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Review Article

Assessment of Groundwater vulnerability to pollution in the southern part of Nile Delta, Egypt

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Abstract

Groundwater pollution is one of the most serious environmental problems in the world. Human activities, e.g. industrial, agricultural and household represent a real threat for groundwater quality. The study has been initiated to assess the present state of the groundwater pollution problem in the study area; its vulnerability assessment to delineate areas that are more susceptible to contamination has become an important element for water resource management and land use planning. The results of this study can be used to determine where communities should undertake aggressive protection of the groundwater. These values were reclassified into three classes: low, moderate and high vulnerable zones. The *high vulnerability zones* of the study area are located in the western part of the study area beside the Rosetta Nile branch, High vulnerable rate in such areas is due to the low thickness of clay cap layer of Holocene aquitard, coarse texture of the soil zone and high downward flows which permit infiltration of more pollutants from the upper Holocene to the underlying Pleistocene aquifer, the risk of vulnerability of groundwater pollution in that area is high. Regional development planners will benefit from knowledge of local sensitive aquifers. The moderate vulnerable zones are located in the middle part of the study area, The low vulnerable zones are well distributed and are mainly located in the middle and east parts of the study area Some low vulnerable zones can also be seen in the north western part.

Keywords: Groundwater vulnerability, groundwater, pollution, Egypt

INTRODUCTION

The continuous development of human society as well as the side effects of land reclamation projects left negative impacts on soil and water resources. Such negative impacts are pronounced in water pollution and soil salinization as well. Moreover, the enormous groundwater withdrawal leads to continuous groundwater depletion. Soil salinization is mainly attributed to the groundwater quality, irrigation systems, types of fertilizers, and the badness of drainage systems too. The chemistry of groundwater is an essential parameter for assessing the environmental characteristics of an area (Gallardo and Tase, 2007). The main factors affecting water quality changes are lithofacies geographical conditions, groundwater recharge and runoff conditions, and the degree of openness of groundwater systems (Xu et al., 2009).
Variation of groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Belkhiri et al., 2010). One objective of this study has been to integrate the impact of extensive land use and Human activities, e.g. industrial, agricultural and household represent a real threat for groundwater quality over long periods of time upon aquifer media as an additional parameter to the environmental model to assess the potential level of groundwater vulnerability to pollution.

METHODOLOGY

Detailed Chemical analyses were carried out for the collected samples. Different methods were used for these analyses, ASTM, American Society for testing and material (2002), (Ca^{++}, Mg^{++}, CO_3, HCO_3, and Cl) were measured volumetrically by titrimetric method. Sodium (Na^+) and potassium (K^+) were determined calorimetrically by means of Flame photometer. Sulphate (SO_4) and Nitrate (NO_3) is determined calorimetrically by means of Ultraviolet spectrophotometer screening method at wave length (690, 220nm). Phosphorus (P+++) is determined calorimetrically by using spectrophotometer at wave length (700 nm). Chemical tests of trace elements (Fe++ and Mn++) were determined by means of Atomic Absorption, COD, NH_3, were measured using multiphotometer. BOD measured using specific apparatus.

The study area

The study area occupies the southern part of the Nile Delta. This area is bounded by longitudes $30^{\circ} 50'$ and $31^{\circ} 20'$ E and latitudes $30^{\circ} 10'$ and $31^{\circ} 50'$ N. (Figure1).

Pollution resources in the study area

The major sources of water pollution can be classified as municipal, industrial and agricultural. For many years, the main goal of treating municipal wastewater was simply to reduce its content of suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria oxidation of dissolved organic matter by means of using biologically active sludge, which is then filtered off and tertiary treatment, in which advanced biological methods of nitrogen removal and chemical and physical methods such as granular filtration and activated carbon absorption are employed**,** Terry (1996).

In Menoufiya governorate there are thirteen waste water stations covering all towns and some villages. Most these stations have small flow rate, (5000 - 20000 m^3/day). Shibine Elkom and Menouf stations have highest capacity and considered the largest flow rate /day, (70000 and 60000 m^3/ day) respectively, (Figure 1).

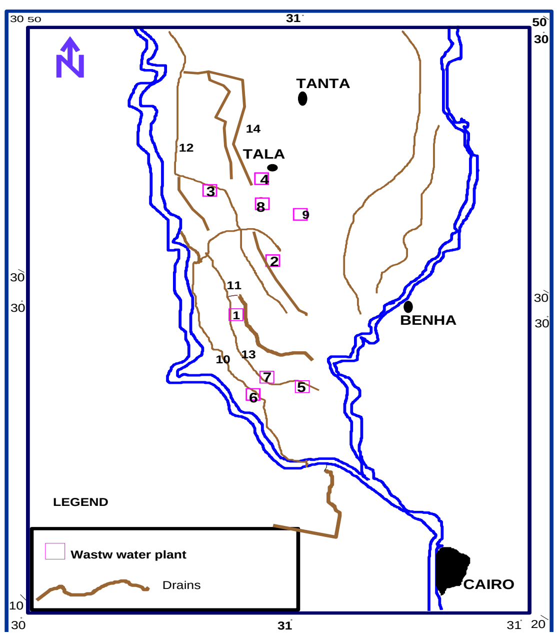

Figure 1. Location map of waste water stations and main drains

Legend NO.	Name	Legand NO.	Name
1	Kafr El Sanabsa	8	Batanun
2	Shibin El Kom	9	Kom ElAkhdar
3	Al Shouhdaa	10	Sabal drain
4	Tala	11	Feraunia drain
5	Ashmoun	12	AlShouhdaa drain
6	Shamma	13	Menouf drain
7	Samadun	14	Tala drain

Table 1. Environmental - chemical analyses for waste water stations in study area

Sample NO.	Station Name	Drain Name	Injection stream	Flow Rate (m^3/day	BOD(mg/l)	COD (mg/l)	NH_3 (mg/l)	Organic load
1	Kafr El Sanabsa	Menouf	Rosetta Branch	60000	60	85	10	3600
2	Shibin El Kom	Sabal	Rosetta Branch	70000	120	250	30	8400
3	Al Shouhdaa	Al Shuhada	Rosetta Branch	10000	60	85	10	550
4	Tala	Tala	Rosetta Branch	10000	55	90	15	550
5	Ashmoun	Sabal	Rosetta Branch	20000	75	120	20	1500
6	Shamma	Sabal	Rosetta Branch	5000	85	160	10	425
7	Samadun	Menouf drain	Rosetta Branch	5000	80	120	10	400
8	Batanun	Tala drain	Rosetta Branch	10000	55	100	10	550
9	Kom ElAkhdar	Tala drain	Rosetta Branch	5000	85	150	20	225

Biochemical oxygen demand (BOD)

Biochemical oxygen demand (BOD) of waste water and surface water is the expression for the amount of oxygen consumed by the decomposition of organic matter in a biochemical process. The BOD content in wastewater in the stations located in study area illustrated that, According to Egyptian Environmental Law (1982), Most waste water stations in the study area exceeded the permissible limit (60 mg/l). The highest value was recorded in Shibin El Kom waste water station 120 mg/l. whereas the lowest value recorded in Mitbera station 38 mg/l. Shibin El Kom waste water station recorded the highest amount of BOD (8400 kg. BOD/day), which injects directly to Sabal drain, followed by Kafr El Sanabsa waste water station (3600 kg, BOD /day) injected directly to Minouf drain. These high loads of BOD resulted from these stations injected directly to Sabal drain and finally to Rosetta branch, (Figure 2).

