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Coupling HYDRUS and MODFLOW for studying Environmental Impact of Wastewater Ponds in Tenth of Ramadan City, Egypt.

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ABSTRACT

Pollution from Industrial waste has become an increasingly serious problem in the developing countries, by posing harm to the human being health and the environment. 10th of Ramadan city considered the first industrial city established in Egypt, all types of wastewater discharged into the oxidation ponds for further treatment. This paper aims at evaluating the impact of the oxidation bonds on the groundwater system in this city, through coupling HYDRUS and MODFLOW for studying contaminates transport in both the unsaturated and saturated zone. The contamination degree of the 15 water samples collected from the wastewater of the oxidation ponds and groundwater wells revealed that both of them are highly contaminated with heavy metals. The migration of heavy metal leachate through unsaturated zone was modeled using HYDRUS 1-D, revealed faster leaching of Sr than Fe along the soil profile. The accumulated concentrations of both elements were estimated at the lower boundary of the unsaturated zone as input parameter in MODFLOW for contaminant transport simulation in saturated zone; it seems that under current development strategy, the effect of the oxidation bond on the groundwater system is limited. The approach here should apply during the selection of any harmful waste disposal facility.

Key words: *Industrial waste, Pollution, Environmental Impact, HYDRUS-1D, MODFLOW-3D*

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I. INTRODUCTION

Industrial waste generated from industrial are not permitted to discharge into the environment without adequate treatment process. In general, industrial wastes classified into organic wastes and inorganic wastes based on their components; into solid wastes, semi-solid wastes and liquid (gaseous) wastes based on their species; into hazardous wastes and common wastes based on pollution characteristics .Pollution from Industrial waste has become an increasingly serious problem in the developing countries. Although very year, large quantities of industrial solid wastes are generated from the growing industries in these countries, there are no adequate treatment and disposal facilities. From this context, developed countries have to confront this as it seriously hindered the development of industries in these countries and done harm to the human being health and the environment. 10th of Ramadan is considered to be first of the industrial cities established in Egypt. There are many industrial zones in the city host several industries (i.e., electronics, food processing, readymade garments, plastic, and paper, textile, building materials, steel, pharmaceuticals and furniture). The oxidation ponds and its surroundings receive an average of 52000 m^3/day of wastewater, which is discharged into the lowlands (northeastern desert area into Wadi El-Watan) by open drainage system and artificial canals **(Taha et al. 2004)**. Oxidation pond (No.1) collects ≈14.000 m^3/day domestic wastewater and oxidation pond No.2 collects domestic and part of industrial wastewater with an average in flow ≈13.000 m^3/day. Oxidation pond (No.3) collects the effluent from heavy industries at an average flow ≈25.000 m^3/day, **(Abd El-Gawad, 2014)**.

RIGW–IWACO (1998) and Khater (2002) revealed that 10th of Ramadan City and its surroundings are located within a medium to high groundwater vulnerability zone based on the absence of a thick clay cap and the depths to aquifer layers, as a result of absence of the formal environmental impact assessment prior to the reclamation projects **(El Araby, 1997),** a deterioration in the hydrogeological and environmental conditions occur. This deterioration can be summarized as following:

- The contamination from unlined wastewater ponds at the northeast of the Tenth of Ramadan city where all the domestic and industrial wastewaters are disposed, **(Abd El-Samie et al., 2002), (RIGWA, 2005), (Abd El-Gawad, 2014) and El Sayed et al., 2012).**
- The water-logging and flooding of soils at the center and the eastern side of the Tenth of Ramadan city **(Eleraki et al., 2010).**

- The increase in soil salinity **(African Water Facility, 2007)** considered the most problematic issues in the study area.

From this context, an attempt has been by integrating the modeling the unsaturated zone / saturated zone for evaluating the environmental impact of those ponds the hydrogeological system in this area. More emphasizes the role of the unsaturated zone on the possible pollution reduction will be discussed.

Two suitable softwares were used for this purpose, simulation of contaminants transport through unsaturated zone were performed using HYDRUS 1D **(Šim□nek et al., 2009)** and MODFLOW **(Mcdonald and Harbaugh. 1988)** with MT3DMS **(Zheng and Wang, 1999)** for saturated zone simulation. Then, this software was coupled in order to represent and model both zones as unique system, considering the effect of unsaturated zone on the transport of contaminants in groundwater.

The vadose zone is of a great concern for the groundwater pollution studies **(Selker, et al., 1999).** It acts as a filter for the aquifers by removing unwanted substances that might come from the ground surface such as hazardous wastes, fertilizers, and pesticides. HYDRUS Model is one of the computer codes which simulating water, heat, and solutes transport in one, two, and three dimensional variably saturated porous media on the basis of the finite element method, based on equation (1) **(Šim□nek, et al., 2009).**

$$\frac{\partial C}{\partial t} = DL\,\frac{\partial 2C}{\partial x2} - vx\,\frac{\partial C}{\partial t} - \frac{\rho}{\theta}\,\frac{\partial C}{\partial t} \pm \left[\!\left[\frac{\partial C*}{\partial t}\right]\!\right] rxn \text{.........}\textbf{Eq. (1)}$$

where, C (mg/L) is the concentration of solute in liquid phase; t (h) is the time; DL (cm^2/h) is the longitudinal dispersion coefficient; v (cm/h) average linear groundwater velocity; ρ (g/cm^3) is the bulk density of aquifer; θ is the volumetric moisture content or porosity for saturated media; C* (mg/g) is the amount of solute sorbed per unit weight of solid; rxn is the subscript indicating a biological or chemical reaction of the solute (other than sorption).

The MODFLOW computer code was used to build a three dimensional model of subsurface water flow. The model describes ground water flow under non-equilibrium conditions in a heterogeneous and anisotropic medium according to the following equation **(Bear, 1979; Bear and Verruijt, 1987).**

The model describes groundwater flow of constant density under non-equilibrium conditions in a heterogeneous and anisotropic medium according to the equation (2) **(Bear, 1979)**, which was solved using the finite difference technique:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W = S_s\frac{\partial h}{\partial t} \text{ ...}\textbf{Eq. (2)}$$

