

Environmental Management of Groundwater in the Eastern Nile Delta, Egypt

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Abstract: This paper is an assessment of the hydrochemical aspects of the groundwater in Eastern Nile Delta region and an evaluation of the different groundwater types and their suitability for using various development sectors (domestic, agriculture and industrial). To evaluate the groundwater quality in the Eastern Nile Delta, chemical analysis was carried out for several groundwater samples collected from either private production wells or national groundwater monitoring network. The results of this study indicated that the groundwater quality which lies within the quaternary aquifer is suitable for human and agriculture purposes in the south of the study area while it is affected by the seawater intrusion in the north. Also, it is clear that the groundwater contains high chlorides, sodium, calcium and sulfates as well as high values of TDS and hardness above the WHO standards in some localities. The concentration of Na, Mg and HCO_3 at some localities near the coast suggests seawater intrusion which is further sustained by a general increase in the value of Cl content and NA/Cl ratio and a decrease in HCO_3 content towards the coast. In the new reclaimed agriculture areas at the desert fringes, high nitrate exists due to the extensive application of fertilizer in agriculture. Detailed vulnerability map for the groundwater pollution was produced using DRASTIC index and Geographical Information System (GIS). Based on the hydrochemical classification, five groundwater types have been delineated within the study area. They are Calcium Bicarbonate $\text{Ca}(\text{HCO}_3)_2$, Magnesium Bicarbonate $\text{Mg}(\text{HCO}_3)_2$, Sodium Bicarbonate NaHCO_3 , Calcium Chloride CaCl_2 and Sodium Chloride NaCl . Some intermediate groundwater sub-types are also recognized in the transitional zones.

Key words: Hydrochemical assessment • Groundwater pollution • Groundwater quality • Contaminations
• Vulnerability • DRASIIC • Nile Delta

INTRODUCTION

Groundwater plays a pivotal role in human life and development. An understanding of the chemical quality of groundwater is essential in determining its usefulness for domestic, industrial and agricultural purposes. Good quality of water has the potential to cause better crop yields under good soil and water management practices. The suitability of irrigation water depends upon many factors including the quality of water, soil type, salt tolerance characteristics of plants, climate and drainage characteristics of soil [1]. Groundwater always contains small amounts of soluble salts. The kind and quality of these salts depend upon the sources for recharge of the groundwater and the strata through which it flows. An excess of soluble salts can be harmful for many crops. Hence, an understanding of the chemistry of groundwater is essential to properly evaluate groundwater quality for drinking and irrigation purposes.

Presentation of geochemical data in the form of graphical charts such as the U.S. salinity diagram and Wilcox salinity diagram help to recognize various hydrogeochemical types in a groundwater basin. Analysis of the chemical constituents of groundwater also sheds light on the geochemical evolution of groundwater, as well as identification of recharge areas. The present study has been undertaken with the objective of (a) evaluation of factors affecting the groundwater quality such as the pollution sources and the aquifer vulnerability (b) chemical characterization of groundwater of the study area and (c) evaluation of the suitability of groundwater in the study area for drinking and irrigation purposes.

Economic development in Egypt and the rapid growth rate in various development sectors are dependent on the availability of water resources. Surface water is used to supply approximately 82% of Egyptian water demand, while groundwater is used to supply about 12%. The remaining which is about 6% is coming from the reuse

of agriculture drainage water and treated wastewater. Increasingly, Egypt has turned to groundwater to satisfy growing demand, at the expense of exceeding safe yield and overexploiting aquifer systems in some areas such as eastern Nile Delta and along desert fringes in the Nile Valley. Groundwater quality is the most important constraint that defines the usage of this water.

Pollution from agricultural and industrial origin threatens the groundwater quality in Egypt. Locally, this pollution is measured in the groundwater at tens of meters depth. Since groundwater is the second main source of freshwater, pollution causes a decrease in the long-term resources of water suitable for human consumption and increasing the treatment costs. In order to get insight in the current situation of groundwater quality and the systematic changes of groundwater quality over time, the National Groundwater Quality Monitoring Network was established in 1998 [2].

Eastern Nile Delta becomes recently one of the most promising areas for development such as land reclamation for agriculture, new residential areas and industrial development. This high rate of development increased the pressure on the available water resources not only due to high demand but also due to its environmental impact on the groundwater quality. More attention and great effort is required to evaluate the water resources in terms of quantity and quality. Many attempts have been done to investigate and evaluate the water resources in this area [3]. In the eastern Nile Delta region seven new residential areas have been constructed namely New Cairo City, Badr City, New Heliopolis City, El Shourok City, Tenth of Ramdan City, El Obour City and New El Salhyia City. Tenth of Ramdan City is also one of the biggest Egyptian Industrial areas. Also there are a lot of reclaimed projects for agriculture. The main sources of water are surface water, groundwater and reuse of both treated wastewater and agriculture drainage water [4].

Geological and Hydrogeological Settings

Location: The study area lies in the eastern of Nile Delta. The area is located between latitudes and longitudes and it is bounded by the Nile River (Damitta Branch) on the west with an area of about as shown in Figure (1).

Geology: Two structural zones can be distinguished, the up thrown south delta block and downthrown north delta embayment, separated by a number of step faults. Tertiary rocks crop out in the Cairo-Suez lithological deltaic plain. The central and northern portions are filled with unconsolidated Quaternary sediments. In the

northern portion the Quaternary sediments are underlain by Pliocene clay; while in the south the Quaternary sediments overlay Miocene deposits as shown in Fig. (2).

Aquifer System: Two main aquifer systems can be distinguished in the region, the Oligocene and the quaternary. The Oligocene occupies the Cairo-Suez foothills; while the Quaternary occupies the major part of the region. The Quaternary aquifer is unconfined in the Rolling Plains and semi-confined in the rest of the area. The aquifer thickness varies from 100 m in the south to 1000 m in the north. In the Quaternary aquifer the major recharge sources are from irrigation (seepage from canals and subsurface drainage); while discharge takes place through groundwater withdrawals and upward leakage (in the north and depressions). In the major part of the Eastern Nile delta, the fresh groundwater is underlain by saline groundwater [5].

Aquifer Hydraulic Parameters: Aquifer horizontal hydraulic conductivity is about 75 m/day; while the vertical hydraulic conductivity about 25 m/day. The porosity of the sediments is about 25% to 30%. The average horizontal and vertical hydraulic conductivity of the semi-pervious layer amounts to 0.25 and 0.01 m/day respectively. Towards the Mediterranean Sea the average vertical hydraulic conductivity decreases to 0.001 m/day [6].

Groundwater Flow: The regional groundwater flow direction is to the north-east, being of relatively low importance compared to the local pattern. Local groundwater pattern are generally a function of irrigation schemes and practices [7].

Pollution Sources: Pollution can be defined as the changes in physical, chemical and biological properties of the water that restrict or prevent its use. Groundwater in the study area polluted artificially due to human activities such as reclamation projects, waste disposal and dumping from industrial projects and leakage from drains or naturally due to saltwater intrusion and the exit of some trace metals in the formation. The potential for groundwater pollution to occur is determined by the interaction between:

- The microbiological or chemical pollutant loading which is being, or might be, applied to the subsurface environment as a result of one or more of the types of human activity and.

