FRAMEWORK FOR EVALUATING THE IMPACT OF URBAN TRANSPORTATION GASEOUS EMISSIONS ON GROUNDWATER QUALITY

Ahmed Elkafoury[1], *Waled Dawoud*[1], *Abdelazim Negm*[2], Mahmoud Bady[3]&Mohamed H. Aly[4]

[1] PhD Students, Environmental Engineering Dept., School of Energy and Environmental Engineering, Egypt-Japan University of Science and Technology (E-JUST), New Borg Al-Arab City, Postal Code 21934, Alexandria (Teaching Assistant, Tanta University).ahmed.elkafoury@ejust.edu.eg

[2] Chair of Environmental Engineering Dept.,School of Energy and Environmental Engineering, Egypt-Japan University of Science and Technology (E-JUST),New Borg Al-Arab City, Postal Code 21934, Alexandria (Seconded from Zagzig University, amnegm@zu.edu.eg), negm@ejust.edu.eg.

[3] Assistant Professor, Environmental Engineering Dept., School of Energy and Environmental Engineering, Egypt-Japan University of Science and Technology (E-JUST), New Borg Al-Arab City, Postal Code 21934, Alexandria (Seconded from Assiut University), mahmoud.bady@ejust.edu.eg.

[4]Professor of Railway and Transportation Engineering, Ex-Chair of Transportation Engineering Dept., Faculty of Engineering, University of Alex., Alex. Egypt, mhafezal@yahoo.com

ABSTRACT

Groundwater quality may be affected by many sources of pollution. One of these sources is the polluted air due to emission from different sources. Among all pollution sources, transportation systems are the major gaseous emitter in urban areas atmosphere. United Nations estimated that over 600 million people in urban areas worldwide were exposed to dangerous levels of traffic-generated air pollutants. Unfortunately, these emissions have wide amplitude of effects. It can precipitate with rain drops to find its way to groundwater reservoirs and decrease groundwater quality. This has great effect of human healthy especially in developing countries where an immutable depends on groundwater for supplying the demand. This paper presents a framework for assessing the effect of gaseous emissions from urban transportation systems on groundwater quality. It applies urban transportation planning process on Tanta city – Egypt as case study to calculate transport demand and amounts of gaseous emissions produced by the transportation system in the city for year 2030. This is done using the transportation planning models. The study also used precipitation rates on Tanta city for estimating amounts of vehicular emissions contaminants infiltrate uncovered soil surfaces A Three dimensional finite difference model is used to predict the migration of these contaminants in soil reaching groundwater reservoirs. The data used for the model operation are collected from previous investigations of the first author. The rate of contaminant migration was found to be highly influenced by the soil permeability and adsorption coefficient. Different scenarios of future transport systems have been studied, namely do nothing scenario, LRT scenario, and public transport scenario. LRT scenario indicated lower rate of contaminant for the ground water in study area than other scenarios.

Keywords: Air pollution, Groundwater, Urban transportation planning, Measures and Scenarios, Contaminates.

1 INTRODUCTION

Rapid economic growth has been beneficial to the cities as they have become centers of production, commerce, education and governance, and other productive activities. This is associated with increase in water demand for industrial, domestic and agricultural uses (Z. Jamshidzadeh& S.A. Mirbagheri, 2011). However, it has also created environmental problems, manifested in the deterioration of air and water quality, insufficient housing and sanitation facilities, traffic congestion and increasing solid waste, among others (Karen et al., 2009).

Groundwater quality may be affected by many sources of pollution. Once groundwater polluted, it can remain so for several decades, or even for hundreds of years until they can be cleaned if cleaning was actually possible (S.M. Ghoraba et al., 2012). The main threat to quality of drinking water sources is constant input of pollutant loads from agricultural areas, roofs, sewers, industry and roads

(GoranVizintin et al., 2009). Currently, there is no good estimate of the aggregate impact of roadtransportation on water pollution and a review of the relevant literature suggests that many estimates of water externalities resulting from motor vehicle transportation are based on educated guesses (Hilary Nixon & Jean-Daniel Saphores,2007) and focus only on the effect of leaking from vehicle storage tanks, road construction processes and highway runoff on principal arterials by deicing salts.

