First-order Euler for the particle tracking algorithm was considered. All the values used in MT3D are in accordance with the reported by Shah (2007a); Khan *et al.* (2008) and Qureshi *et al.* (2011).

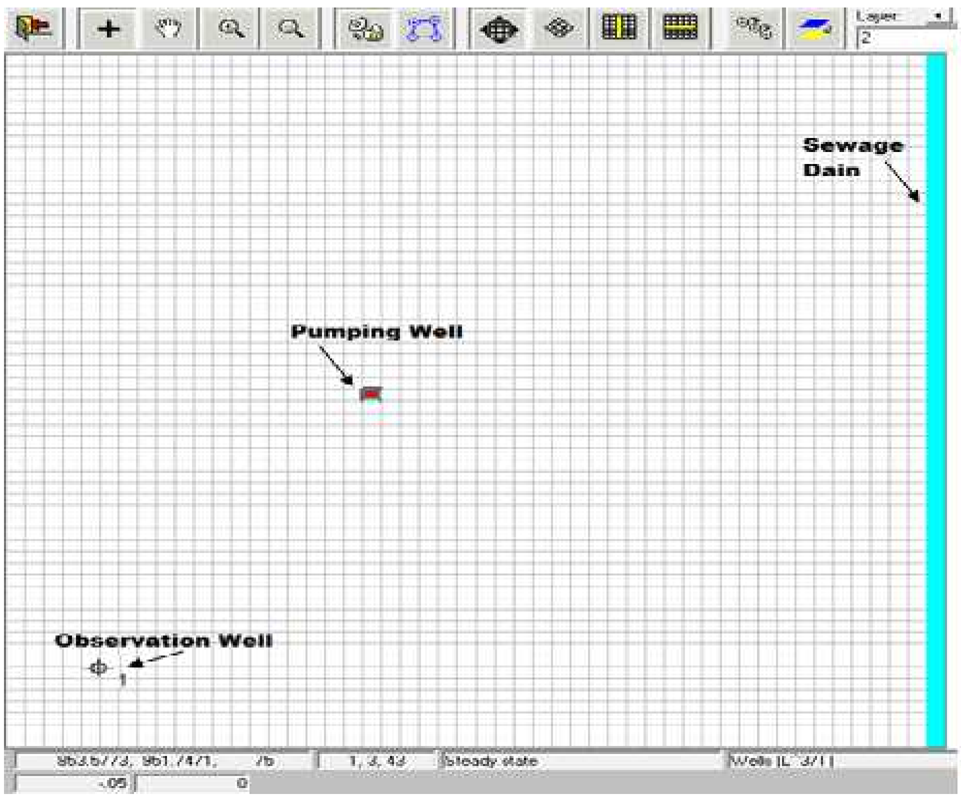

Figure 1. Model domain.

Table 2. MT3D input values.

Parameter	Value	Unit
Boundary Condition	1	-
Initial Condition	0	-
Source Concentration	12500	µg/m^3
Advection Package Maximum Number of total moving particles	250000	-
Dispersion		
TRPT	0.1	-
TRPV	0.1	-
Chemical Reaction Parameters		
ρ_b	2000	kg/m^3
Kd	0.000125	m^3/kg
R	2	

TRPT is the ratio of the horizontal transverse dispersivity to the longitudinal dispersivity. TRPV is the ratio of the vertical transverse dispersivity to the longitudinal dispersivity. ρb is bulk density of the porous medium, R is Retardation factor and Kd is distribution coefficient.

Table 3. Simulation time and concentration distance.

Time (days)	Layer I		Layer II		Layer III	
	Distance (m)	Concentration mg/l	Distance (m)	Concentration mg/l	Distance (m)	Concentration mg/l
35	320	723	320	723	320	723
70	350	1160	350	1160	350	1160
104	380	1810	380	1420	380	1440
138	400	2150	400	1870	400	1790
173	420	2430	420	2150	420	2060
208	450	2600	450	2380	450	2330
243	480	2820	480	2610	480	2550
277	500	3090	500	2980	500	2870
312	510	3260	510	3070	510	3000
347	550	3446	550	3230	550	3170
381	580	3730	580	3440	580	3370
1096	1000	7020	970	5630	920	5120

RESULTS AND DISCUSSION

Considering the groundwater conditions during 2011 as “initial conditions”, a number of future steps were simulated to observe the future response of the aquifer. The model was run to simulate the hydrodynamics of groundwater flow up to the year 2014. The outputs of MODFLOW model were used with the solute transport model to study the possible changes in the groundwater salinity over the observed period. Model predicted the behavior of groundwater for 2011-2014. The predicted value of the concentration and their distance travelled after different time intervals in the first, second and third layer at the end of the simulation is shown in Table 3.