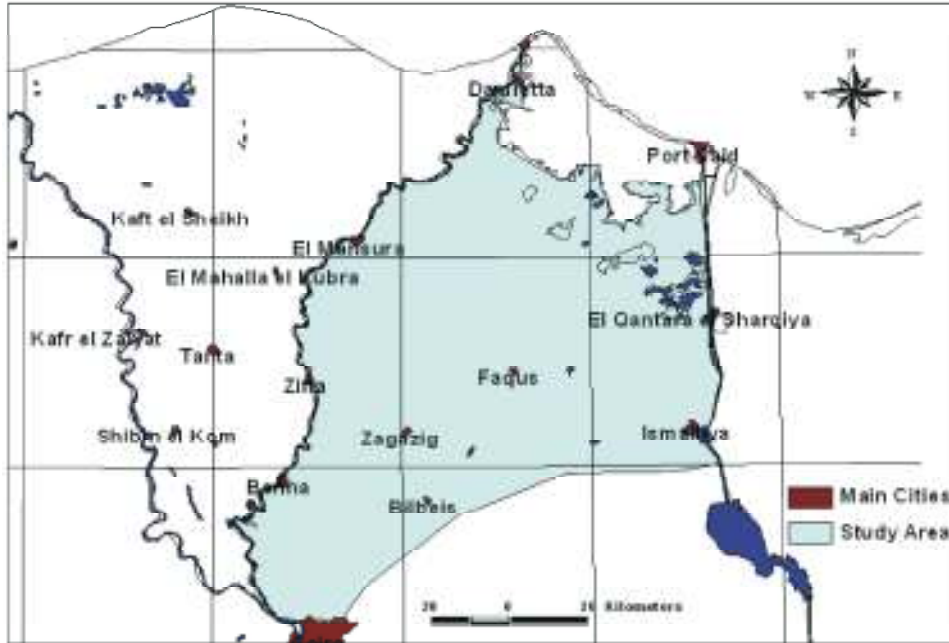


Fig. 1: General location map for the study area

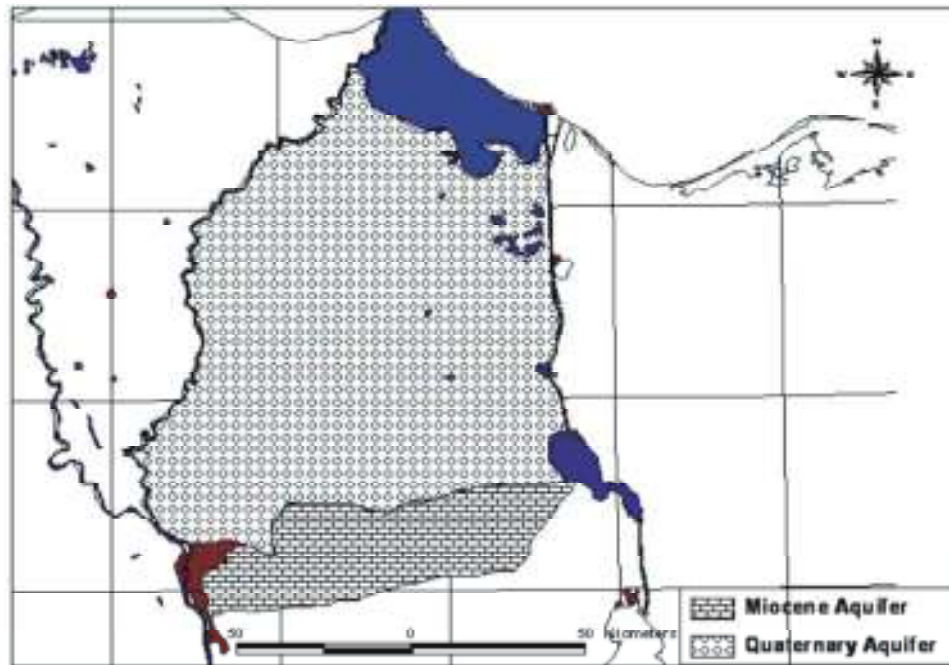


Fig. 2: Aquifer Types within the Study Area

- The aquifer vulnerability, which depends on the intrinsic physical characteristics of the soil and strata separating the aquifer from the land surface.

The matrix in Figure (3) shows the potential for groundwater pollution, however it does not assign quantitative scores, but rather depicts a relative

classification of pollution potential and the components of both pollutant loading and aquifer vulnerability can have broad ranges from low to high. Thus, a combination of high pollutant loading and high aquifer vulnerability provide the most extreme pollution potential in the top right corner of the figure. Adopting this approach, it is possible to envisage situations in which an aquifer is

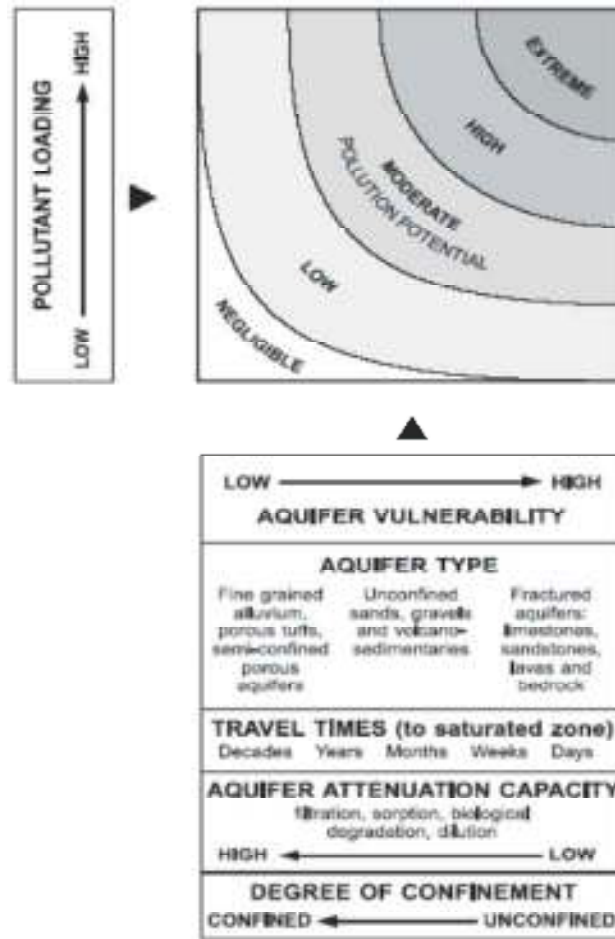


Fig. 3: Groundwater pollution potential

highly vulnerable, but there is little or no danger of pollution because there is no pollution load, or vice versa [8]. Both are consistent in practice. The former might occur on an uninhabited coral limestone island and the latter where an urban area with many small pollution sources is separated from an underlying deep aquifer by a thick sequence of impermeable clays or silts. The main pollution sources can be classified to three main categories as follows:

Wastewater Leakage: The wastewater leakage can be from either the domestic areas due to use the oxidation bond for the preliminary treatment or from the leakage from the sewerage network. Also, the area is served by many drains such as Gabal Al Asfar, Belbies, Qalubya, Bahr El Baqar and El Wadi drains. The main function of these drains is to collect the agriculture drainage water but they are also used to collect untreated wastewater. Bahr El Baqar drain receives untreated/primary treated wastewater starting from east Cairo at the discharge point

from Al Gebal Al Asfar treatment plant crossing the study area from south west to north east as shown in Figure (4). The length of the drain is about 170 km and its annual discharge is about 2 million m³ disposed to Al Manzala Lake. Saad (1997) concluded that 58% of the total drainage water of Bahr El Baqar drain comes from agriculture drainage, 2% from industrial drainage and 40% from domestic drainage as shown in Table (1).