Where K_{XX}, K_{yy} and K_{zz} are the hydraulic conductivity along the x, y, and z coordinate axes, (Lt^{-1}); h is the potentiometric head (L); W is a volumetric flux per unit volume and represents sources and/or sinks of water (t); Ss, is the specific storage of the porous material (L^{-1}); and t is time (t). In general, S_s, K_{xx}, K_{yy}, and K_{zz} may be functions of space (S_s = Ss(x,y,z), $K_{xx} = K_{xx}(x,y,z)$, etc.) and W may be a function of space and time (W = W(x,y,z,t)). Moreover, due to the hydrodynamic dispersion, the concentration of a solute will decrease over distance. Generally speaking, the solute will spread more in the direction of groundwater flow than in the direction normal to the groundwater flow, because longitudinal dispersivity is typically 10 times higher than transverse dispersivity. The transport of a conservative solute in a one-dimensional system can be described by the advection-dispersion equation (3):

$$\frac{\partial C}{\partial t} = -v\frac{\partial C}{\partial x} + D\,\frac{\partial 2C}{\partial x2} \text{ ...}\textbf{Eq. (3)}$$

Where: ∂C/∂t is the change in concentration over time, the first term on the right-hand side represents advection and the second term represents hydrodynamic dispersion. The advection-dispersion equation may be solved analytically or numerically under different initial and boundary conditions. MT3DMS was used to predict heavy metal transport using lead as the surrogate. This engine is the best choice when biodegradation is not a factor when dealing with heavy metals that are persistent **(Prommer et al., 2002).** The adsorption coefficients were also most appropriate with the MT3DMS engine with heavy metal only having one oxidation state. The model run for numerous iterations and outputs recorded at different time intervals to show the size and extent of the heavy metal plume.

1.1 Site Description

10^{th} of Ramadan is located on the Cairo-Ismailia desert highway, 46 km from Cairo and 20 km from the city Belbeis, road. It is located between latitudes 30° 15′ N and 30°35′ N and longitudes 3° 50′ E and 32° 00′ E, Fig. (1).

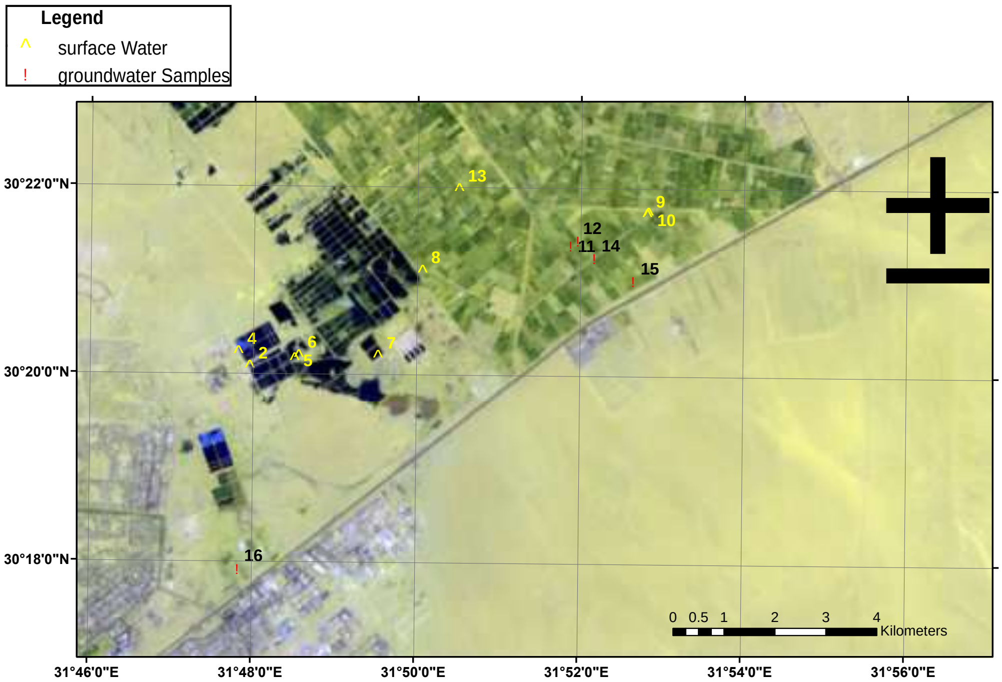

Fig (1): Location map of the study area showing the collected water samples.

The climate of the study area is arid to hyper-arid and it is hot and rainless in summer, whereas cold with occasional showers in winter. The climatic data are summarized in Table (1), **(Climate-Data.org, 2013).**

Table (1): Climatic data of 10th of Ramadan city **(Climate-Data.org, 2013).**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C	18.5	19.9	23.6	27.9	32	34.5	34.9	34.7	32.1	30	25.2	20.6	27.83
Daily mean °C	13.1	14	17	20.4	24.2	27	28	28.1	25.7	23.6	19.7	15	21.32
Average low °C	7.8	8.2	10.4	13	16.5	19.6	21.1	21.5	19.3	17.3	14.2	9.5	14.87
Average precipitation (mm)	7	4	3	2	0	0	0	0	0	2	4	4	26

Geomorphologically, 10th of Ramadan city occupies a portion of the rolling plain of the old delta; it is bounded by Ismailia canal on the North and West and on the South by a tactical escarpment along 10th of Ramadan fault. Its altitudes vary from 12 m amsl in the north, to about 180 m amsl in the south**, (El Sayed, 2012)**. The 10th of Ramadan city is located on the gravelly fluviatile plains. These plains occupy the area west of the cultivated lands of the Nile Delta and extend to Suez Canal.

Geologically, 10th of Ramadan is underlain generally by sedimentary rocks of Tertiary and Quaternary age **(Said 1990),** Fig. (2), the soil sequence in Tenth of Ramadan consists of graded sandy soil with clay and shale lenses of Pleistocene age, which covers nearly 85% of the study area particularly to the north and east, **(EEBS, 2004).** The clay lenses are of limited extent; its thickness varies between 1 m and more than 10 m. Tertiary rock units. The Tertiary deposits cover about 15% of the total area, and consist of sands and clays of shallow marine origin **(Said 1981).**

