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An Innovative Nitrate Pollution Index and Multivariate Statistical Investigations of Groundwater Chemical Quality of Umm Rijam Aquifer (B4), North Yarmouk River Basin, Jordan

Mutewekil M. Obeidat[1], Muheeb Awawdeh[2], Fahmi Abu Al-Rub[3] and Ahmad Al-Ajlouni[4]
[1]Jordan University of Science and Technology, Faculty of Science and Arts, Irbid,
[2]Yarmouk University, Faculty of Science, Irbid,
[3]Jordan University of Science and Technology, Faculty of Engineering, Irbid,
[4]Jordan University of Science and Technology, Faculty of Science and Arts, Irbid, Jordan

1. Introduction

The chemical quality of the groundwater is modified by several factors, such as interaction with solid phases, residence time of groundwater, seepage of polluted river water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Stallord and Edmond, 1983; Dethier, 1988; Faure, 1998; Umar et. al., 2006; Giridharan et al., 2008). Recently, there has been a tendency for groundwater quality deterioration, which has been caused by human activities (Dragon, 2008). The quality of water is of vital importance for humans, since it is directly linked with human welfare (Gupta et al., 2008). Poor water quality adversely affects the plant growth and human health (WHO, 1984; Hem, 1991; Karanth, 1997). Globally, nitrate is among the most common groundwater contaminants (Rajmohan and Elango, 2005). Potential sources of nitrate in groundwater include: fertilizers, septic tank effluent, municipal sewage, animal feedlots, decaying vegetation, and atmospheric deposition (Spalding and Exner, 1993; Wilhelm et al., 1996). In addition to the presence or absence of potential sources, field characteristics such as soil conditions, recharge rates, and depth to groundwater ultimately dictate an aquifer's vulnerability to nitrate contamination (Enwright and Hudak, 2009). Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall quality of water for human consumption (Vasanthavigar et al., 2010). It is an important parameter for demarcating groundwater quality and its suitability for drinking purposes (Mishra and Patel, 2001; Naik and Purohit, 2001; Avvannavar and Shrihari, 2008). There is a wide range of water quality indices that have been developed and used to classify water quality, which can be categorized based on the used variables (Terrado et al. 2010). Based on the considered variables, three classes of WQIs can be recognized:

1. Physiochemical variable WQIs such as those developed by Canadian Council of Ministers of the Environment (2001).

It is worth mentioning that the types of these WQIs depend on the used variables and the ultimate use of the index.

2. Biological WQIs such as those developed by Armitage et al. (1983). Biological water quality can be assessed based on different types of aquatic organisms (Terrado et al. 2010).
3. Hydro-morphological indices

Hydro-morphological indices take into consideration some characteristics of the fluvial ecosystem that do not relate to water quality directly (Terrado et al. 2010).

Many difficulties in data presentation, handling and interpretation could arise if the number of the data becomes large. Therefore, multivariate statistical techniques have become a powerful tool to handle and reduce large volume of water quality data. Statistical techniques, particularly multivariate statistics such as factor analysis are widely used tools for the identification of groundwater contamination (Grande et al., 1996). Many hydrochemical studies worldwide have shown that multivariate statistics significantly help classify and identify different factors controlling groundwater quality (Cloutier et al., 2008; Farnham, 2003; Belkhiri et al., 2010; Prasanna et al., 2010). Multivariate statistics help identify spatial and temporal variations in water quality and sources of contamination (natural and anthropogenic) by analyzing similarities/dissimilarities among the sampled sites (Andrade et al., 2008). Cluster analysis is carried out to reveal specific links between sampling points, while factor analysis/principal component analysis is used to identify the ecological aspects of pollutants on environmental systems (Ganfopadhyay et al., 2001; Kim et al 2009). Factor analysis enables both the classification of groups of data set and hydrochemical facies investigation and also the interpretation of their origin (Dalton and Upchurch 1978; Lawrence and Upchurch 1983; Dragon 2008). Jordan is an arid to semi-arid country with a land area of 89,206 km^2 that has suffered deficits in water resources since the 1960s. It ranks as one of the world's four most water-stressed countries. Moreover, Jordan is facing the problem of water resources contamination with different types of pollutants. The main objectives of the present study are (1) to assess the Umm Rijam (B4) groundwater pollution by nitrate using an innovative nitrate pollution index, and (2) to assess the groundwater quality of the B4 using multivariate statistical methods, namely cluster analysis (CA) and factor analysis (FA).

2. Study area

The Yarmouk River originates on the south-eastern slopes of Mount Hermon in Syria. The main trunk of the Yarmouk forms the present boundary between Syria and Jordan for 40 km before it becomes the border between Jordan and Israel. Yarmouk River Basin (YRB) is shared between Jordan and Syria. Only 1,424 km^2 of the basin total area (7,242 km^2) lie within the borders of Jordan (Fig. 1). The Yarmouk River average flow of 500 mcm/yr provides almost half of the surface water resources of the Jordan River. The climate is semi-arid with annual rainfall ranging from about 133 mm in the east to about 486 mm in the west. Geologically, Wadi Shallala Chalk Formation (B5) of early Middle-early Late Eocene age and Umm Rijam Chert Limestone Formation (B4) of Paleocene age overly the study area. It is composed mainly of limestone, chalk, and chert and reaches a maximum thickness of more than 200 m. The B5/B4 is the uppermost aquifer in the northern part the YRB (Fig. 2), where groundwater is stored under phreatic conditions. The B5/B4 is moderately jointed and fractured, and it is only slightly karstified. Many springs emerging from the B4 aquifer show chemical or bacteriological contamination (Chilton 2006). The subsurface geology consists of the Upper Cretaceous rock formations. From a hydrogeological point of view there are two important formations: Wadi Sir Limestone formation (A7) of Turonian age and Amman Silicified Limestone Formation (B2) of Campanian age. The two formations are hydraulically interconnected and considered as one aquifer, and they form the middle aquifer system. The B2/A7 consists of massive limestone, chert, dolomite, dolomitic limestone with intercalations of marl and chalk. The upper aquifer system (B5/B4) is separated from the middle aquifer system by the marly Muwwaqqar aquiclude (B3).