In 2008, road transportation accounted for 23% of the total world greenhouse gas (GHG) emissions from energy, but it represented the highest growth in emissions of all sectors (IEA, 2012). Therefore, most studies of the environmental impacts of road transport focus on air pollution. In the coming decades, road transport is likely to remain a large contributor to air pollution, especially in urban areas (Vicente Franco et al., 2013). Among transportation gaseous emissions, Nitrogen dioxide (NO_2) is a major concern relating groundwater quality. NO_2, which is formed as a result of combustion processes, is highly reactive and combines with water to form nitric acid (HNO_3). It can precipitate with rain drops to find its way to groundwater reservoirs and decrease groundwater quality. The effects of acid rain on the environment can be serious. It damages plants, poisons the soil, changes the chemistry of lakes, streams and groundwater reservoirs (Chen et al., 2013). Acid rain can also increase the weathering of silicate minerals in soils. This leads to a loss of mineral structure and possibly reduced fertility (Efe, 2012).

Worldwide, NO_2emissions sources are dominated by combustion processes in road transport with a 40% share in 2005(V. Vestrenget al., 2009). This paper tends to present a framework for assessing the effect of gaseous emissions from urban transportation systems of Tanta City on groundwater quality. It applies urban transportation planning process on Tanta city – Egypt as case study to calculate transport demand and amounts of gaseous emissions produced by the transportation system in the city for year 2030. This is done using the transportation planning models. The study also used precipitation rates on Tanta city for estimating amounts of NO_2infiltrate soil surfaces. A Three dimensional finite difference model is used to predict the migration of these contaminants in soil reaching groundwater reservoirs.

2 FRAMEWORK FORMATION

This paper provides a general framework to integrate thetransportation planning models and water quality models for assessing the effect of gaseous emissions from urban transportation systems on groundwater quality.

The frame work consists of two main parts; urban transportation planning process and groundwater quality model. The first part tends to calculate amounts of gaseous emission produced by the transportation system in the study area for a target year. For this purpose, full transportation planning process should be performed as the transportation emission models (part of the transportation planning process) uses the output of other models in the transportation planning process as an essential input for calculating transportation emissions. Transportation planning process includes analysis of socio-economic data, producing trip generation model, forecasting of the trip generation of different transportation zones in the study are, distribution of trips among different transportation zones, modal split, assignment of trips for the road network and making the operational and environmental evaluation including calculating emissions using transportation emission model (COPERT4 emission model).

Together with atmospheric data, land use data and soil profile data, amount of transportation emissions is used as an input in the groundwater quality model. This is used to calculate amount of acid rains. Also, the migration of acid rains through soil shall be predicted using Modflow incorporated with MT3DMS code. Figure 1 shows a schematic diagram of the proposed framework.

The frame work represent the prediction of NO2 emission the transportation system in Tanta city for different transportation scenarios in a target year 2030 using transportation emission models based on the results of the transportation planning process. Also, the frame work shows how NO2 emissions can reach groundwater reservoir through acid rains and spatial distribution of contaminant concentration over the study area.