Pollution from Agriculture Activities: The study area can be classified to three categories regarding the agriculture activities as follows:

- The first is the old fertile cultivated land. In these areas the aquifer is overlain by semi-confined silty clay layer and the agriculture areas are well served with surface and subsurface drainage network. However, the unofficial use of agriculture drainage water (about 36%) for irrigation and uncontrolled use of fertilizers and pesticides are affecting the quality of the groundwater.

Table 1: Sources of Wastewater and the discharge to Bahr El Baqar Drain

Drain	Source of Wastewater	Wastewater Flow m ³ /d
Belbies Drain	Berka WWTP	300, 000
	Al Gebal El Asfar Drain	1, 000, 000
Total Discharge Into Belbeis Drain		1, 300, 000
Qalubiya Drain	Shebeen El Kanater Drain	600, 000
	El Asloughi Drain	90, 000
	Benha City	42, 000
	Industrial Wastes from Sharqiya Gov.	17, 030
Total Discharge Into Qalubiya Drain		749, 030
Total Discharge Into Bahr El Baqar Drain		2, 049, 030

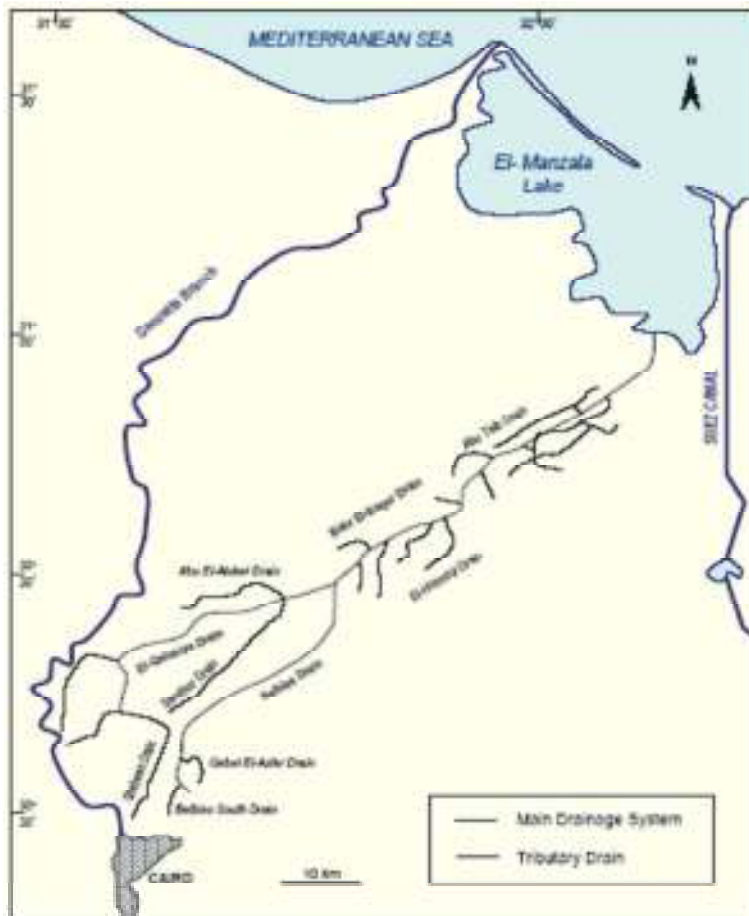


Fig. 4: Bahr El-Baqar drain system in the east Nile Delta

- The second is the new reclaimed areas with high permeable and loose sandy soil. The soil is not fertile and application of fertilizers is very high to increase the productions. The nitrate concentration in these areas is very high.
- The third is the desert fringes with no agriculture activities.

The groundwater within the study area in some localities contains increment concentrations of both heavy metals and pesticide residues. However it is still

lower the standers. This is most probably caused by the combination of long-term cultivation in the same soil. However, organo-chloro-pesticides have not been applied to the recently cultivated desert areas.

Pollution from Industrial Activities: The existence of many industrial activities in the new settlement areas (El-Obour, Badr, Tenth of Ramadan and El-Salyia Cities) results in a variety of pollutants which are of a great concern to the deterioration of groundwater quality within the study area. The types of pollutants are mainly

depending on the type of industrial activities. The collected wastewater from these industrial areas is discharged to oxidation ponds that may be poor protected and not sealed, that resulting in direct recharge to the underplaying groundwater by seepage through the unsaturated zone. The extent of groundwater pollution due to waste percolation depends on the pollution load, rate of recharge, the period of leakage, type of the disposal and the behavior of pollutants in the groundwater environment (unsaturated and saturated). In a homogeneous porous medium, percolating water will tend to take the vertical direction. In heterogeneous medium percolating water may become perched above layers of low permeability (lateral flow).

In Tenth of Ramadan City as an example, the capacity of the three oxidation ponds is not enough to accommodate the collected effluent. Overflow from the ponds is discharged into Wadi El-Watan about 15 km northeast of Tenth of Ramadan City by artificial and natural canals and is collected in low lands. This row wastewater is used for irrigation of new reclaimed area with out any treatment. The areas of oxidation ponds overflow channels and the irrigated areas with this row wastewater are classified as high pollution load.

Aquifer Vulnerability Development

Background: Before we can consider the evaluation of groundwater vulnerability to pollution, it is necessary to define the term vulnerability. The term vulnerability has been defined and used before in the area of water resources, but within the context of system performance evaluation, e.g. the definition given by [9]. They authors present an analysis of system performance, which focuses on system failure. They also define three concepts that provide useful measures of system performance: (1) how likely the system is to fail is measured by its *reliability*, (2) how quickly the system returns to a satisfactory state once a failure has occurred is expressed by its *resiliency* and (3) how severe the likely consequences of failure may be is measured by its *vulnerability*. This concept of vulnerability defined in the context of system performance may also be used in the context of groundwater pollution if we replace "system failure" by "pollutant loading". The severity of the consequences are measured in terms of water quality deterioration, regardless of its value as a resource (for example, regardless of whether or not the aquifer is being used for public supply or is given any use at all). However, the concept of vulnerability has not yet been unambiguously defined in the context of groundwater pollution and the term has been used to

mean different things. Often, the term "vulnerability to pollution" is used with a composite meaning that would perhaps be better described by risk of pollution. We believe that the most useful definition of vulnerability is one that refers to the intrinsic characteristics of the aquifer, which are relatively static and mostly beyond human control. We propose that groundwater vulnerability to pollution be defined, in agreement with the conclusions and recommendations of the international conference on "Vulnerability of Soil and Groundwater to Pollutants", held in 1987 in The Netherlands, as *The sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer*.