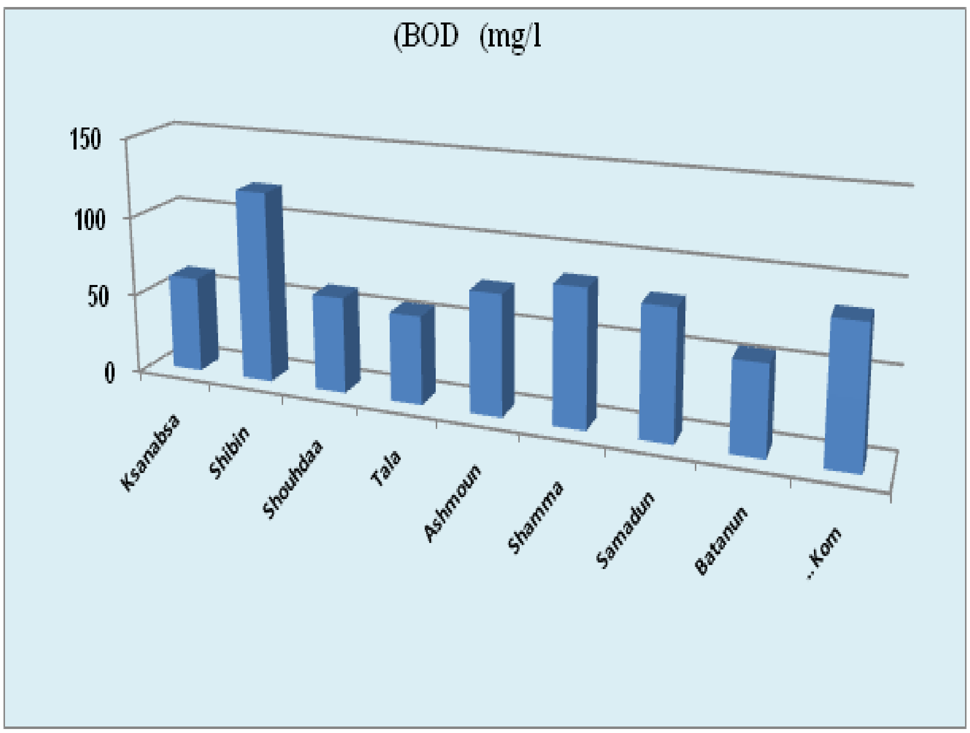

Figure 2. Biochemical oxygen demand (BOD) from wastewater stations

Chemical oxygen demand (COD)

Chemical oxygen demand (COD) is an expression for the amount of oxygen consumed by the decomposition of organic matter in a Chemical process. COD is used as a measure of the oxygen equivalent of the organic matter content of sample that is susceptible to oxidation by a strong chemical oxidant Burns and Marchal (1965). Chemical analysis for the COD value in wastewater stations in study area indicated that the waste water effluent of Shibin El Kom station was the highest value among all stations in the study area 250 mg/l followed by Kafr El Sanabsa waste water station 85 mg/l. High content of COD contributes in surface water pollution and it may cause groundwater pollution, Figure 3. According to Egyptian Environmental Low (1982), most samples collected from waste water stations in study area exceeds the maximum permissible limit, (80 mg/l).

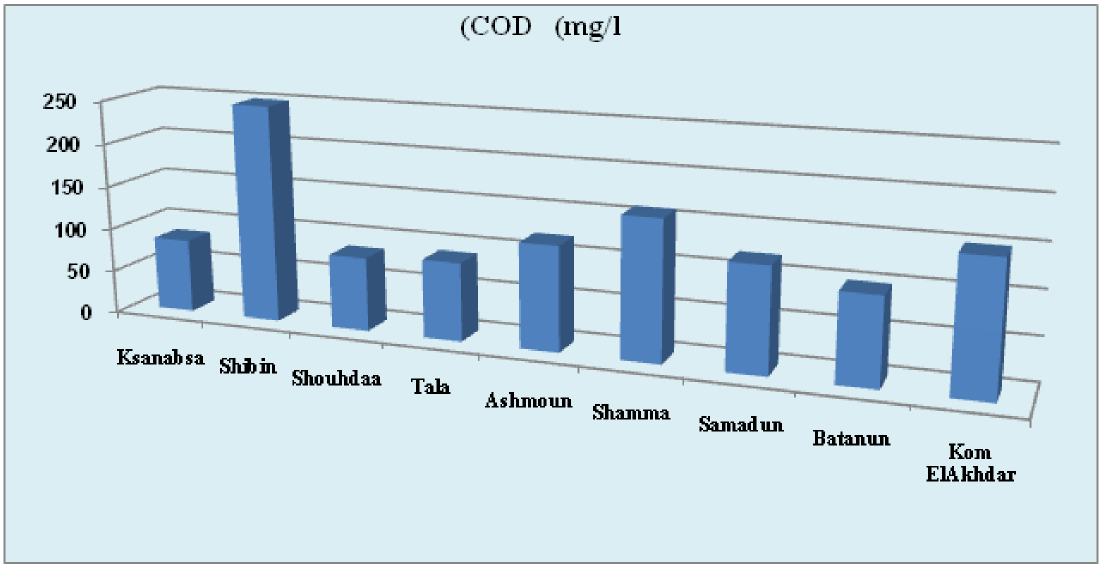

Figure 3. Chemical oxygen demand from waste water stations

Pollution with ammonia

Ammonia (NH_3) present naturally in surface and waste water. Its concentration generally is low in groundwater but in some natural surface water and waste water vary from 10 Ug/l to more than 30 mg/l, Terry (1996). NH_3 content in Shibin El Kom waste water station was the highest value among all stations in the study area (30 mg/l). Kafr El Sanabsa, Ashouhda, Batanoun, Shamma and Samadoon stations were recorded (10 mg/l). According to Egyptian Environmental Low (1982), all samples collected from waste water stations in study area exceeded the permissible limit, (1.0 mg/l), (Figure 4).