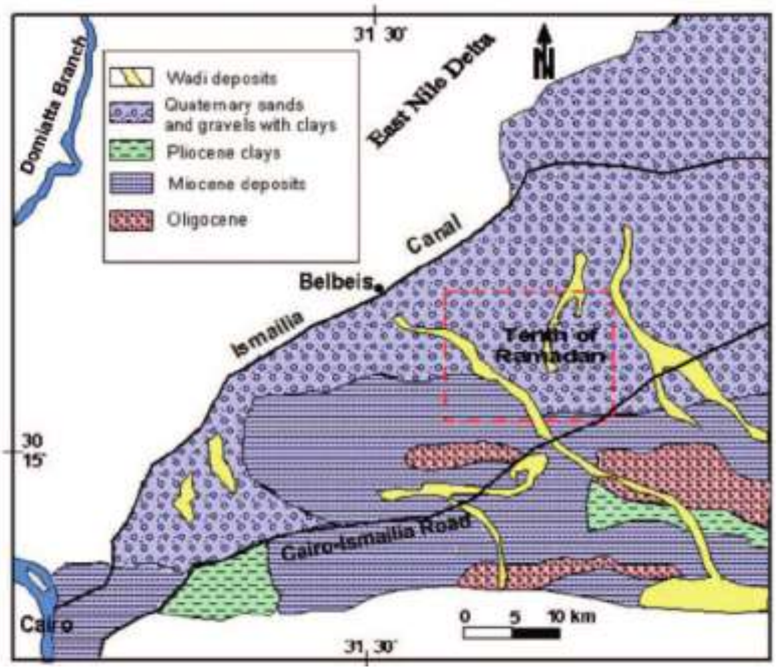

Fig. (2): Geological map of the study area **(modi□ed after CONCO 1987).**

Hydrogeologically; the fresh water Pleistocene aquifer (unconfined) represents the main groundwater aquifer, it is composed mainly of sand and gravel sands with clay intercalations that reach 50% in the west near the Nile Delta and decrease eastward and northward **(El-Mahmoudi et al. 1998)**. The thickness of the Pleistocene aquifer is up to 200 m, the depth to groundwater varies from 60 m inside the city to 90 m in the wells along Belbies road, and the salinity ranges between 1000 and 3000 ppm **(RIGW 2005).** The Ismailia Canal considered the main source of recharge, and discharge from the aquifer generally takes place as result of pumping for domestic and industry purposes. The Miocene aquifer is restricted to the south and the east of the Tenth of Ramadan city, with limited areal distribution. It is composed of alternating sandy limestone and clay lenses of loose quartz sand and marl, **(Abdel Baki et al., 1995)**, this aquifer includes more clay intercalations with high slope to South direction, and the water mostly exists under partially confined conditions due to presence of clay beds, **(El Shazly et al., 1975).** Recharge to this aquifer thought to be through faults **(El-Shazly et al., 1975)** and the aquifer thickness is not accurately determined due to partial penetration of the wells. The generalized flow direction is from southeast to north and northwest **(Abou Heleika** and **Atwia, 2014).** The hydraulic conductivity in the area of study has an average of 40m/day and the average specific yield is about 0.2 **(El Sayed et al., 2012).**

II. MATERIAL and METHODS

A total number of 15 samples 6 wastewater samples, 4 surface water samples and 5 groundwater samples) were collected during winter 2016, Fig. (1). Three sets of analyzed water samples were taken from each of the above water points for different measurements. The first set was for the measurement of TDS, major cations, anions, trace elements, and total organic carbon (TOC). The second one included acidified samples by (nitric acid) for the measurements of trace elements and soluble heavy metals. The third one collected in special container for the measurements of biological oxygen demands (BOD) and chemical oxygen demands (COD). These water samples were subjected to both field and laboratory analyses. The field analyses include EC (µs/cm), Eh , pH, and Dissolved Oxygen (DO) which had been measured using Ec/Eh/pH meter Jenway, model (3150), DO meter WTW, model (oxi 315I), respectively. The laboratory analyses includes the determination of major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^- ,and SO_4^{2-}) and trace elements (Al, B, Cd, Co, Cr, Cu, Fe , Mn ,Mo, Ni, Pb, Sr, V, and Zn). Measurements were carried out by Inductively Coupled Argon Plasma (ICAP) Poma 6500 Spectrophotometer (Unicom, UK). The analyses were carried out according to the standard methods **(Rainwater and Thatcher, 1960), (Fishman and Friedman, 1985), (APHA, 1998) and (ASTM, 2002).** The obtained chemical data are expressed in milligram per liter (mg/l). The whole hydrochemical data have been treated and analyzed for calculating water contamination index and evaluating its suitability for human. Furthermore, coupling and integrating the modeling the unsaturated zone / saturated zone for evaluating the environmental impact of those ponds on the hydrogeological system in this area using HYDRUS and MODFLOW software. The applied approach in this paper is illustrated in Fig. (3).