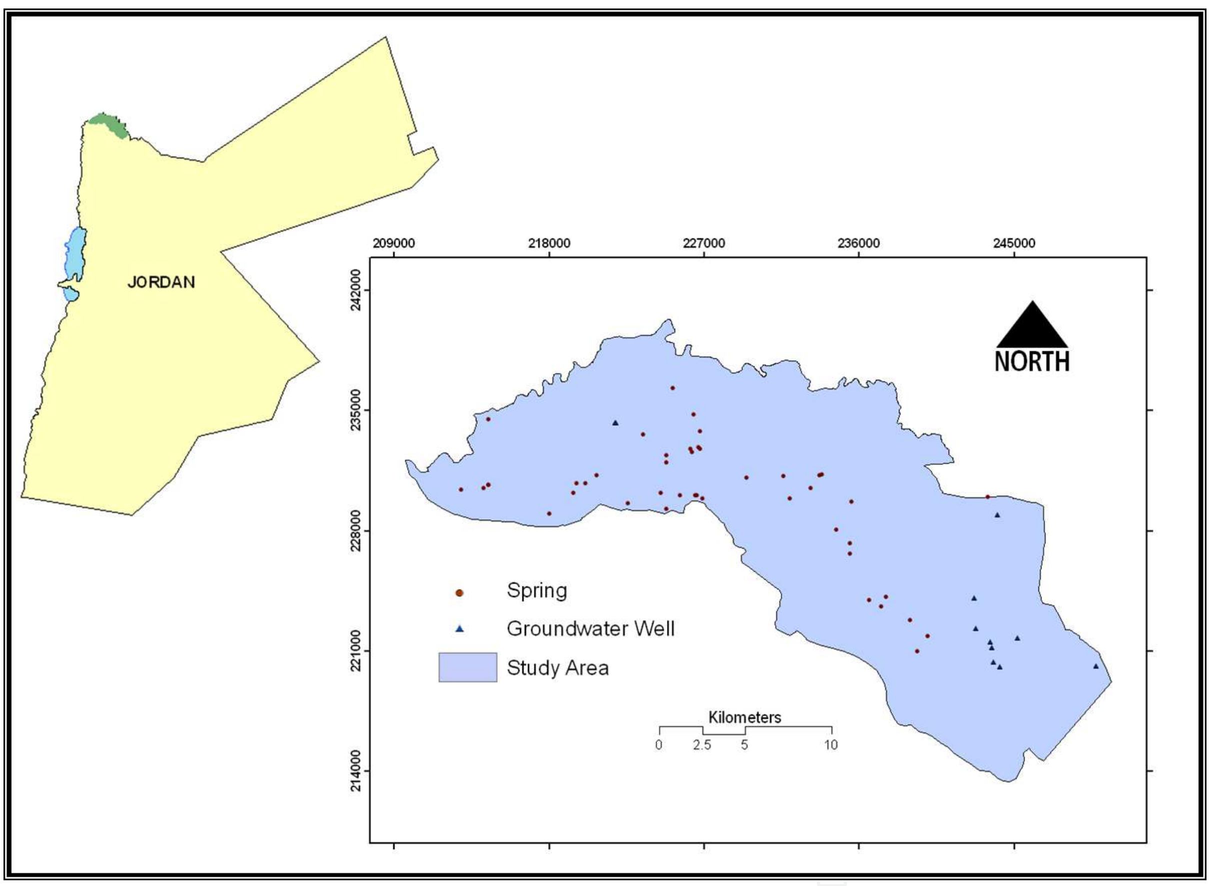


Fig. 1. Location map of the study area

3. Material and methods

3.1 Sampling and analytical procedures

Altogether 881 samples were used in the present study. The samples were taken from 12 wells and 43 springs representing the upper aquifer system (B4). The data involve those samples taken by the authors in 2007 and those retrieved from the open files of Water Authority of Jordan (WAJ). The data covers the period 1969-2009. The methods described by

(APHA, 1998) were followed during field and laboratory work. Electrical conductivity (EC), temperature and pH were measured in situ using portable meters. Prior to sample collection, well purging was performed for those wells which were not being pumped at the time of sampling. The goal was to ensure that the water sample truly represents the properties and conditions of the subsurface environment. Water was pumped from the well until the temperature, EC and pH became constant. The collected samples were investigated for the following hydrochemical parameters: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), nitrate (NO_3^{-}), total hardness (TH), and total dissolved solids (TDS). Na^{+} and K^{+} were determined by using flame photometer. Ca^{+2}, Mg^{2+}, HCO_3^{-} and Cl^{-} were analyzed by volumetric titration method. SO_4^{2-} and NO_3^{-} were analyzed spectrophotometrically.

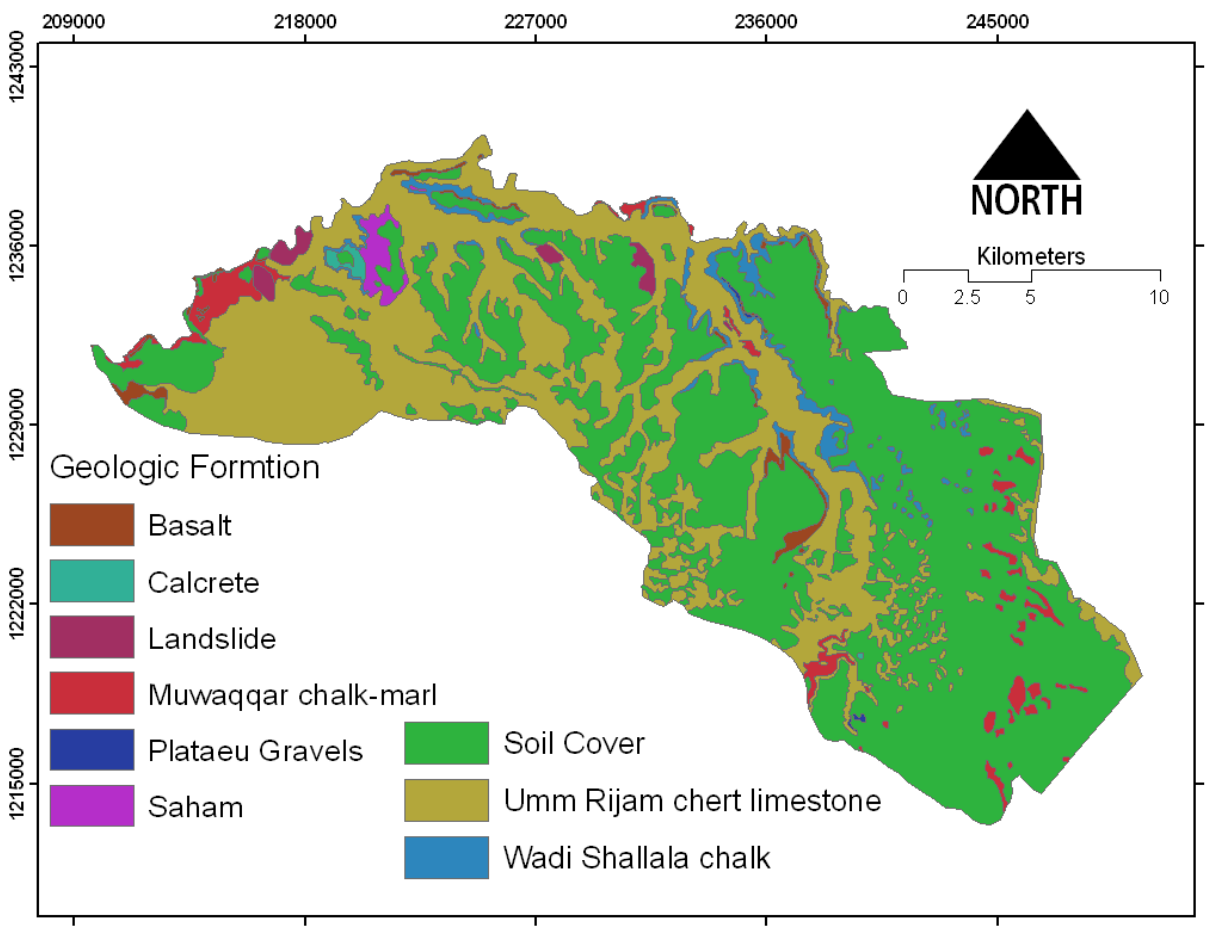


Fig. 2. Geological map of the study area

The total dissolved solids (TDS) content was calculated by using equation 1 (APHA, 1998), and the total hardness (TH) was calculated according to equation 2 (Todd, 1980)

$$TDS(mg/l) = Ca + Mg + Na + K + 0.5 * HCO_3 + Cl + SO_4 + NO_3 \quad (1)$$

$$\text{TH as } CaCO_3 \text{ (mg/l)} = 2.5 * Ca + 4.1 * Mg \quad (2)$$

Only samples with error in the cations-anions balance of ≤ 5% were used in this study. The error was calculated by using equation 3 (Edmond et al. 1995):

$$\text{Error\%} = \left| \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \right| * 100 \quad (3)$$

3.2 Nitrate pollution index (NPI)

For the purpose of this study, a single-parameter water quality index called nitrate pollution index (NPI) is developed following two steps:

First step. The selection and justification of the pollution indicator namely the nitrate ion (NO_3^-)

Nitrate is the most frequently human-introduced pollutant into groundwater, and nitrate contamination of groundwater has become a common problem worldwide (Wakida et al. 2005). Potential sources of nitrate in groundwater resources include nonpoint sources such as intensive agricultural activities and unsewered sanitation in densely populated area, and point sources such as irrigation of land by sewage effluents (McLay et al., 2001). Because of its weak coordination to positive species and high solubility in water, nitrate is not strongly adsorbed to soil colloids and is highly mobile within the soil liquid phase. In strong oxidizing groundwater, nitrate the stable form of nitrogen, and it moves with no or little transformation and little or no retardation (Freeze and Cherry, 1979). Chronic exposure to high nitrate concentration in drinking water has been linked to adverse health effects on humans, such as colon and rectum cancers, methemoglobinemia in infants, and non-Hodgkin's lymphoma (Ward et al., 1996; Knobeloch et al., 2000; De Roos et al., 2003). Groundwater with nitrate concentration exceeding the threshold of 20 mg/L as NO_3^- is considered contaminated due to human activities (referred to as human affected value, HAV) (Spalding and Exner, 1993). The maximum acceptable nitrate concentration for drinking water is 50 mg/L as NO_3^- (WHO, 1993). The main goal of the proposed NPI is to assess the extent, to which the groundwater in the area under consideration is polluted with nitrate due to human activities. The HAV of 20 mg/L is considered.