Thus defined, vulnerability is distinct from pollution risk. Pollution risk depends not only on vulnerability but also on the existence of significant pollutant loading entering the subsurface environment. It is possible to have high aquifer vulnerability but no risk of pollution, if there is no significant pollutant loading; and to have high pollution risk in spite of low vulnerability, if the pollutant loading is exceptional. It is important to make clear the distinction between vulnerability and risk. This because risk of pollution is determined not only by the intrinsic characteristics of the aquifer, which are relatively static and hardly changeable, but also on the existence of potentially polluting activities, which are dynamic factors which can in principle be changed and controlled.

Considerations on whether a groundwater pollution episode will result in serious threat to groundwater quality and thus to its (already developed, or designated) water supply are not included in the proposed definition of vulnerability. The seriousness of the impact on water use will depend not only on aquifer vulnerability to pollution but also on the magnitude of the pollution episode and the value of the groundwater resource.

Aquifer vulnerability can be subdivided simply into five broad classes as shown in Table (2). Extreme vulnerability is associated with aquifers having a high density of open fractures and with shallow water tables, which offer little chance for pollutant attenuation.

The Index of Vulnerability DRASTIC: DRASTIC is a groundwater quality index for evaluating the pollution potential of large areas using the hydrogeologic settings of the region [10, 11 &12]). This model was developed by EPA in the 1980's. DRASTIC includes various hydrogeologic settings which influence the pollution potential of a region. A hydrogeologic setting is defined as a mappable unit with common hydrogeologic

Table 2: Broad classification of aquifer vulnerability (after Foster *et al.*, 2002).

Vulnerability class	Definition
Extreme	Vulnerable to most water pollutants with relatively rapid impact in many pollution scenarios
High	Vulnerable to many pollutants, except those highly absorbed and/or readily transformed, in many pollution scenarios
Moderate	Vulnerable to some pollutants, but only when continuously discharged or leached
Low	Only vulnerable to the most persistent pollutants in the long-term, when continuously and widely discharged or leached
Negligible	Confining beds are present and prevent any significant vertical groundwater flow

characteristics. This model employs a numerical ranking system that assigns relative weights to various parameters that help in the evaluation of relative groundwater vulnerability to contamination. The hydrogeologic settings which make up the acronym DRASTIC are:

[D] Depth to Water Table: Shallow water tables pose a greater chance for the contaminant to reach the groundwater surface as opposed to deep water tables.

[R] Recharge (Net): Net recharge is the amount of water per unit area of the soil that percolates to the aquifer. This is the principal vehicle that transports the contaminant to the groundwater. The more the recharge, the greater the chances in contamination transports to the groundwater table.

[A] Aquifer Media: The material of the aquifer determines the mobility of the contaminant through it. An increase in the time of travel of the pollutant through the aquifer results in more attenuation of the contaminant.

[S] Soil Media: Soil media is the uppermost portion of the unsaturated / vadose zone characterized by significant biological activity. This along with the aquifer media decides the amount of percolating water to the groundwater surface. Soils with clays and silts have larger water holding capacity and thus increase the travel time of the contaminant through the root zone.

[T] Topography (Slope): The higher the slope, the less is the pollution potential due to higher runoff and erosion rates which include the pollutants that infiltrate into the soil.

[I] Impact of Vadose Zone: The unsaturated zone above the water table is referred to as the vadose zone. The texture of the vadose zone determines the time of travel of the contaminant through it. Authors of this model suggest that the layer that most restricts the flow of water be used.

[C] Conductivity (Hydraulic): Hydraulic conductivity of the soil media determines amount of water percolating to the groundwater through the aquifer. For highly permeable soils, the travel time of pollutant is decreased within the aquifer.

The major assumptions outlined in DRASTIC are:

- The contaminant is introduced at the surface
- The contaminant reaches groundwater by precipitation
- The contaminant has the mobility of water
- The area of the study site is greater than 100 acres

DRASTIC evaluates pollution potential based on the above seven hydrogeologic settings. Each factor is assigned a weight based on its relative significance in affecting pollution potential. Each factor is further assigned a rating for different ranges of the values. The typical ratings range from 1-10 and the weights from 1-5. The higher the DRASTIC index, the greater the relative pollution potential [13]. The DRASTIC Index, a measure of the pollution potential, is computed by summation of the products of rating and weights of each factor as follows:

$$DRASTIC\ Index = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad Eq. (1)$$

where:

- D_r = Ratings to the depth to water table
- D_w = Weights assigned to the depth to water table
- R_r = Ratings for ranges of aquifer recharge
- R_w = Weights for the aquifer recharge
- A_r = Ratings assigned to aquifer media
- A_w = Weights assigned to aquifer media
- S_r = Ratings for the soil media
- S_w = Weights for soil media
- T_r = Ratings for topography (slope)
- T_w = Weights assigned to topography
- I_r = Ratings assigned to vadose zone
- I_w = Weights assigned to vadose zone

C_r = Ratings for rates of hydraulic conductivity
 C_w = Weights given to hydraulic conductivity

Using GIS for Mapping the Aquifer Vulnerability: GIS [14, 15 & 16] software has been used to map the vulnerability as it has the index facilities as shown in Figure (5) using the rating factors shown in Table (3). Based on the DRASTIC index, the study area was divided into four categories: low, moderate, high and very high as shown in Figure (6). The sites with high and very high categories are more vulnerable to contamination and hence can be reviewed by a specialist. These weights are relative and a site with low pollution potential need not necessarily mean that it is free from groundwater contamination but it is relatively less susceptible to contamination compared to the sites with high or very high DRASTIC ratings.

Groundwater Quality Characterization

Data Evaluation and Analysis: Groundwater samples were collected from the national groundwater quality network and analyzed for various chemical parameters (Table 4) as described by the American Public Health Association [17]. Figure (7) shows the geographical distribution of the national groundwater quality monitoring network wells within the study area. These parameters include pH, electrical conductivity, total dissolved solids and important cations such as calcium, magnesium, sodium and potassium as well as anions such as carbonates, bicarbonates, chlorides, nitrates, sulfates and fluoride. The pH and electrical conductivity (EC) were measured in the field by means of a pH meter and digital conductivity meters, respectively. Sodium and potassium were determined by flame photometer. Total hardness (TH) as CaCO₃, calcium (Ca²⁺), magnesium (Mg²⁺), carbonate (CO₃²⁻), bicarbonate (HCO₃⁻) and chloride (Cl⁻) were analyzed by volumetric methods. Nitrate (NO₃⁻) and fluoride (F⁻) were determined using ion analyzer.

Sulfates (SO₄²⁻) were estimated by using the calorimetric technique. Groundwater quality for drinking purposes was analyzed by considering the WHO [18]. The quality parameters like salinity and Electrical Conductivity (EC), (Doneen, 1964), toxicity due to chloride and sodium (SAR) and parameters causing miscellaneous problems to soil-water-plant relationships (bicarbonate, RSC, sulfate) were determined to assess the irrigation suitability and drinking of the groundwater.

