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Investigation of the impact of the implementation of the coastal aquifer management plan on nitrate pollution in Gaza Strip Aquifer using modeling techniques

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Abstract

Groundwater is the principal source of public water supply and for satisfying the daily water needs. The Gaza strip coastal aquifer is suffering from salinity and contamination due to human activities especially agriculture activities. Although, the nitrate is necessary for agriculture activities it can affect the groundwater quality if leached nitrate from the soil into freshwaters after some time. The main objective of this research is to evaluate the current situation of the Gaza strip coastal aquifer and to predict the nitrate concentrations resulting from agriculture activities over the next twenty years using modelling approach. 3D Numerical groundwater flow modeling was developed to simulate the impacts of transport of nitrate loading from agricultural land on groundwater system using finite difference method GMS 10.4 software (MODFLOW 2005 code and MT3DMS package). Five management scenarios were considered to study the effect of pumping and recharge parameters on the groundwater flow system and the impacts of transport of nitrate loading from agricultural areas on the aquifer. Ten different wells were selected to investigate the impact of management scenarios on the nitrate concentration. All management scenarios indicated that there is a relationship between the water level and nitrate concentration in aquifer therefore the rates of nitrate concentration in the southern regions of Gaza strip is more than the northern regions.

1. Introduction

Groundwater is the main source of freshwater that is essential for other human activities such as agriculture, industry, and domestic consumptions. Groundwater is contaminated when the concentration of contaminant exceeding the tolerable upper limit and limit its potential use. Agricultural land made up 157.50 km, equivalent to 43% of Gaza strip Area. Although, the nitrate is necessary for agriculture activities it can affect the groundwater quality if leached nitrate from the soil into freshwaters after some time. Therefore, high rates of nitrate concentration will be observed due to excessive use of N-fertilizers in agricultural activities. The issue of high nitrate levels in drinking water decreases the oxygen-carrying capacity of hemoglobin in human blood, which can threaten the health of human. Thus, the effective management of water resources is important to minimize the danger to human life.

Efforts were made by PWA for the development of plans like; CAMP and NWP plans to enhancement of water quality in Gaza strip despite the political and financial difficulties. A model is conceptual descriptions created towards representation for physicals system through mathematical equations.

Modeling of groundwater flow focuses primarily on determining of flow rate, groundwater heads and flow direction through aquifers. These determinations are indicating to as simulation. Moreover, the transport models have become an essential application to study groundwater quality issue. The movement of contaminants and chemical variation of pollutants in the groundwater can be simulated by solute transport models. Solute transport model requires the preparation of a groundwater flow model (Zheng and Bennett 1995) Solute transport models can be used to compute and predict the concentration of a dissolved chemical species in an aquifer at any time (Fryberg 1988).

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2. METHOD

The research methodology was divided into three basic phases. The research objective and data collecting and analysis are the first phase of the model. The quantity and quality of data involved in the modelling of groundwater system plays a fundamental role in the accuracy of numerical model results. Therefore, data collection is considered as a critical step in preparation of the model. Collected data are processed by using Geographic Information Systems GIS and Excel spreadsheets. Initially, the research started by collecting the available updated and recorded data from several sources and by different personal interaction with local professionals. Data include (Digital Elevation Model (DEM) of Gaza Strip, Groundwater level from 2000 to 2018, Groundwater quality parameters measurements for 2014-2020, Pumping rate records for 3600 wells, Rainfall measurements and other relevant climate data from 1980 to 2019, Geological data for Gaza Coastal Aquifer, Drilling completion records of wells and topographic data for Gaza Strip.

The second phase of the model consists of code selection and designing the numerical model. A new version of MODFLOW, called MODFLOW-2005 was used for the realization of the 3D numerical flow model.

The model calibration is completed in last phase of the model. The main objective of calibration is to check the reliability of the model by adjusting independent variables (parameters and fluxes) until reaching results within sensible ranges that represent the actual situation. The approach followed in groundwater modeling of this paper is summarized in Fig 1.

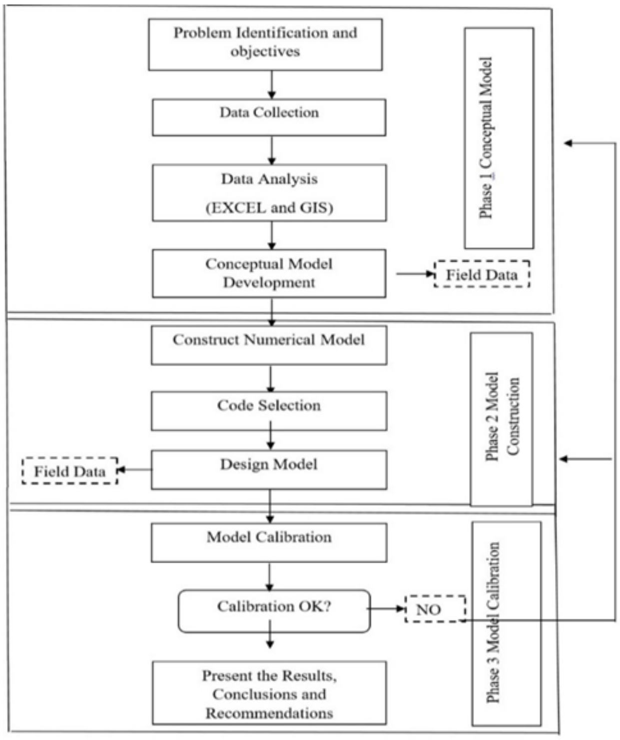

Figure 1. Flow chart illustrating the approach followed in groundwater modeling

3. STUDY AREA

Gaza strip situated on the Palestinian coast of the Mediterranean Sea with a length of 40 km, ranges from 6 to 12 km in width and has a total land area of 365 km^2. The region is bordered on the south by the Negev Desert and Egyptian Sinai Peninsula, the Mediterranean Sea to the west and occupied Palestine in 1948 to the east (Fig 2).

Gaza strip has an arid semi-humid due to its location in the transitional zone between desert of the Sinai Peninsula in Egypt and the Mediterranean Sea along the coast (Hallaq 2008). As result of Gaza strip location close to the sea, there is a gradual variation in Gaza Strip temperatures throughout the year, the mean monthly temperature ranges from about 17.6 C° in January to 29.4 C° in August.

The humidity rate in Gaza Strip is vary throughout the day in both season where the proportion of humidity in summer during the daytime is about 65% and 85% at night time while in winters the humidity rate is about 60% during the day and night times. The average annual potential evaporation is slightly elevated. The potential evaporation rate is estimated at about 1200 to 1400 mm/yr.