Second step. Calculation of the NPI

The NPI for a given site (well/spring) was calculated by using the following relation:

$$NPI = \frac{C_s - HAV}{HAV} \quad (4)$$

Where

Cs is the analytical concentration of nitrate in the sample

HAV is the threshold value of anthropogenic source (human affected value) taken as 20 mg/L

Then, the water quality was classified into five types based on the NPI values: clean (unpolluted), light pollution, moderate pollution, significant pollution, very significant pollution with the NPI value: <0, 0-1, 1-2, 2-3, > 3, respectively.

3.3 Cluster analysis (CA) and factor analysis (FA)

According to Liu et al. (2008), factor analysis and cluster analysis yield the common and similar relationships among hydrochemical variables by revealing multivariate patterns that may help classify the original data. Before analysis, the data used in the present study was subjected to standardization so as to increase the influence of variables whose variance is small, to reduce the impact of variables whose variance is large, to eliminate the influence of different units of measurement, and to render the data dimensionless (Dillon and Goldstein, 1984). It was done by a preparation of a correlation matrix of the data from which initial factor solutions were extracted by the principal component analytical method (Olobaniyi and Owoyemi 2006). Factor extraction was done with a minimum acceptable eigenvalue of one. The varimatrix rotation method was used to extract the final factors. Finally, factor's score was computed. Cluster analysis groups cases into classes based on similarities within a class and dissimilarities among different classes (Belkhiri et al., 2010). In the present study, the k-means cluster analysis was applied. This procedure attempts to identify relatively homogeneous groups of cases based on selected characteristics, using an algorithm that can handle large numbers of cases. The distance between clusters centers is calculated. Distances are computed using simple Euclidean distance. Factor and cluster analyses were performed using SPSS 13.0 for Windows.

4. Results and discussion

4.1 General hydrochemistry

The descriptive statistics of the hydrochemical parameters used in the study are presented in table 1. The pH value ranges between 6.8 and 8.5 with an average of 7.65. The groundwater can be described as neutral to slightly alkaline. The electrical conductivity is in the range 295-4220 µS/cm with an average of 791 µS/cm. Calcium concentration ranges between 26.45 and 281.72 mg/L with an average of 80.04 mg/L. Magnesium concentration is in the range 0-166.47 mg/L with an average of 37.61 mg/L. Sodium is in the range 2.3-565.8 mg/L

Parameter	Average	Minimum	Maximum	St.d.
pH	7.65	6.8	8.5	0.29
EC (µS/cm)	790.83	295	4220	480.42
Ca^{2+} (mg/L)	80.04	26.45	281.72	26.45
Mg^{2+} (mg/L)	37.61	0	166.47	24.15
Na^{+} (mg/L)	52.74	2.3	565.8	60.16
K^{+} (mg/L)	7.00	0	163	12.82
HCO_3^-(mg/L)	241.99	91.5	431.27	59.19
Cl^- (mg/L)	88.45	8.52	927.26	102.09
SO_4^{2-}(mg/L)	32.35	0	863.04	48.90
NO_3^- (mg/L)	45.75	0	794.81	66.87
TDS (mg/L)	593.12	221.25	3165	98.90
TH mg/l as $CaCO_3$	345.40	73.65	1075.31	131.62
CA-I	0.314	-0.025	0.565	
CA-II	0.076	-0.004	0.285	

Table 1. Univariate statistics of the hydrochemical parameters

with an average of 52.74 mg/L. Potassium concentration ranges between 0-163 mg/l with an average of 7 mg/L. Bicarbonate concentration is in the range 91.5-431.27 mg/L with an average of 242 mg/L. Chloride concentration is in the range of 8.52-927.26 mg/L with an average of 88.45 mg/L. Sulfate concentration ranges between 0-863.04 mg/l with an average of 32.35 mg/L.

The TDS content ranges between 221.25-3165 mg/L with an average of 593.12 mg/l. As shown in Fig. 3a, about 87% of the samples can be classified as freshwater based on the classification of Davis and Dewiest (1967). Total hardness is in the range 73.65-1075.31 mg/L with an average of 345.40 mg/L. Only 1.51% of the samples can be classified as soft-moderately hard water (Fig. 3b).