Table 3: Used Rating Factors for Vulnerability Mapping

Parameter	Range		Rate
	From	To	
Depth to groundwater (m)	0	5	10
	5	10	8
	10	20	6
	20	30	4
	30	40	2
	40 +		1
Aquifer Recharge (mm/year)	0	10	1
	10	20	2
	20	40	4
	40	60	6
	60	100	8
	100+		10
Hydraulic Conductivity (m/day)	0	1	1
	1	5	2
	5	10	4
	10	20	6
	20	40	8
	40+		10

Statistical Approach for Mapping Groundwater Quality

Data: A map is a drawing of some attribute of an area as it would appear if it was seen from above: it is a special type of graph that shows observations in geographical space mapped in two dimensions by making a scaled (and therefore usually simplified, generalized) image. For technical reasons, elements on a map can only be displayed with limited accuracy. In order to show not more than what is known, this display accuracy should not exceed the extent to which the elements are known and generally this is solved by choosing a proper scaling and display resolution. In the environmental sciences it is very common that the ‘observations’ shown on a map do not directly portray observed phenomena but quantities that are only known approximately and in this case the need to limit the display accuracy becomes more important.

Errors in maps, the discrepancies between what the map shows and the part of reality aimed at, can be ascribed to location errors and attribute errors. Errors that accrue from location uncertainty will not be addressed here. Attribute error is the discrepancy between the value shown at a certain location on a map and the real, true value that the map aimed to show. Attribute errors usually stem from incomplete knowledge of the attribute in the map area and these errors occur easily when we have to estimate the attribute from measurements: the measured sample is often difficult and expensive to obtain and reflects only a small fraction of the population.

