



Ain Shams University  
Faculty of Engineering  
Irrigation and Hydraulics department

GROUNDWATER POLLUTION RISK ASSESSMENT IN SEMI – ARID  
REGIONS (CASE STUDY: SADAT CITY)

Submitted By  
Eng. Ahmad Mohamed Ahmad Alkhadrawy

A Thesis  
Submitted In Partial Fulfillment of The  
Requirements for the Master of Science (M.Sc.) Degree  
In Civil Engineering  
(Irrigation and Hydraulics)  
Supervisors

Prof. Dr.Nagy Ali Ali Hassan  
Professor of Irrigation and  
drainageFaculty of engineering  
Ain Shams University

Prof. Dr.MahaAbdelslam Omar  
Professor of Groundwater Hydrology  
Research Institute for Groundwater

Dr. Peter Hany S. Riad  
Assistant Professor of Groundwater Hydrology  
Irrigation and Hydraulics Department  
Faculty of engineering  
Ain Shams University

Cairo 2018



Ain shams university  
Faculty of engineering  
Irrigation and Hydraulics department

Approval sheet

This is to approve that the thesis presented by ` **Eng. Ahmad Mohamed Ahmad Alkhadrawy**

To the Irrigation and Hydraulics department– Faculty of Engineering- Ain Shams university ` **GROUNDWATER POLLUTION RISK ASSESSMENT IN SEMI – ARID REGIONS (CASE STUDY: SADAT CITY)**, for the Master of Science (M.Sc.) in Civil Engineering Irrigation and Hydraulics has been approved by the examining committee.

Examiners committeeSignature

**Prof. Dr.KhaledShafiek Hafez Elkholy**

Professor of Environmental Hydraulics

Faculty of engineering-Ain Shams University

**Prof. Dr. Osama KhairySalehEraky**

Professor of hydraulics

Faculty of Engineering - Zagazig University

**Prof. Dr. Nagy Ali Ali Hassan**

Professor of Irrigation and drainage

Faculty of engineering - Ain Shams University

**Prof. Dr.MahaAbdelslam Omar**

Professor of Groundwater Hydrology

Research Institute for Groundwater

Date: 25 March 2018

## Statement

This dissertation is submitted to the Faculty of Engineering-Ain Shams University for the degree of Master of Science (M.Sc.) in Civil Engineering (Irrigation and Hydraulics).

The work included in this thesis was carried out by the author in the department of Irrigation and Hydraulics, Faculty of Engineering-Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

Date:

Name: Ahmad Mohamed Ahmad Alkhadrawy

Signature:

## Researcher Data

- Name: Ahmad Mohmad Ahmad Alkhadrawy
- Date of birth: 27/4/1981
- Place of birth: Cairo – Egypt
- The last scientific Certificate: Structure Engineering Diploma
- Field of specification: Structure
- University issued The degree: Ain Shams
- Date of issued degree: 2009
- Current job: Team leader Design engineer inEngineering Consultancy and Technical Services in Arab Contractors Company

## ACKNOWLEDGEMENTS

Praise is to ALLAH who guided and aided me to finish this work and give me the ability to success.

I wish to express my thanks to Prof. Dr. Nagy Ali AliHassan, Professor of irrigation and drainage, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, for supervising this work, continuous encouragement, ideas ,constructive comments and his insightful academic advising throughout my study.

The author wishes to express his deep gratitude to Prof. MahaAbd El-Salam from the Research Institute of Groundwater (RIGW) in Egypt. My grateful appreciation is also extended to Dr. Peter HanyRiad, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, for his kind supervision, encouragement discussion, fruitful comments and valuable advice, and special thanks extend to his father Prof. Dr.HanysobhyRiad, public works Department , for his kindness , encouragement and support to me during my undergraduate and postgraduate studies.

All thanks to all myparents to help me to complete this work and always pushing me a head in all my education stages.