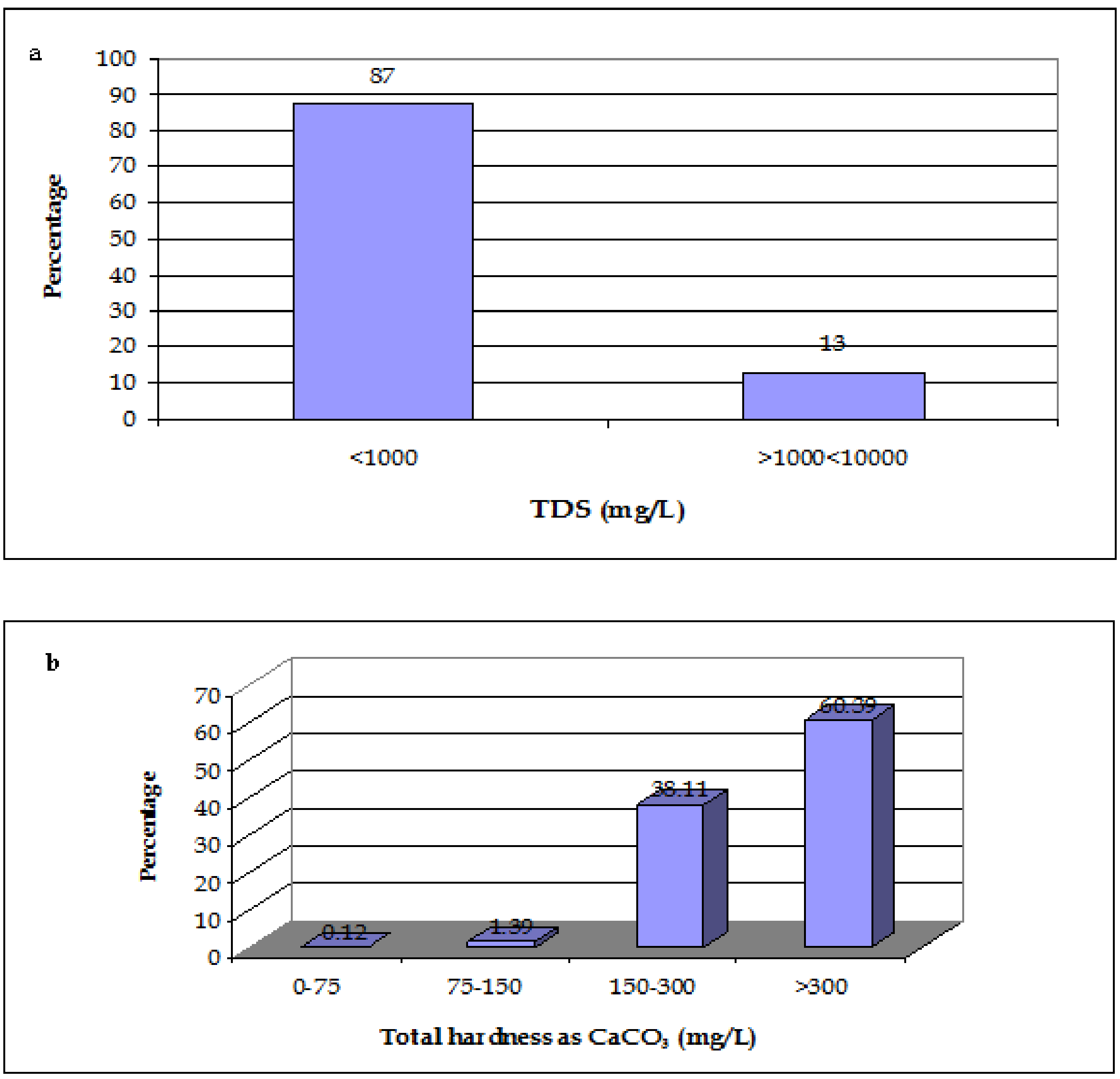


Fig. 3. Groundwater classification based on the: (a) TDS content (mg/L), and (b) total hardness as $CaCO_3$ (mg/L)

By using the trilinear (Piper) diagram, the groundwater can be categorized into the following groups (Fig. 4):

a. Normal earth alkaline water with prevailing bicarbonate
b. Earth alkaline water with increased portion of alkalies with prevailing bicarbonate
c. Earth alkaline water with increased portion of alkalies with bicarbonate and sulfate

Schoeller (1967) indicated that the ion exchange between the groundwater and its host environment during residence or travel can be understood by studying the chloro-alkaline indices, i.e. CA-I [(Cl^- - Na^+ + K^+) / Cl^-], and CA-II [(Cl^- – Na^+ + K^+) / (SO_4^{2-} + HCO_3^- + CO_3^{2-} + NO_3^-)]. Na^+ and K^+ ions in water are exchanged with Mg^{2+} and Ca^{2+} ions; positive value of the indices indicates base-exchange reaction whereas negative value indicates chloro-alkaline disequilibrium (Gupta et al., 2008). This reaction is known as cation–anion exchange reaction. During this process the host rocks are the primary sources of dissolved solids in the water. Schoeller indices reveal that more than 96% of the B4 groundwater has positive values indicating a base-exchange reaction (table 1).

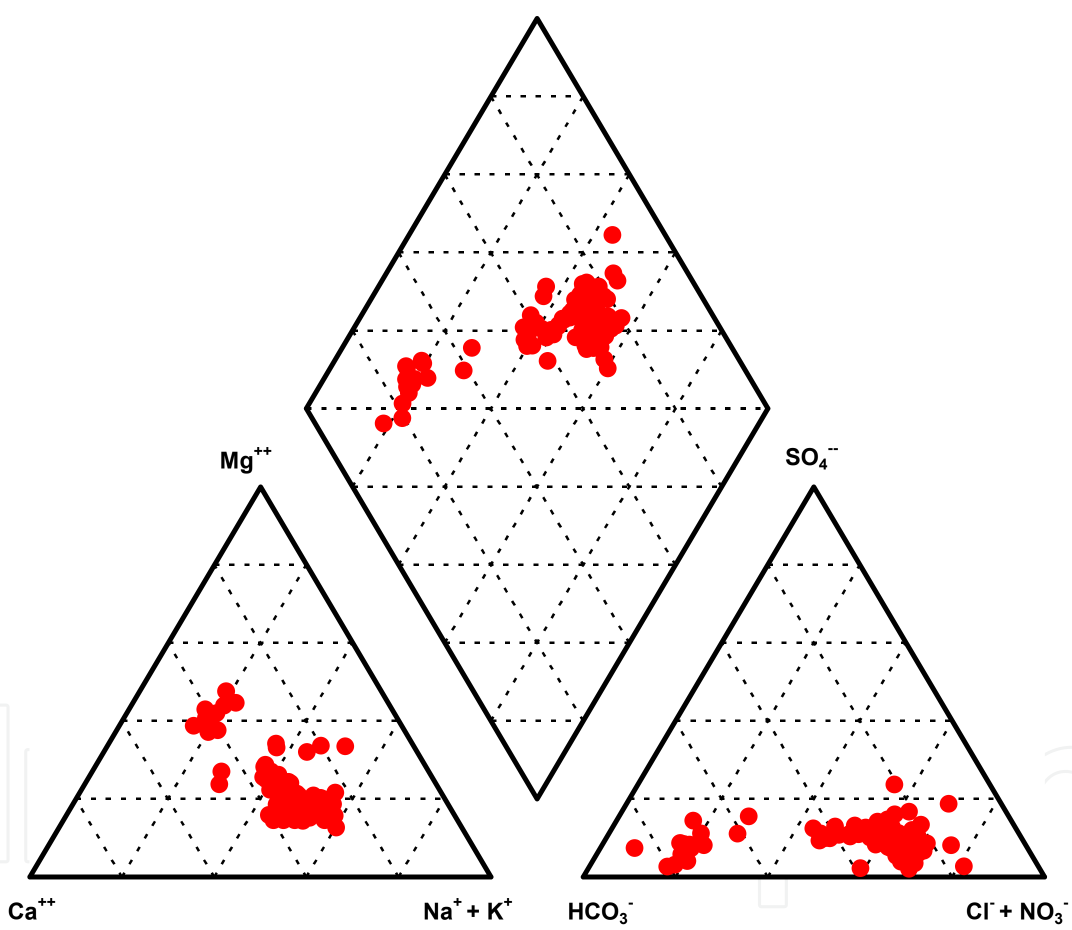
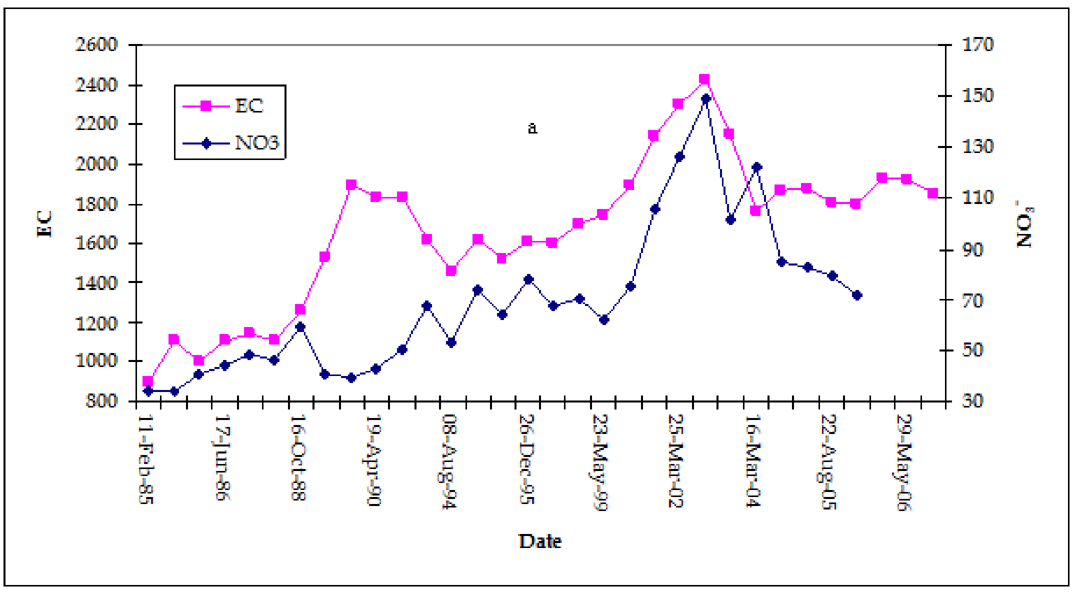


