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Simulation of Contaminants Transport and Groundwater Flow for Basrah Landfill Site

Abstract- *groundwater aquifers is mostly effected from landfills due to intrusion of leachate from its base b. Active surface of landfills represents main source for leachate generation during rains or may be due to direct contact with groundwater, leading to the transport 5 pollutants from landfill which is intrudes to the aquifer under the landfill. In this research a 3-dimensional simulation models was constructed and calibrated to characterize groundwater flow and leachate pollution transport from Basrah province main landfill site. The selected study area is Al-Rafdhia landfill site, which is lie at Al-Zubair district (southern part of Iraq at Basrah). The model used in the simulation was Visual MODFLOW finite difference approach. All the required landfill and aquifer parameters, stressing and recharge estimates from field and laboratories works, Basrah climate data, observations, soil investigation reports and previous studies for the same region and then used in the model or adjusted by calibration. Six-month observation period was achieved to estimate the monthly state variables data such as heads and physical-chemical leachate and groundwater characteristics by measurement and sampling from the groundwater selected wells. Many soils and water samples were collected to know the aquifer characteristics and analyze the pollutants concentration values. Accordingly, the calibrated model was used to simulate the flow and pollution transport at current year and then used for prediction of future changes in water levels and landfill contaminant transport in the aquifer for planning period of 15 future years. The final simulation and predication results show that the landfill represent main source of contamination and the pollution would occur in the aquifer at high levels and with approximate lateral transporting of 285 m/year if the current state of solid waste disposal continue with increase of pumping from the aquifer from its current rate with future. The groundwater flow and concentration profiles for pollutants with time and spaces from the pollution sources was predicated and a 3-D representation were done for pollutants spreading for specific pollutants.*

Keywords- *Landfill. Pollution. Leachate. Groundwater. Visual MODFLOW.*

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1. Introduction

Groundwater contamination is one of the serious environmental problems that these days human face to it. Contamination of groundwater is mostly effected due to the process of industrialization and urbanization that has progressively developed over time without any regard for environmental consequences. The solid waste disposal landfills are one of the principal point sources of contamination that affect the quality of groundwater in the highly permeable surficial aquifer systems. In recent times, the impact of leachate on groundwater and surface water has get more attention due to its overwhelming environmental significance. Leachate migration from wastes sites or landfills give a high danger to water resource if not managed.

The groundwater pollution from landfills has given rise to a many of researches. Numerical models were also developed to simulate the ground-water flow and contaminant transport through the aquifers. Many cities, which have large landfill areas and depend upon groundwater, are particularly affected by this problem [1].

Al-Rafdhia (Zubair) aquifer in Basrah is a good example for landfill pollution problems where this area contain largest landfill site and have many agricultural field which depends mainly on groundwater. Basrah province is critical situation in water resources that requires immediate efforts to improve the water situation in terms of quality and quantity were demand greatly exceeds water resources supply. This research aims are: (i) study of contaminants transport from landfill zone at Al-Rafdhia area aquifer and (ii) pollutants contamination spreading prediction through groundwater flow for the aquifer. The model was uses the collected data to predicate the pollution concentration profile through groundwater aquifer. A proper waste management con be done after predication of groundwater pollution under

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the landfills. Groundwater pollution prediction serve as a first step to improve the environment.

2. Site Description and Hydrology

The study site located in the south east of Iraq in Basrah province where its locates between (738600 and 755000)E and (3357430 and 3373270)N, with area of (300 km^2) and with average ground elevation of 20 m above mean sea level. The landfill examined in this paper is lie in Al-Rafdhia region within Al-Zubair district, located at 35 km southwest of Basrah near the main highway to Safwan city where the site was originally a borrow pit for lateritic soil with a depth of 12-14 m and equal to groundwater table.
Figure 1 shows the study area and landfill site, where the horizontal dimensions of about 17.5 x 17.5 km and landfill extend surface area of about 1.5 x 1.5 km and started operation in 2009 with an average about 1200 to 1300 ton/day of solid waste is filled on the site with the solid waste filling depth varying from 6 to 8 m (appendix A).
The solid wastes filled on this site are mainly from domestic, commercial and industrial sources, however because of population increasing; about 5% of solid waste is added yearly. Al-Rafdhia land filling dumpsite is surrounded by many agricultural areas, which are depended mainly on groundwater for irrigation in which they are very affected by groundwater contamination due to the leach out of pollutants from the landfills.
There are many groundwater wells in the study area including some wells within 3000m close to the landfill site. Groundwater aquifer in the study area is an unconfined with alluvial deposits soils, which are composed mainly of sand and gravel as shown in some of soil investigation for projects achieved in the site (Figure 2) [2].
The study aquifer represent as apart lie within Dibdibba aquifer, where the top part of Dibdibba Sandy formation, clastic sand unconfined usages with high permeability soil condition.
All agricultural areas in the study region was irrigated with water pumped from the same aquifer [3].
Morphologically, the study area is a flat surface that generally slopes towards northeast with large borrow pits. The groundwater flow direction is from the south-west to the north east towards the Shat Al Basrah river with average hydraulic gradient of about 0.0018 [3,4].
Based on the climatic data of Al-Basra meteorological station for the period 1980-2015, the climate for the study site characterized by hot, dry climate and high wind velocity in summer, and cold, humid and little to moderate rainfall in winter. In general, the study area located within semi-arid zone with average annual precipitation of 152 mm/year.

3. Methodology

In this paper, numerical modeling package, Visual MODFLOW (version 4.2.) was used to simulate and predict the variability of groundwater flow and pollutants transport spilled from landfill. Visual MODFLOW is a powerful software package using MODFLOW, MODFLOW SURFACT, MODPATH, MT3D/MT3DMS, MGO, Win PEST etc. [5]. This software consists of input, run and output phases. In first phase, characteristics of aquifer and groundwater and boundary conditions are assigned. Run phase is designed to translate input phase into the standard input for simulation. Output illustrates results of simulation-included concentration of contamination, water levels, flow and so on .
This technique is used for predication the fate and transport of pollutants from landfill of Al-Rafdhia. Estimation the concentration of pollutants would be important to know amount of pollutants intrusion in future. It might be serve to control pollution in landfill.