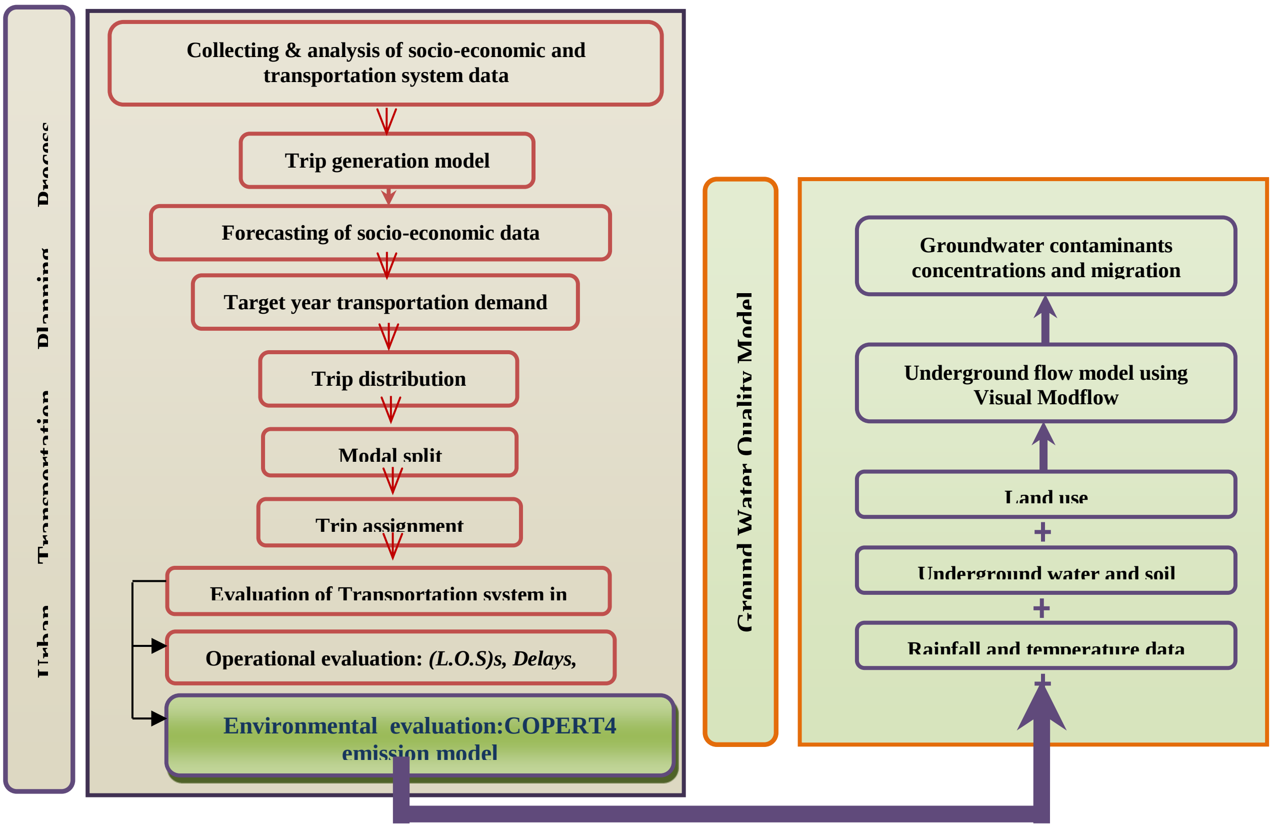

Figure 1. Framework for assessing the effect of gaseous emissions from urban transportation systems on groundwater quality

3 THE STUDY AREA AND DATA COLLECTION

The study area is Tanta City. It is the country's fifth largest populated area, with an estimated 445,560 inhabitants in year 2012.Total area of the city is 12.5 km^2. Tanta city is the capital of Gharbia Governorate (Biggest governorate in middle of Nile Delta - Egypt). It is 94 km north of Cairo and 130 km southeast of Alexandria. It is the center for the cotton-ginning industry, biggest commercial city in the delta and has the main railroad hub of the Nile Delta. The City is enclosed between two canals from the east and west, city topography generally flat with gentle slope to the north. Administratively, Tanta city is divided into two main residential districts: First district and Second district. Every district is divided into 7 zones shown in Fig. 2.

Figure 2. Administrative divisions of Tanta city

Several water treatment plants are used to feed Tanta city water needs using surface water from three plants produces 67 m3/day and groundwater from 10 plants produces 92.515 m3/day representing 58% of total daily amount of water production of the city. There are 8 groundwater stations including 42 wells for groundwater production in the city.

The transportation demand of the city is covered by 5 road dependent transport modes, namely, Public bus, Collection Taxi, Taxi, Private cars and Motorcycle with percentage 33%, 27.2%, 21.2%, 13.2%,5.4% respectively. The road network in Tanta city consists of 198.4 km of paved roads. The road network of the study area suffers from operational problems such as low level of service, very low speeds, congestions, higher of accidents rate and delaysbesides major environmental problems including high emissions and noise rates caused by the transportation system(M. Hafez et al., 2012).

The soil data was determined from Soil Mechanics and Foundation Engineering Laboratory, Faculty of Engineering, Tanta University. These data are used to the Modflow/MT3D operation.