Figure 2. Location of Gaza strip (Abd Rabou 2019)

The average rainfall in the northern regions is different from southern regions, reaching 522 mm/yr in the northern areas and 225 mm/yr in the southern areas (Authority 2012). Gaza Strip has several types of soil that are loess, dark brown/silty clay, sandy, loessal sandy. The Gaza strip aquifer has a different width where the width ranging from 15 km northbound to around 20km southbound, while the groundwater depth ranging from 20 m in the southeast to 180 in the northwest (Fig 3).

The Gaza strip coastal aquifer composed of two different ages, the Pleistocene Kurkar and recent (Holocene age) sand dunes. The fundamental ingredient of Kurkar Group are Aeolian calcareous sandstone, marl, marine, reddish silty sandstone, clays, and conglomerates.

The Kurkar Group is dispersed in parallel to the coastline, from north to south of the Gaza Strip. It is stretch about 15-20 km inward and divide the aquifer into four-separated sub-aquifer, refer to as A, B1, B2, C, where it un-conformably topped with Eocene age chalks and limestone, or the Miocene-Pliocene age Saqiye Group, and clay stones.

Israeli studies proposes that the Kurkar Group becomes more clastic towards the east. The distinct 'layering' of sedimentary cycles becomes less clear, and the presence of red silty-clayey sandstone becoming more dominant. In addition, along the courses of main drainage, alluvial clays and soils become more obvious such as Wadi Gaza Clay layers were created as a result of the melting of glaciers and snow cover, which in turn lead to an increase in the sea level, this resulted in marine sediments led to formation of clay layers.

Clay formations are of two types: marine and fluvial. Marine clays are existed along the shore, at various depths within the formation. They pinch out about 5 km from present shoreline, and on the basis of existing data, appear to become more important towards the base of the Kurkar Group (Jamal and Yaqubi 2001).

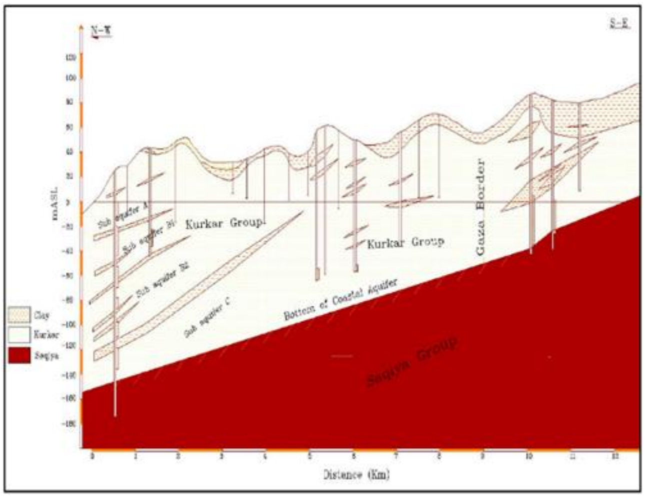

Figure 3. Geological cross section of Gaza strip coastal aquifer (Greitzer and Dan 1967)

4. DEVELOPMENT OF GROUNDWATER MODEL

4.1. Groundwater Flow Model

Conceptual groundwater flow model has been developed using three-dimensional finite difference method through GMS 10.4 software, MODFLOW 2005 code. Actually, after years of over pumping there are no significant changes in the hydraulic head, these would indicate that groundwater system reached to steady state. Consequently, year 2018 was stablished as steady state.

4.2. Model Building in GMS

The Gaza strip groundwater model is constructed based on a 200x200 m finite difference grid. The model domain covers an area of 365 km^2 and divided into 260 columns and 105 rows, vertically, the model thickness was divided into seven layers. Model cells that fall outside the study area and/or depth of interest have been inactivated. The Gaza strip groundwater flow model consisting of 191,100 cells (62,980 active cells and 128,120 inactive cells) (Fig 4).

4.3. Model Boundary Conditions

The Gaza strip groundwater flow model have been assigned boundary conditions as shown in Fig 4.

In Gaza strip groundwater model, the shoreline is represented as Specified Head boundary CHD with constant head zero m while the eastern border represents the borderline between Gaza strip and occupied territories, this border is represented as general head boundary GHB. Groundwater levels at the general head boundaries were estimated based on the average groundwater level measured by monitoring wells bores in proximity to the model boundary.

The GHBs were setup in the numerical groundwater model to represent amount of groundwater entering and leaving the model. The northern and southern border were assigned as a no flow boundary. In general, a no-flow boundary condition implies that the component of flux in the direction normal to the boundary is zero. The direction of groundwater flow is perpendicular to the shoreline, from east to west. That means the discharge across northern and southern boundaries equal zero.

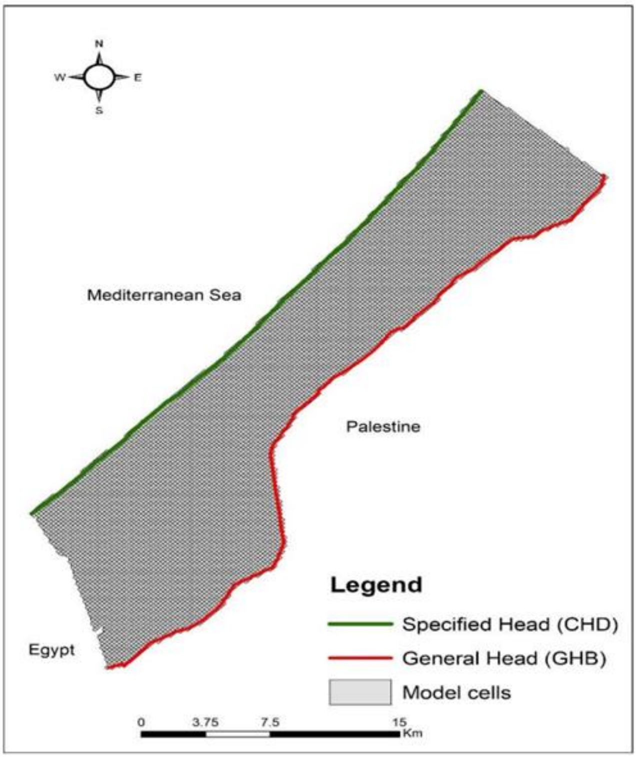

Figure 4. Boundary conditions and grid of Gaza strip Groundwater flow model

4.4. Freshwater Abstraction

Freshwater is extracted from the pumping wells thus information about abstraction rate of freshwater and well's location is required to the groundwater flow model. There are about 6000 wells in the Gaza strip classified into agriculture and municipal wells, about 72% of these wells are used for agriculture purpose, and about 1700 wells classified as and municipal wells. Allowed pumping rate to agriculture wells shall not exceed 50 m^3/d. pumping wells have been incorporated in the Gaza strip groundwater flow model using the MODFLOW 2005 'WELL1- Well' package and screen extent data.