4. Field Works and Laboratory Analysis

The field works are included the detailed field surveys to investigate all study area and groundwater characteristics. Many soils and water samples were collected to know the aquifer characteristics and analyze the pollutants concentration values. In the monitoring process, different devices such as level, tape, sounder and GPS were used to measure the groundwater level and sampling monthly for the period (Sep, 2015; Feb, 2016). Four points for groundwater monitoring and sampling were selected, the first point (S1) represent Al-Rafdhia landfill (main pollutants source), the other three points (W1, W2 and W3) are some wells which is closer to the solid waste dumpsite as shown in Figure 3. The three bore well samples W1, W2 and W3 were selected within a distances of 2400, 4700 and 5100m respectively away from landfill site.

The leachate and groundwater samples were collected in clean plastic bottles of 1.5 L and then transported to the laboratory for chemically analyzed. All the samples were analyzed for relevant physical-chemical parameters according to internationally accepted procedures and standard methods (appendix A).The parameters analyzed in the groundwater and leachate samples include: Total nitrogen (TN), Sulfates (SO_4), Chloride (Cl), Bicarbonates (HCO), Total dissolved solids (TDS), pH, Phosphor (P) and some heavy metal such as; lead (Pb), Potassium (K), Nickel (Ni) and iron (Fe).

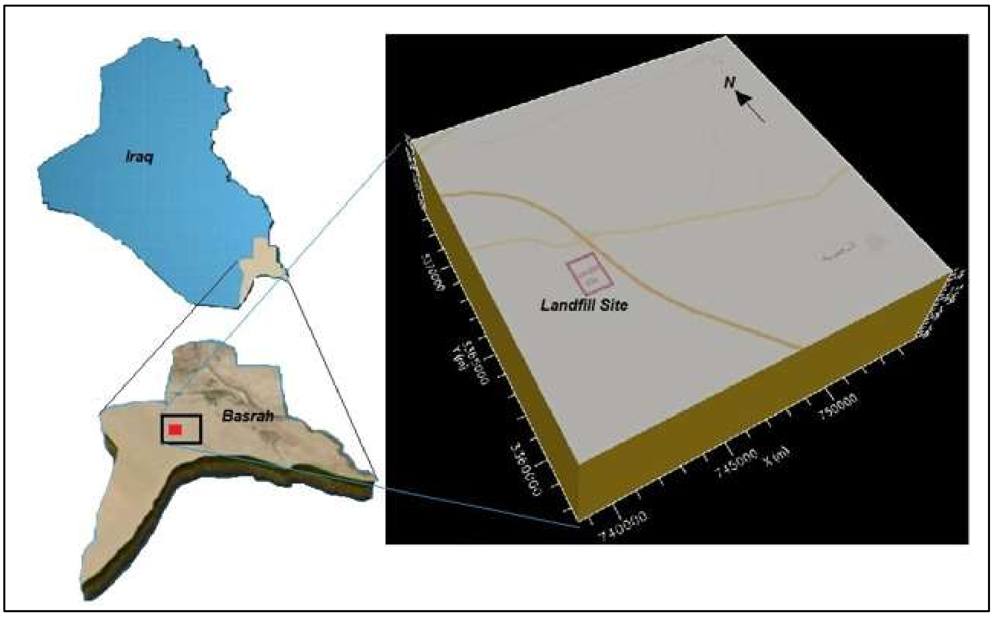

Figure 1: Location map for the study region of Basrah landfill site

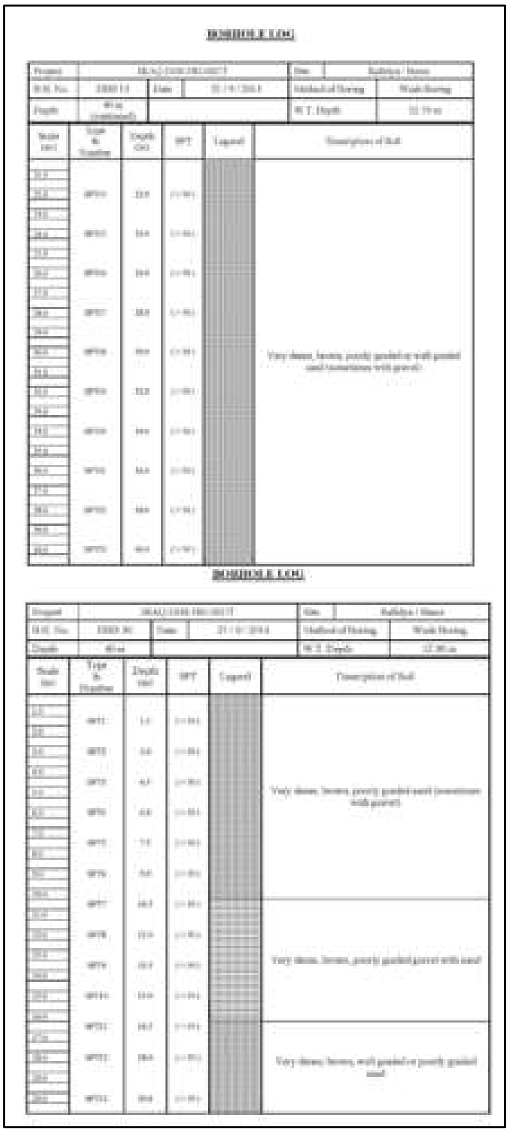

Figure 2: Geological cross section for two selected borehole logs in the study area aquifer show soil profile [2]

The contaminants selection that must be modeled in this work was based on screening the effective pollutant that relied on concentrations in site-specific leachate samples, susceptibility to concentration limits in irrigation water. The screening indicated that chloride would be the most critical pollutants for ground water resources due to its high concentration, effect on irrigation and conservative with transport and time [6]. Chloride was selected as an indicator for the numerical simulations, where the other pollutants can be determined at any time and space proportionally from chloride concentrations.