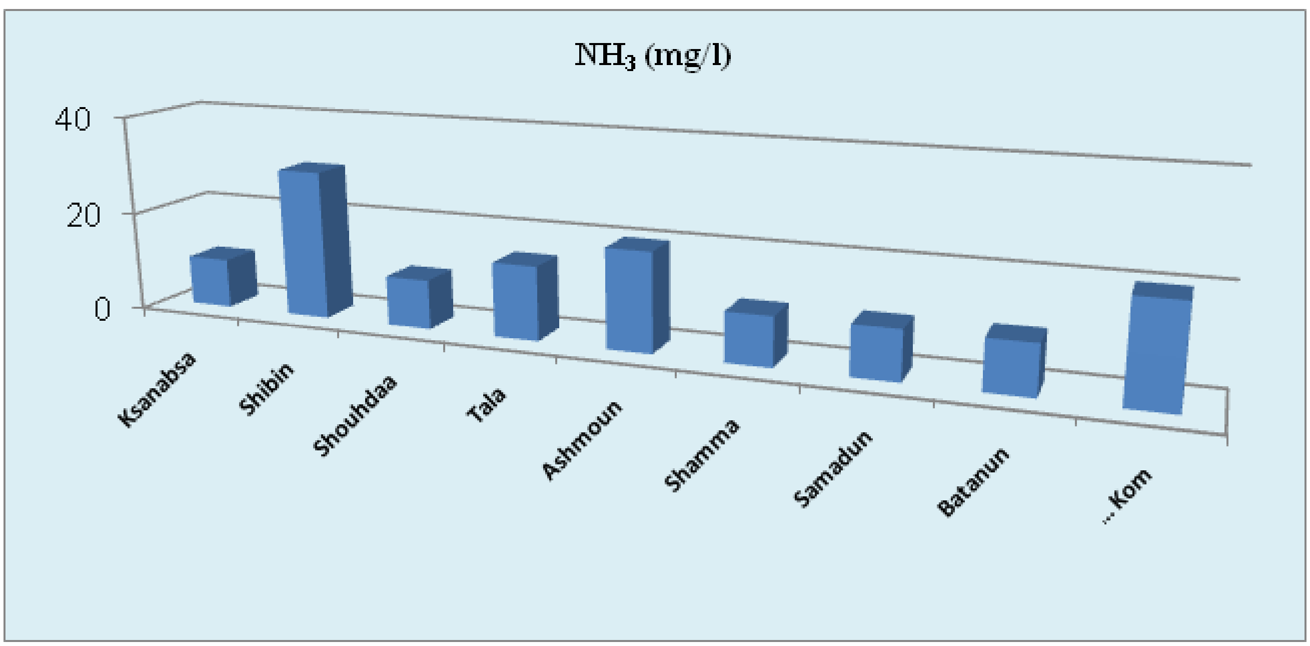

Figure 4. Pollution with (NH_3) from wastewater stations

Organic load is an expression for the amount of organic matter that needs decomposition in a biochemical process. Measuring the BOD in sample in kg/day is an expression for the organic load. the organic load content of Shibin El Kom station was the highest value among all stations in the study area 8400 kg/day followed by Kafr El Sanabsa waste water station 3600 kg/day. High content of Organic load contributes in surface water pollution and it may cause groundwater pollution (Figure 5).

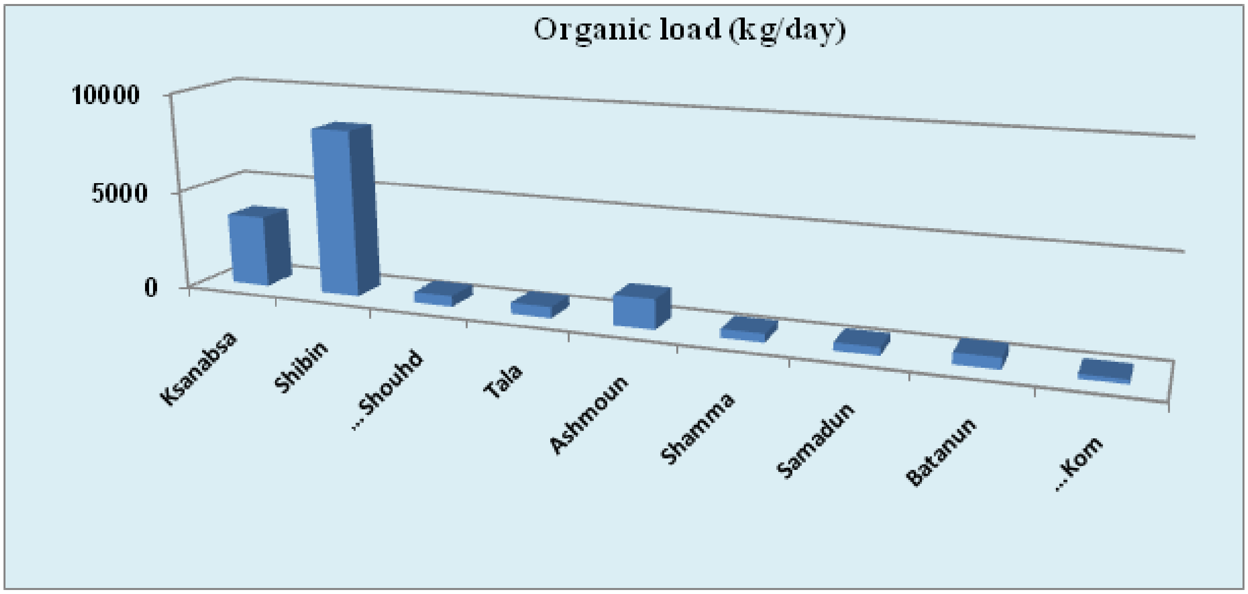

Figure 5. Organic load in wastewater stations

Microbial pollution

Data resulted from tested samples shows that Total *coliform* is more than the recommended limits according to the Egyptian Environmental Low (1982), ranges from 2000 colony /100 in Tala and Kafr Esnabsa to 70000 colony /100 ml (Shibin Elkom station)(Figure 6).

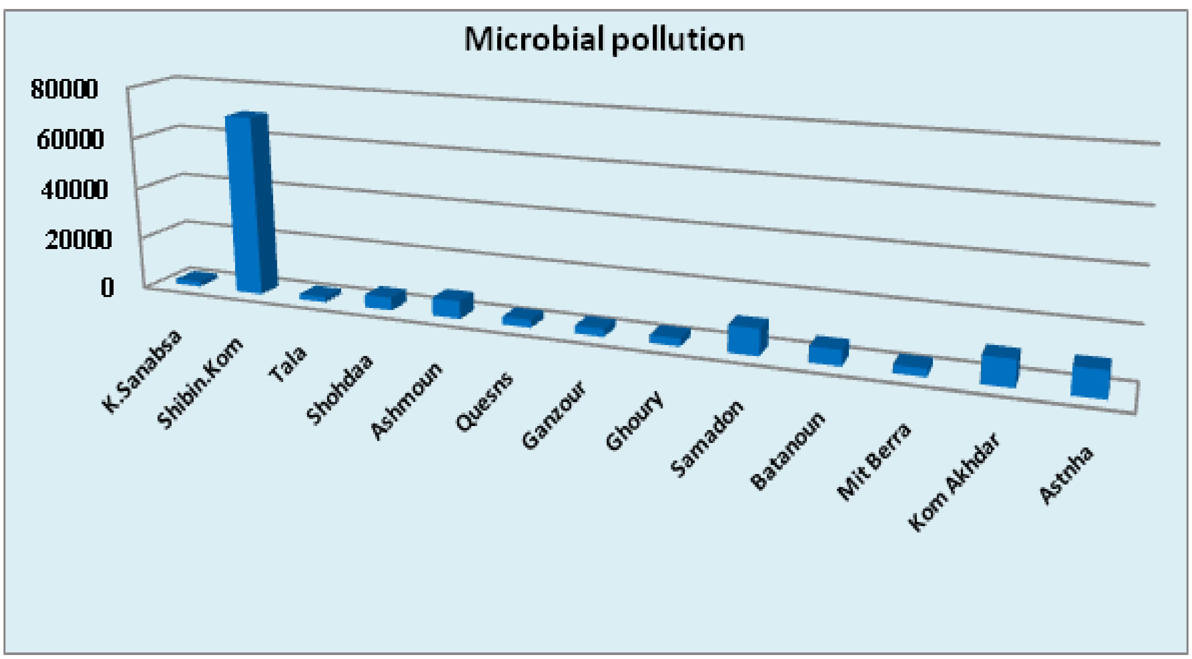

Figure 6. Microbial pollution from wastewater stations

Table 2. Maximum permissible limits for different pollutants according Environmental Egyptian Law (1982)

Parameters in mg/l	River Nile	Nile branches and Main canals	Drains
BOD (mg/l)	6	6	10
CO (mg/l)	10	10	15
NH3 (mg/l)	0.50	0.50	0.50
Total *Coliform* (Colony/100 ml)	5000	5000	5000

Agriculture sources

Agriculture activities are divided into contaminants associated with agricultural drainage water, animal waste, chemical fertilizers and pesticides.

Phosphate pollution

Phosphate content in the collected groundwater samples ranged from 0.005mg/l at the north-western part of study area near Rosetta branch to 0.95 mg/l at the north part of the majority of groundwater collected samples (Figure 7) and. Generally, phosphates enter the water supply from agricultural fertilizer run-off, water treatment, and biological wastes and residues. The highest concentrations recorded in southern west part of the study area according to water flow.