4 MODELS USED IN THE STUDY

In this paper, for spatial calculation of transportation emissions, total amount of NO_2 produced in year 2030 by the transportation system in the study area is calculated using COPERT4 (Computer Programme to Calculate Emissions from Road Transport, version 4). COPERT is a model used by European countries for estimating transport emissions and projections from road transport for the compilation of CORINAIR (Co-ORdinatedINformation on the Environment in European Community-AIR).This model is funded by European Environment Agency (EEA) and developed by the Laboratory of Applied Thermodynamics in the Aristotle University of Thessaloniki.

The methodology used for emission estimation in COPERT4 is part of the EMEP6/CORINAIR7 Atmospheric Emissions Inventory Guidebook (AEIG) (Myung et al., 2004). The last update of the methodology is published in (Leonidas Ntziachristos et al., 2012). The average speed emission model COPERT4 is (and has been) extensively used for network emission modeling in Europe and other parts of the world (Sharma P. and Khare M. 2001).In COPERT4, road vehicles are usually classified according to their level of emission control technology, which is actually defined in terms of the emission legislation with which they are compliant. For every pollutant, an (average speed) emission factor (g/km) is assigned each vehicle class with a specific fuel type and engine capacity. Accordingly, an emission factor (E_f) can be assigned for each vehicle category with respect to vehicle type, emission legislation class together with the and fuel type. COPERT4 database assigns an emission factor equation of a continuous and (often) non-linear functions of the average speed for each vehicles category as follows:

$$E_{fik} = f(V) \tag{1}$$

Where:E_{fik} : emission factor of pollutant (i) for vehicle of emission legislation (k)

V: average travel speed on the road link

On the other hand, a mass transport model (MT3D) which incorporated into the Visual MODFLOW environment is used simulates advection, dispersion, and reaction of solutes in groundwater. In this model, the only migration mechanism that will be simulated is the linear diffusion model of a single contaminant (Nitrate). Nitrate is associated with nitric acid and acid rain which is formed from transportation gaseous emissions of NOx as follows:

$$2\,NO_2 + H_2O \rightarrow HNO_2 + HNO_3$$
$$3\,HNO_2 \rightarrow HNO_3 + 2\,NO + H_2O$$
$$4\,NO + 3\,O_2 + 2\,H_2O \rightarrow 4\,HNO_3$$

5 APPLICATION OF THE PROPOSED FRAMEWORK ON TANTA CITY

The application of the frame work of evaluating the impact of transportation gaseous emissions on groundwater quality in Tanta city depends mainly on the research done by (M. Hafez et al., 2012) on Tanta city. This research has performed the urban transportation planning process on Tanta city for the target year 2030. For Tanta city as case study, according to Egypt State of Environment Report 2010 which includes the distribution of percentage of vehicles in different age range, the emission legislation can be identified for every age range as shown in Table 1. An average NO_2 equivalent emission factor (g/km) is assigned from COPERT4 database for each mode of transport based on equation 1 and Table 1 as follows:

1- For Private cars and Taxis

$$E_F=0.11(1.34433+0.024733\mathbf{V}+1.47E\text{-}05\mathbf{V}^2) + 0.21(1.493889+0.00592\mathbf{V}+0.0001222\mathbf{V}^2+0.143333e^{0.099\mathbf{V}})+ 0.35(1.467\text{-}0.002\mathbf{V}+0.0001093\mathbf{V}^2)+ 0.11(0.106\text{-}0.00158\mathbf{V}+0.0000071V2) +0.11[\frac{(0.284\text{-}0.00869\mathbf{V}+0.000114\mathbf{V}^2)}{(1\text{-}\ 0.0234\mathbf{V}+0.000443\mathbf{V}^2)}]+\ 0.11[\frac{(0.0929\text{-}0.00149\mathbf{V}+0.00000655\mathbf{V}^2)}{(1\text{-}\ 00122\mathbf{V}+0.0000397\mathbf{V}^2)}] \quad (2)$$

2- For Microbus

$$E_F=0.11(5.1234\text{-}0.1189\mathbf{V}+0.000816V2) + 0.21(5.1234\text{-}0.1189\mathbf{V}+0.000816\mathbf{V}^2) + 0.35(3.57405\text{-}0.07536\mathbf{V}+0.0005285\mathbf{V}^2) + 0.33(1.700748\text{-}0.02672\mathbf{V}+0.00020204\mathbf{V}^2) \quad (3)$$