Tables (1 to 3) show the laboratory analyses of analytical parameters for the measured initial hydraulic head and the concentrations of specified selected pollutants from the landfill point and observed wells during the study period.

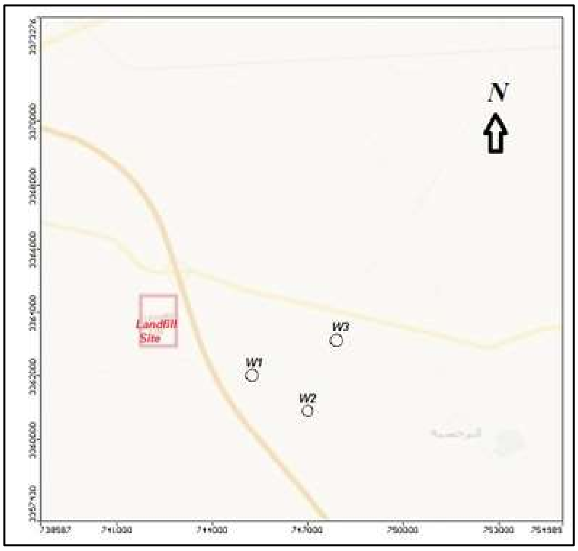

Figure 3: Sampling point of landfill and monitoring wells distribution in the study area

Table 1: Initial hydraulic heads and parameters concentrations for observed wells samples for the period (Sept 2015; Oct 2015)

Samples	Groundwater elevation (m)	Parameters concentrations (mg/l)										
		T(N)	SO_4	Cl^-	HCO_3	TDS	pH	P	Pb	K	Ni	Fe
S1	10.0	600	5765	15250	55360	43000	6.9	0.55	10.1	3560	0.42	9.3
W1	8.60	190.8	4218	6415	4965	19340	6.4	0.35	2.86	1468	0.33	4.8
W2	7.25	28.6	3885	5280	2910	12750	7.0	0.19	1.80	815	0.31	1.75
W3	6.95	2.8	3450	3600	1750	10845	6.5	0.15	1.93	148	0.27	1.35

Table 2: Initial hydraulic heads and parameters concentrations for observed wells samples for the period (Nov 2015; Dec 2015)

Samples	Groundwater elevation (m)	Parameters concentrations (mg/l)										
		T(N)	So_4	Cl^-	HCO_3	TDS	pH	P	Pb	K	Ni	Fe
S1	10.1	585	4730	14680	51420	41900	7.0	0.48	9.3	3050	0.49	8.8
W1	8.65	185	3575	5810	5075	17820	6.8	0.42	1.45	1550	0.37	5.3
W2	7.37	32.7	2430	4915	3025	11770	7.1	0.22	0.97	790	0.24	2.25
W3	7.10	9.5	2108	4108	1547	9680	6.7	0.19	0.86	115	0.15	1.81

Table 3: Initial hydraulic heads and parameters concentrations for observed wells samples for the period (Jan 2016; Feb 2016)

Samples	Groundwater elevation (m)	Parameters concentrations (mg/l)										
		T(N)	SO_4	Cl^-	HCO_3	TDS	pH	P	Pb	K	Ni	Fe
S1	10.13	596	4520	14965	52800	42760	7.2	0.51	9.9	3115	0.40	7.5
W1	8.65	168	3185	5755	5270	17560	7.0	0.38	2.5	1437	0.28	3.8
W2	7.40	45.7	2090	4615	3120	12070	7.1	0.25	0.75	915	0.20	2.9
W3	7.14	11.8	1879	3974	1380	9940	6.5	0.20	0.64	165	0.13	1.95

Note: (each value represent average from three samples)

5. Simulation Model Setup

A conceptual model for the study area was constructed with total effective area of 300 km2, and model thickness of 70 m as shown in Figure 4. The model with surface distances of 17.5 x 17.5 km where it extended toward the east and north to reach near Shat Al-Basrah to get best expression for boundary conditions for river edge. For the study area aquifer a uniform spaced, finite-difference grid model was constructed so that the north represent the y-axis and x-axis represent the east. The grid consists of 100 rows and 100 columns, regularly spaced grid in horizontal and longitudinal directions. A seven cell (layer) in the vertical direction with constant thickness (ΔZ) of 10 m topping by land surface elevation. The base of the layer is set at an elevation of 50 m under water table to ensure all the wells at full penetration within the model. The total number of model regularly spaced cells is 10000 cells. Each cell is 175 × 175 m in the horizontal plane as shown in Figure 4.

The well package were used for aquifer stressing where all the known production wells were determined as shown in Figure 5. More than 120 wells found in the study area boundaries, stressing the aquifer with an average well abstraction of 200 m^3/day which represent the main source of fresh water for agricultural fields in the region [7].

Constant concentration were assigned to landfill site as a boundary condition of the model with a specified pollutants concentration of (15250 mg/l) because the landfill bed level is below or at same of constant groundwater levels at the borrow pits of the landfill site. The chloride concentration was chosen among the specified pollutants parameters for simulation as constant concentration source. The other pollutants can be estimated proportionally from simulated chloride estimation at any time and distance. The constant and initial concentrations and heads were calculated from the measured water levels and pollutants concentrations at that boundaries and specific points during the period of observations. At the land surface, a Neumann-influx boundary condition was assigned and the recharge of the aquifer represents by the recharge package [8,9]. The sources of the recharge are rainfall and return flow with proportion of infiltration of 20% from rainfall with estimated value of (30.4 mm/yr)[10] . The total period of simulation predication was planned for 15 years from 2016 until 2031; the 15-year simulation period is separated to 15 stress periods.