Nitrate pollution

Conversion of the organic nitrogen to Nitrate (NO_3) by oxidation is known as nitrification. This processes that normally occur above the water table generally in the soil zone. Nitrate is high soluble in water, it is very mobile in groundwater and migrates to larger distances from the input areas. Moreover, NO_3^- is hardly subjected to adsorption by soil, RIGW/ IWACO (1989, b). The collected groundwater samples display low content of nitrate in most study area mean where NO_3^- increased in localities over the permissible limits. Nitrate contents ranged from 1.5 mg/l at the northern part of the study area to 60 mg/l at the western part of the study area. Highest concentration of nitrate (89 mg/l) was recorded at El Rahawy village in Giza Governorate. Slightly increases in nitrate contents in Rahawy station well may be attributed to the recharging pollution of sanitary drainage from El Rahawy drain according to local movement of groundwater Figure 8). According to WHO (2005) maximum limit for nitrate in drinking water is 45 mg/l.

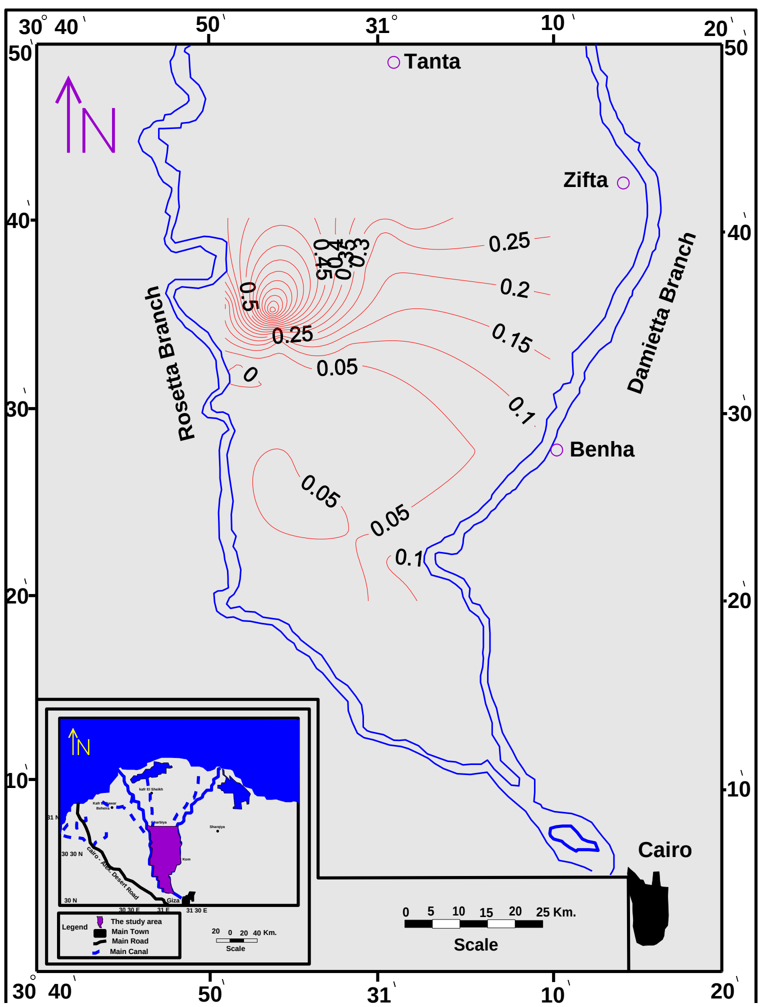

Figure 7. Phosphate pollution map

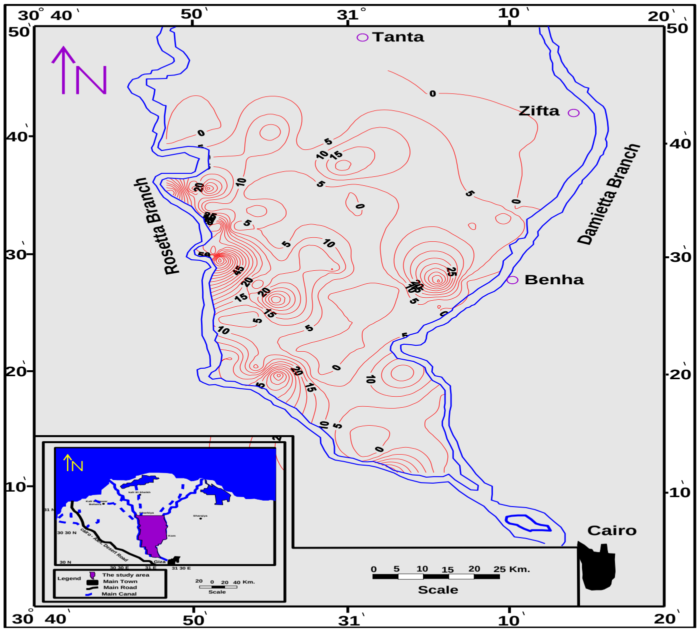

Figure 8. Nitrate pollution map

Hydrochemical aspects of groundwater

PH value in the all samples that collected from the groundwater in study area lies in safe limits for drinking and irrigation purposes. Total hardness in groundwater in study area ranged between 104 mg/l at Astnha near Damietta branch to 400 mg/l in the north. Salinity contents show increasing from south to north direction, it has values from 240 mg/l at well NO.54 to 810 mg/l at the north direction. Hydrochemical parameters of groundwater show large variation with movement from south to north. The increase of salinity in the North direction may be due to effect of vertical downward seepage of sanitary and agricultural waste water as well as the dissolution of salts from the sediments of the aquifer itself according to flow direction. The majority of groundwater samples have calcium contents ranging from 10 to 100 mg/l. Magnesium content ranged from 8.3 mg/l at Barhim village near Rosetta branch to 58.3 mg/l at Nader village in the north direction. The concentration of sodium ion increased toward the north and western direction according to groundwater movement due to active cation exchange and leaching processes of Na-minerals (Na-feldspars) present in aquifer material, and releasing sodium ion. The concentration of chloride ion in groundwater samples ranged from 26 mg/l at the south near Baguriya canal to 160 mg/l at the northern part of study area. Sulfate contents ranged from 21 mg/l at both east and west study area) to 180 mg/l (at Bemem village in the north. Bicarbonate content in groundwater samples has wide range from 104 mg/l at Begeram village near Damietta branch in eastern part of the study area to 340 mg/l at Mit Khalaf village in the northern part.

Correlation coefficient of chemical ions

The relationship between salinity contents and the other ions indicates that bicarbonate; calcium and magnesium are the effective ions which caused an increase in salinity content and change in groundwater quality. Salinity displays moderate linear relationship with calcium and bicarbonate ions, these elements show moderate correlation coefficients with salinity content (0.56 and 0.50 respectively). Sodium, potassium, chloride and sulphate show poor linear relationship with salinity, it has low correlation coefficient 0.11, 0.27, 0.26, and 0.38 respectively (Table 3).

Table 3. Correlation coefficient of chemical ions of groundwater in study area

	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}
TDS	1							
Ca^{+2}	0.44	1						
Mg^{+2}	0.17	0.35	1					
Na^{+}	0.03	0.14	0.38	1				
K^{+}	0.28	0.00	0.11	0.43	1			
HCO_3^{-}	0.56	0.50	0.29	0.17	0.09	1		
SO_4^{--}	0.40	0.52	0.53	0.22	0.38	0.08	1	
Cl^{-}	0.26	0.01	0.72	0.55	0.30	0.12	42	1

Geochemical classification of groundwater

The geochemical classification of groundwater is based on ion relationships, the most common are the tri linear diagram of Piper (1953) Piper's trilinear diagram for groundwater wells consequently show that (Figure 9), the projection of chemical composition of groundwater on the diamond field revealed that most of water chemical compositions are plotted in sub-area 9 (48 wells), and in subarea 5 (28 wells) this diagram reflects fresh water and that reflects Ca-HCO_3 and $MgHCO_3$ water type. Finally, the Pleistocene aquifer of the study area has two main water types, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ water type which reveals initial phase or groundwater mineralization.