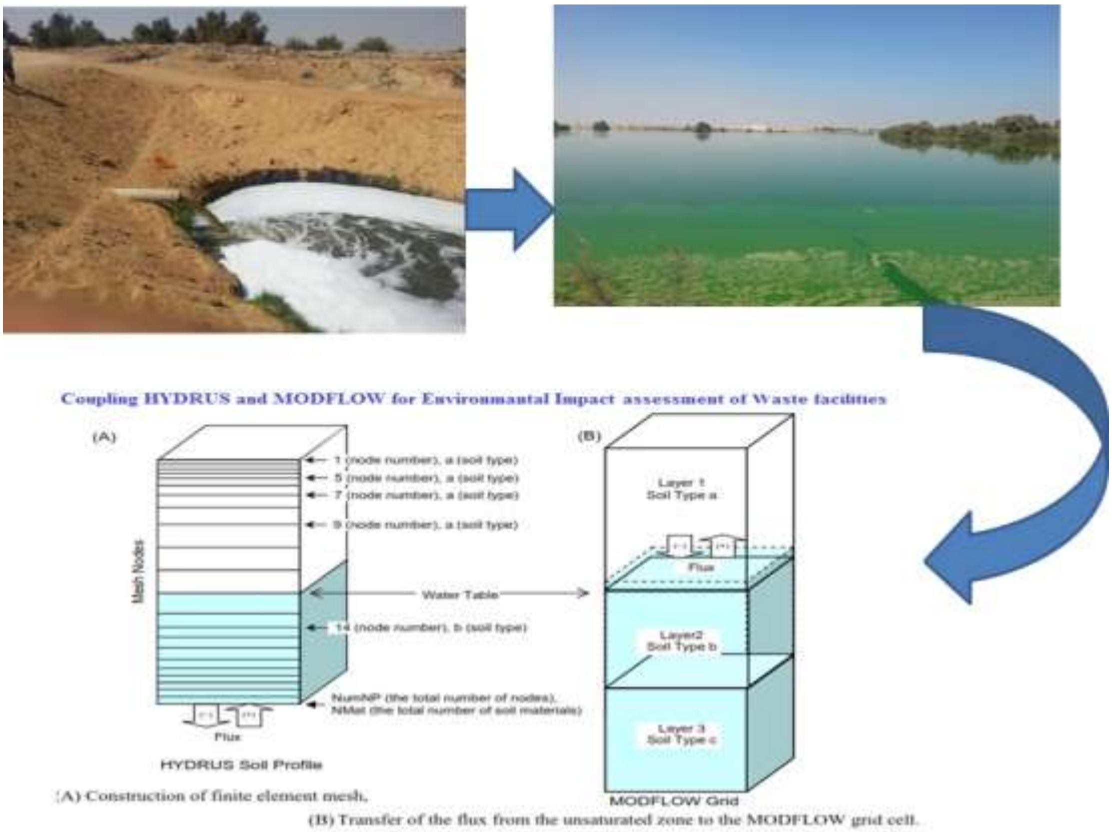

Fig.(3) Diagram showing the approach used in this work

2.1 HYDRUS-1D Processing

HYDRUS model applied in this paper based on the unsaturated zone available data beneath the wastewater ponds (i.e; topography, water table level, and stratigraphic sector of the study area). Starting from these data, the investigated site beneath the ponds performed as one domain with a representative one-dimensional soil profile, Fig. (4A).that consisted of three layers, sand (3.5 m), clay (0.5 m), and sand (1.5 m), that characterized by a specific stratigraphy according to **Eleraki et al (2010)**. Three observation nodes were considered at different depths along the soil profile; 0.5 m, 3.0 m, and 4m, Fig. (4B).

The meteorological data in Table (1); they represent the mean annual behavior of precipitation, that was introduced in the calculations. The initial water content, θ of the soil profile is set at 0.1 (default setting) for 5 m depth of soil profile. The water flow parameter, which is relevant for this profile imported from the model soil catalog. For the water flow boundary conditions, the upper boundary condition is set as an atmospheric boundary with surface runoff, while the lower boundary condition is considered to be a free drainage. Soil transport parameters imported for each contaminates with respect to the layer type. The soil distribution coefficient or adsorption coefficient k_d is a measure of the chemicals ability to leach the contaminates through the groundwater. The values of k_d was set for Fe at 0.32, 0.89, and 0.32 for each layer of the soil profile. On the other hand, it was set at 0.022, 0.069 and 0.022 for Sr for each layer of the soil profile. The diffusion coefficients, for both Fe and Sr in free water were considered to be zero.

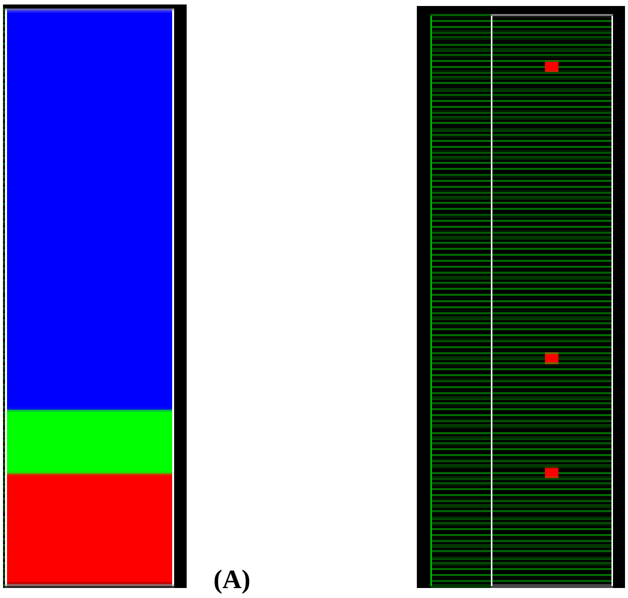

Fig. (4): (A); Profile module; used for specification of soil properties, (B); the position of the observed nodes.

2.2 MODFLOW Processing

2.2.1 The Conceptual Model

The available data for both Quaternary and Miocene aquifers were analyzed to evolve a groundwater flow regime in the study area. The study area was divided into 100 cells in the x-direction and 100 cells grids in the y-direction. The conceptualization of the model has been done based upon the hydrogeological information and data obtained from previous studies **(Hefny et al., 1980), El-Haddad (1996), (Research Institute of Groundwater, 1994) and (Abou Heleika and Atwia, 2014) (Khalil, 2015).**

The conceptual model of the study area assumed one complex layer, as contribution from the Miocene aquifer is occurring through the subsurface faulted where; Miocene blocks are juxtaposed next to the Quaternary sediments, Fig. (5). the thickness of this layer assumed 200 m, taking into consideration the surface elevation (amsl) contour. The value of contour at each cell at center of the block is noted with x-coordinates and y-coordinates imported into the model as ground elevation from DEM with resolution of 90 m x 90 m to show the terrain of the study area.

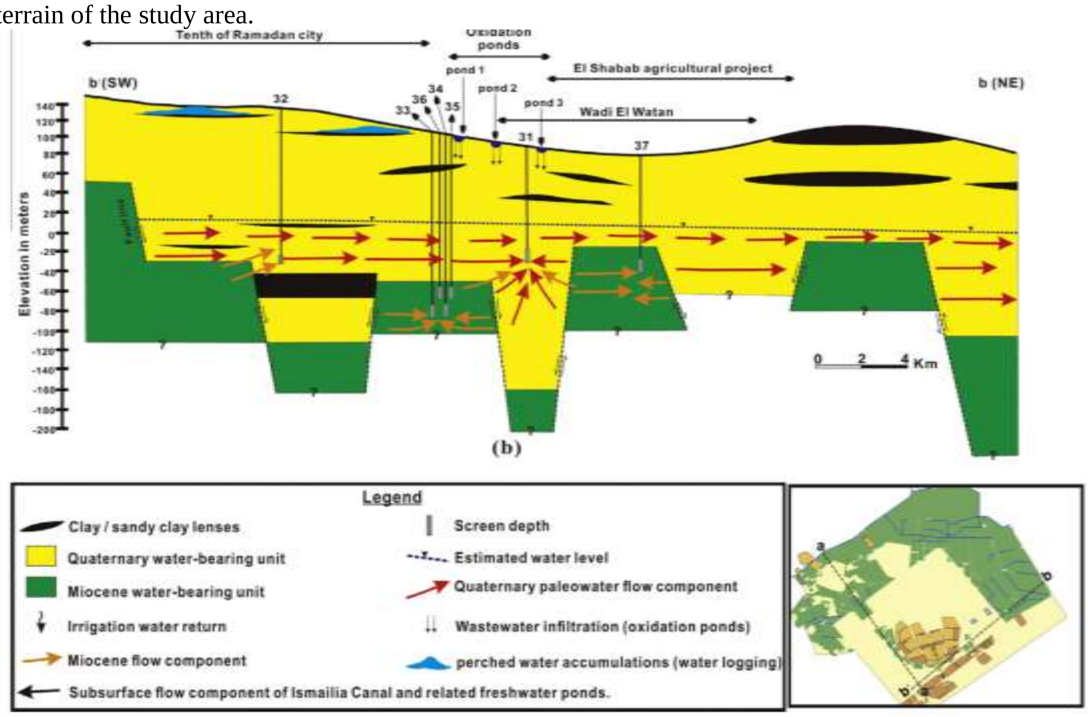

Fig. (5): A General cross section of the study area, **(Mahmoud et al, 2015)**

2.2.2 Model boundaries

According to the hydrogeological conceptual model the following hydrological boundary conditions were set, Fig. (6a), as follow.