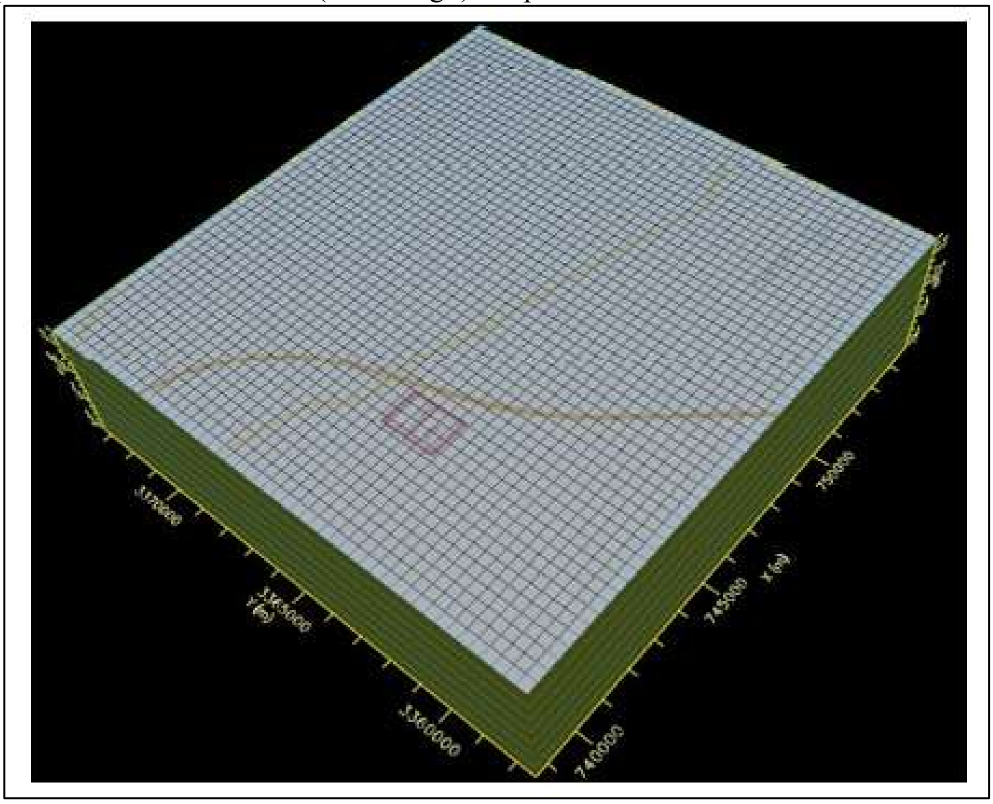

Figure 4: The conceptual model and the finite difference grids for the study area aquifer

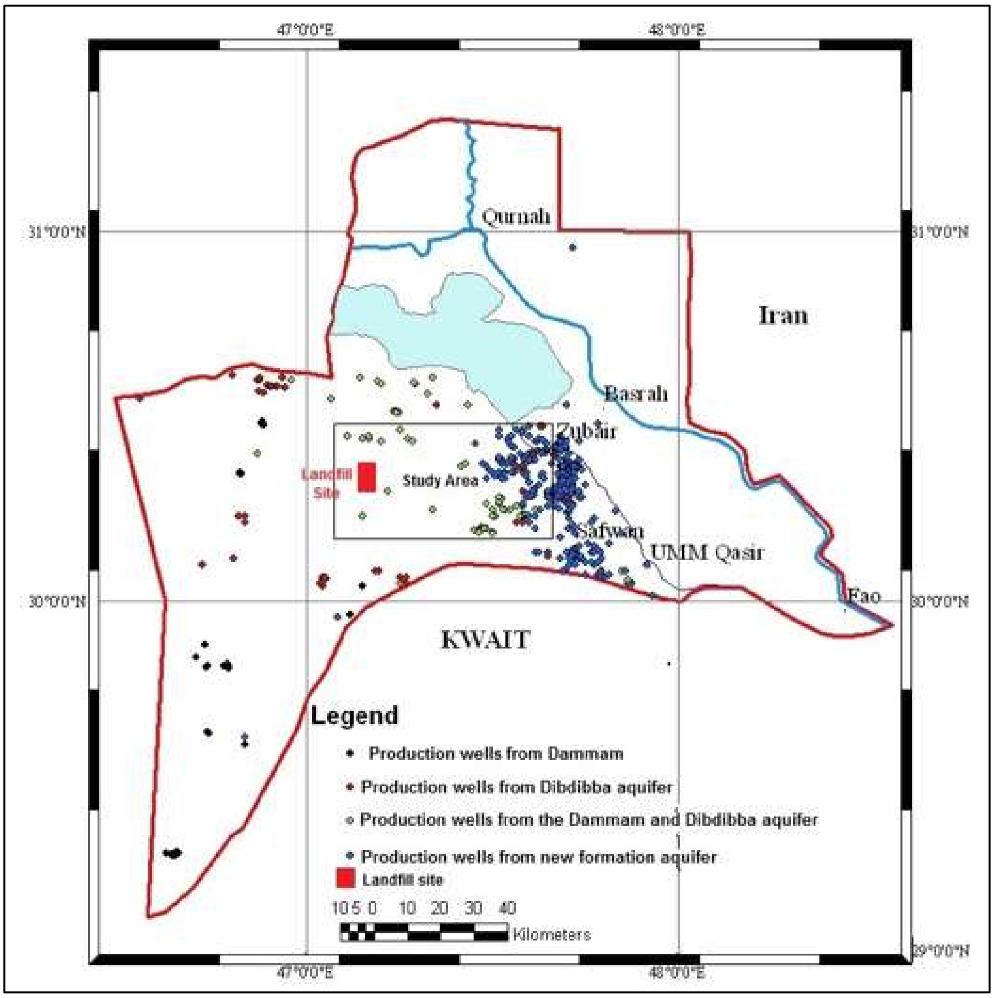

Figure 5: Production wells distribution in the study area aquifer [7]

6. Aquifer Parameter and Modeling Data

Hydraulic aquifer parameters are estimated from field works, laboratory testing, soil investigation reports that were done for Rafdhia DGS / Iraq DGS Project [2] and previous study for the same region. According to the laboratory tests and historical data from Basrah groundwater directorate and literature studies for the study aquifer, the values of hydraulic conductivity (K) was mostly within a range of 80-120 m/day and specific yield (Sy) of about 15-25%. Some of aquifer hydraulic parameters such as vertical permeability (Kv) and longitudinal and transvers dispersivities (αL and αT) were estimated from soil properties standards tables or from other researches done at state of Kuwait [11, 12]. The groundwater levels at present state are found at about 8-13 m depth from land surface, Table 4 summarizes the study aquifer input parameters for simulation model.