3- For Motorcycles

$$E_F=0.11(0.14665+0.00077\mathbf{V}+1.1E\text{-}05\mathbf{V}^2+1.52E\text{-}07\mathbf{V}^3+4.87E\text{-}09\mathbf{V}^4\text{-}\ 3.55E\text{-}11\mathbf{V}^5) +0.21(0.14665+0.00077\mathbf{V}+1.1E\text{-}05\mathbf{V}^2+1.52E\text{-}07\mathbf{V}^3+4.87E\text{-}09\mathbf{V}^4\text{-}\ 3.55E\text{-}11\mathbf{V}^5) +0.35\ (0.20314\text{-}\ 0.00466\mathbf{V}+0.000187\mathbf{V}^2\ \text{-}\ 3E\text{-}06\mathbf{V}^3+2.9E\text{-}08\mathbf{V}^4\text{-}\ 1.06273E\text{-}10\mathbf{V}^5) +0.33\ (0.204664\ \text{-}\ 0.00831\mathbf{V} + 0.000273\mathbf{V}^2 - 4.1E\text{-}06\mathbf{V}^3 + 3.46E\text{-}08\mathbf{V}^4\text{-}\ 1.10943E\text{-}10\mathbf{V}^5) \quad (4)$$

4- For Buses

$$E_F=0.11e^{\left[\left(4.13419+\frac{1.33176}{\mathbf{V}}\right)-(0.4008\ \mathrm{Ln}\mathbf{V})\right]}+0.21e^{\left[\left(4.13419+\frac{1.33176}{\mathbf{V}}\right)-(0.4008\ \mathrm{Ln}\mathbf{V})\right]} + 0.175(e^{\left[\left(4.13419+\frac{1.33176}{\mathbf{V}}\right)-(0.4008\ \mathrm{Ln}\mathbf{V})\right]} + (e^{\left[\left(3.71692+\frac{1.56968}{\mathbf{V}}\right)-(0.4242\mathrm{Ln}\mathbf{V})\right]}) +0.0825(e^{\left[\left(3.71692+\frac{1.56968}{\mathbf{V}}\right)-(0.4242\ \mathrm{Ln}\mathbf{V})\right]}+e^{\left[\left(3.79546+\frac{2.04915}{\mathbf{V}}\right)-(0.4344\ \mathrm{Ln}\mathbf{V})\right]} +e^{\left[\left(3.9621+\frac{2.60028}{\mathbf{V}}\right)-(0.5476\mathrm{Ln}\mathbf{V})\right]} + 29.9889*0.99703^{\mathbf{V}}*\mathbf{V}^{-0.4376}) \quad (5)$$

Table 1. Emissions legislation for different percentage of vehicle in different age ranges of vehicles in Tanta city transportation system

Age range	% of vehicles belongs to the age range	Emission legeslations
More tahn 35 years *(production year before 1975)*	11%	ECE,ECE-15.00 and ECE 15.01
25 – 35 years *(production year from 1975 to 1985)*	21%	ECE-15.00, ECE 15.01, ECE 15.02 and ECE 15.03
15 – 25 years *(production year from 1985 to 1995)*	35%	ECE-15.04 and EURO 1
Less than 15 years *(production year 1995 to 2010)*	33 %	EURO 2, EURO 3 and EURO 4

In the three transportation scenarios, average travel speed (km/hr) of road network links in each transportation zone is taken from (M. Hafez et al., 2012). The average speed of road network linksis used as an input in the COPERT4 model to calculate NO_2 emissions in each transportation zone. The results are given in Table 2.

To determine the concentration of nitrate in acid rain precipitation, Butler et al. (2003) found that the Nitrate concentration around 7.0 µeq/l (433 mg/L) for each ton/km2 of NO_2 equivalent gaseous emissions. This can be used to determine NO2 concentration of different transportation zones for the three transportation scenario. Results are shown in Table 2. Picioreanu et al. (1997) recommends a diffusion coefficient of nitrate in water to be 1700 µm2/s. Fetter (1993) recommend 5% to 10% of the model extension for the dispersion coefficient, a value of 5% was taken.