a) Fixed Head boundary from the northwestern direction (Ismailia canal).
b) General Head boundary at the southeastern direction.
c) No flow boundaries assigned at the edges of the model area.
d) Recharge boundary of 14mm /year and an evapotranspiration rate of 2920 mm/year were applied to the model based local data (General Authority of Meteorological Stations, 2000).
e) Oxidation ponds added as constant concentration with concentration obtained from the HYDRUS results.
f) Production wells (wells mapped in the area)

2.2.3 Model parameters

The conductivity was adapted from the work of **Khalaf and Gad (2015).** Porosity and bulk density were collected from **Shata (1978).** Values that were required for each layer included storativity, specific yield, conductivity, and porosity; they were adapted from **Gad (1995), Afify (2004), and Ismail (2008).** MODFLOW was set to 7300 days (20 years approximately) that may represent the minimum time frame required for any sustainable development project.

2.2.4 Calibration of the model

The results of the hydraulic head computed by the model were calibrated against the observed head in some wells. Based on these results, Standards Error of the Estimation (SEE) was 0.074 m. A root mean squared (RMS) value of 0.179 m was achieved during calibration with a normalized RMS 9.397%, as illustrated in Fig.(6b).

After the calibration process; the model can accurately reflect the characteristics of actual groundwater flow in the study area and provide a reliable foundation for forecasting the groundwater solute transport model.

(a) **(b)**

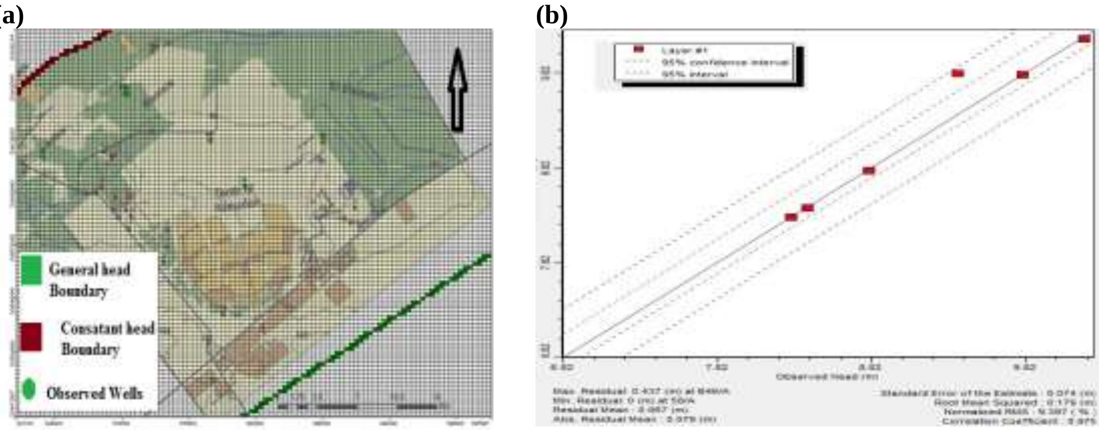

Fig. (6): (a) Conceptual model of the study area, **(b)** Calibration of the unsteady state for the year 2017.

III. RESULTS AND DISCUSSION

3.1 Trace element

Despite of the fact that trace elements constitute only 1% of the naturally occurring dissolved constituents in groundwater, they can sometimes make it unacceptable for consumption. Physico-chemical conditions such as temperature, pH, DO, BOD and Eh often enhance their dissolution in aqueous systems. The trace elements analysis of the collected water samples are presented in Table (1).

Table (1a): Physical properties of the collected water samples in the study area.

ID	Type	Elevation(m)	Eh(mv)	pH	EC (µs/cm)	Temp(ºC)	DO (mg/l)	TDS (mg/l)
1	Pond	98	-230	6.76	2126	30.4	0.06	911
2	Pond	98	-80	8.32	1920	30.4	12.67	867
3	Pond	97	-108	7.58	2601	29.3	0.29	1238
4	Drain	92	-58	7.75	1879	27.1	1	759
5	Pond	92	-168	9.15	2196	29	15.91	1168
6	Pond	92	-250	6.62	3815	30.5	1.16	1875
7	Ismailia canal branch		-37	8	461	28.9	9.73	220
8	Ismailia canal branch		-16	8.12	445	28.4	9.42	219
9	Ismailia canal branch		-9	8.41	636	29	10.4	293
10	Miocene aquifer	77	-11	8	5070	27	8.35	3156
11	Miocene aquifer	81	1	8.4	2865	27.3	8.04	1624
12	Ismailia canal branch		3	8	444	28.5	8.3	230
13	Miocene aquifer	88	-22	7.9	3370	26.5	5.57	2035
14	Miocene aquifer	85	27	7.7	8830	27.5	7.15	5330
15	Miocene aquifer	101	20	7.7	9550	27.5	6.2	5494

Table (1b): Trace elements (mg/l) results of the collected water samples in the study.

ID	Al	B	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Sr	Zn
1	0.0783	0.006	0.1301	0.0006	0.001	0.0684	0.006	0.1462	0.0611	0.028	0.008	0.6674	0.0305
2	0.0448	0.006	0.1301	0.0006	0.001	0.0221	0.006	0.1418	0.0316	0.0182	0.008	0.8595	0.0083
3	0.0303	0.006	0.1301	0.0006	0.001	0.0634	0.006	0.115	0.1566	0.0283	0.008	0.7038	0.0073
4	0.0797	0.006	0.1301	0.0006	0.001	0.0644	0.006	0.2096	0.033	0.0228	0.008	0.6035	0.0322
5	0.01	0.006	0.1301	0.0006	0.001	0.0371	0.006	0.2074	0.0499	0.0246	0.008	0.5538	0.0249
6	0.1205	0.006	0.1301	0.0006	0.001	0.1299	0.006	0.5405	0.3179	0.0294	0.008	1.138	0.0336
7	0.028	0.006	0.1301	0.0006	0.001	0.01	0.006	0.02	0.002	0.002	0.008	0.3625	0.0006
8	0.2633	0.006	0.1301	0.0006	0.001	0.01	0.006	0.02	0.002	0.002	0.008	0.3975	0.0006
9	0.0224	1.462	0.1301	0.0006	0.001	0.0361	0.006	0.082	0.002	0.002	0.008	2.054	0.0181
10	0.101	0.006	0.1301	0.0006	0.001	0.01	0.006	0.02	0.002	0.002	0.008	0.4904	0.0006
11	0.01	1.462	0.1301	0.0006	0.001	0.01	0.006	0.02	0.002	0.002	0.008	0.5191	0.0006
12	0.2316	0.006	0.1301	0.0006	0.001	0.01	0.006	0.0494	0.002	0.002	0.008	0.9739	0.0017
13	0.1287	0.0996	0.1301	0.0006	0.001	0.01	0.006	0.0948	0.002	0.002	0.008	1.577	0.0369
14	0.01	0.006	0.1301	0.0006	0.001	0.0244	0.006	0.02	0.002	0.002	0.008	8.391	0.2193
15	0.01	0.006	0.1301	0.0006	0.001	0.0214	0.006	0.02	0.002	0.002	0.008	10.66	0.0149