7. Simulation Model Results

First run for the simulation model was achieved for model calibration. The first run of model results were at year 2015 and used for calibration to compare between the calculated heads data and those observed heads in the three groundwater monitoring wells. Based on these results, Standards Error of the Estimation (SEE) was 0.14 m, a root mean squared (RMS) rate of 0.142 m was achieved for calibration with coefficient of determination (R2) = 0.9875. After completing the calibration of the model and adjust some of the sensitive parameters such as (K and recharge percolation ratio) by using Best fitting for the flow and transport simulation model, the developed model was then used to simulate the groundwater levels, pollutants concentration, flow, and movement at the current year (2016) and then will be used for 15 future years predication.

I. Groundwater Levels, Concentrations and Flow

The simulated results for steady state groundwater levels at year 2016 are shown in Figure 6. It's clear from the Figure 6 that the initial water levels decrease linearly from south-west to north-east towards Shatt-Al-Basrah drain river with average hydraulic gradient of about 0.0009.

Figure 7 shows the initial steady state groundwater flow directions and velocity vector distribution for the aquifer at year 2016. Under natural conditions, groundwater flow direction in the study region is towards Shatt-Al-Basrah Drain River.

II. Simulation Predication for Pollutant profile

The predicated simulation was achieved for 15 future years using the first run results of year 2016 as initial conditions and then used with details recharges data and climate data for transient state of simulation for stressing aquifer by expected pumping from existing wells during 2016-2031 .

Figures 8, 9 and 10 show a 2-dimentional representation for the future changes in the predicted water levels and chloride concentrations as a selected pollutant corresponding to the extent of pollutants from the landfill source in the aquifer through three selected periods during the simulation years (2016-2031).

Figures 11, 12 and 13 show a 3-dimentional representation for the future changes in the predicted water levels and chloride concentrations corresponding to the extent of pollutants from the landfill source in the aquifer through the simulation years (2016-2031.(

Figure 14 shows the predicated pollution concentration variation with distance away from landfill for three future periods. It's clear from the figure the pollution concentration levels increase with time and decrease with distance away from landfill towards the flow direction.

8. Summary and Conclusions

The main aim of this research is evaluate the effect of landfill leachate contamination spreading transport through groundwater. Based on the data from this research, the Al-Rafdhia landfill, operational since 2009, is in the initial stabilization process and the leachate was as constant source of pollution. Although leachate was with high contents of inorganic and organic pollutants as well as the heavy metals concentrations as a toxic nature. The analyses and simulation data indicate the leachate from landfill represents the main point source for most of pollutants because groundwater flow direction is outward away from Al-Rafdhia landfill site, and the contamination concentration was decreases as we go away from the Al-Rafdhia landfill site along the flow of groundwater .

The model gave good results for pollution distribution in the aquifer. The pollution transport at this aquifer will be at rate of 285 m/year. On the other hand, the simulation results show that, in year 2031 the pollutant will reach to a distance of 4 km from the landfill and to a depth more than 60 m at these conditions of pumping and recharges.

9. Recommendations

- The results support the need for continuous monitoring of the groundwater.
- Re- designing for solid waste landfill with non-impermeable protection under it such as clay or plastic cover to prevent leachate from getting to groundwater, adoption of a sustainable land management of solid waste and new designs for landfill construction methods must be achieved to prevent groundwater contamination
- Landfills bed elevation must be higher than maximum groundwater elevation and leachate collection systems must be stored the liquid without any contact with water table.
- The perspiration must be prevented to reach the landfill by clay caps and then to decrease runoff from carrying contaminants from the landfill into the groundwater.
- Decrease the wells numbers and pumping from wells close to landfill site to slow the pollutants transport away from landfill.

Table 4: Original aquifer parameters assigned for Al-Rafdhia aquifer

Parameter	Value
Hydraulic conductivity K_{xy} (m/d)	90
Hydraulic conductivity K_z (m/d)	50
Total porosity (%)	32
Effective porosity (%)	28
Specific yield	0.25
γ_s: Average soil dry density (Kg/m^3)	1.78
α_L : longitudinal dispersivity (m)	15
α_T : transverse dispersivity (m)	1.5
α_v : vertical dispersivity (m)	0.15
fluid viscosity for water (kg.m/sec)	0.001