4.5. Hydraulic Conductivity

The hydraulic conductivity is a basic parameters of groundwater flow model it plays a significant role in the measurement of hydraulic head.

The initial measurements of hydraulic conductivity have been obtained based on the previous researches and reports of pumping test carried out in Gaza strip. The horizontal hydraulic conductivity for aquifer ranging from 20 – 60 m/d with an average of 30 m/d and the aquitard the horizontal hydraulic conductivity is varied from 0.004 – 0.80 with an average of 0.2 m/d.

The vertical hydraulic conductivity was identified 8-10% of horizontal hydraulic conductivity. The other properties were set 0.3 for aquifer and 0.45 for aquitard and the specific storage rate was established 0.0001 m^{-1}.

The initial values of hydraulic properties used in the model development is shown in Table 1.

Table 1. Initial values of hydraulic properties used in the model development

Layer type	HK, VK (m/d)	Specific Storage (m^{-1})	Porosity
Aquifer (L1, L3, L5, L7)	HK: 30, VK: 3	10^{-4}	0.3
Aquitard (L2, L4, L6)	HK:0.2, VK: 0.02	10^{-4}	0.45

4.6. Recharge

The groundwater recharge for Gaza aquifer was estimated using coefficient values of recharge (Table 2) based on the type of soil (Fig 5) and the annual average rainfall for the past 10 years for each rain station. For representing the territorial distribution of regional average rainfall, Thiessen method was used. In Thiessen method, the rainfall is calculated as the nearest neighbor value (Viessman and Gary 2002; Wilson 1998). The concept of Thiessen method is that the area is subdivided into Thiessen polygons based on the rainfall station. The recharge polygons used in the model was obtained through the intersection between soil type map and the measurements of rain station in Gaza Strip for the rainfall for the past 10 years.

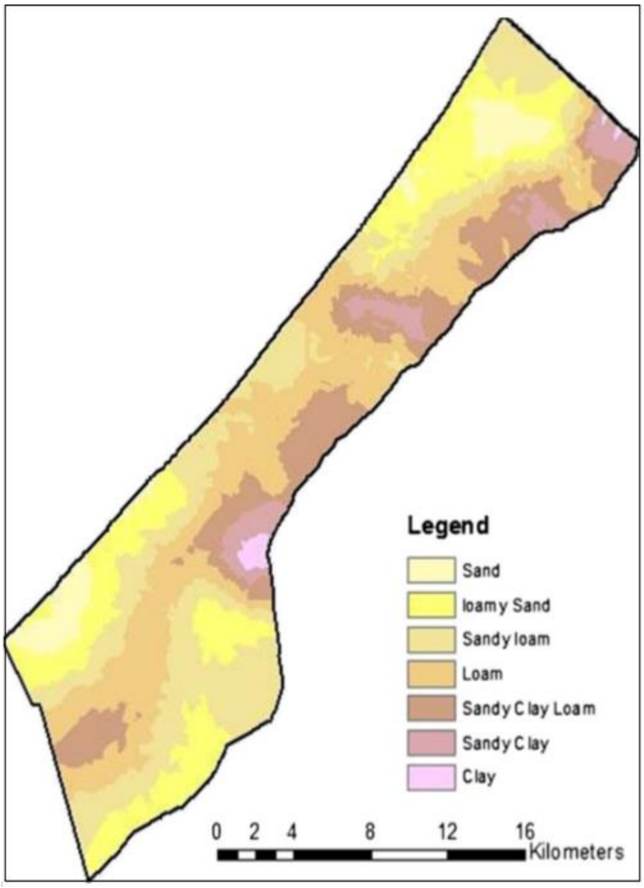

Figure 5. Soil map of Gaza strip (Abu Samra 2014)

Table 2. Recharge coefficient values (Semli, 2013)

Soil Types	RCH Ceof
Dark Brown/ Silty Clay	0.03
Sandy Regosols	0.7
Losses Soil	0.15
Lossal Sandy Soil	0.25
Sandy Lossal Soil	0.3
Sandy Lossal Soil over Loess	0.35

4.7. Groundwater Flow Model Calibration

The Gaza strip groundwater flow model was calibrated under steady state conditions using 41 observation wells (Fig 6). The initial values of hydraulic conductivity were obtained based on previous studies and the initial values of recharge package have been modified based on section 4.5. Three methods of calibration have been used to calibrate the model. The first method is manually calibrated. For this method, the parameters of steady state conditions have been modified manually. The manually calibrated model produced unreasonable results therefore, zone calibration with ranges (method 2) was used to optimize the initial parameter estimates. Actually, zone calibration produced unacceptable results. The manual and zone calibration have been followed by automated parameter estimation using PEST (method 3). The results of PEST produced high level of heterogeneity in aquifer layers. Consequently, pilot point technique has been used to mathematically enhance the initial parameter estimates of hydraulic properties. The scatter plot of the fit between computed and observed heads shown in Fig 7. The calibrated groundwater level for the first layer is presented in Fig 8. The steady state calibration has shown statistics parameters for calibrated head, these parameters shown in Table 3. The results showed variations of horizontal hydraulic conductivity in the first and last layers, the values ranged between 35 m/d north and 23 m/d south of the Gaza strip.