Fig. 4. Trilinear presentation of the groundwater

4.2 Spatial and temporal variation

The temporal variations of some hydrochemical parameters of the groundwater are presented in Fig. 5. For well AD1251, there was a slight increase in all hydrochemical parameters from February 1985 until August 1987, but since October 1988 until September 2002, there was a dramatic increase. Since September 2003, there was a dramatic decrease in all hydrochemical parameters. This is can be attributed to the fact that Al Ramtha wastewater treatment plant was established in 1988. At the beginning, the plant worked as stabilization ponds, but in 2003, it was changed to activated sludge. Well AD1251 is located just a few kilometers downstream of the plant. The spatial distribution of the EC and nitrate concentration is presented in Figs. 6 and 7, respectively. Three zones of the electrical conductivity can be observed: (1) east, where the electrical conductivity reaches 2668 µS/cm, (2) northwest, where the electrical conductivity ranges between 1520 and 2268 µS/cm, and (3) central part of the study area, where the electrical conductivity is less than 662 µS/cm.



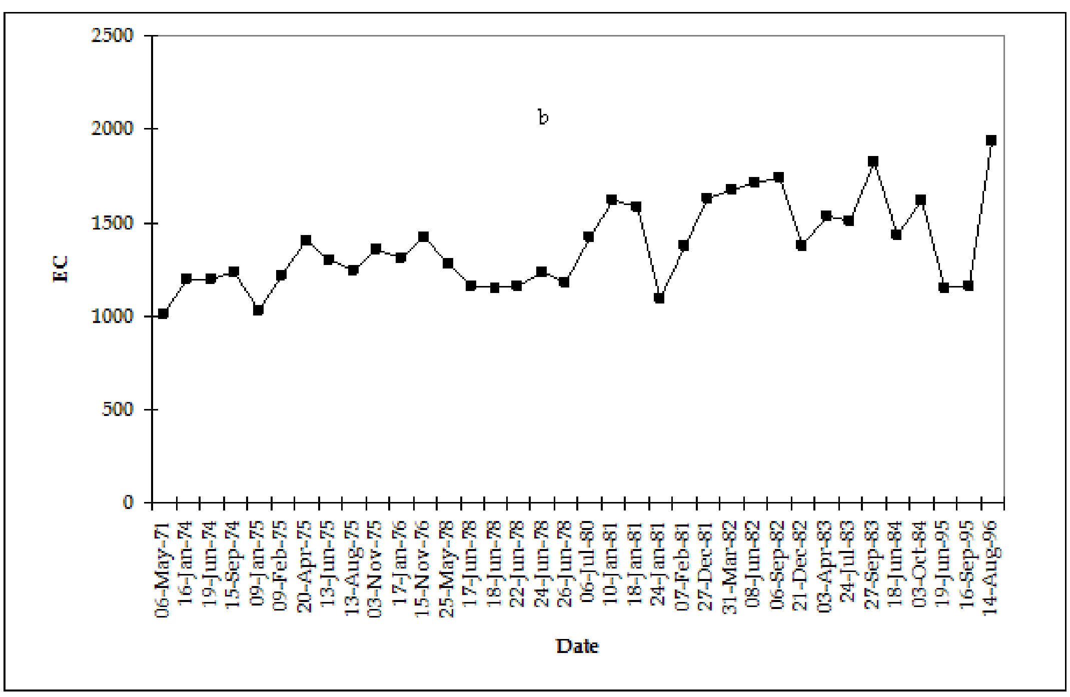


Fig. 5. Temporal variation of the EC (µS/cm) and NO_3^- (mg/L) for well AD1251 (a), and EC (µS/cm) for well AD1213 (b).

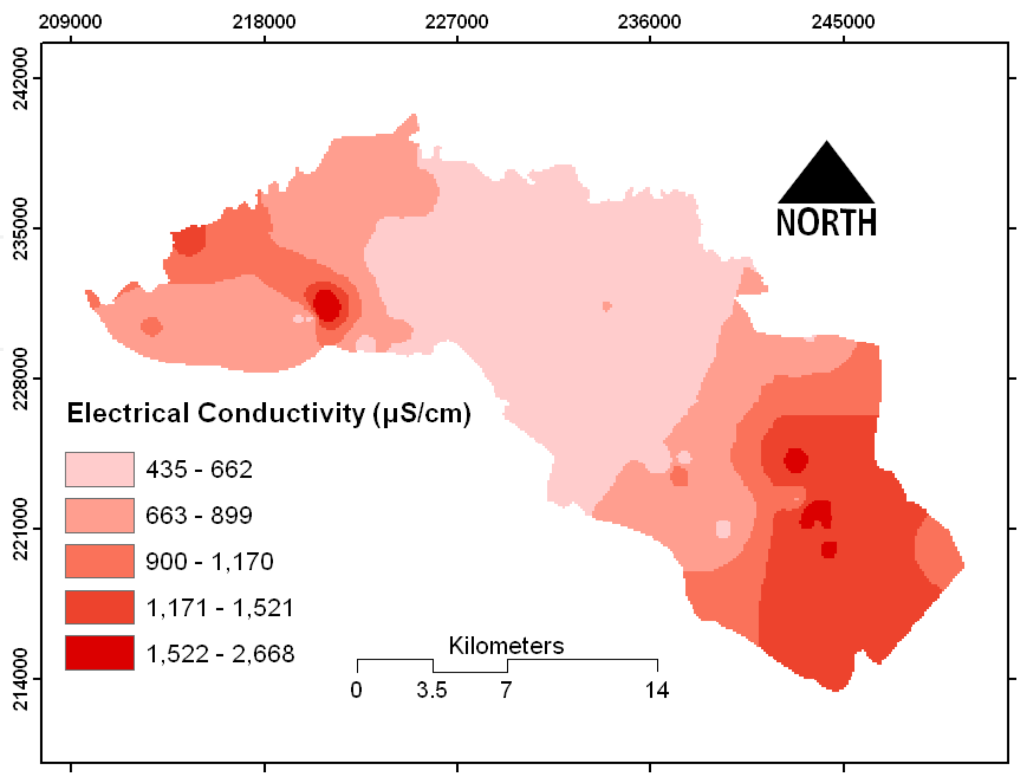


Fig. 6. Spatial distribution of the average of the EC (µS/cm)