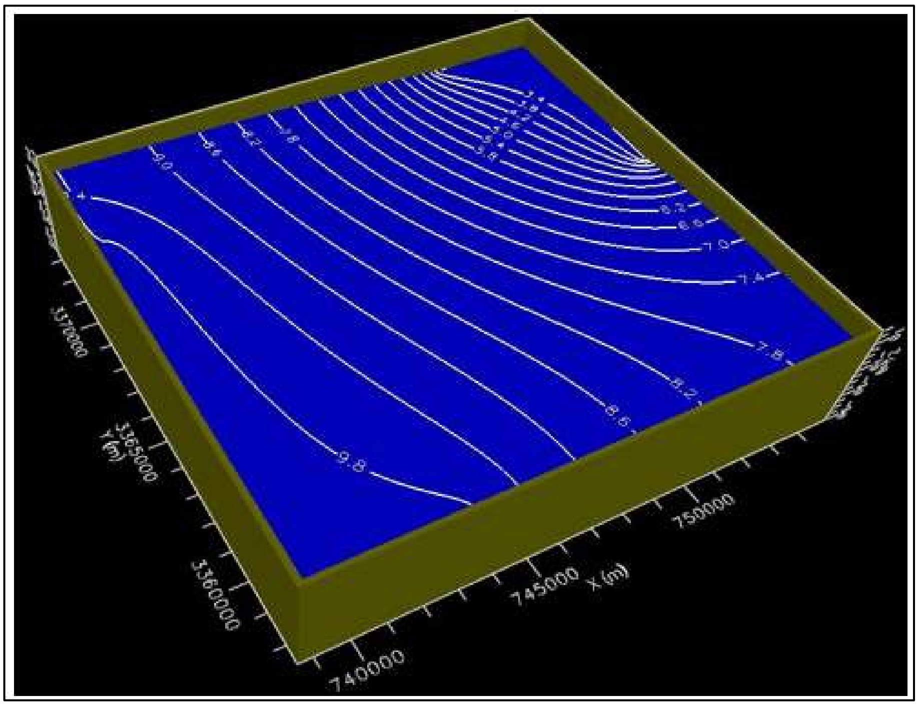

Figure 6: Initial or steady state groundwater levels contours for Al-Rafdhia aquifer

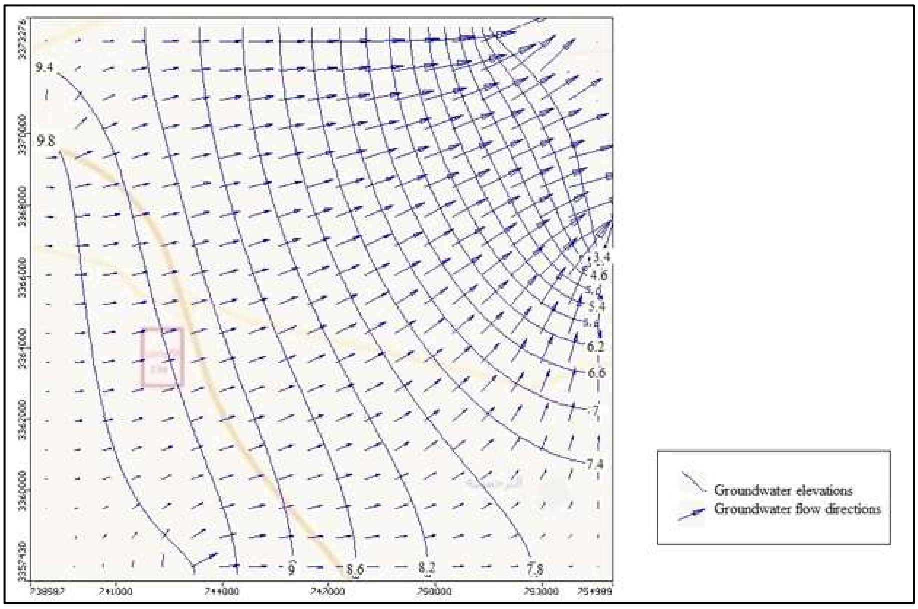

Figure 7: Initial Groundwater flow directions at year 2016

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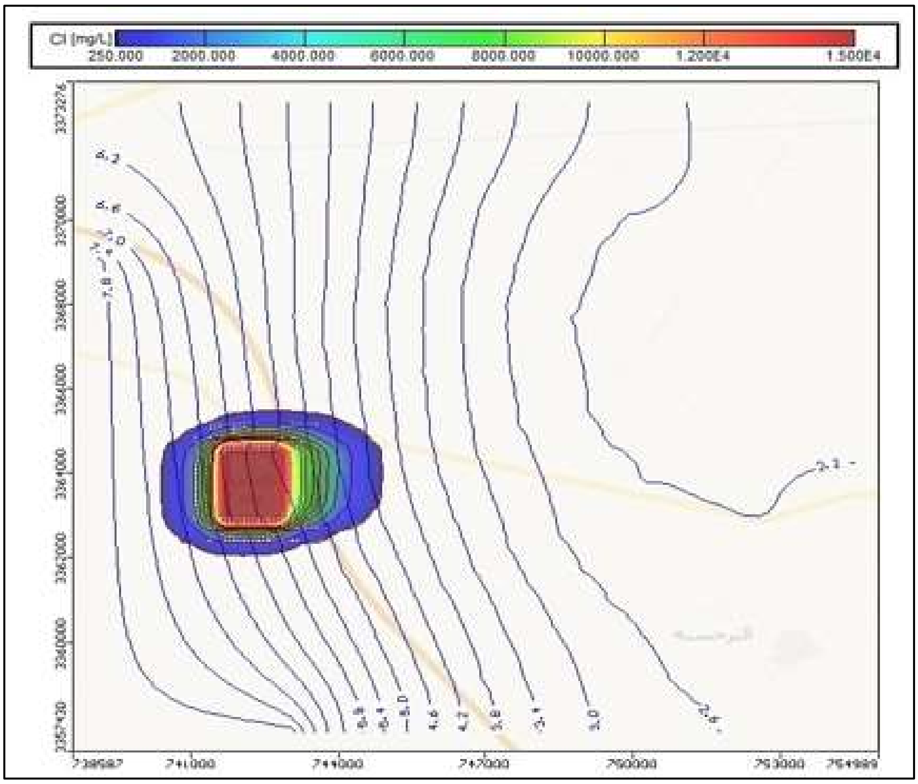

Figure 8: Extent of chloride concentrations pollutants from the landfill after 5-years