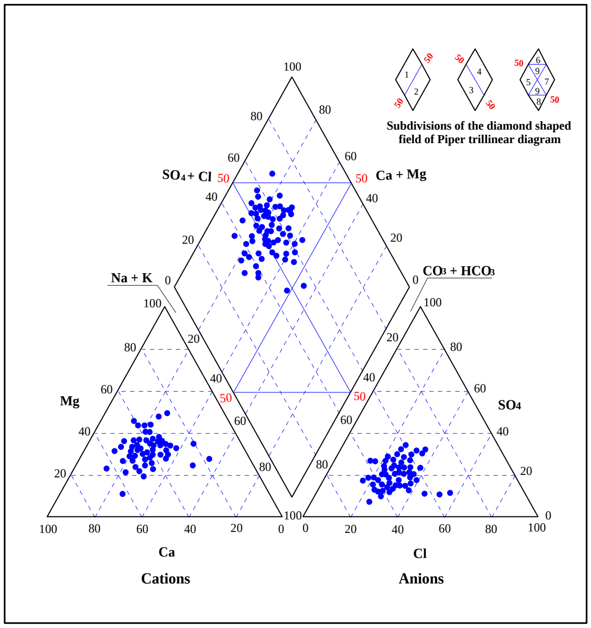

Figure 9. Piper trilinear diagram for groundwater samples

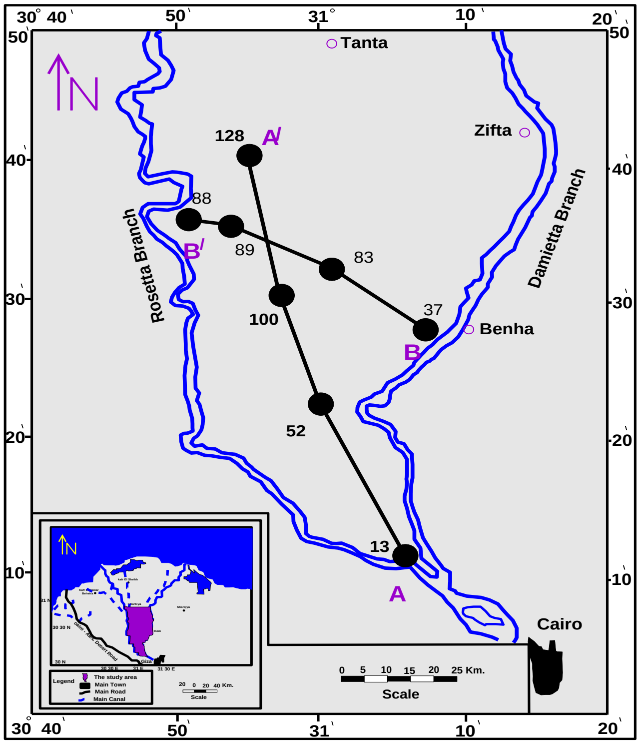

Figure 10. Hypothetical cross sections along the Quaternary aquifer

Along the south – north (Profile A – A\)

This profile passes through four deep productive wells representing the Pleistocene aquifer along distance of about 55 Km (Figure 11). This hydrochemical profile is developed along the Pleistocene aquifer in the study area from south to north direction, where the general flow of groundwater is in the same direction.

From this profile the following points could be concluded:

The total mineralizations (TDS) are increase in the north direction in the same direction of groundwater flow to reach their maximum values at well No. 128 (735 mg/l) in northern part of study area.

The behavior of different ions concentration is developed along the profile where there is superiority of Cl over Na in most groundwater samples in this profile, indicating precipitation of terrestrial salts.

Bicarbonate contents represent about 37.55 % from TDS at southern part (Well No. 13) and about 45.46 % at northern part (Well No. 128).The concentration of bicarbonate are generally increase with groundwater flow direction.

The concentration of sulphate and chloride are generally increase groundwater flow direction along this profile follow the geochemical evolution system reported by Burdon (1958), this suggestion is agreement with the fact that there is recharge and groundwater flow from south to north direction.

Concerning the metasomatic change of water chemistry in horizontal direction, it is clear that the groundwater of the Pleistocene aquifer in this profile has change in groundwater composition, one can notice that $Ca(HCO_3)_2$, $MgHCO_3$ and $MgSO_4$ salts increased towards south direction, while NaCl and $MgCl_2$ salts decrease in the same direction.

The assemblage of salts combination (I), , NaCl, $MgCl_2$,$MgSO_4$, $CaSO_4$, $CaHCO_3$ is the dominant in groundwater samples in south direction while the assemblage of salt combination (**II**), NaCl, $MgCl_2$, $MgSO_4$ $MgHCO_3$ and $CaHCO_3$ is dominant in groundwater samples in the north direction. The ions displays different grades of one stage of mineralization along this profile, the first grade is ($HCO_3 > SO_4 > Cl$) (sample NO. 13). And the second degree is a less advanced stage of mineralization at second point ($HCO_3 > Cl > SO_4$) (sample NO.128) this related to irrigation canals net in the study area which act as a recharge source.

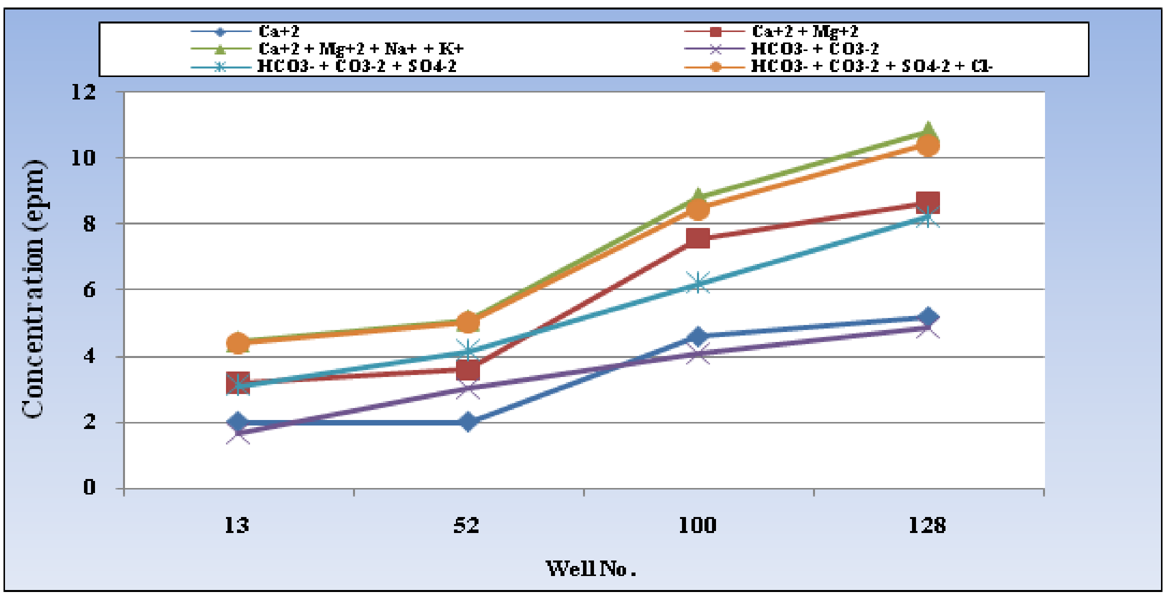

Figure 11. Spatial variation along the south – north (profile A – A\)

According to the previously mentioned data from both physico-chemical and bacteriological analyses, where the high loads of BOD and COD resulted from these stations injected directly to El-Rahawy, Sabal and Tala drains and finally to Rosetta branch, it is clear that all drains selected in this study are seasonally suffering from chemical and bacteriological pollution with varying levels and varying nature, being maximum at El-Rahawy, Sabal and Tala drains in which the levels of pollution fluctuated between them from one measured parameter to another.