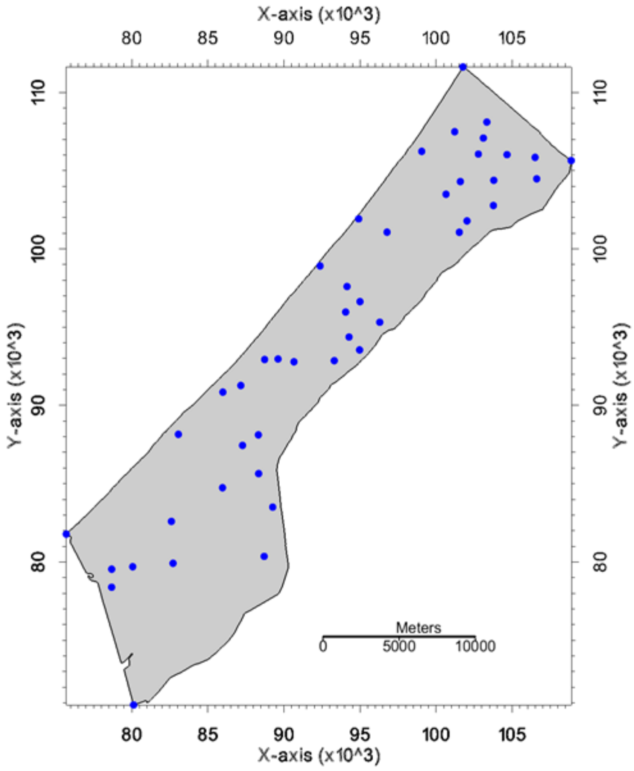

Figure 6. Observation wells used to calibrate the model

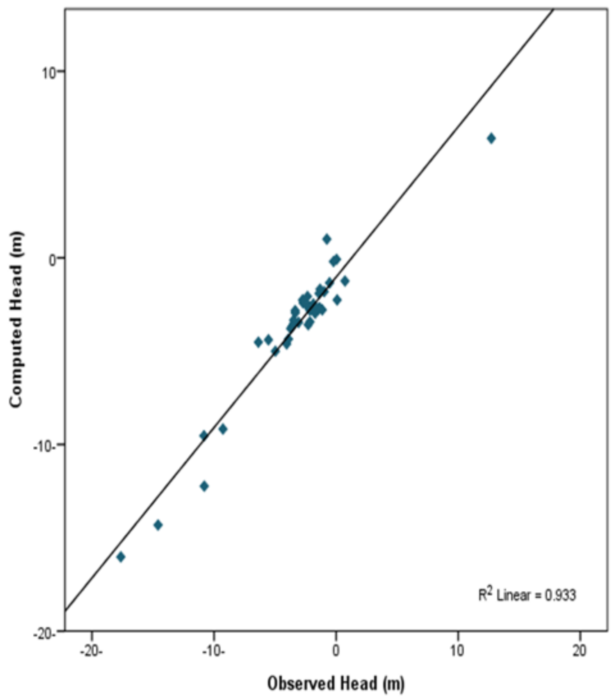

Figure 7. Scatter plot of computed and observed heads

Table 3. Statistical parameters of the model

Parameter	Value (m)
Mean Residual Head	0.40
Mean Absolute Residual Head	0.90
Root Mean Square Residual Head	1.39

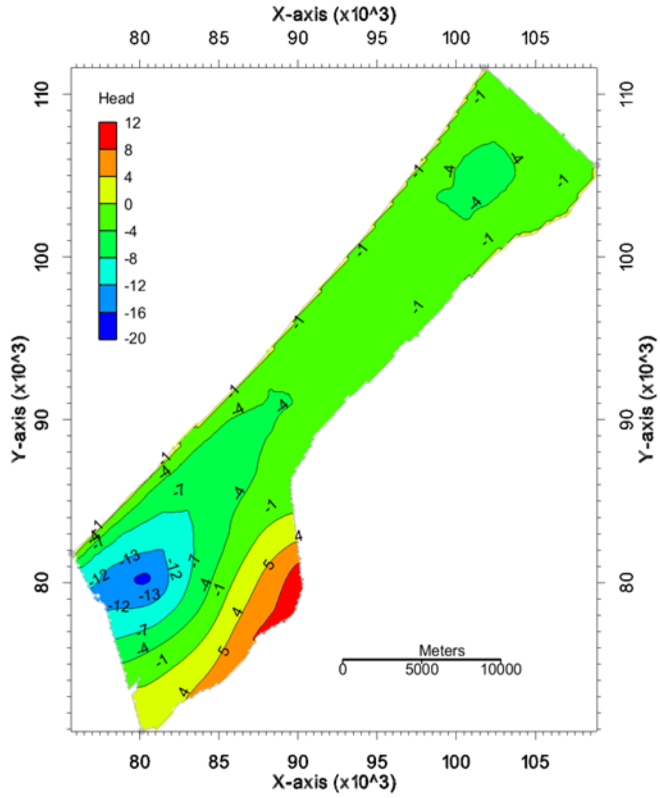

Figure 8. Calibrated groundwater head for year 2018

5. TRANSPORT MODEL

The Gaza strip groundwater flow model has been calibrated under steady state condition. The model has been converted to transient model (2019-2020) and developed based on the calibrated steady state results.

5.1. Initial Conditions

The initial head is a basic parameter used for solving the advection-dispersion equations of transport model. Initial conditions of the transport model indicate to the spatial distribution of starting concentration simulation. Using reasonable initial concentration conditions assist in a model convergence. The measurements of nitrate concentration of the year 2020 which obtained from laboratory readings according to PWA have been used as initial concentration.

5.2. Transient Transport Model Calibration

The calibration process requires improvement of model parameters. In transport model, the mass loading rates and soil properties parameters like longitudinal dispersivity are the most common parameters that impact on the output in MT3DMS. Those parameters were calibrated using trails and error process. The calibration value of longitudinal dispersivity was estimated 15 m and horizontal dispersivity was valued 1.5 m while vertical dispersivity equals 0.15 m. The computed and observed concentration are shown in Fig 9 and Fig 10 at the years 2019 and 2020 respectively. Simulated NO_3 concentration for the initial year 2020 shown in Fig 11.