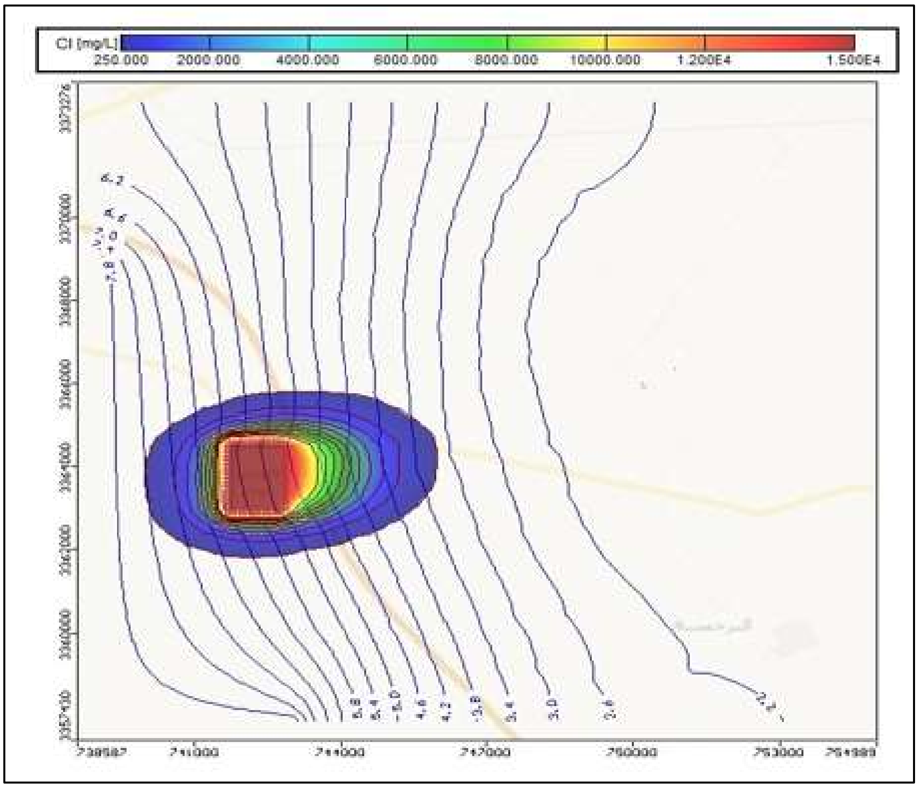

Figure 9: Extent of chloride concentrations pollutants from the landfill after 10-years

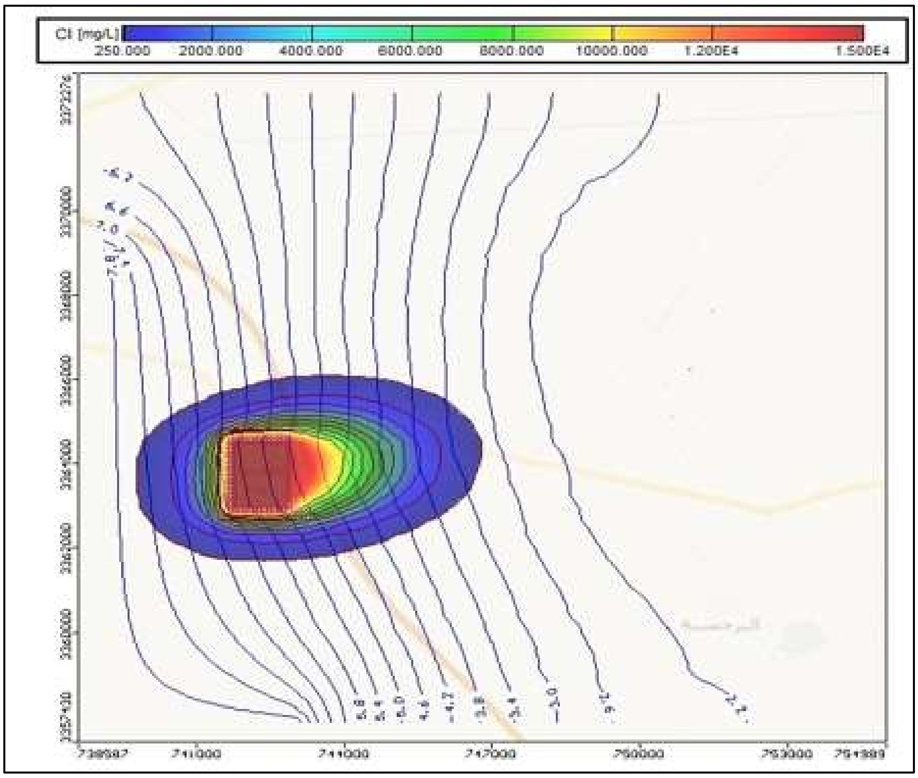

Figure 10: Extent of chloride concentrations pollutants from the landfill after 15-years

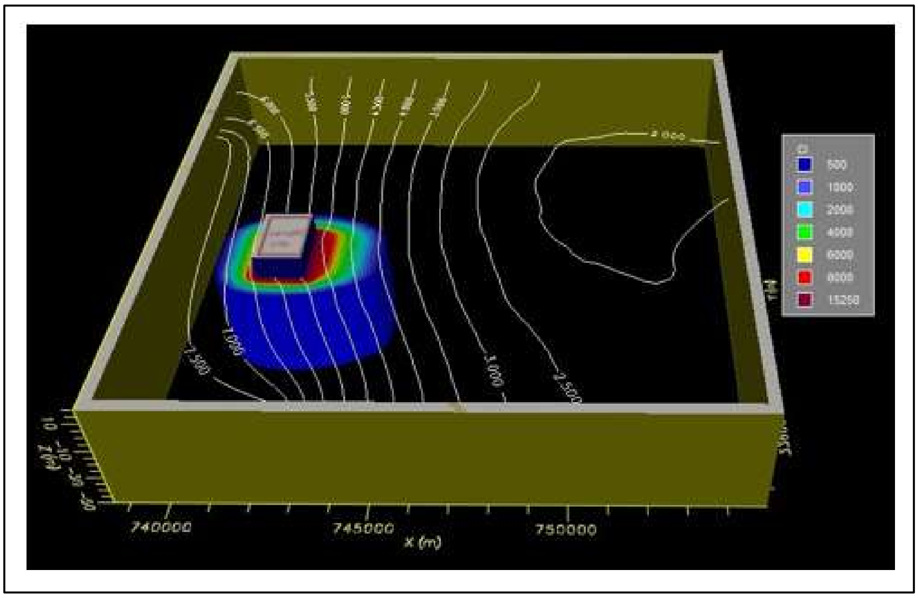

Figure 11: 3-D profile for extent of chloride concentrations pollutants from the landfill after 5-years