The high concentration of the organic matter is considered to be the ultimate reductant in the natural environment; it consumes dissolved oxygen, revealing the decrease in DO concentration in some ponds and the high concentration of DO in pond nos (6 and 3) mainly attributed to the application of aeration system as remedial action in this pond. The concentrations of Al and Sr in Ismailia Canal were exceeding the permissible limits for drinking water **(WHO, 2011),** the concentration of Al ranged from 0.028 to 0.26 mg/l with average 0.16 mg/l, and the concentration of Sr ranged from 0.97 to 0.36 mg/l with average 0.56 mg/l. On the other hand in the groundwater samples, the concentration of B, Cr , and Sr were exceeding the permissible limits for drinking water **(WHO, 2011),** ranged from 0.006 to 1.46 mg/l with average 0.61 mg/l, from 0.01 to 0.036 mg/l with average 0.02 mg/l, and from 0.52 to 10.66 mg/l with average 4.64, respectively. The bonds are highly polluted with Al, Cr, Fe, Mn, Ni, and Sr. Their concentration were above the permissible limits for drinking water **(WHO, 2011).,** ranged from 0.01 to 0.1205 mg/l with average 0.006 mg/l, from 0.022 to 0.13 mg/l with average 0.064, from 0.115 to 0.54 mg/l with average 0.23 mg/l, from 0.032 to 0.32 mg/l with average 0.108 mg/l, from 0.018 to 0.029 mg/l with average 0.025 mg/l, from 0.554 to 1.138 mg/l with average 0.75 mg/l, respectively. A contamination index method has been applied for more insights on the contamination degree.

3.2 THE CONTAMINATION INDEX (CD)

The contamination index method summarize the degree of contamination that can potentially harm the quality of the domestic water, it combines the effect of several quality parameters **(Prasanna et al, 2012**) and is computed as follows

$$CD = \sum_{i=1}^{n} \left(\frac{Cfi}{CAi}\right) - 1 \qquad (4)$$

Where CFi is the contamination factor for the i^{th} component, Cfi is the analytical value for the i^{th} component, CAi is the upper permissible concentration of the i^{th} component and CD is a sum of the contamination factors of the individual parameters that exceed their respective permissible values. CF calculated for every sample independently, values are grouped into three categories regarding contamination level as follows: low contamination if CD values are lower as one, medium contamination when CD = 1-3, and when CD is higher than three the contamination is considered to be high **(Beckman et al. 1998).**

Table (2): Contamination Index (CD) for collected water samples in the study area.

Sample Type	Sample Id	CD	Sample Type	Sample Id	CD
Pond	1	5.22	**Groundwater**	10	12.02
Pond	2	4.44		11	-4.59
Pond	3	5.15		13	6.76
Drain	4	5.88		14	65.88
Pond	5	4.8		15	86.38
Pond	6	26.79			
Surface Water	7	-7.38			
	8	-5.89			
	9	-5.85			
	12	0.18			

Based on the calculated results in Table (2); it was revealed that all groundwater samples were high contaminated except sample 12, as well as the degree of contamination in ponds is high especially pond no 7 which acquire the highest degree of contamination. On the other hand, the surface water samples from Ismailia canal is low contaminated in trace element. The correlation between the contamination index and different quality parameters have been tested to elucidate the contribution of these parameters in enhancing the contamination degree. Table (3) showing that highest correlation was mainly attributed to Fe , Sr , Cr, and Al, respectively. Those significant correlations indicate that they may have originated from common sources, preferably from anthropogenic activities. Moreover, it is also due to the textile/dyeing and paint industries, or pesticides.

Table (3): Correlation coefficient between Contamination Degree index and different water quality parameters.

	Al	*Cr*	*Fe*	*Mn*	*Ni*	*Sr*	*Zn*	*Eh*	*pH*	*EC*	*DO*	*CD*
Al	1.00											
Cr	0.82	1.00										
Fe	0.72	0.84	1.00									
Mn	0.58	0.88	0.82	1.00								
Ni	0.36	0.76	0.41	0.69	1.00							
Sr	0.66	0.65	0.77	0.80	0.21	1.00						
Zn	0.65	0.59	0.58	0.21	0.38	0.07	1.00					
Eh	-0.45	-0.64	-0.58	-0.59	-0.72	-0.42	-0.53	1.00				
pH	-0.84	-0.79	-0.44	-0.60	-0.63	-0.55	-0.39	0.53	1.00			
EC	0.56	0.87	0.86	0.99	0.68	0.80	0.27	-0.65	-0.55	1.00		
DO	-0.65	-0.67	-0.19	-0.43	-0.63	-0.21	-0.31	0.19	0.87	-0.34	1.00	
CD	0.76	0.84	0.97	0.91	0.50	0.86	0.47	-0.61	-0.57	0.93	-0.31	1.00

The relationship between the water pH and metal load was computed **(Ficklin et al. 1992; Caboi et al. 1999).** Based on Fig. (7); all groundwater samples classified as near neutral–high metal.