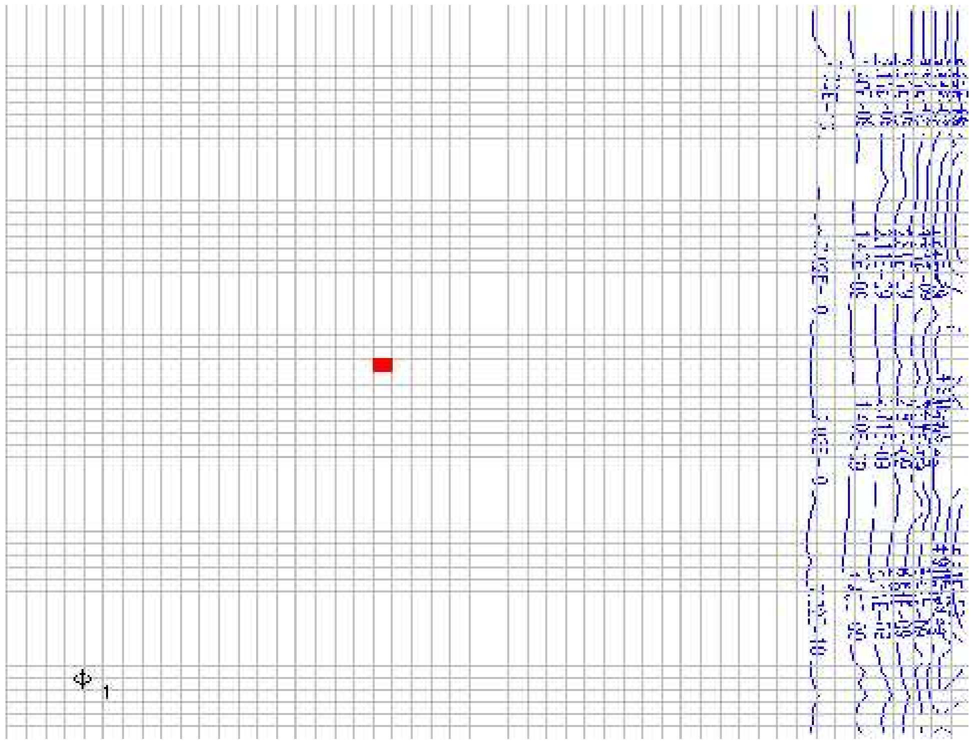

Figure 2. Groundwater concentration in 1st Layer after 1096 days.

After simulation time of 35 days the concentration travelled towards pumping well was 320 m and the concentration variation was 723 mg/l in all three layers. After simulation time of 173 days the concentration travelled towards pumping well was 420 m and the concentration variation was 2430, 2150 and 2060 mg/l in the first, second and third layer, respectively. After simulation time of 381 days the concentration travelled towards pumping well was 500 m and the concentration variation was 3730, 3440 and 3370 mg/l in the first, second and third layer, respectively. After simulation time of 1096 days (3 years) the concentration travelled towards pumping well was 1000, 970 and 920 m and the concentration variation was 7020, 5630 and 5120 mg/l in the first, second and third layer, respectively. The behavior of changing the quality of groundwater due to the transport of solute after 3 years in the first, second and third layers are shown in Figure 2, 3 and 4, respectively. Groundwater concentration in all layers upto 70 days of simulation was same due to same response of aquifer type but concentration varied afterwards. The difference in concentration distance travelled was difficult to observe in all layers upto 2 years of simulation. Results showed that the concentration is increasing towards the tubewell as time passing. The concentration traveled distance and concentration intensity was high in first layer due to that sewerage drain lies in this layer and the concentration travelled more rapidly towards pumping well because of higher horizontal hydraulic conductivity than the vertical hydraulic conductivity.