## Contents

1	Introduction .....	1
1.1	General .....	1
1.2	Definitions and Advantages .....	1
1.3	Problem Definition.....	1
1.4	The Research Objectives.....	2
1.5	Methodology .....	2
1.6	Thesis Structure.....	2
2	Literature Review .....	3
2.1	Introduction .....	4
2.2	Capture Zone .....	4
	Analytical Models .....	<b>Error! Bookmark not defined.</b>
	Arbitrary Fixed Radius Model .....	<b>Error! Bookmark not defined.</b>
	Calculated Fixed Radius Model .....	<b>Error! Bookmark not defined.</b>
	Theis model .....	<b>Error! Bookmark not defined.</b>
	Numerical (Semi-Analytical) Models .....	<b>Error! Bookmark not defined.</b>
	RESSQC Model .....	<b>Error! Bookmark not defined.</b>
	MWCAP Model .....	<b>Error! Bookmark not defined.</b>
2.3	Cases of groundwater pollution by Industrial, chemical and Bacterial pollution .....	<b>Error! Bookmark not defined.</b>
2.4	Case studies .....	5
	Case study in Portugal.....	5
	Case study in Lahore, Pakistan .....	6
	Case study in Kabul basin, Afghanistan .....	9
2.5	Groundwater in Egypt.....	10
	Pollution of Groundwater in Egypt.....	12
	Nile aquifer system.....	12
	POLLUTION SOURCES .....	15
	Environmental impact .....	19
	SAMPLING AND ANALYSIS .....	19
	Miocene (Moghra) Aquifer .....	21
	Quaternary Aquifer .....	24

3	: Case study (Sadat city).....	27
3.1	Introduction .....	28
3.2	El-Sadat City physical settings .....	28
	Geographic location and area distribution .....	28
	Climate .....	30
	Water resources .....	30
	Water Recharge in the city .....	31
	Land Use.....	31
	Residential .....	31
	Industrial.....	31
	Agricultural .....	32
	Geological and Hydrogeological Setting .....	34
	Groundwater in study area .....	35
	Groundwater Hydrochemistry .....	38
	Electric conductivity (EC) and total dissolved solids (TDS).....	38
	Nitrates concentration .....	40
	Alkali and Sodium Adsorption Ratio (SAR) .....	40
	HydrogenIonConcentration(pH) .....	42
	GroundwaterofQuaternaryOrigin .....	42
	Geochemical Classification (Trilinear Diagram) .....	43
	Interaction between Water and Rocks.....	44
	Anticipated Pollution Sources.....	45
	El-Sadat city wastewater treatment plant.....	49
4	: Model Governing Equations .....	51
4.1	Introduction .....	52
4.2	Saturated Groundwater Flow in a Porous Media.....	52
	Darcy's Law and Dupuit Assumptions for Phreatic Aquifers.....	52
	Continuity Equation .....	53
5	: Groundwater flow modeling and pollutant transport model.....	56
5.1	Introduction .....	56
5.2	Data Manipulation using ArcGIS 10.3 .....	57
5.3	Selection of the numerical model and solver:.....	60

5.4	Numerical Model Design .....	61
5.5	Model elevations .....	61
5.6	Boundary conditions (B.C) .....	62
	Initial Model inputs .....	62
	Model elevations .....	62
	Boundary conditions .....	63
	Initial Model inputs .....	64
	Specific Yield (Sy) .....	64
	Specific Storativity ( $S_0$ ).....	65
	Porosity (n).....	65
	Recharge .....	65
5.7	Model Calibration .....	66
	Model Calibration Objectives .....	68
	Calibration general assumptions .....	68
	Calibration procedure .....	69
	Steady State Calibration Results .....	70
5.8	Study the movement of particles pollutants to wells: .....	72
5.9	Pollutant transport model to wells: .....	75
5.9.	Remedial Solutions to minimize or eliminate the pollutant transport .....	87
	Scenario 1: Using a long diaphragm Wall.....	87
	Scenario 2: Long diaphragm wall and preventing pollution from close areas.....	89
	Scenario 3: Shorter length of diaphragm wall and preventing pollution from close areas .....	91
	Scenario 4: Using Artificial Recharge Basin before capture zone.....	93
6	: Conclusions and Recommendations .....	96
6.1	Conclusions: .....	97
6.2	Recommendations:.....	97
	References .....	98
	Arabic Summary .....	102