Three hydro-stratigraphic layers were defined at the site based on data collected from sixteen boreholes distributed along the city, the data were provided by Soil Mechanics and Foundation Engineering Laboratory, Faculty of Engineering, Tanta University. The top layer was defined as fill layer consists of brick and brown silt with average thickness of 1.5m, followed by a layer of brown silt to sandy silt with average thickness of 4.5m, and followed by a layer of yellow, medium to coarse sand to the end of boring. The groundwater level is changed with time, in this model it will be assumed at constant level of (-1.50m).

Table 2.Transportation system NO_2 emission density and corresponding NO_3 concentration in different transportation zones in Do-nothing, LRT and Public Transport scenario for target year 2030

Transpor-tation Zone Code	**Area** (km^2)	**Do–nothing Scenario**		**(LRT) Scenario**		**Public Transport Scenario**	
		Monthely density of NO_2 equivelent emission (kg/ km^2 · month)	NO_3 Concentrations (mg/L/Year)	Monthely density of NO_2 equivelent emission in (kg/ km^2 · month)	NO_3 Concentrations (mg/L/Year)	Monthely density of NO_2 equivelent emission (kg/ km^2 · month)	NO_3 Concentrations (mg/L/Year)
1	0.49	1300	6754.8	100	519.6	449	2333.0
2	0.63	1493	7757.6	78	405.2	471	2447.3
3	0.63	851	4421.7	39	202.6	276	1434.0
4	1.05	427	2218.6	11	57.1	122	633.9
5	0.82	384	1995.2	37	192.2	192	997.6
6	1.1	2795	14522.8	125	649.5	647	3361.8
7	0.76	731	3798.2	42	218.2	203	1054.7
8	1.42	248	1288.6	23	119.5	133	691.0
9	0.64	730	3793.0	46	239.0	333	1730.2
10	0.81	470	2442.1	33	171.4	220	1143.1
11	1.04	872	4530.9	81	420.8	419	2177.1
12	1.03	1055	5481.7	128	665.0	641	3330.6
13	1.25	1611	8370.7	183	950.8	874	4541.3
14	0.83	411	2135.5	20	103.9	178	924.8

A 3-dimensional representation of the city was created in Visual MODFLOW. This model domain was created as a 5600m by 6400m grid in the X and Y direction (corresponding with east-west and north-south, respectively), with a general uniform grid spacing of 100m between grid nodes, refined to 50m uniform spacing in recharging areas as shown in Figure 3.Three hydro-stratigraphic layers were defined at the Site based on data collected from sixteen soil borings completed during the last two years and within the Tanta city, soil anisotropy was assumed, thus vertical conductivity (Kz) was established as 0.1(Kx=Ky).Uniform Elevations for each layer were assumed. In order to provide uniform cell sizing in the z direction for the model, the thicker sand layer were subdivided into roughly equivalent layers, exhibiting the same hydrogeological properties.

The four model boundaries were modeled as constant head boundaries, also Tanta city was enclosed by two channels which were modeled as river boundaries. A value of between 5% and 20% of annual precipitation is recommended as anestimate of recharge when other data are not available (Waterloo, 2005), based on this guidance, recharge was set equal to 20% of annual precipitation given in Table 3 . Data in Table 2 are taken from (www.climate-charts.com).

The calibrated/validated MODFLOW/MT3DMS model was used to evaluate the effect of various transportation scenarios on the groundwater contaminant with nitrate due to acid rains. The first evaluated scenario was the Do-Nothing scenario which shows maximum concentration of nitrate in groundwater with maximum value of 8 mg/L as shown in Fig 4. The second evaluated scenario is the LRT scenario which shows minimum concentration of nitrate with maximum value of 1.8 mg/L as shown in Fig 5. The last evaluated scenario is the Public Transport scenario which shows small concentration of nitrate with maximum value of 6.1 mg/L as shown in Fig 6.