Along the southeast -northwest (profile B – B\)

This profile passes through four deep wells. The total salinity of the groundwater along this profile is increase in the northwest direction to reach their maximum value at well NO.88, (728 mg/l). Bicarbonate content represents 51.05 % from TDS at southeast (well No. 37) then gradually decreases to minimum of 44 % from TDS at northwestern part. While the concentration of SO_4 and Cl are generally increase in the northwest direction along this profile follows the geochemical evolution system reported by Burdon (1958), concerning the metasomatic change of water chemistry in horizontal direction, it is clear that the groundwater of the Pleistocene aquifer in this profile has change in groundwater composition, one can notice that, NaCl, $MgCl_2$, Na_2SO_4, $MgSO_4$ and $Ca(HCO_3)_2$ salts has changed behavior between increasing and decreasing, this behavior may relate to irrigation canals net in the study area. The assemblage of salts combination KCl, NaCl, $MgCl_2$, $MgSO_4$ $MgHCO_3$ and $CaHCO_3$, is the dominant in groundwater samples along this profile. Presence of $MgCl_2$ in all wells in the profile reflect the effect of marine salt pollution with possible contribution of cation exchange phenomena resulting from the presence of clay intercalated with the Plistocene aquifer in the study area. The ions displays one grades of metasomatism along this profile, grade is ($HCO_3 > Cl > SO_4$). These agree with the general gradient of chemical evolution of groundwater.

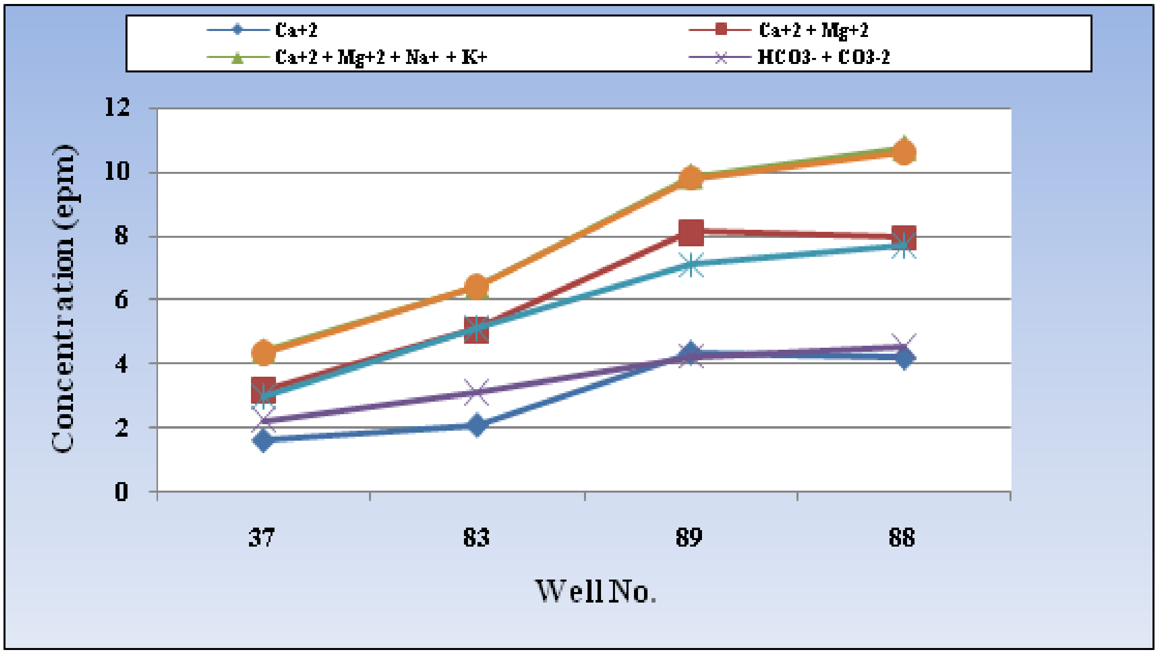

Figure 12. Spatial variation along the east – west profile B – B\

Assessment of groundwater vulnerability

The main sources of pollution in the study area and the hydrogeological parameters that control vulnerability in the study area will be discussed here below.
1-The thickness of the covering clay cap,
2-Depth to the groundwater table of the aquifer
3-Upward seepage or infiltration (vertical flow)
4. Hydrogeological characteristics

4.1. The thickness of the covering clay cap

Groundwater aquifer belongs to early and middle Pleistocene time and is composed mainly of thick layers of quartzite sand and pebbles that occur above El-Wastani formation (Rizzini et al., 1978). This aquifer is capped with Holocene aquitard. The top clay and silt layer acts as a cap for the main quaternary aquifer, this unit represents the Nile alluvium deposits that belong to Holocene time. It is mainly composed of Nile silt, sandy clay, and clayey sand (Farid, 1980). The water in this layer is in connection with the groundwater in the main underlying aquifer through a vertical flow in the form of downward leakage (infiltration) or upward seepage (groundwater logging). The thickness and lithological characteristic of clay top layer are very important in retaining many pollutants during their way downward to the aquifer. The areas of small thickness less than 10 m and coarse texture sediments such as sand display high infiltration and conductance while the areas of large thickness more than 10 m and fine texture sediments such as silt and clay display low infiltration and conductance (Figure 13). The thickness of top Holocene equated (Figure 14) shows wide range from 5 to 20 m in the study area (Dahab, 2003).

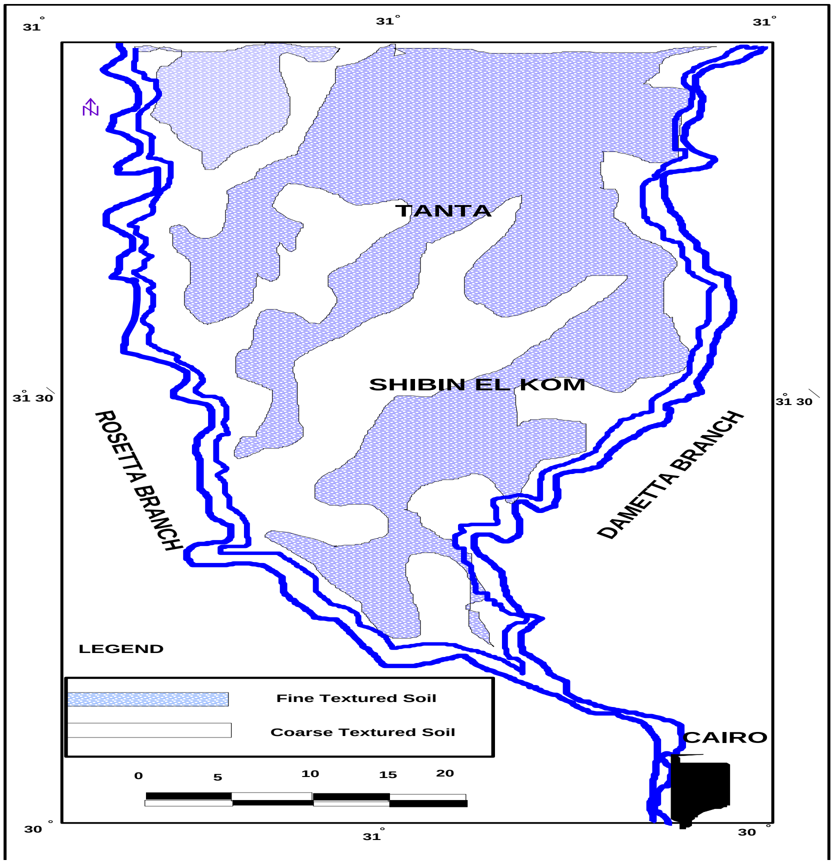

Figure 13. Soil classification in the study area (after Radi, 1993)