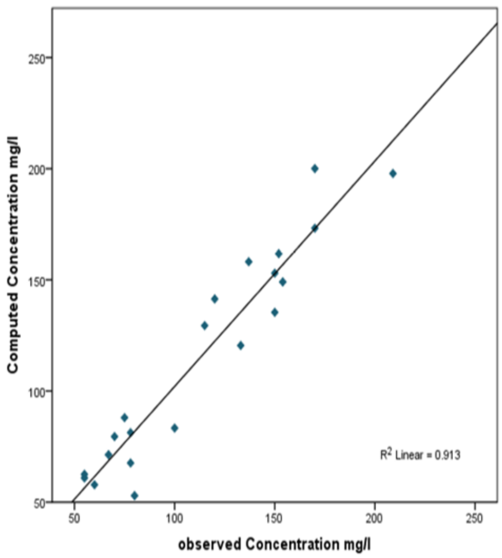

Figure 9. Scatter plot of computed and observed NO_3^- concentration in 2019

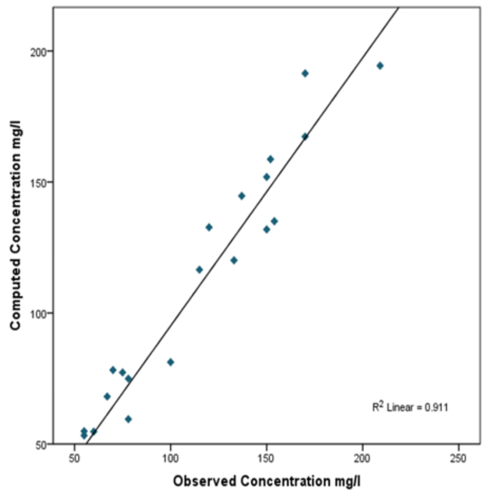

Figure 10. Scatter plot of computed and observed NO_3^- concentration in 2020

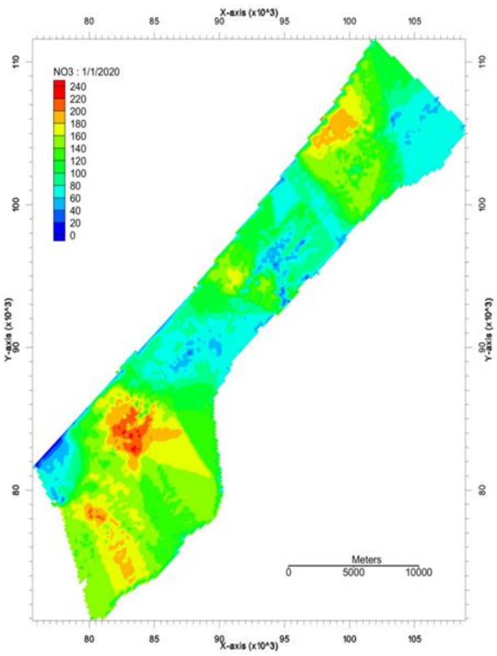

Figure 11. Simulated NO_3^- concentration for the year 2020

6. MODEL SCENARIOS MANAGEMENT

Calibration of groundwater flow model is a fundamental phase for prediction the nitrate concentration in the future. The calibration results were reasonable by numerical model used three-dimensional finite difference method by GMS MODFLOW for groundwater flow model and MT3DMS code for transport model.

The model management scenarios are important in order to find the best solutions to manage the abstraction and to creating the best available techniques to protect the groundwater from contamination.

Five management scenarios were considered to study the effect of pumping and recharge parameters on the groundwater flow system and the impacts of transport of nitrate loading from agricultural areas on the aquifer. These management scenarios developed based on plan adopted by Palestinian Water Authority for the management of water resources. Ten different wells were selected to investigate the impact of management scenarios on the nitrate concentration.

The scenarios properties can be described as the following points:

1. Current Situation (Sc.1).
   - Study the aquifer without any change neither in groundwater flow properties nor transport parameters over the simulation period.
2. Pumping management based on CAMP (Sc.2).
   - Production of the wells for after 2020 have been reduced on average 45-50% compared to 2015. Where the total production of Agricultural wells and municipal wells in 2015 were 95 and 86 MCM respectively.
3. Increasing the recharge (Sc.3).
   - Increasing the recharge rate using treated wastewater in the nitrate concentrations.
   - Injection wells have been used to add the treated wastewater in the depression regions.
   - The total treated wastewater used to increase the recharge rate increased gradually from 40 MCM in 2010 to 60 MCM in 2020. Over the simulation period the recharge rates was fixed at 60 MCM/year.
4. N-Fertilizers Management (Sc.4).
   - Reduction of the nitrogen used in fertilizers that loading in agricultural zones by 50% where the total amount of NO_3^- loaded in the model is 22,942.3 kg/d
5. Bringing all the previous scenarios together (Sc.5).

7. RESULTS AND DISCUSSIONS

In this study, two various purpose wells from each governorate with total ten wells were selected to investigate the impact of different management scenarios on the nitrate concentration over the next 20 years. The location of studied wells is presented in Fig 11.

Scenario 1

The first scenario simulates the work as usual without any change neither in groundwater flow properties nor transport parameters over the simulation period from initial year 2020 to 2040. Simulation results show that there is an increase in NO_3^- concentration in the wells located in cultivate areas. The average nitrate concentrations after 20 years reached 551 mg/l.

Obviously, this high rate of concentration is due to the excessive pumping and indiscriminate use of N-fertilizers during agriculture activities and this is clear evidence of the deterioration in the groundwater quality.

Table 4 shows the initial and predictive of nitrate concentration according to the first scenario (Sc.1) for the studied wells.

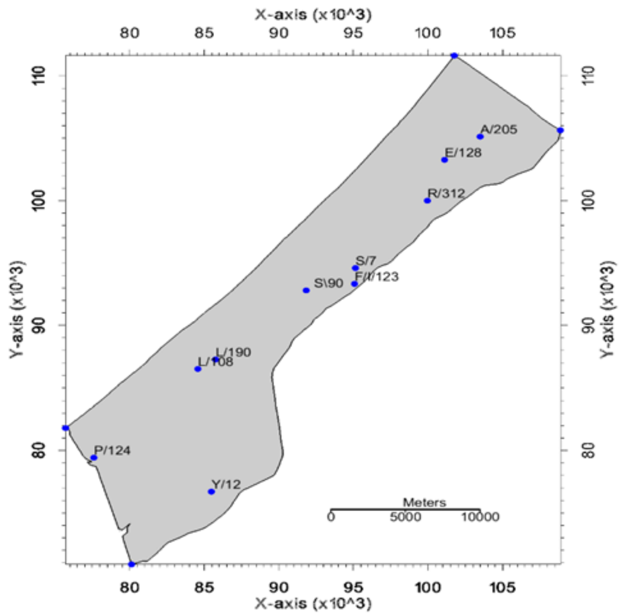

Figure 12. Spatial distribution map of studied wells

Table 4. Initial and predictive of nitrate concentration according to the first scenario (Sc.1)

Well ID	Governorate	Well Type	NO_3^- Concentration mg/l	
			2020	2040
A/205	North	Domestic	64.41	29.76
R/312	Gaza	Domestic	136.37	179.83
S/90	Middle	Domestic	53.48	31.95
L/190	Khanyounis	Domestic	105.83	250.08
P/124	Rafah	Domestic	50.47	41.41
E/128	North	Agriculture	150.45	80.46
S/7	Gaza	Agriculture	85.57	200.95
F/I/123	Middle	Agriculture	75.82	208.52
L/108	Khanyounis	Agriculture	168.73	551.87
Y/12	Rafah	Agriculture	150.57	350.24
Average			104.1	192.5

Scenario 2

The second scenario studied the nitrate concentration in the study area under the implementation of CAMP plane that aim to improve the groundwater level by decreasing the pumping rate from the aquifer by 50%.

Reduction of pumping rate is one of important options that can be used to improve the groundwater level and to manage the water resources in the future.

Simulation results indicated that the reduction of pumping rate would improve the water level slightly thus, the NO_3^- concentration decrease slightly where the average nitrate concentrations after 20 years decreased by 21.53 mg/l compared to current situation sc1.

Table 5 shows the nitrate concentrations for studied wells under the influence of the second scenario.