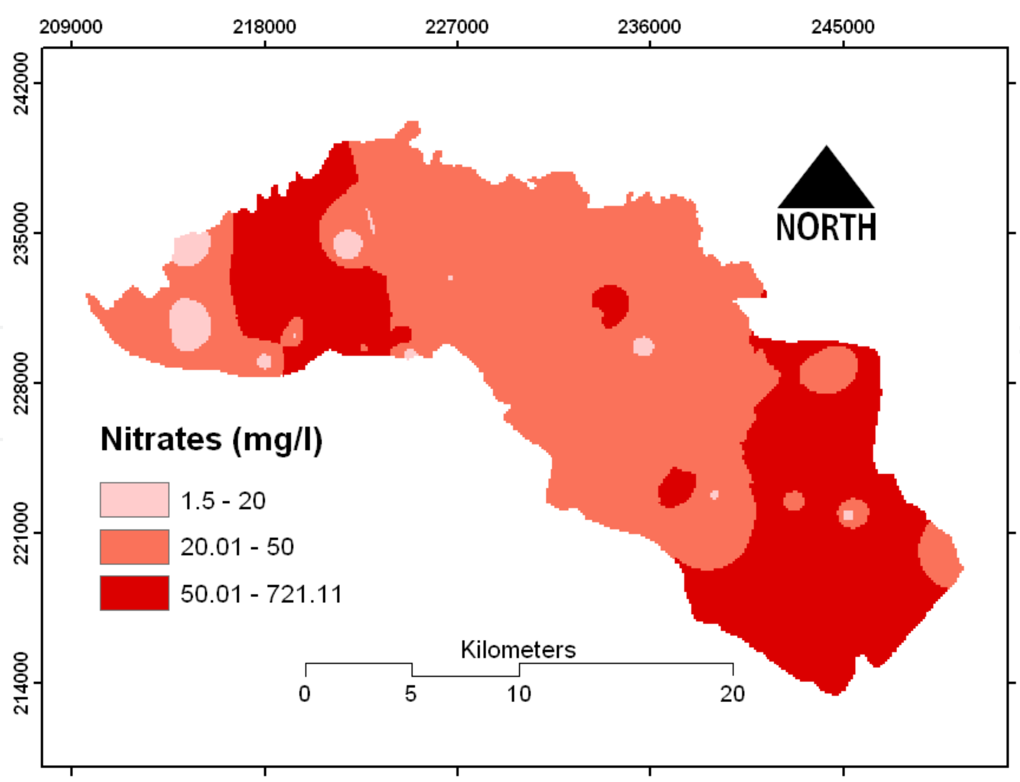


Fig. 7. Spatial distribution of the average nitrate concentration (mg/L as NO_3^-)

Nitrate concentration higher than 50 mg/L is found in the eastern and northwest parts of the study area, and concentration in the range of 20-50 mg/L is found in the central part of the study area. The spatial variation of the hydrochemical parameters reflects the hydrogeological situation and land use practices in the study area. Generally, high concentrations of all parameters were observed where the depth to the water table is less than 40 m, and where the land use is urban.

4.3 Nitrate concentration and the NPI

Nitrate concentration in the study area is in the range 1-794.81 mg/L with an average of 45.75 mg/L. The nitrate concentration was grouped into one of three classes (Fig. 8a).

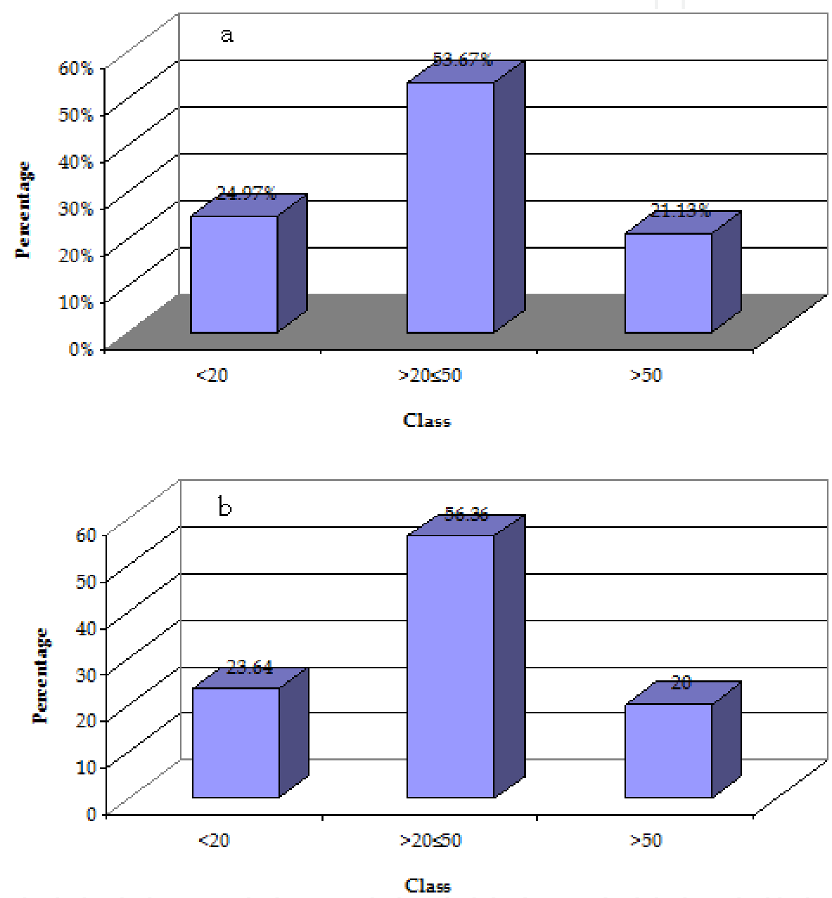


Fig. 8. Frequency distribution of the nitrate concentration (mg/L): (a) total samples, and (b) sampled sites (wells/springs)

i) low (<20 mg/L), ii) medium (≥ 20 mg/L to <50 mg/L), and iii) high (≥50 mg/L). Nitrate concentrations in the high class exceed the recommendations for drinking water set by WHO (1993). The medium class involves samples with nitrate concentrations high enough to indicate the influence of human activities (Spalding and Exner, 1993). The low class involves samples with a low risk for humans or the environment. About 75% of the samples has nitrate concentration exceeding the threshold value of anthropogenic source or the human affected value (HAV). More than 56% of the sampled sites has nitrate concentration of more than 20 mg/L and less than 50 mg/L, and 20% of the sampled sites has nitrate concentration of more than 50 mg/L (Fig. 8b). Based on the NPI values, five water classes were identified: clean, light pollution, moderate pollution, significant pollution, and very significant pollution, corresponding to NPI values of <0, 0-1, 1-2, 2-3, and >3, respectively. The sites (wells and springs) belonging to the classes significant and very significant pollution have nitrate concentration exceeding the maximum permissible limit of drinking water quality standards given by the WHO (1993). The spatial distribution of the NPI is presented in Fig. 9. Two major zones of very significant pollution is revealed: northwest and southeast of the study area. In the study area, there are two major potential sources of nitrate in groundwater: untreated/treated domestic wastewater and agricultural fertilizers. This can be indicated by the high content of E. Coli and total coliform recorded in wells and spring such as AD1251, AD1296, AD1046, AD1050, AD3027, AD1105, AD3057, AD3015, AD0536, AD1281, AD1280, AD0630, AD0600, AD0580, AD0560, AD1296, and AD0741. Moreover, a significant correlation coefficient exists between nitrate and potassium concentrations (table 2).