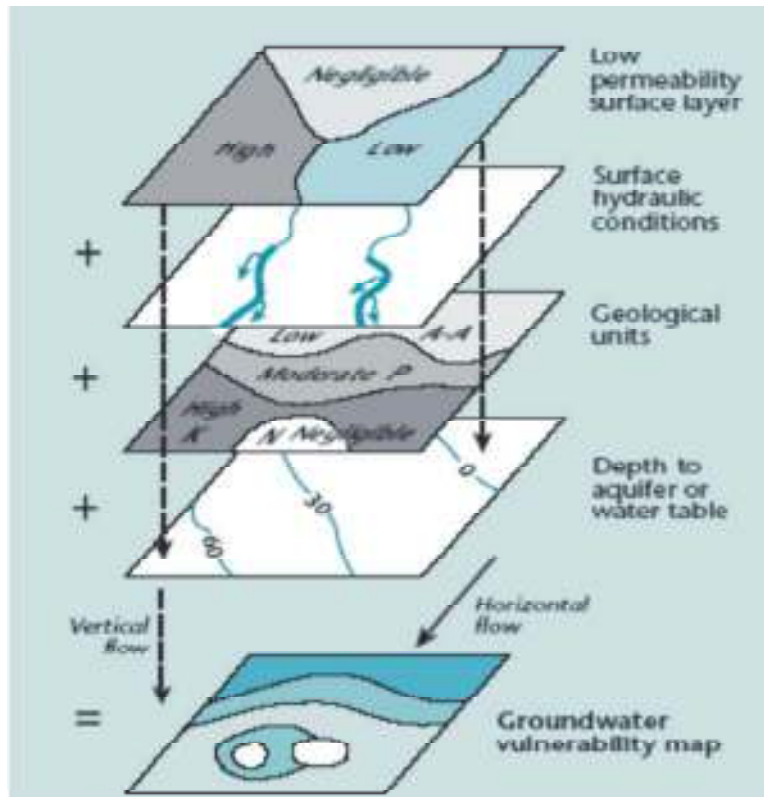


Fig. 5: Combining factors to make a vulnerability map using GIS

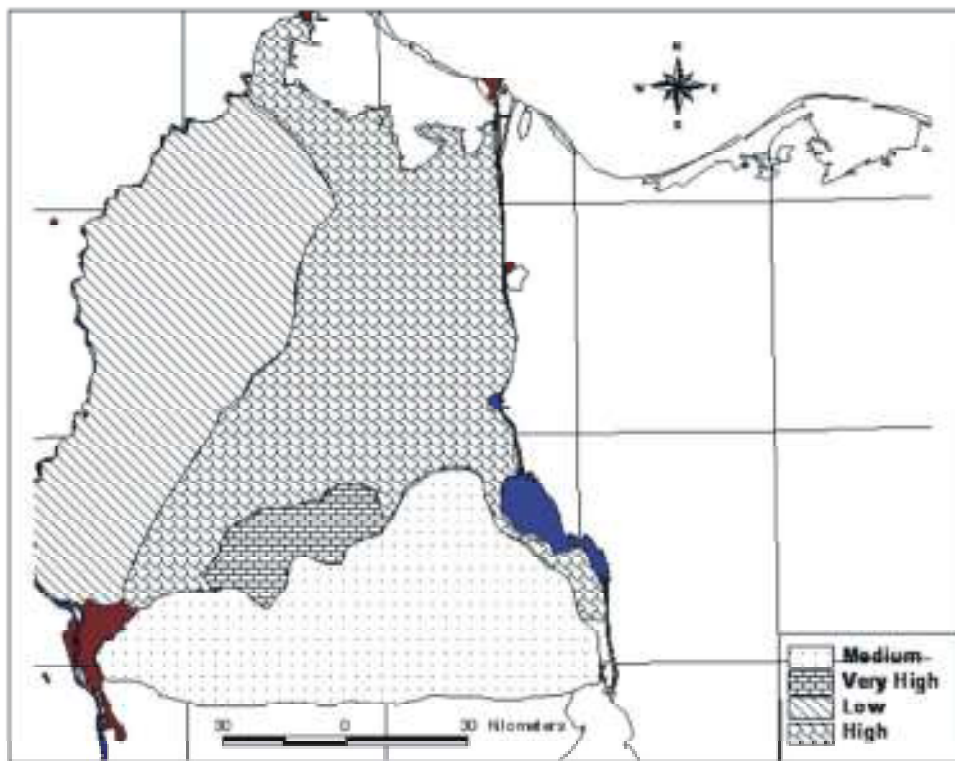


Fig. 6: Groundwater Vulnerability Map for the Study Area

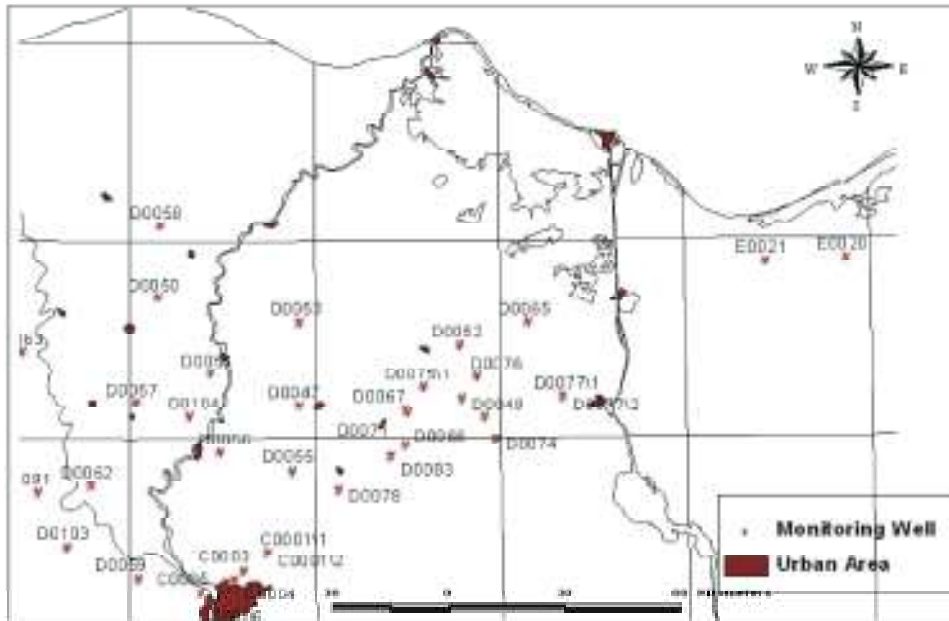


Fig. 7: Location Map for the Monitoring Wells

Furthermore the spatial variation in the measured values can be large. The goal of both monitoring and modeling groundwater quality is to gain understanding of the spatial and temporal variation in groundwater quality. Figure (8) shows the mapping of the TDS within the study area using the statistical approach.

RESULTS AND DISCUSSION

Suitability of Groundwater for Drinking Purpose: The suitability of irrigation water depends upon many factors including the quality of water, soil type, salt tolerance characteristics of plants, climate and drainage characteristics of soil [1]. The pH values of groundwater in the study area range from 7.37 to 8.51, indicating an alkaline type of groundwater. The electrical conductivity (EC) values range from 300 to 4300 micromhos/cm. The larger variation in EC is mainly attributed to anthropogenic activities and to geochemical processes prevailing in this region. Total dissolved solids (TDS) in the study area vary in the range from 234 to 3160 mg/l. TDS values obtained in the study area are beyond the desirable limits and 12 samples out of the 31 have TDS values more than the permissible limits, making the water unsuitable for various domestic activities.

The groundwater in the study area falls under fresh (TDS<1000 mg/l) to brackish (1000<TDS<3000 mg/l) types of water [19]. In the study area, the sodium concentration in groundwater ranges from 23 to 995 mg/l.

The concentration of calcium in the study area ranges from 8.83 to 218 mg/l. The major source of magnesium in the groundwater is due to ion exchange of minerals in aquifer formation by water and the samples of the study area vary in the range from 4.35 to 24.56 mg/l. The concentration of potassium varies from 2.24 mg/l to 19.6 mg/l.

Bicarbonate is the dominant anion, followed by chloride and sulfate. Bicarbonate in the study area ranges from 18 to 478 mg/l, the source of most of the bicarbonates in the water being sewage and various human activities. Water with a high concentration of bicarbonates may cause white deposits on fruits and leaves, which is undesirable. The concentration of chloride ranges from 2.4 to 1187 mg/l; the large variation is attributed to geochemical processes and to contamination by sewage wastes. Nitrate concentration in the study area varies in the ranges from 0.25 to 141 mg/l and only five samples are above the desirable limits for potable water. The main source of nitrate in the groundwater is attributed to decaying organic matter, sewage wastes and increased usage of fertilizers especially in the new reclaimed desert fringes with sandy loose soils as shown in Figure (9). Sulfate varies from 8.72 to 520 mg/l. The fluoride content in the groundwater shows a range of 0.05-1.6 mg/l. The occurrence of low fluoride concentration in the groundwater may be either due to absence of fluoride containing minerals in the strata through which the groundwater is circulating.

Table 4: Groundwater quality results (2012-2014)