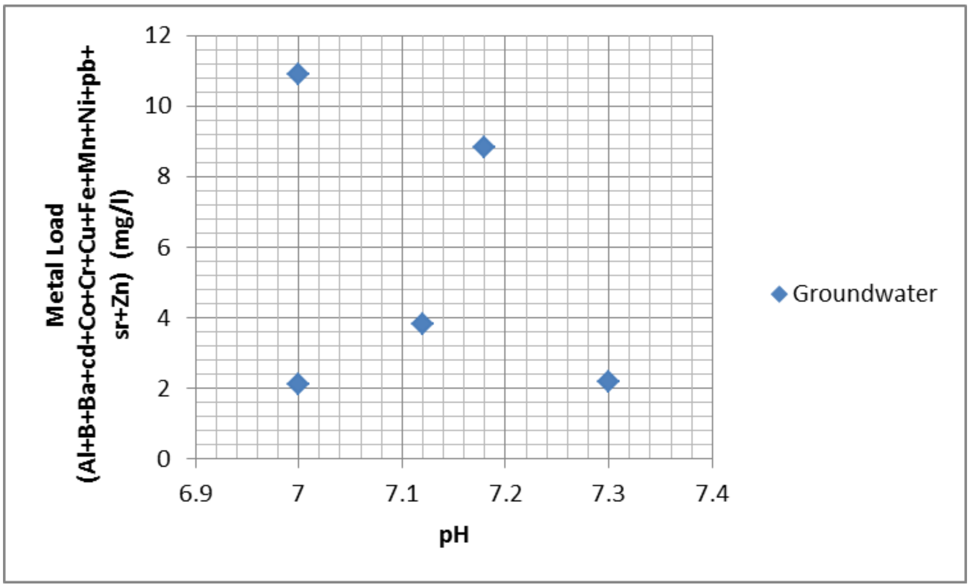

Fig (7): Metal Load (Al+B+Ba+cd+Co+Cr+Cu+Fe+Mn+Ni+pb+sr+Zn) in (mg/l) vs pH

Fe and Sr are considered to be the highest exceeded trace elements in both oxidation bonds and groundwater, which nessissate studying the leaching of these elements through the unsaturated zone, in addition to their dispersion in groundwater.

3.3 Contaminant transport in unsaturated zone using HUDRUS 1-D

The initial concentrations of both Fe and Sr were set, based on their actual concentration of bond no (6) which is considered the most polluted one, at 0.5 mg/l and 1.138mg/l, respectively. Moreover, the model was run for 7300 days (2017-2037).
The variation of the hydraulic conductivity with the depth is illustrated in Fig. (8a), revealing that the soil type playing an important role in on the hydraulic conductivity values variations.

Figures (8b) and (8b) reveal that the concentration of Sr appear at 4m (at time less than 1000 day), while Fe concentration started to appear at 4m at time 6000 days revealing that; the Sr concentration was leached faster than Fe along the soil profile. The accumulated concentration of both Fe and Sr at the lower boundary was found to be 0.819 mg/l and 0.112 mg/l, respectively.

The adsorption coefficient is considered one of the most important factors influencing the migration of the leachate through the soil profile in this case. Smaller the adsorption coefficient of solutes in soil, the lesser is the solute adsorbed by the soil and hence, the leachate speed increases as the k_d value decreases. Based on the concentration of Fe after leaching through the unsaturated zone; the high concentration of iron in groundwater might not attributed to the contamination from the oxidation ponds, but might be attributed to the corrosion of well casing and other pipes, in addition to that, bacterial activities may also have an effect. The high content of iron in oxidation pond is due to the heavy industries in the Tenth of Ramadan City especially in the industrial third area.

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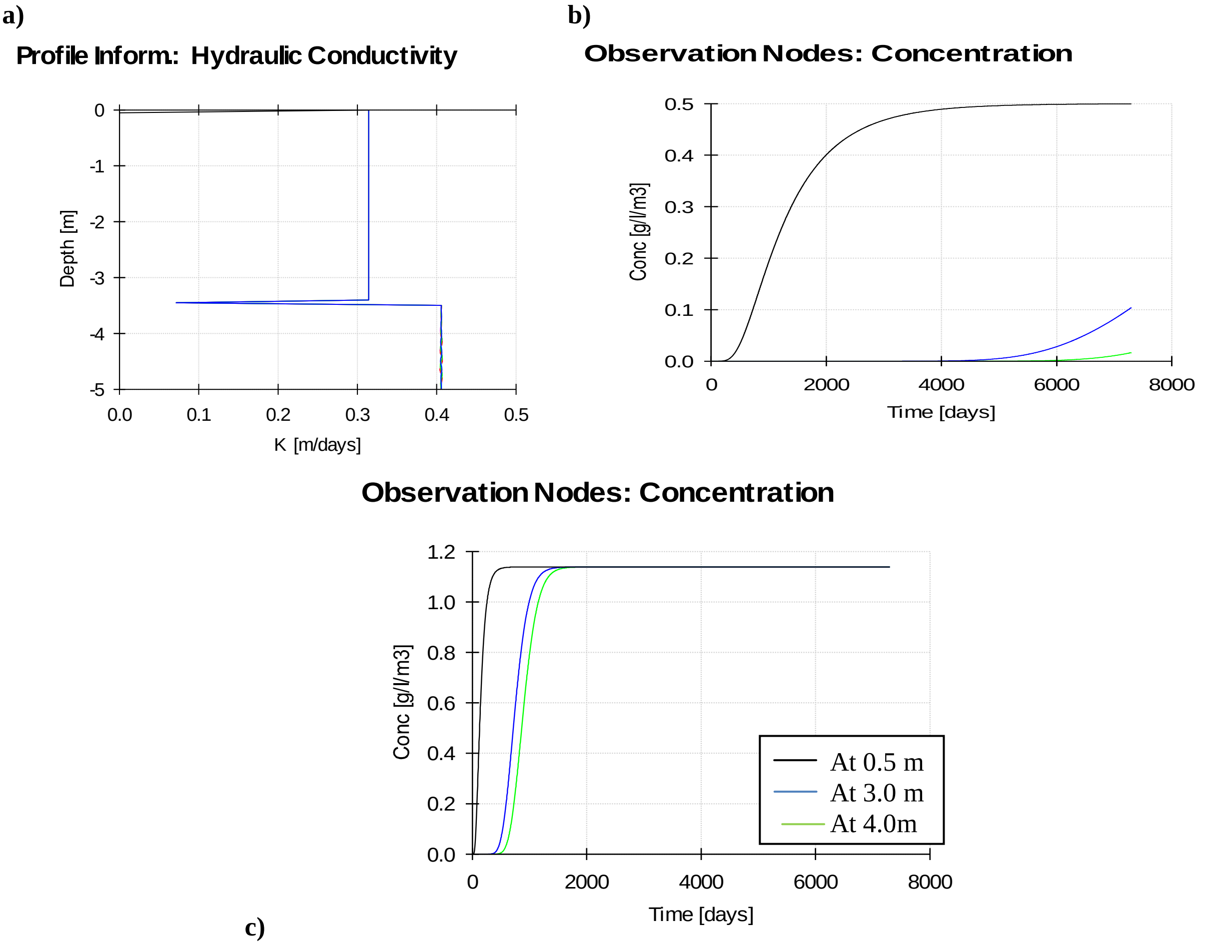

Fig. (8): (a) variation of the hydraulic head with the soil depth, (b) Sr concentration in the soil profile during the simulation time at different depths, (c) Fe concentration in the soil profile during the simulation time at different depths.