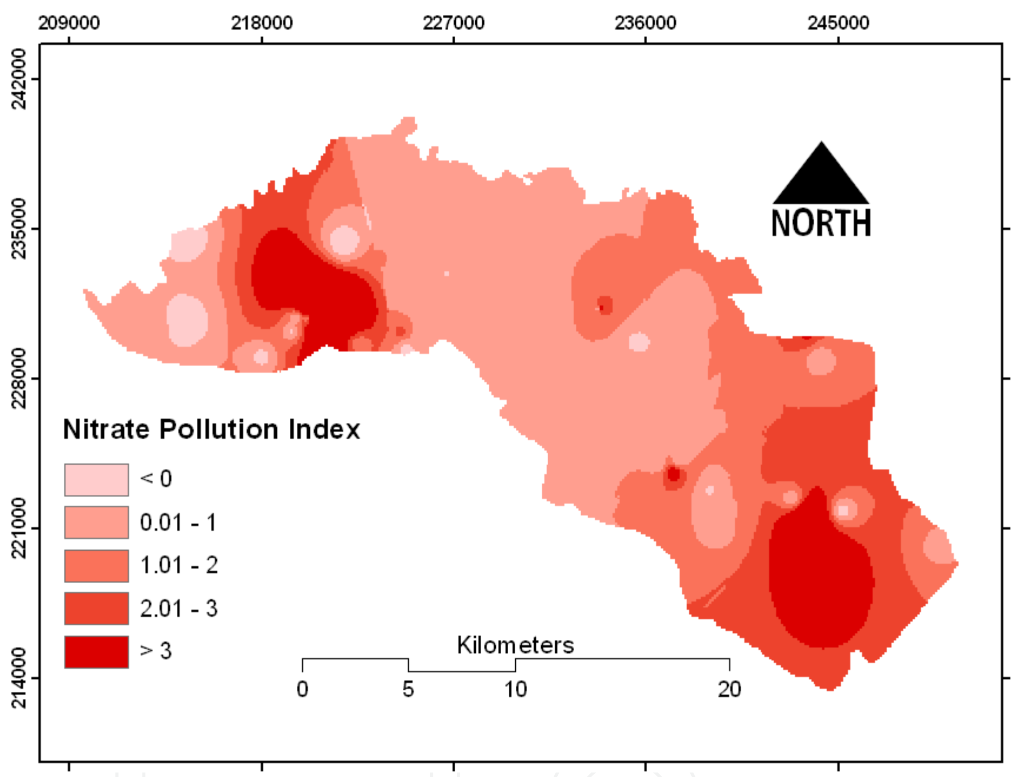


Fig. 9. Spatial distribution of the NPI

Parameter	pH	HCO_3	Ca	Cl	EC	Mg	K	Na	SO_4	NO_3
pH	1.000	-0.419	-0.382	-0.219	-0.253	-0.204	-0.074	-0.212	-0.099	-0.147
EC	-0.253	0.269	0.631	0.917	1.000	0.147	0.525	0.900	0.624	0.638
HCO_3^-	-0.419	1.000	0.584	0.126	0.269	0.350	0.099	0.141	0.123	0.046
Ca^{2+}	-0.382	0.584	1.000	0.487	0.631	0.192	0.623	0.446	0.344	0.648
Cl^+	-0.219	0.126	0.487	1.000	0.917	0.103	0.375	0.967	0.582	0.541
Mg^{2+}	-0.204	0.350	0.192	0.103	0.147	1.000	0.062	0.097	0.265	0.011
K^+	-0.074	0.099	0.623	0.375	0.525	0.062	1.000	0.321	0.246	0.823
Na^+	-0.212	0.141	0.446	0.967	0.900	0.097	0.321	1.000	0.593	0.503
SO_4^{2-}	-0.099	0.123	0.344	0.582	0.624	0.265	0.246	0.593	1.000	0.213
NO_3^-	-0.147	0.046	0.648	0.541	0.638	0.011	0.823	0.503	0.213	1.000

Table 2. Bivariate statistics of the hydrochemical parameters

4.4 Multivariate analysis

4.4.1 Cluster analysis

Cluster analysis is a classification that places objects into more or less homogeneous groups in a manner so that the relation between groups is revealed. The results of k-means clustering of the B4 groundwater are compiled in table 3. Three clusters were identified with distinct cluster centers. **Cluster 1** has the highest ionic concentration and comprises only 0.3% of the total samples. This cluster is highly nitrated with a nitrate concentration of 355 mg/L. **Cluster 2** has total dissolved solids content intermediate to cluster 1 and 3, and it involves 81% of the samples. The groundwater belongs to this cluster can be classified as freshwater. This cluster has a nitrate concentration of 30 mg/L, which exceeds the threshold value of anthropogenic source. **Cluster 3** comprises 18.6% of the total samples. The water belongs to this group can be classified as brackish water, and it contains high nitrate concentration (110 mg/L) exceeding the WHO (1993) standards for drinking water. The three clusters are shown in Fig. (10a) as Schoeller diagram on a semilogarithmic paper, with the data plot on parallel lines. The data which plot on parallel lines reflect dilution of a saline water type with fresh water (Mazor, 1991). The total dissolved content (TDS) and chloride concentration were plotted using a scatter diagram as shown in Fig. (10b). Three distinct groups can be clearly seen. Such pattern indicates mixing and progressive change in concentrations.

Parameter	Cluster		
	1	2	3
pH	8	8	8
EC	3,442	609	1,634
Ca^{2+}	146.9189	74.5637	104.7756
Mg^{2+}	37.4560	35.7162	40.7068
Na^{+}	127.58	29.11	168.16
K^{+}	69.5	4.7	13.9
HCO_3^-	239.61	240.27	251.34
Cl^-	278.297	49.441	289.685
SO_4^{2-}	95.60	19.36	87.00
NO_3^-	355	30	110

Table 3. Results of the k-means cluster analysis

4.4.2 Factor analysis

Table 4 shows the eigenvalues (>1) of the three extracted factors, their percentage of variance, and cumulative percentage of variance of hydrochemical parameters of the B4 groundwater. It is found that the three factors account for 76.78% of the total variance. Table 5 shows the loadings for the varimatrix-rotated factor matrix in the three factor model. According to Liu et al. (2003), the terms strong, moderate, and weak, which are applied to factor loadings, refer to absolute loading values of >0.75, 0.75-0.5 and 0.5-0.3, respectively.

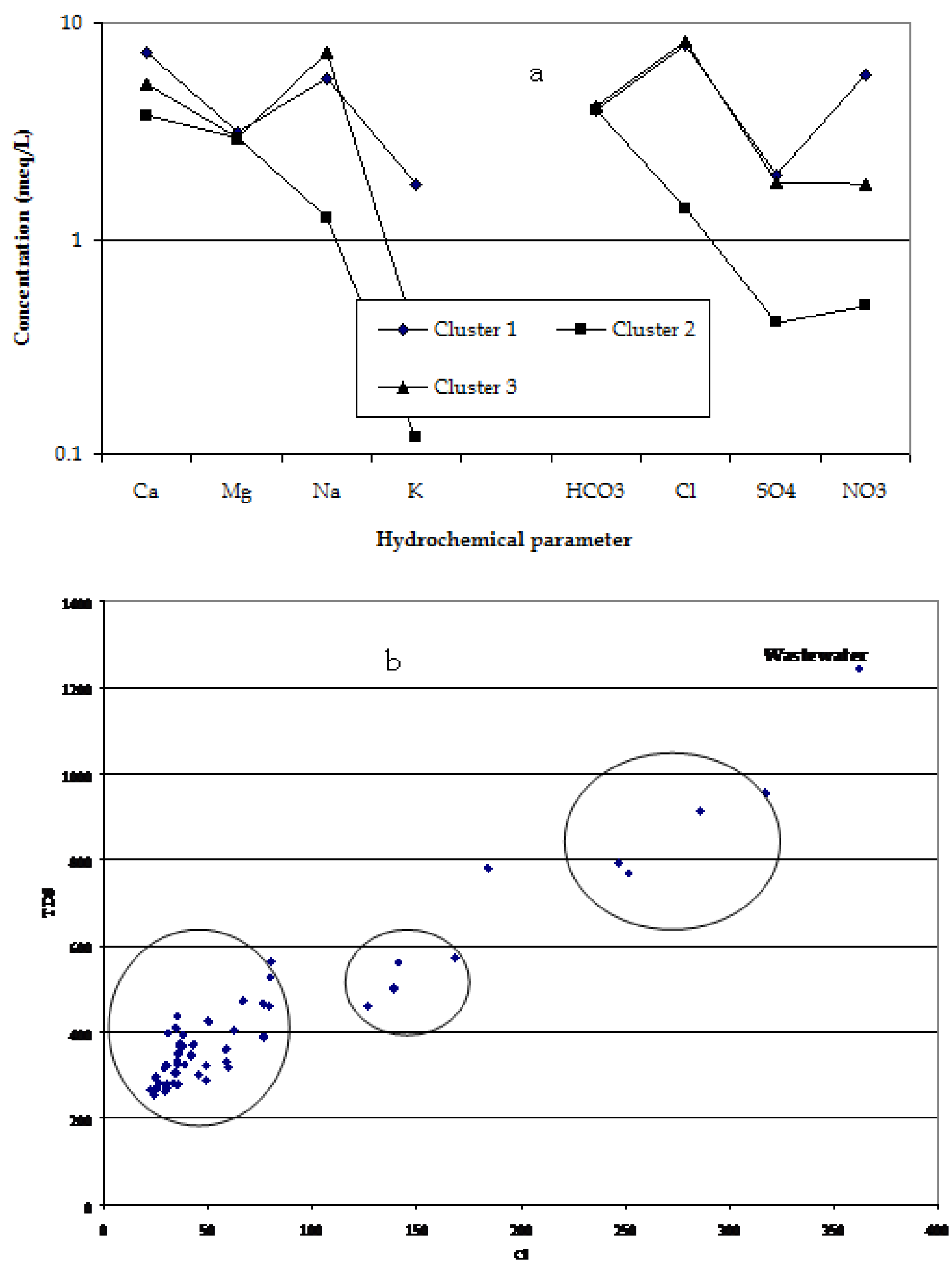


Fig. 10. Schoeller diagram presentation of the three clusters (a), and composition diagram of the chloride versus TDS (b)