Table 3. Precipitation and relative humidity in Tanta City

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation Mean Monthly Value	13.0	8.0	7.0	3.0	2.0	0.0	0.0	0.0	0.0	2.0	4.0	12.0
Relative Humidity Mean Value	72.0	69.0	68.0	60.0	57.0	58.0	66.0	71.0	69.0	67.0	70.0	71.0

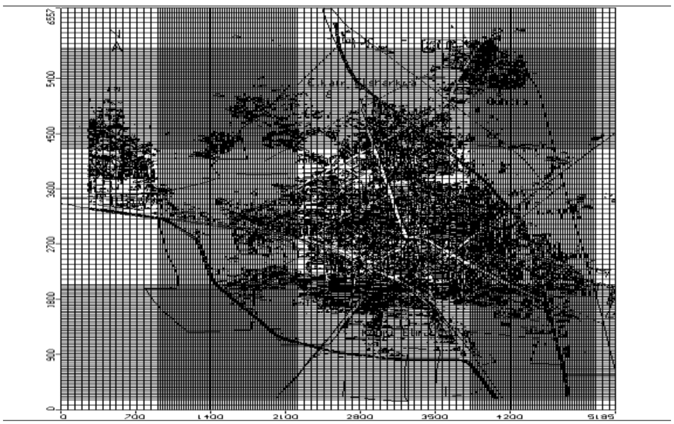

Figure 3. Visual Modflow model grid

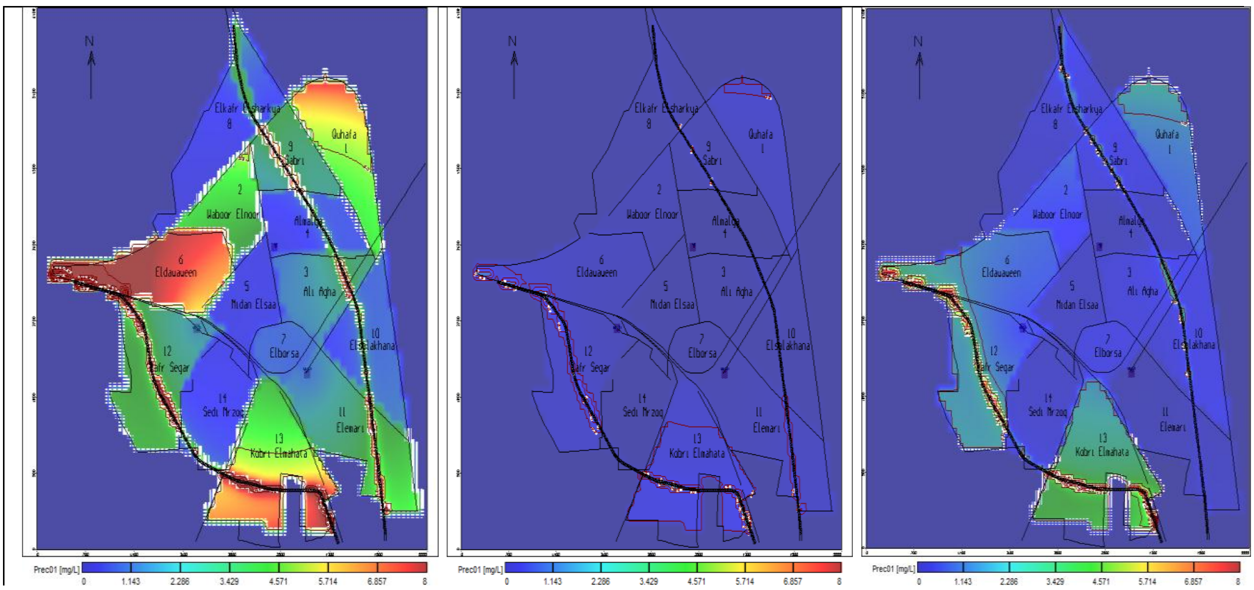

Figure 4. Do-Nothing scenario Nitrate concentration – current situation

Figure 5. LRT scenario Nitrate concentration – future scenario

Figure 6. Public Transport scenario Nitrate concentration – future scenario

6 CONCLUSION

Three-dimensional groundwater flow and solute transport model was created to assess the effect of gaseous emissions due to transportation systems on groundwater quality in Tanta City. The model indicates:

1. There is a potential risk for the contamination of groundwater in Tanta City from the gaseous emission due to current transportation systems.
2. The transportation systems in Tanta City need re-planning in order to use more conservative and less emission systems.
3. LRT transportation scenario shows the minimum effect of gaseous emission on groundwater quality due to the small amount of emissions.
4. The migration of nitrate in soil is very limited due to the small precipitation rate above the city, also due to the low permeability of the surface soil.

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