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3.4 Contaminant transport in saturated zone using MODFLOW

The results from MODFLOW simulation at its current situation, with pumping rate $40m^3$/day/well, Drawdown in some parts in the study area occur at the end of the simulation (7300 day), Fig. (9a), the highest decline in the predicted hydraulic head in the eastern south part of the study area might attribute to the increase in aquifer thickness and increase in sand ratio. Moreover, replenishment occurs for the system from Ismailia canal at the northwestern part.

Using the output concentration of both Sr and Fe at the bottom layer of the HYDRUS model as an input data in MODFLOW for simulating the effect of this leaching from the bonds on the groundwater system, the results showed a limited plume expansion for both Sr and Fe, as illustrated in Figs (9b and 9c) after 20 years simulation time. This reveals that the oxidation bonds have less serious impacts on the groundwater system in the study area. This limitation in expansion of the plume for both Fe and Sr could be attributed to decrement in the simulated velocity the hydrogeological system from 0.2m/day to 0.08 m/day at the end of 20 years of simulation.

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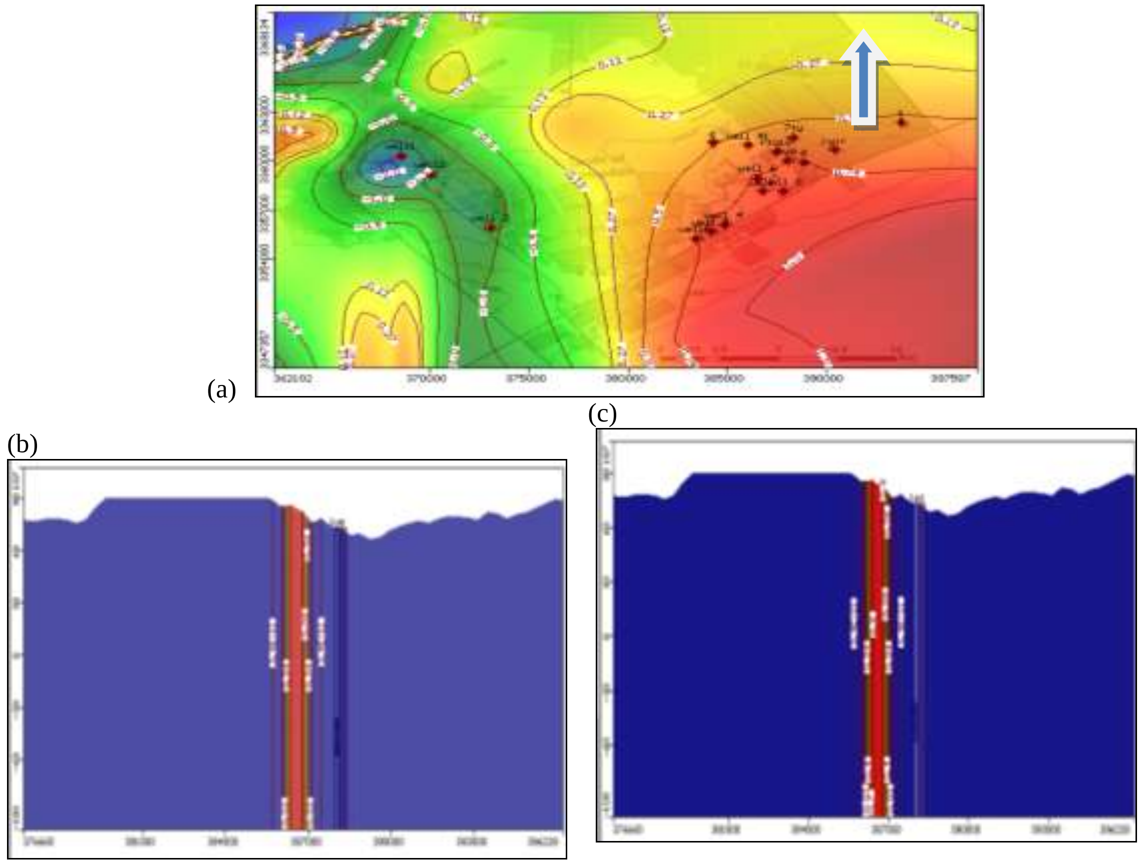

Fig. (9): (a) Expected drawdown in the head for the study area at the end of 20 years., (b) Cross section along the study area showing the extent of Sr plume at the end of 20 years simulation, (c) Cross section along the study area showing the extent of Fe plume at the end of 20 years simulation.

Another scenario applied for both Fe and Sr by increasing their concentration to 200 mg/l to test the extent of the natural attenuation of the aquifer material against the contamination load, the results showed that the natural attenuation capacity of groundwater is relatively high. The plume extent did not exceed 500 m from the location of the oxidation bonds after the end of the simulation. This results revealing that, for future development planning in the area, any additional new wells should be located beyond distance 500 m from the location of these bonds. The approach applied in this work should be applied during the selection of any harmful waste disposal facility.

CONCLUSION AND RECOMMENDATIONS

The paper deals with the impact of waste water bonds on the quality of groundwater system in 10^{th} of Ramadan City, where the wastewater from both industrial effluents and domestic sewage is drained into three incompletely lined oxidation ponds and then directly used for irrigation of new reclaimed areas. The results show that the oxidation ponds are highly polluted by heavy metals and it is highly recommended that wastes from oxidation pond must not use in irrigation without proper treatment. Under current development strategy, the effect of the oxidation bond on the groundwater system seems to be limited, because of the absorption capacity of the soil. However, on the long run, the mobility of heavy metals might occur if the adsorption capacity of the soil reached; so more insight on the natural attenuation capacity is imperative for this area. The treatment of soluble heavy metals, biological and organic pollutants in industrial drains and human activity before disposal of industrial wastes into oxidation bonds. Alternatively, the treatment could be performed at the industry's site where it may be recycled in the plant. New drilled wells should be located far away from pollution sources and observation wells should installed around oxidation ponds for periodic monitoring. In general, applying the integrated approach of the modeling the unsaturated zone / saturated zone for evaluating the environmental impact industrial bonds on the groundwater system; is considered a constructive approach that can be used before planning and choosing the optimal hazardous disposal sites, or even in choosing the best location for less vulnerable groundwater wells in these areas.

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