## List of Figures

Figure 2.1: Horizontal and vertical capture zone (Landmeyer, 1994) .....	4
Figure 2.2: Typical capture zone delineation using the arbitrary fixed radius model (Modified from U.S. Environmental Protection Agency, 1987). (Landmeyer, 1994) .....	<b>Error! Bookmark not defined.</b>
Figure 2.3: 3D capture zone (typical capture zone delineation using the arbitrary fixed radius model) (Modified from U.S. Environmental Protection Agency, 1987). (Landmeyer, 1994) .....	<b>Error! Bookmark not defined.</b>
Figure 2.4: Typical capture zone delineation using the calculated fixed radius model and then volumetric-flow equation (modified from U.S. Environmental Protection Agency, 1987). (Landmeyer, 1994) .....	<b>Error! Bookmark not defined.</b>
Figure 2.5: A) fragrant low-density Actions. B) Halogenated high-density hydrocarbons following a commercial spilling (modified from Lawrence and Foster, 1987) .....	<b>Error! Bookmark not defined.</b>
Figure 2.6: Groundwater provide contamination routes by on-site sanitation	<b>Error! Bookmark not defined.</b>
Figure 2.7: Landfill sites Locations and water sampling around Lahore city .....	7
Figure 2.8: Structure of regular dumped material at landfills in Lahore city (based on Haydar et al., 2012 and LWMC department) (Muhammad, Zhonghua,2014)....	8
Figure 2.9: Study area of Kabul Basin, Afghanistan, with major surface-water features. (Broshears, 2005, et al) .....	9
Figure 2.10: Main Aquifer Systems in Egypt (AMAAR). .....	11
Figure 2.11: General hydrogeological cross segment of Nile aquifer in Nile valley (Shamrukh,Abd Elwhab,2009) .....	13
Figure 2.12: Schematic chart demonstrates the groundwater contamination from waste room in Nile aquifer. (Shamrukh,Abd Elwhab,2009) .....	14
Figure 2.13: Aquifers in the western Nile Delta.....	21
Figure 2.14:The Base of Quaternary aquifer contour map.....	22
Figure 2.15:The base of Moghra aquifer contour map.....	23
Figure 2.16:Regional Lithological Cross Section for Western Nile Delta (after RIGW) .....	23

Figure 2.17: Hydrogeological cross-section (M-M') in the study area.....	24
Figure 2.18: Salinity map of western Nile Delta. (Riad, 2012).....	26
Figure 3.1: The study area location .....	29
Figure 3.2: El-Sadat City Land use and groundwater flow directions .....	30
Figure 3.3: A detailed land use map .....	33
Figure 3.4: Proposed greenways for El-Sadat City .....	34
Figure 3.5: Western Nile Delta of The groundwater aquifers .....	35
Figure 3.6: Depth to Groundwater map.....	36
Figure 3.7: Depth to Groundwater, map.....	37
Figure 3.8: Groundwater piezometric map.....	37
Figure 3.9: The studied wells location maps .....	38
Figure 3.10: TDS distribution in (mg/l) for shallow and deep groundwater in Sadat City.....	40
Figure 3.11: NO <sub>3</sub> Distribution in (mg/l) for shallow and deep groundwater in Sadat City.....	40
Figure 3.12: Groundwater for watering.....	42
Figure 3.13: Trilinear plan for the groundwater examples gathered from the Quaternary aquifer at the research place .....	44
Figure 3.14: mean concentration values of the pond and groundwater samples ...	45
Figure 3.15: Pollution Risk from Surface Activities (RIGW, 2002), .....	47
Figure 3.16: Local Monitoring Network .....	48
Figure 3.17: schematic diagram of the treatment plant at El-Sadat City .....	50
Figure 3.18: El-Sadat city treatment plant from Google Earth .....	50
Figure 4.1: A control volume for groundwater flow .....	54
Figure 5.1: Base map of the modeled area including the El-Sadat City .....	58
Figure 5.2 : DEM conversion to UTM system using 3Dem program.....	58
Figure 5.3: Study area DEM on ArcGIS program.....	59
Figure 5.4: Points that cover the study Area. ....	59
Figure 5.5: Interpolation surface of the study Area.....	60
Figure 5.6: Plan view of the top layer imported levels in the numerical model ...	62
Figure 5.7: Plan view of the top layer imported levels in the numerical model ...	63
Figure 5.8: The recharge boundaries for the study area .....	65
Figure 5.9: The movement of groundwater .....	67
Figure 5.10: Piezometric map for groundwater levels in 2006 with 22 observation points used for calibration .....	68
Figure 5.11: Calculated vs. observed piezometric levels results.....	71
Figure 5.12: Water budget after model calibration and verification. ....	72
Figure 5.13: pollutants movement and the time of arrival of the places water withdrawal. ....	73
Figure 5.14: calculation of capture zone by using equation curve.....	74
Figure 5.15: capture zone location in El Sadat city.....	75