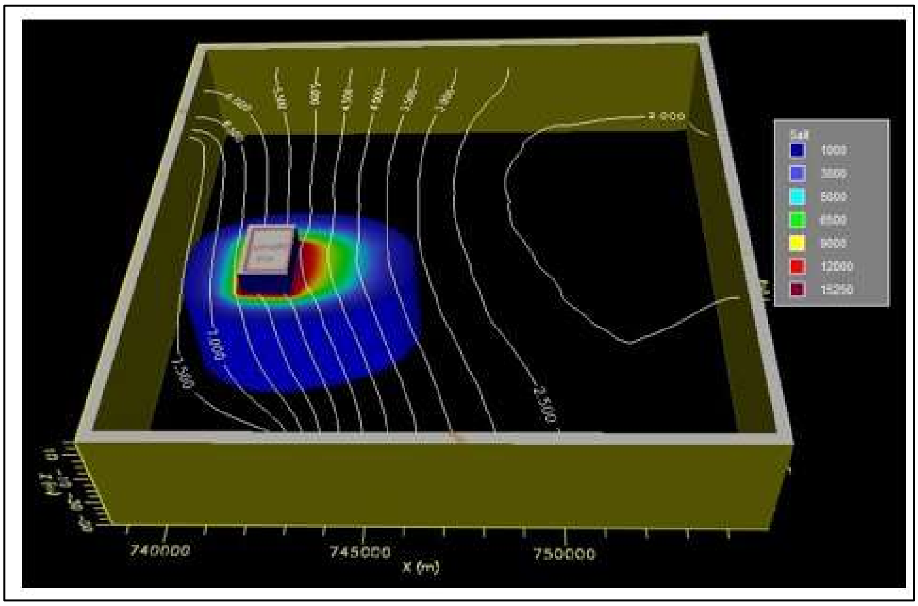

Figure 12: 3-D profile for extent of chloride concentrations pollutants from the landfill after 10-years

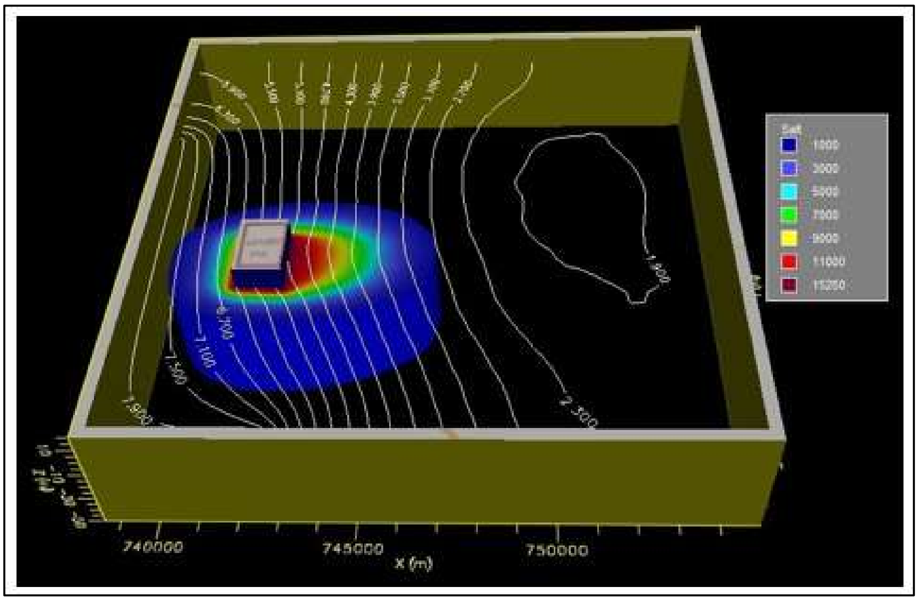

Figure 13: 3-D profile for extent of chloride concentrations pollutants from the landfill after 15-years

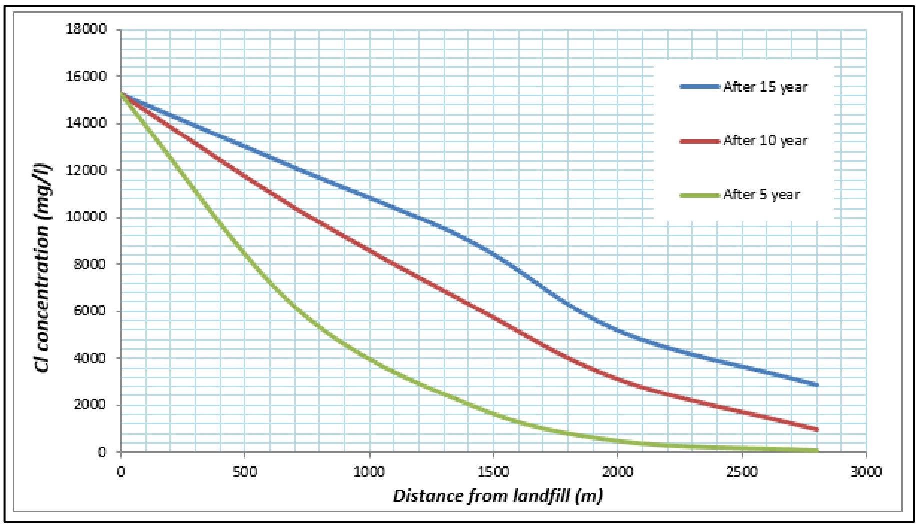

Figure 14: variation of pollution concentration with distance from landfill with time

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Author(s) biography

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Currently working in Basrah University/ Engineering College since 2000 as a lecture at Civil Engineering department with more than 17 yrs of vast experience in teaching and many features of engineering projects

Appendix A: Some of landfill and works pictures