Table 5. Initial and predictive of nitrate concentration according to the Second scenario (Sc.2)

Well ID	Governorate	Well Type	NO3- Concentration mg/l	
			2020	2040
A/205	North	Domestic	64.41	38.01
R/312	Gaza	Domestic	136.37	150.60
S/90	Middle	Domestic	53.48	31.75
L/190	Khanyounis	Domestic	105.83	278.59
P/124	Rafah	Domestic	50.47	41.21
E/128	North	Agriculture	150.45	93.88
S/7	Gaza	Agriculture	85.57	194.67
F/I/123	Middle	Agriculture	75.82	178.79
L/108	Khanyounis	Agriculture	168.73	441.83
Y/12	Rafah	Agriculture	150.57	260.34
Average			104.1	170.97

Scenario 3

The third scenario proposed to simulate the impact of increasing the recharge rate using treated wastewater in the nitrate concentrations. Injection wells have been used to add the treated wastewater in the depression regions. Increasing the recharge is the best option to improve the groundwater level and to manage the groundwater in the future.

The simulation results indicated that the nitrate concentration has further improved over the next 20 years where the average nitrate concentrations after 20 years decreased by 47.72 mg/l compared to current situation sc1.

Table 6 shows the nitrate concentrations for studied wells under the increased the recharge.

Table 6. Initial and predictive of nitrate concentration according to the third scenario (Sc.3)

Well ID	Governorate	Well Type	NO_3^- Concentration mg/l	
			2020	2040
A/205	North	Domestic	64.41	20.84
R/312	Gaza	Domestic	136.37	120.66
S/90	Middle	Domestic	53.48	30.46
L/190	Khanyounis	Domestic	105.83	45.46
P/124	Rafah	Domestic	50.47	13.07
E/128	North	Agriculture	150.45	79.80
S/7	Gaza	Agriculture	85.57	192.33
F/I/123	Middle	Agriculture	75.82	192.33
L/108	Khanyounis	Agriculture	168.73	449.21
Y/12	Rafah	Agriculture	150.57	304.38
Average			104.1	144.78

Scenario 4

This scenario investigated the impact of reduction of the mass of N-fertilizers loading at cultivate areas by 50%. The cultivate areas used in the model is shown in Fig13. The total area of the cultivate zones in the study area is 48,490,959 m^2.

The simulation results show that the readings of nitrate concentration have significantly decreased, where the average nitrate concentrations after 20 years are estimated at 104.71 that means the average nitrate concentrations after 20 years decreased by 87.79 mg/l compared with work as usual scenario (sc.1).

Table 7 shows the nitrate concentrations for studied wells under N-Fertilizers Management (sc.4).

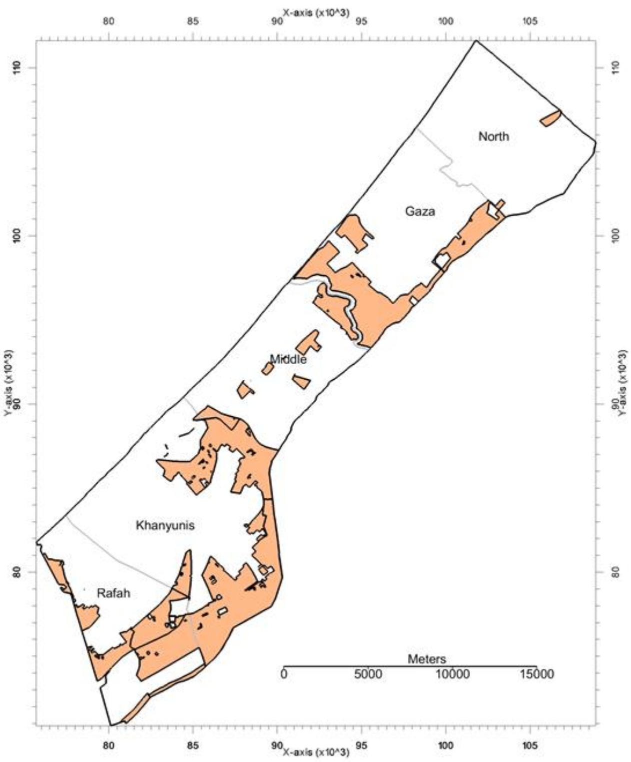

Figure 13. Agricultural areas of Gaza strip used in the model

Table 7. Initial and Predictive of Nitrate Concentration According to the Fourth Scenario (Sc.4)

Well ID	Governorate	Well Type	NO_3^- Concentration mg/l	
			2020	2040
A/205	North	Domestic	64.41	26.37
R/312	Gaza	Domestic	136.37	136.50
S/90	Middle	Domestic	53.48	31.51
L/190	Khanyounis	Domestic	105.83	144.59
P/124	Rafah	Domestic	50.47	35.79
E/128	North	Agriculture	150.45	80.64
S/7	Gaza	Agriculture	85.57	108.73
F/I/123	Middle	Agriculture	75.82	88.51
L/108	Khanyounis	Agriculture	168.73	252.48
Y/12	Rafah	Agriculture	150.57	142.31
Average			104.1	104.71

Scenario 5

This scenario studied the nitrate concentration in the study area when bringing all the previous scenario together. The simulation results show a significantly decreased in the nitrate concentrations. This means decreasing the abstraction from aquifer, increasing the recharge rate using treated wastewater and decreasing the mass loading of N-fertilizers by 50% are the main options that could be used to management the groundwater and protect the groundwater from nitrate contamination.

Table 8 shows the average nitrate concentration of the studied wells where the average concentration after 20 years is estimated at 58.17 mg/l.

Table 8. Initial and predictive of nitrate concentration according to the fifth scenario (Sc.5)

Well ID	Governorate	Well Type	NO_3^- Concentration mg/l	
			2020	2040
A/205	North	Domestic	64.41	2.70
R/312	Gaza	Domestic	136.37	44.21
S/90	Middle	Domestic	53.48	25.95
L/190	Khanyounis	Domestic	105.83	13.89
P/124	Rafah	Domestic	50.47	3.53
E/128	North	Agriculture	150.45	52.30
S/7	Gaza	Agriculture	85.57	77.37
F/I/123	Middle	Agriculture	75.82	73.79
L/108	Khanyounis	Agriculture	168.73	138.17
Y/12	Rafah	Agriculture	150.57	149.82
Average			104.1	58.17

Overall discussion

This section describes the General results for the five scenarios regrading to nitrate concentration by the end of simulation period (2040). Simulation of current situation has shown that there is a decline in the water level and deterioration in water quality. However, the highest nitrate concentrations are founded in the southern regions of the Gaza strip, where the concentration in khanyounis city reached to about 300 mg/l in the initail year 2020 while the concentration after 20 years reached nearly 550 mg/l in the same city. The concentration rates in the northern regions were below 200mg/l. This due to the low proportion of the agricultural area in the northern regions of the Gaza strip. However, the management scenarios showed improvements in the water level and improvements in the readings of NO_3^- concentration.

Two various purpose wells were selected from studied wells to study the impact of the implementation of CAMP plan on the nitrate concentration. These wells are L/108 for agricultural well and R/312 for domestic well. Fig 14 shows the optimal scenario for domestic well is increasing the aquifer recharge through treated wastewater using injection wells in the depression regions. While Fig 15 shows the best scenario for agricultural well is decreasing the mass loading of N-fertilizers this due to its location in the agricultural zones.