Figure 5.16: The beginning of pollutants and the time of arrival to the place of water withdrawal. ....	76
Figure 5.17 : Capture zone for 1000 days (particles circular path lines backward) – increment 100 days .....	77
Figure 5.18: Capture zone for 10,000 days (particles circular path lines backward). ....	77
Figure 5.19: forward movement after 10,000 days, with time interval 730 days ..	78
Figure 5.20: forward movement after 40,000 days, with time interval 730 days ..	79
Figure 5.21: forward movement after 60,000 days, with time interval 730 days ..	80
Figure 5.22: Plume of pollution and concentration observation wells.....	81
Figure 5.23: Pollution transport after 1000 days .....	82
Figure 5.24: Pollution transport after 5000 days .....	83
Figure 5.25: Pollution transport after 10000 days .....	84
Figure 5.26: Pollution transport after 20000 days .....	85
Figure 5.27: Pollution transport after 40000 days .....	85
Figure 5.28: Pollution transport after 60000 days .....	86
Figure 5.29: Pollution concentration at observation wells 1 and 2 .....	86
Figure 5.30: The diaphragm wall to protect the wells area .....	87
Figure 5.31: Pollution concentration at observation wells 1 and 2 after adding wall after 60,000 days.....	88
Figure 5.32 Pollution transport up to 60000 days with sheet pile wall .....	89
Figure 5.33: shows the concentration versus time at observation wells 1 and 2. ..	90
Figure 5.34: Pollution concentration at observation wells 1, 2 and 3 after adding wall.....	90
Figure 5.35: Sheet pile walls with shorter total length = 29 km .....	91
Figure 5.36: Pollution concentration distribution after adding shorter wall and preventing recharge from close industrial zone.....	92
Figure 5.37: Pollution concentration at observation wells 1, 2 after adding wall..	93
Figure 5.38: Using Artificial Recharge Basin before capture zone .....	94
Figure 5.39: Pollution concentration distribution Using Artificial Recharge Basin .....	94
Figure 5.40: Pollution concentration at observation wells 1 and 2 after using artificial recharge basin.....	95

## List of Tables

Table 2-1: The drinking water standards set by the Environmental Protection Agency (EPA). (Riad, 2012) .....	<b>Error! Bookmark not defined.</b>
Table 2-2: Water Budget Calculation of the River Nile System .....	16
Table 2-3: Industrial Wastewater Discharge to the River Nile System .....	16
Table 2-4: Pollution Loads Discharged to Different Districts .....	17
Table 2-5: Measure of Pesticides and Chemical Fertilizers Used in Egypt (AbdElwahab and Badawy, 2004) .....	18
Table 3-1: A statement on industrial projects in El-Sadat City .....	32
Table 3-2: The mean principles of demolished ions of Quaternary .....	43
Table 3-3: Location and function of the local monitoring network in El-Sadat City .....	48
Table 5-1: The ranges of hydraulic values assumed or estimated in the model are summarized 5.4.2.5. Coefficient of soil permeability (k) .....	64
Table 5-2 : Summary of steady-state calibration statistics in model .....	71

## List of abbreviation

BCM	Billion Cubic meter
d	Average diameter of particles
EC	Electrical conductivity
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
GIS	Geographic Information System
Mn	Manganese
n	porosity
NO <sub>3</sub>	Nitrate
OC	Organic chlorine
OP	Organ phosphorus
PSQCA	Pakistan Standards and Quality control Authority
Q	The pumped flow Rate
Q <sub>B</sub>	Subsurface flow over boundary
Q <sub>L</sub>	Leakage component leaving adjacent aquifers
Q <sub>N</sub>	Natural groundwater recharge or discharge
Q <sub>R</sub>	Exchange with surface water
Q <sub>W</sub>	Local discharge or recharge such as wells
r	radius
RIGW	Research institute of Groundwater.
R <sub>n</sub>	Reynolds number
SAR	Sodium Adsorption Ratio.
SO <sub>4</sub>	Sulfate
t	Time
TDS	Total dissolved Solids.
UNEP	United Nations Environment Programme
v	Critical seepage velocity
v <sub>i</sub>	Average discharge in the i direction
VMF	Visual Modflow
WHO	World Health Organization
Δ Q <sub>s</sub>	Change in storage Q <sub>s</sub>
Δ t	Time increment
υ	Kinematic viscosity of water