Well ID	Sample Date	Trace Metals (ppm)					Cations (ppm)					Anions (ppm)					pH	EC	TDS (ppm)	
		Ba	Cu	Fe	Mn	Sr	Zn	Ca	K	Mg	Na	Cl	NO2	NO3	SO4	HCO3				NH4
C0001\1	1/16/2012	0.11	0.00	0.08	0.41	1.29	ND	74.50	19.60	21.80	93.90	130.70	ND	58.60	141.38	64.00	6.47	7.59	900.00	613.80
C0001\1	1/17/2014	0.11	0.03	0.09	0.27	1.29	0.03	86.40	15.90	17.30	94.00	88.32	0.07	19.74	93.34	222.50	1.30	7.69	987.00	528.00
C0002\2	1/1/2012	0.05	ND	ND	0.17	0.99	ND	70.00	13.70	19.00	101.00	137.13	ND	13.36	150.00	200.00	1.18	7.37	800.00	637.20
C0002\2	1/17/2014	0.06	0.05	0.03	0.08	2.04	0.58	98.10	7.43	31.70	154.00	178.00	0.03	29.44	203.92	292.50	1.69	7.37	1480.00	1267.00
C0003	1/16/2012	0.17	0.00	0.25	1.55	0.90	0.01	60.10	5.56	19.20	34.49	86.15	ND	2.54	70.13	154.00	0.13	7.69	480.00	366.30
C0003	1/18/2014	0.05	0.03	0.15	0.20	0.36	0.09	35.30	2.28	10.10	35.80	38.56	0.17	4.33	44.58	87.50	0.26	7.38	401.00	2003.00
C0004	1/15/2012	0.12	ND	0.72	0.80	0.86	ND	48.40	4.68	13.30	69.80	75.25	ND	2.54	57.69	129.50	0.42	7.53	510.00	366.90
C0004	1/18/2014	0.06	0.05	0.24	0.18	0.59	0.03	37.20	2.24	16.30	46.60	60.40	0.03	24.87	28.74	175.00	0.91	7.42	583.00	257.00
D0047	1/26/2012	0.02	0.00	0.62	0.45	0.50	ND	31.30	3.03	12.80	97.10	54.32	ND	0.25	50.00	217.00	2.60	8.12	490.00	354.20
D0047	1/31/2014	0.06	0.05	0.80	0.68	0.40	0.01	52.50	2.46	18.20	108.00	81.05	0.07	1.83	77.45	185.00	2.08	7.81	743.00	530.64
D0049	1/28/2012	0.50	ND	3.02	1.27	2.00	0.00	202.00	16.10	57.80	546.00	937.85	ND	ND	430.00	234.00	2.60	7.90	3080.00	1993.80
D0049	2/3/2014	0.38	0.07	1.68	0.71	1.52	0.01	218.00	13.70	51.60	801.00	1018.91	0.07	ND	469.50	200.00	2.86	7.70	3440.00	2780.01
D0050	2/4/2012	0.14	0.01	0.51	0.67	0.58	ND	43.70	3.67	17.60	48.40	53.91	ND	0.08	17.02	180.00	1.30	7.83	470.00	329.70
D0050	2/10/2014	0.19	0.05	0.46	0.67	0.84	0.05	85.20	3.17	18.20	41.50	65.19	ND	1.77	15.58	188.00	1.56	8.32	550.00	422.43
D0052	2/11/2012	0.50	ND	0.51	2.00	1.92	0.01	52.10	9.35	48.90	199.00	322.80	ND	3.50	95.40	260.00	1.95	7.47	1593.00	805.22
D0052	2/8/2014	0.68	0.06	0.24	1.37	2.02	0.04	122.00	8.83	53.60	194.00	372.75	0.07	ND	107.12	342.00	1.56	7.40	1650.00	1206.34
D0055	1/26/2012	0.13	ND	0.64	0.80	0.79	0.01	57.50	5.89	18.90	79.90	110.32	ND	1.10	40.63	189.00	1.56	7.66	710.00	493.50
D0055	1/31/2000	0.15	0.22	1.24	0.60	0.99	0.08	46.00	5.54	22.70	76.30	119.87	0.03	2.90	37.39	180.00	1.69	7.70	766.00	495.71
D0058	2/4/2012	0.08	0.00	0.70	0.80	1.60	ND	39.10	15.20	68.90	829.00	1107.20	ND	2.03	105.90	250.00	2.27	8.13	4300.00	3160.30
D0058	2/10/2014	0.12	0.03	0.29	0.18	1.51	0.30	86.00	14.30	61.90	741.00	1187.00	ND	5.52	144.00	294.00	1.04	7.98	4200.00	2537.20
D0066	1/27/2012	0.19	ND	1.05	0.11	0.32	ND	41.50	6.13	12.00	30.80	17.67	ND	0.35	8.73	195.00	1.04	7.53	300.00	234.00
D0066	2/8/2014	0.19	0.27	0.57	0.05	0.30	0.02	33.20	5.58	13.60	23.90	0.77	23.80	0.07	0.00	0.00	135.00	ND	365.47	237.32
D0067	1/28/2012	0.21	ND	0.12	0.40	1.80	0.01	128.00	10.20	42.50	87.90	370.00	ND	1.40	144.00	18.00	1.56	7.80	1390.00	923.90
D0067	2/10/2014	0.17	0.13	0.34	0.05	0.28	0.01	32.30	5.76	12.70	24.80	16.53	ND	3.53	24.25	130.00	1.04	7.98	370.00	251.90
D0071	2/2/2012	0.05	ND	ND	ND	0.99	0.00	36.90	3.53	12.80	726.00	152.65	ND	38.85	100.00	310.00	0.65	8.51	2600.00	1689.90
D0071	2/7/2014	0.04	0.02	0.37	ND	1.38	0.09	68.10	2.70	16.50	738.00	2.04	1.70	ND	15.50	0.00	326.00	ND	1829.01	1172.44
D0077\1	2/11/2012	0.01	ND	0.01	ND	0.07	ND	10.60	3.76	6.41	500.00	204.80	ND	119.40	160.50	468.00	1.30	8.31	1792.00	927.88
D0077\2	2/11/2014	0.12	ND	ND	ND	0.21	ND	8.83	3.61	4.63	528.00	268.60	ND	100.80	195.50	374.00	0.65	8.29	1932.00	933.52
D0077\1	2/8/2012	0.20	0.02	0.03	ND	0.48	ND	19.30	3.65	7.83	539.00	239.45	0.10	141.43	201.70	478.00	1.30	8.46	1979.00	1632.49
D0077\2	2/8/2014	0.10	0.18	0.22	0.07	0.22	0.02	15.70	3.20	3.33	430.00	335.19	0.13	112.33	241.40	387.00	1.04	8.47	2020.00	1530.13
D0083	2/2/2012	0.08	ND	ND	ND	1.00	0.01	67.20	5.52	13.40	995.00	953.20	ND	9.80	520.00	165.00	0.65	8.19	3600.00	2322.90

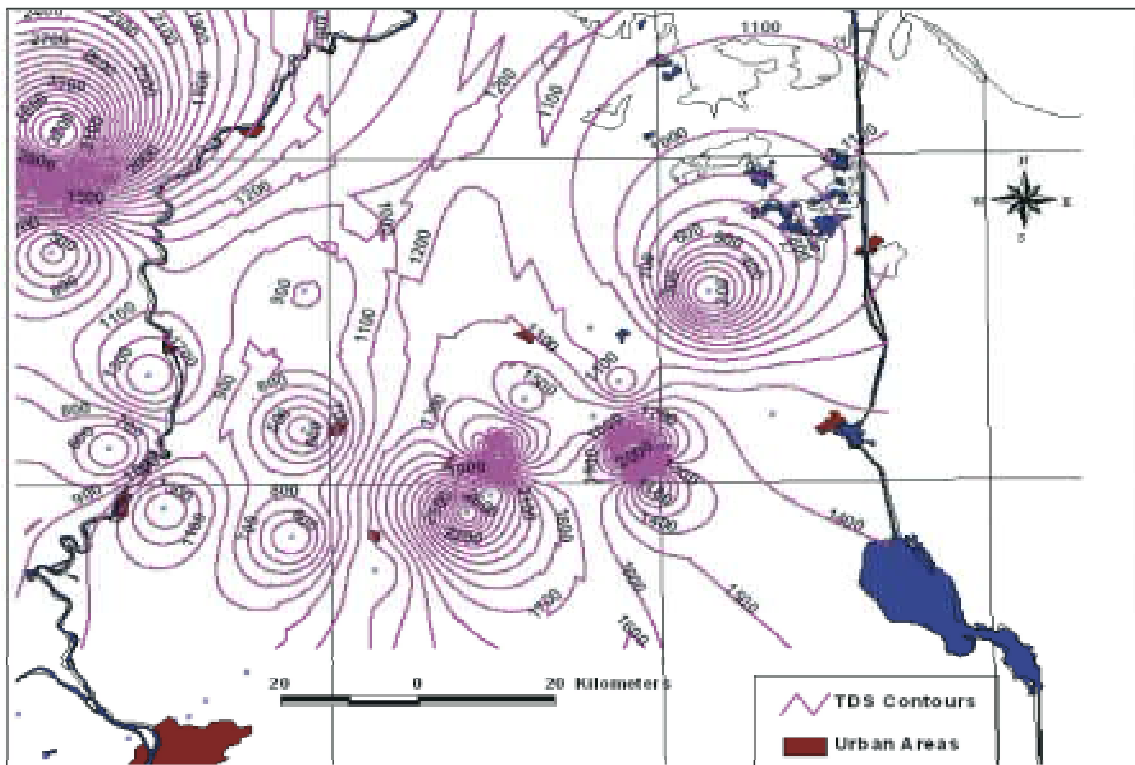


Fig. 8: Contour map for TDS

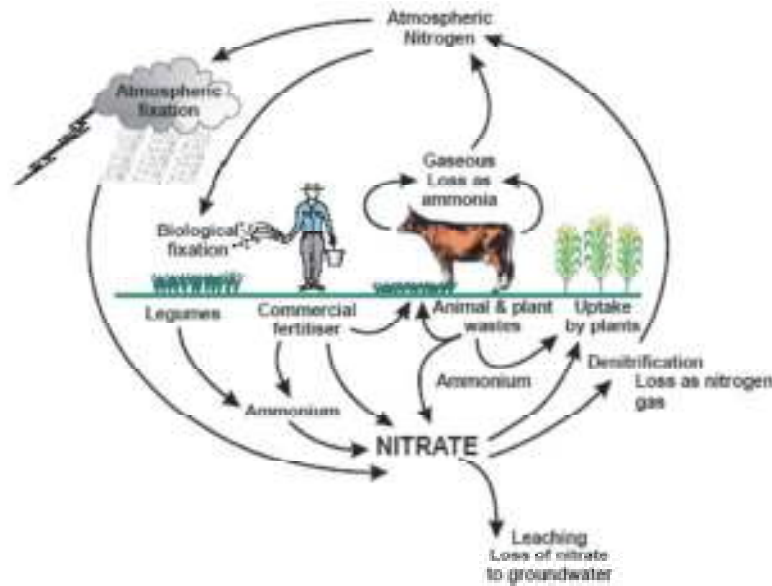


Fig. 9: Physical and chemical behavior of nitrogen in an agricultural area [21]