Overall, the current situation will increase the average nitrate concentration by 4.42 mg/l annually while management pumping scenario will decrease the annual rising in the concentration by 1.08 mg/l compared to work as usual scenario (sc.1). Increasing the recharge using injection wells in the depression regions and reduction of mass loading of N-fertilizers by 50% have also been implemented. The simulation results of Sc.3 and Sc.4 showed an increased in the average nitrate concentration by (2.03 and 0.03 mg/l) respectively.

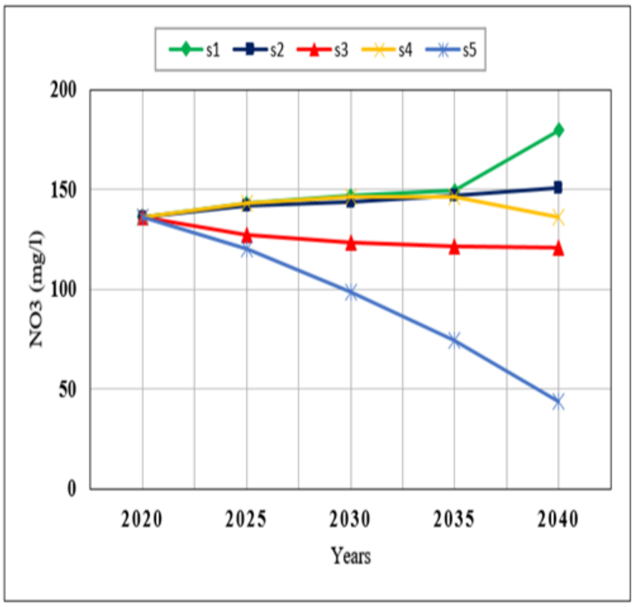

Figure 14. NO_3 concentrations for domestic well R/312 under implementation of CAMP plan

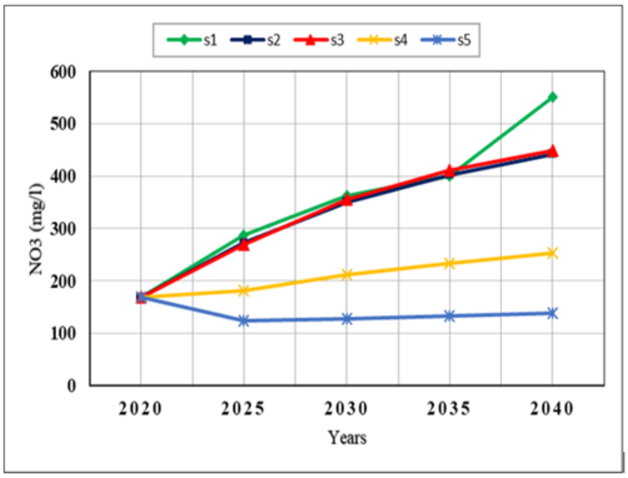

Figure 15. NO3 concentrations for agricultural well L/108 under implementation of CAMP plan

The simulation results also indicated that the average nitrate concentration will be decreased by 2.30 mg/l annually when implementing all scenario together (sc.5) as shown in Fig 16 and Table 9.

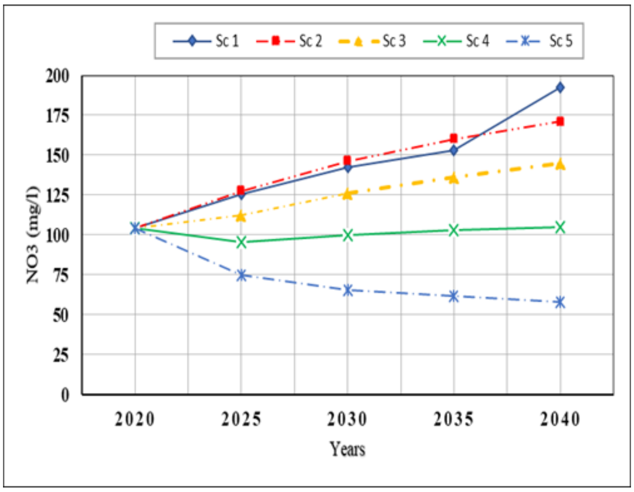

Figure 16. Average simulated Nitrate concentrations for all management scenarios

Table 9. Average simulated Nitrate concentrations for all management scenarios

No	Scenario	Initial Concrnt-ration (mg/l) 2020	Average Predicted Conc. After 20 Years (mg/l)	Average Annual Change (mg/l)
1	Current Situation	104.17	192.51	4.42
2	Decrease Abstraction	104.17	170.97	3.34
3	Increase Recharge	104.17	144.78	2.03
4	Reduction of Mass Loading of N- fertilizers	104.17	104.71	0.03
5	Bring all Scenario togother	104.17	58.17	-2.3

8. CONCLUSION

Development of the Gaza groundwater conceptual model was applied using the data on geology, soil, climate, land use, information about wells and abstraction actually; there was a lack of information such as recharge estimation of the aquifer and poor distribution of some data. However, the numerical groundwater flow model was developed to simulate the Gaza groundwater system and nitrate transport using a finite difference method through GMS 10.4 MODFLOW code and MT3DMS package.

Based on the water level over previous years indicates that the Gaza aquifer has reached to steady state. Consequently, year 2018 was established as a steady state. The model was calibrated using three methods are manual, zonal with ranges and pilot point technique.

The developed numerical model was applied to investigate the overall regional effect of pumping and recharge parameters on the groundwater system and the impacts of transport of nitrate loading from agricultural land on groundwater system for five future management scenarios. Therefore, transient transport model has been developed and the transport parameters (i.e., dispersivity) were calibrated.

Reduction of N-fertilizers loading at cultivate areas by 50% (scenario 4) showed improved in nitrate concentration where the annual change in the concentration was reduced to 0.03 compared to current situation Sc.1. Bringing all scenarios together (scenario 5) is the optimal scenario where the annual average change in nitrate concentration decreased by 2.30 mg/l after 20 years.

Generally, the nitrate concentration in the northern regions of the Gaza strip is lower than in the southern regions. Moreover, excessive pumping effects on the rates of nitrate concentration but the effects are not considerably as compared with reduction of N – fertilizers loading at cultivate areas. The NO3 concentration over the simulation period under the implementation of the CAMP plans are presented in Fig 17 – Fig 20.