## Abstract

In arid and semi-arid regions, such as in Egypt, groundwater is considered one of the main sources of water where there is a lack of surface water, like in the western and eastern deserts. Groundwater is usually used in various purposes such as domestic, industrial and agriculture. Due to the rapid expansion and uncontrolled plans of the reclamation lands (national projects and private farms) and new communities, especially in the Delta fringes. Accordingly, groundwater in such new cities should be wisely used, monitored and protected from pollution sources. Pollution sources in these cities come from industrial, agricultural seepage, leakage from wastewater treatment plants and sewer systems.

The area of interest in this study is El Sadat city, which is one of the largest and relatively new industrial cities in Egypt. It has been constructed more than 3 decades ago. It is located in the Western Nile Delta fringes, on the Cairo-Alexandria Desert Road between km 93 and km 103 from Cairo. El Sadat city and its surroundings mainly depend on groundwater for domestic, agricultural and industrial purposes. The industrial area is located in the eastern portion of the city and consists of more than 450 factories.

Sadat city is located where the two-aquifer systems overlap (the Nile Delta aquifer and Moghra aquifer). The two aquifers are separated by a semi-pervious clay layer ranging in thickness from 5 to 10 m. Due to the difference in hydraulic heads, groundwater recharge occurs from the Quaternary aquifer to the Moghra aquifer. The regional direction of groundwater flow is northeast southwest.

Sadat city is considered a vital area in the western Nile Delta fringes due to its various industrial and agricultural activities; therefore, it is needed preventive and protective measures. To maintain groundwater potential in terms of quantity and quality in order to sustain the development plans of this city at present and future as well.

This research study is dealing with a critical problem as Sadat Industrial City suffers of leakage from industrial zone, which is very close to the wells field. This means that undesirable heavy elements still exist and may pollute the groundwater on the future and cause health problems.

ArcGIS and Visual MODFLOW have been used to simulate the groundwater flow movement for the area of interest. The final result of the calibration has been used

to simulate the industrial pollutant transport rates and directions by transport MODFLOW model.

The conceptual model showed that the pollution moves from the industrial areas towards the main city drinking wells, which located near the industrial zone. However, the rate of pollutant transport is too slow, which can give a chance to be controlled before reaching the wells field. Another output was concluded from the model calibration and the model water budget that there are many unregistered wells withdrawing which can be misleading to the actual situation in the city and can rapid the pollutants transport.

The model main governing parameters and studies made can be summarized in the following points:

- 1- The water bearing formation in the study area is made of one unconfined quaternary aquifer system.
- 2- Hydraulic parameters of the aquifers (e.g.:  $K_h$ ,  $K_v$ ,  $S_y$ ,  $S_s$ ,  $n$ ).
- 3- The flow system of the groundwater in the Quaternary aquifer in the study area is governed by a surface water network from El-Nubariya Canal at the North and Nile River branch at the East.
- 4- Discharge of groundwater in the quaternary aquifer takes place through: production well fields and withdraw which have been represented as negative recharging areas.
- 5- Several maps like digital elevation map (DEM), Piezometric map, satellite maps and wells data have been used in the model calibration and to study the hydrodynamics of the groundwater movement.
- 6- Particles pathlines (forward and backward) were assigned to study the pollution movement and speed from the industrial area and the wells field capture zone.
- 7- Several scenarios have been suggested and simulated to reduce or eliminate the pollutant movement towards the supplying wells. These scenarios are:
  - Using a long diaphragm wall.
  - Long diaphragm wall and preventing pollution from closed area.
  - Shorter length of diaphragm wall and preventing pollution from close area.
  - Using artificial recharge basin before capture zone.

After a detailed study for each scenario, conclusions and recommendations were drawn out.

### **- Keywords:**

Arid and semi arid areas, Pollutant transport, groundwater, El-Sadat City, ArcGIS, Modeling.