It could be also due to too rapid freshwater exchange, with the result that the normal process of concentration through evaporation or evapotranspiration is not very effective in raising the fluoride content of the groundwater to high values prevalent in some parts of the study area.

Suitability of Groundwater for Irrigation Purposes:

Irrigation water containing a high proportion of sodium will increase the exchange of sodium content of the soil, affecting the soil permeability and texture. This makes the soil difficult to plough and unsuitable for seeding emergence [21]. If the percentage of sodium is high in irrigation water, calcium and magnesium exchange with sodium, thus causing deflocculation and impairment of the tith and permeability of soils [20]. A sodium percentage of more than 60% is considered unsafe for irrigation. The values for the percent sodium in the study area range from 12-94%. Based on conductivity classification 67 % groundwater falls in “tolerable” (1000-1500 micromhos/cm) and 38 % under “safe” (<1000 micro mhos/cm) category. For groundwater classified on chloride, 56 % of water sample is “safe”, 22 % is “tolerable” and 22 % of water samples fall under the “health hazard” category. According to the Residual Sodium Carbonate (RSC) concentration, groundwater sample falling under different categories is given in the Table (5). The sodium adsorption ratio (SAR), which is one of the most reliable indices used in expressing or determining the exchangeable sodium in the soil was calculated using Equation (4):

Table 5: Classification of Irrigation Water on the Basis of RSC

Category	RSC (meq/l)	No. of Samples	Percentage(%)
Safe	Less than 1.25	19	61
Marginal	From 1.25 to 2.5	8	26
Unsuitable	More than 2.5	4	13

$$SAR = \frac{Na^+}{\sqrt{(Ca^{++} + Mg^{++})/2}} \quad \text{Eq. 2}$$

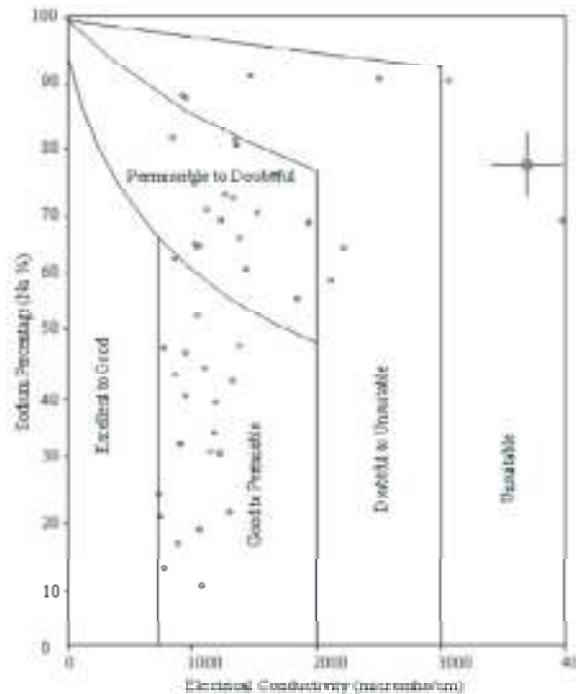


Fig. 10: Wilcox diagram for irrigation of the water [23]

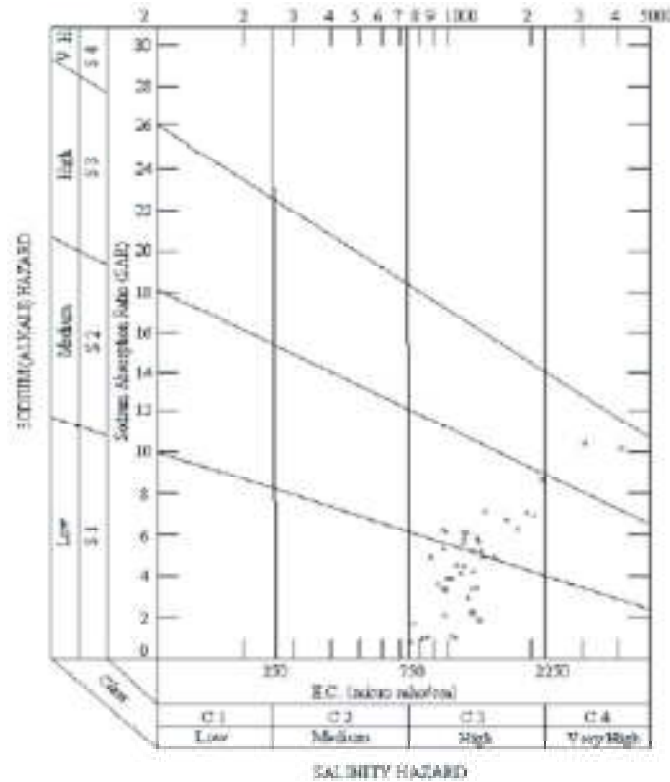


Fig. 11: U.S. salinity diagram for classification of irrigation water

According to this classification, low-salinity water (<math>< 200 \text{ mg/l}</math>) may be used for all types of soils. Most of the groundwater samples of the study area fall into the category of the good to moderate (C3-S1) (59%) and 37% under C3-S2 category. According to the Wilcox irrigation water classification scheme, the majority of the water samples (46%) fall under a “good to permissible” category and 37% under a “permissible to doubtful” category. The analysis data was also plotted on a Wilcox diagram and U.S. salinity diagram for classification of irrigation water [22] as shown in Figure (10) and Figure (11).

CONCLUSIONS AND RECOMMENDATION

Multivariate time series of hydrological and groundwater quality variables were obtained from the National Groundwater Quality Monitoring Network in the Eastern Nile Delta Region to evaluate and assess the suitability of the groundwater for both drinking and agriculture. The use of GIS provides a rapid and simple tool of groundwater quality mapping and assessment. It is able to display the aerial distribution parameters efficiently and summarize the information without losing some of this information that defines groundwater quality.

For this reason, it could be linked with DRASTIC method to develop the aquifer vulnerability map. It may be of particular interest in areas which have a complex hydrogeochemistry, in which there a marked interplay of processes, both natural and anthropogenic, is contributing to the decline in groundwater quality.

Groundwater quality has been analyzed to classify the groundwater into different categories for the drinking and irrigation purposes. The groundwater quality in the study area is alkaline in nature and falls under fresh (

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