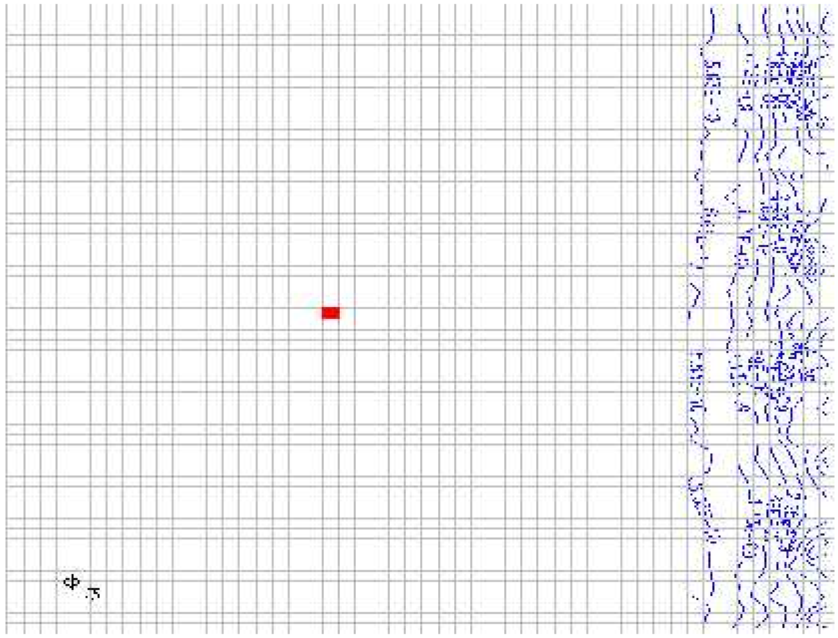

Figure 3. Groundwater concentration in 2nd Layer after 1096 days.

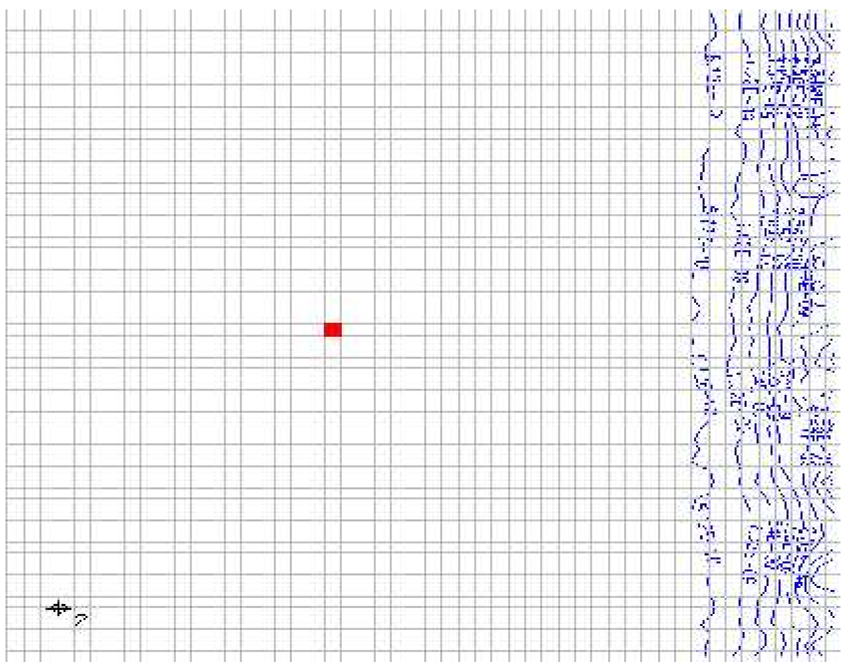

Figure 4. Groundwater concentration in 3rd Layer after 1096 days.

CONCLUSION

The model results point out that there is a need in water quality development. Since the area of good quality water and bad quality are located closely, so there would be chance of saline water interruption into fresh water area. Concentration travelled much depends upon the horizontal hydraulic conductivity than vertical hydraulic conductivity because Kh is higher than the Kv. It was found that the groundwater quality became very much severe for irrigation upto 1 km from drain. The results showed that if drain is passing near agriculture land then tubewell could be installed at a distance of 2 km for a long time running. After 3 years of simulation only 1096 m area was deteriorated due to the impact of sewerage drain. It was suggested that, if any farmer wants to install tubewell within 2 km then after 2, 3 years conjunctive irrigation should be applied.

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