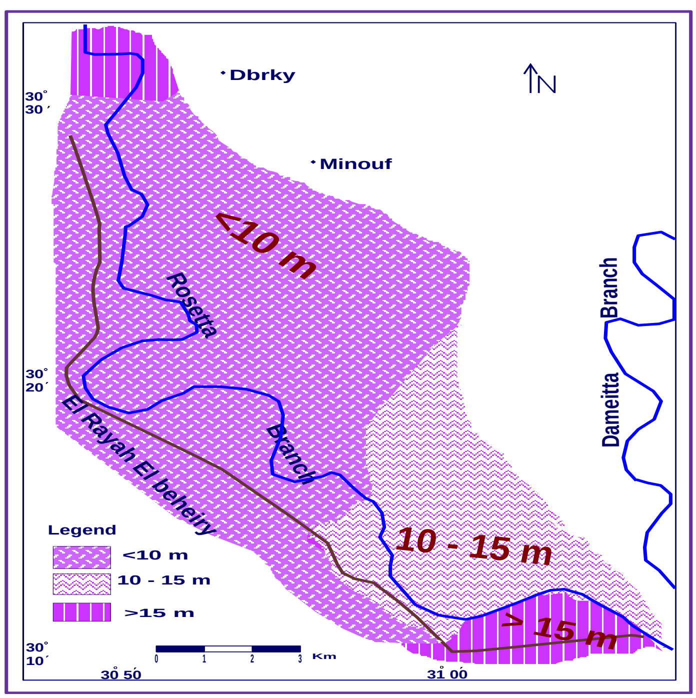

Figure14. Thickness of clay cap in the study area (after RIGW/IWACO, 1989, a)

The vertical hydraulic conductivity of the clay cap plays important role, it ranges between 50 and 500 mm/day. The value of the vertical hydraulic conductivity of the clay cap layer increases with increasing grain size texture and small thickness.

Depth to the groundwater table

From the depth to water map (Figure 15) Depth to water and peizometric heads of the existing observation wells were measured during December 2013. Depth to water and potentiometric map were constructed (Figure15). Depth to groundwater decreases towards Rosetta branch and decrease close main irrigation canals and El-Rayahat. It ranges between 2.0 m. at the North West and 10 m. at the south east. Potentiometric heads decrease from the southeastern part to the north and northwestern parts; they range from 17.0 m above MSL at the eastern part to 6.0 m above MSL close to North western part around Rosetta branch. , the groundwater show low depths (less than 2.5 m) in areas close to the Rosetta branch which indicate high vulnerability to pollution in this area. Areas of high depth more than 4m indicate moderately vulnerability to pollution such areas. From the flow net map of the study area the general direction of groundwater movement is from south east to the North West towards Rosetta branch which acts as a main drain for drainage water of most drains along its course and that leads to high vulnerability to pollution in the areas adjacent the branch.

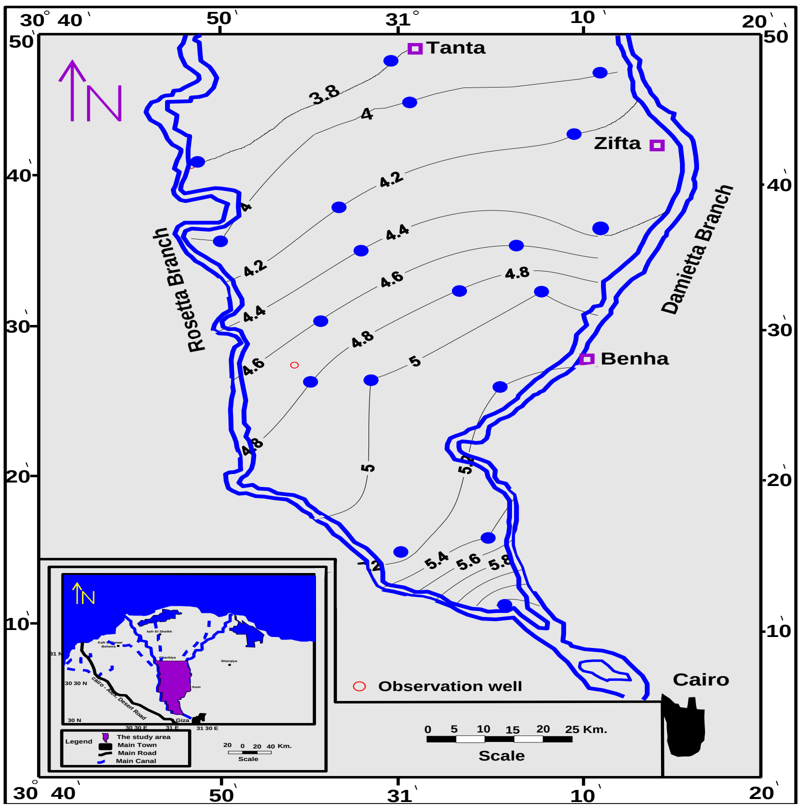

Figure 15. Depth to groundwater in Pleistocene aquifer

Upward seepage or infiltration (vertical flow)

The upward groundwater flow dominates the north –eastern part of the area extending along the Damietta branch, and the downward groundwater flow dominates the south-western part of the area extending along the Rosetta branch. In the middle part of the area, there are alternated bands of upward and downward flow**.**

Hydrogeological characteristics

The most important hydrogeological characteristics that influence on groundwater vulnerability are discuses as follow,

A-vertical hydraulic conductivity: The value of the vertical hydraulic conductivity of the clay cap layer increases with increasing grain size texture and small thickness. The areas of high vertical hydraulic conductivity, small thickness (less than 10m) and coarse texture increase vulnerability while the areas of low vertical conductivity, fine texture sediments (high content of clay) indicate more retaining of pollutants.

B- The transmissivity values of the underlying Pleistocene aquifer range between 2000-3000 m^2/day (Dahab, 2003) and that value reflects high pollutants transmissivity in this layer and increases the vulnerability to pollution in the surrounding area.

Classification of groundwater vulnerability

According to the previous discussion Classification of groundwater vulnerability, the study area was divided into three vulnerable classes these classes indicate areas of higher, moderate, and low groundwater vulnerability (Figure 16)

Classification of groundwater vulnerability depending on five main factors that are; vadose zone, Soil media and its texture, Depth to water, Aquifer media, and hydraulic Conductivity and Table 4 modified after RIGW/IWACO (1989, a) shows the classification of groundwater vulnerability according to the conditions of the area under investigation. The study area was divided into three vulnerable classes these classes indicate areas of higher, moderate, and lower groundwater vulnerability

Table 4. Guidelines of the groundwater vulnerability

Vulnerability character	Higher	Moderate		Lower	
Thickness of clay cap	<10m	<10m	10-15 m	>15m	>10m
Vertical direction of flow	Downward infiltration	Upward seepage	Downward infiltration	Downward infiltration	Upward seepage
Type of soil	Sandy or silty(coarse)	Sandy or silty (coarse to fine)	Silty clay (fine to coarse)	Clay (fine)	Silty clay (fine to coarse)

.