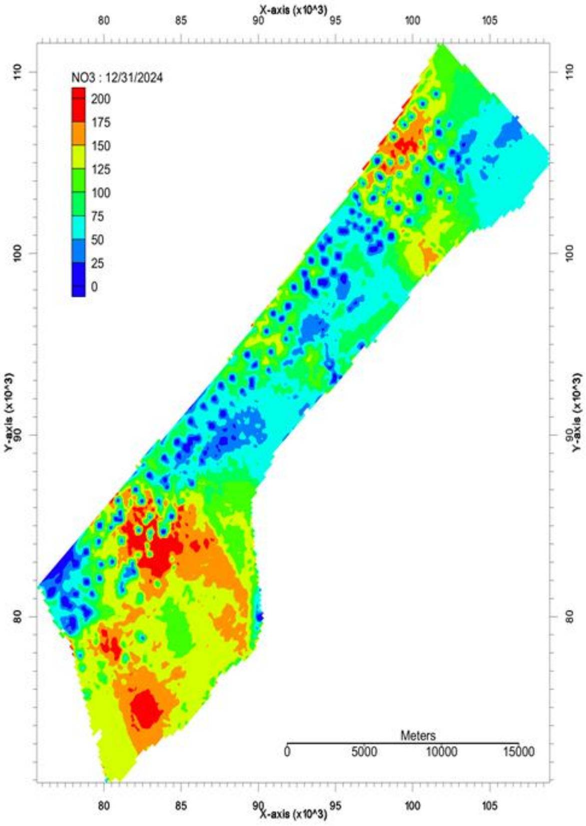

Figure 17. NO_3^- concentrations under Sc.5 for year 2025

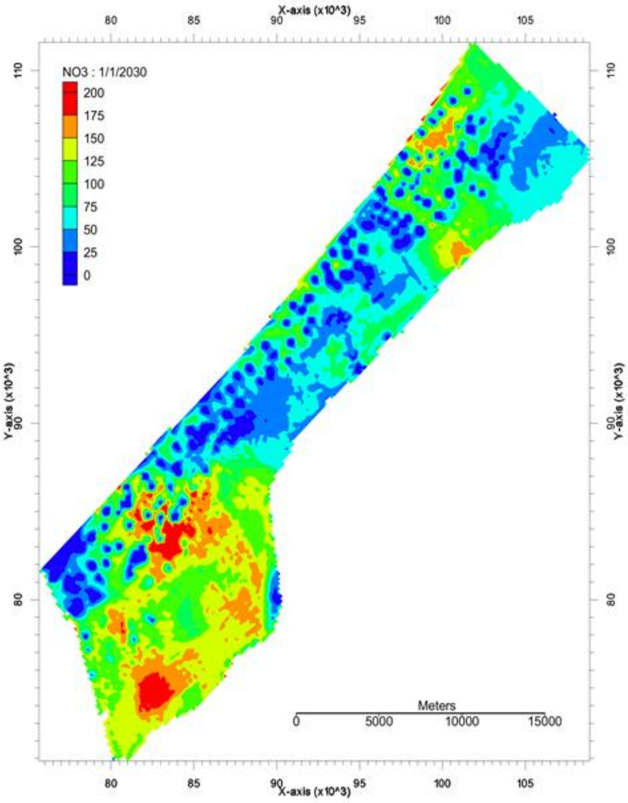

Figure 18. NO_3^- concentrations under Sc.5 for year 2030

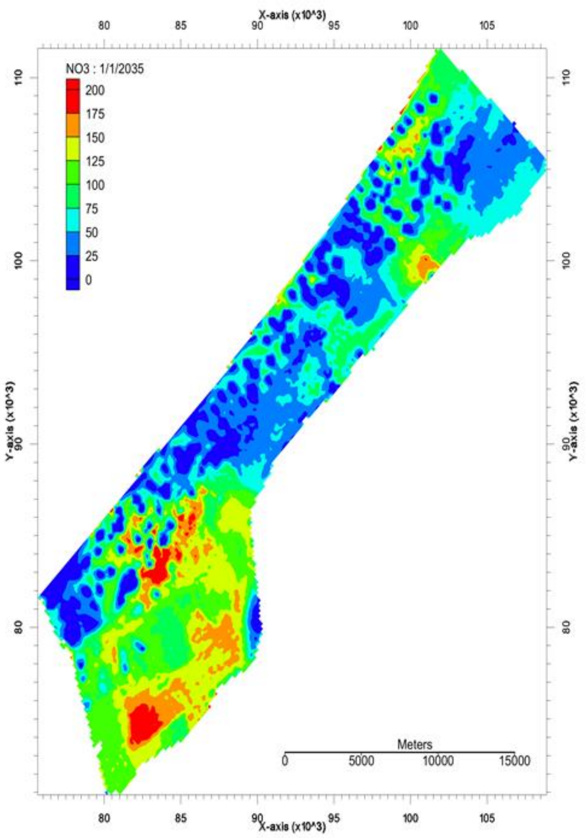

Figure 19. NO_3^- concentrations under Sc.5 for year 2035

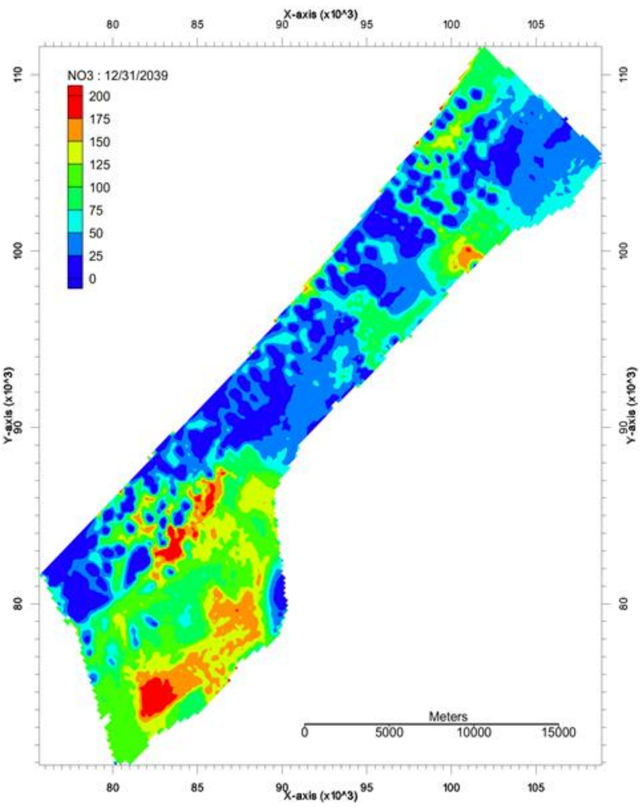

Figure 20. NO_3^- concentrations under Sc.5 for year 2040

Author contributions

Abdallah Jaroun: Investigation, Software, Validation, Writing-Original draft preparation **Ayşe Yeter Günal:** Methodology, Visualization, Writing-Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

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