The different classes of groundwater vulnerability of the study area will be discussed according to (figure 16) as follows;

(1) Higher vulnerable areas:

1- The *high vulnerability zones* of the study area are located in the western part of the study area beside the Rosetta Nile branch, High vulnerable rate in such areas is due to the low thickness of clay cap layer of Holocene aquitard, coarse texture of the soil zone and high downward flows which permit infiltration of more pollutants from the upper Holocene to the underlying Pleistocene aquifer, the risk of vulnerability of groundwater pollution in that area is high.

The results of this study can be used to determine where communities should undertake aggressive protection of the groundwater. Regional development planners will benefit from knowledge of local sensitive aquifers

(2) Moderate vulnerable areas: The *moderate vulnerability zones* of the study area are located in the middle part of the study area. These are characterized by fine texture sediments, relatively large thickness of the covering clay cap (10-20 m) and moderate leakage factor which resist downward infiltration of pollutants into the underlying aquifer. The groundwater in these areas can be polluted with pollutants but may be less than the higher vulnerable areas.

(3) Low vulnerable areas: The groundwater in these areas is more safety compared with high and moderate vulnerable area. This is due to large thickness of the covering clay cap more than 20m), fine texture of sediments, high leakage factor and high hydraulic resistance to percolate vertical downward flow into the underlying aquifer. The groundwater in these areas is most protected from pollutants so these areas are the most suitable areas for sustainable development.

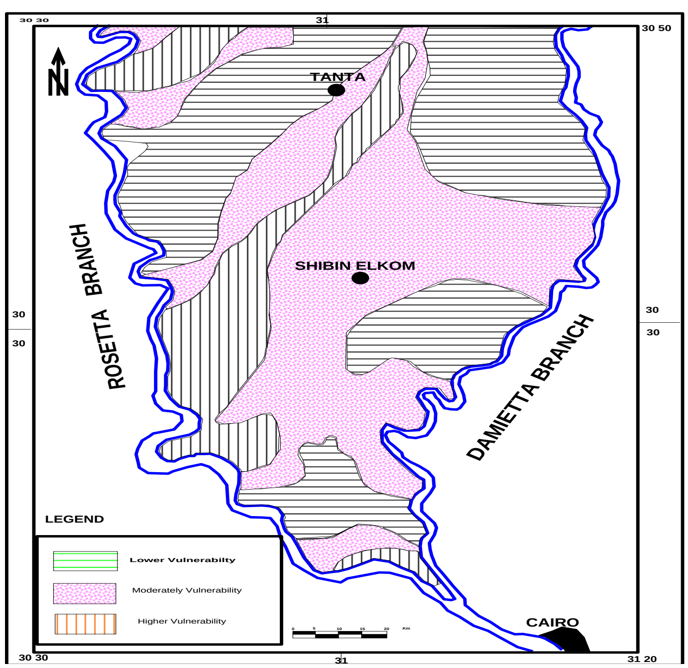

Figure 16. Vulnerability classification map of the study area

CONCLUSION

The study area occupies the southern part of the Nile Delta. This area is bounded by longitudes 30° 50\ and 31° 20\E and latitudes 30° 10\ and 31° 50\N , groundwater plays an important role in water supply. Excessive abstraction and anthropogenic activities have altered groundwater quality in the study area. This study utilized Zekester model (2000) and GIS technique to assess the aquifer vulnerability. Five environmental parameters which include Impact of vadose zone, Soil media and its texture, Depth to water, Aquifer media, and hydraulic Conductivity were used to represent the hydro geological setting of the study area. According to the results of the groundwater vulnerability assessment, the study area has been divided into three zones: low groundwater vulnerability risk zone; moderate groundwater vulnerability risk zone and high vulnerability zone. The result of groundwater contamination analysis shows that the aquifer is polluted although the intrinsic vulnerability assessment. Groundwater at area closed to Rosetta Nile branch which have high vulnerability can be a threat for public health if serious action is not taken to stop further pollution

RECOMMENDATIONS

The results of this study recommended the following:

1- Raise the efficiency of sewage stations where the output rate is still high pollution and is a danger to discharge into the drains

2- Enforcement of all articles of law 48/1982 regarding the protection of River Nile and waterways from pollution.

3- Monitoring of River Nile water regularly in order to record any alteration in quality.

References

ASTM, American Society for testing and material (2002). In "water and environmental technology" annual book of ASYM standars, Sec. 11, Vol. 11.01 and 11.02, West Conshohocken, U.S.A.

Belkhiri L, Boudoukha A, Mouni L, Baouz T (2010). Application of multivariate statistical methods and inverse geochemical modeling for characterization of groundwater - A case study: Ain Azel plain (Algeria). Geoderma. 159: 390–398.

Burdon DJ(1958). Metasomatism of groundwater at depth, UNESCO course on Hydrology, Desert Institute, Cairo, Egypt.

Burns ER, Marchal A (1965). Correction for chloride interference in the chemical oxygen demand test J. Water Pollut. Control Fed. 37:1716

Dahab KA(2003). Influence of hydrogeologic flow pattern and aquifer material on water quality and mineral contents: Case Study, Nile Delta Egypt. Sci. J. Fac. Sci. Menoufia Univ. 17: 65 -86.

Farid MS(1980). Nile Delta groundwater study. M. Sc. Thesis Fac. of Eng. Cairo Univ.

Gallardo AH, Tase N(2007). Hydrogeology and geochemical characterization of groundwater in a typical small-scale agricultural area of Japan. *J. Asian Earth Sci.* 29(1): 18-28. [doi:10.1016/j.jseaes.2005.12.005]

Piper AM(1953). "Agraphic representation in the Geochemical interpretation of groundwater analysis" Am. Geophis. Union Transactions. 25: 914-923.

Rady S(1993). Pollution of groundwater resources in the southern part of the Nile Delta, Egypt and its impacts on the development plans. M.Sc. Thesis, Geology department, Fac. of Sci. Menoufia Univ.

RIGW/IWACO (1989, a). Development and management of groundwater resources in the Nile Valley and Delta: Vulnerability of groundwater to pollution in Nile Valley and Delta. (Case study Cairo mapsheet). Research Inst. For groundwater, Kanater El- Khairia, Egypt.

RIGW/IWACO (1989, b). Development and management of groundwater resources in the Nile Valley and Delta: Assessment of groundwater pollution from domestic activities. Research Inst.for groundwater, Kanater El-Khairia, Egypt.

RIGW/IWACO (1990, a). Development and management of groundwater resources in the Nile Valley and Delta: Assessment of groundwater pollution from agricultural activities. Research Inst.for groundwater, Kanater El-Khairia, Egypt.

Rizzini A(1978). "Stratigraphy and sedimentation of Neogene – Quaternary section in the Nile Delta area. IEOC, 5 th exploration seminar of EGPC, Cairo, Marine geol. 27: 327-348.

Terry LA(1996). "Water Pollution" ENVIRON. LAW PRACT. 4(1): 19-29. Egyptian Environmental Law (1982).

Todd DK(1959). Groundwater Hydrology 2 nd edition., John Wiley and Sons Inc., New York, U.S.A. Pp.336

World Health Organization (WHO) (2005). International standards for drinking waters. 5th Edition, Vol. 1 Geneva, Switzerland.

Xu ZH, Li YF, Jiang L, Hou GC, Hu AY(2009). Geochemical modeling of Huanhe water-bearing layers in South Ordos Basin. *J. Arid Land Resources and Environ.* 23(9): 160-168. (in Chinese).

Zekster IS(2000). "Groundwater and the environment". Lewis publishers London, New York. Pp. 175.