Factor 1, which accounts for 47.05% of the total variance, has strong positive loadings on electrical conductivity, chloride, sodium and sulfate. This factor is termed as the "**salinity factor**" in reference to salt halite (Cloutier et al. 2008), indicating salinization of the groundwater due to mixing freshwater with saline water introduced into the aquifer by overpumping or infiltration of treated/untreated wastewater. **Factor 2** explains 16.27% of the total variance, and has strong positive loadings on nitrate and potassium, and moderate loading on calcium, and weak loadings on the electrical conductivity and chloride. This factor is termed as "**pollution factor**", indicating anthropogenic impacts from agricultural and domestic wastewater. **Factor 3** accounts 13.46% of the total variance, and has strong positive loading on bicarbonate, moderate positive loadings on calcium and magnesium, and moderate negative loading on the pH. The presence of bicarbonate, calcium, and magnesium reflects signatures of natural water recharge and rock–water interaction (Prasanna et al. 2010). This factor can be termed as the "**hardness factor**", since calcium and magnesium are generally used to calculate the hardness. The factors' scores were mapped to assess the processes affecting the groundwater quality in the study area (Fig.11). According to Olobaniyi and Owoyemi (2006), a factor score larger than +1 indicates intense influence by the process, whereas a very negative factor score (< -1) indicates that the area is unaffected by the process. Near zero factor score suggests moderate influence. Groundwater in the east and northwest parts of the study area is more saline than groundwater in the central part. Groundwater with highest hardness is found in the northwest part of the study area. Contamination of groundwater by nitrate together with potassium is prevailing in the west part of the study area.

Factor	Eigenvalue	% of variance	Cumulative variance %
1	4.705	47.050	47.050
2	1.627	16.271	63.322
3	1.346	13.460	76.781

Table 4. Eigenvalue (>1), percentage of variance, and percentage of cumulative variance of the three factors

Parameter	Factor		
	1	2	3
pH	-0.093	-0.125	**-0.678**
EC	**0.835**	0.454	0.185
Ca^{2+}	0.270	**0.705**	**0.526**
Mg^{2+}	0.163	-0.142	**0.629**
Na^{+}	**0.921**	0.249	0.073
K^{+}	0.163	**0.900**	0.012
HCO_3^-	0.009	0.141	**0.859**
Cl^-	**0.908**	0.305	0.069
SO_4^{2-}	**0.784**	-0.002	0.163
NO_3^-	0.304	**0.896**	-0.030

Table 5. Loadings of the varimatrix-rotated factors

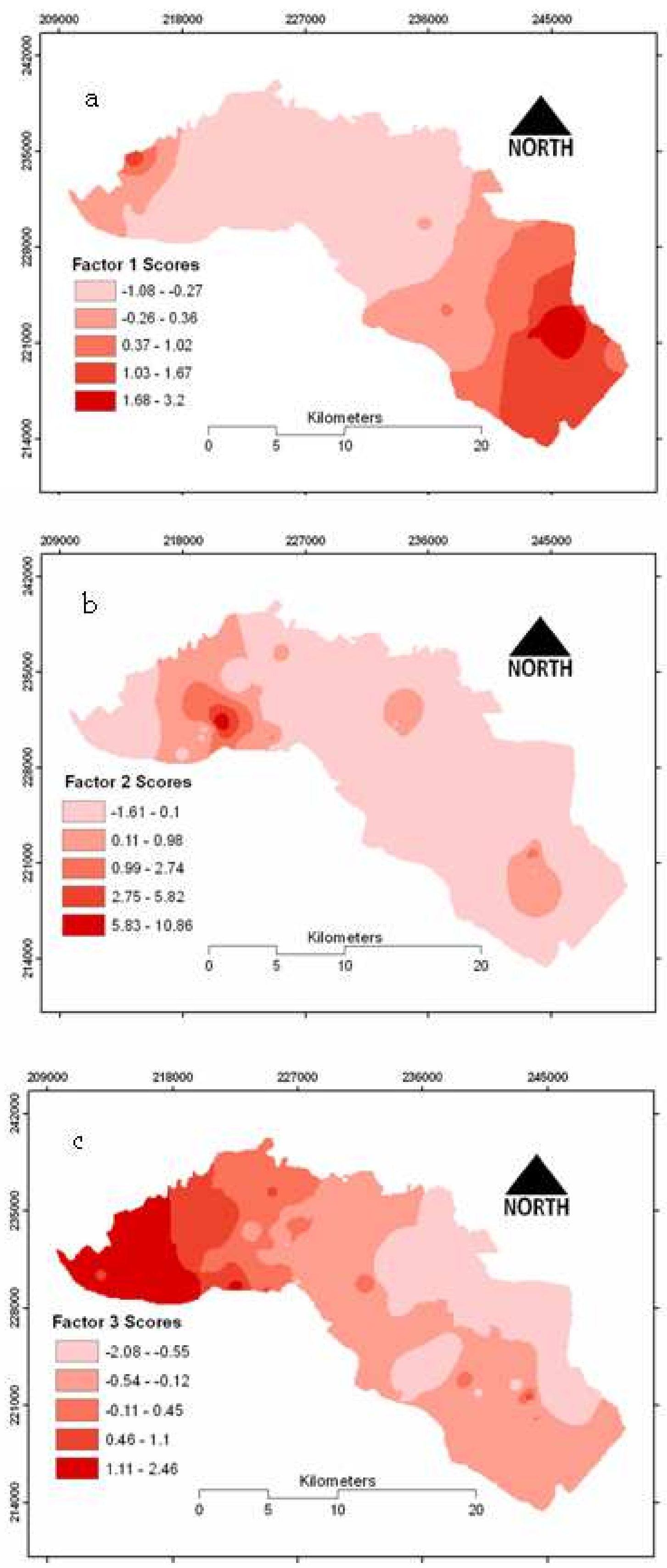


Fig. 11. Map of the three factors' scores

5. Summary and conclusions

This study has revealed that the phreatic groundwater in the northern Yarmouk basin is contaminated by nitrate to a high and variable degree. It is found that nitrate concentration (as mg/L NO_3^-) ranges from 1 and 795 mg/L, with an average of about 46 mg/L. More than 76% of the sampled sites has nitrate concentration in excess of the human affected value (20 mg/L), and about 20% of the sampled sites has nitrate concentration higher than the WHO standards of drinking water quality (> 50 mg/L). The highest nitrate concentrations were found for those wells/springs where the depth to groundwater is less than 30 m below ground surface. This study has developed a new water quality index named nitrate pollution index (NPI). It was generated using a simple mathematical equation which relates the analytical nitrate concentration to the threshold value of anthropogenic source of nitrate (HAV). The sampled sites were classified by using the NPI into the following classes: clean, light pollution, moderate pollution, significant pollution, and very significant pollution, corresponding to NPI values of <0, 0-1, 1-2, 2-3, and >3, respectively. The wells/springs which fall in the significant and very significant pollution classes have nitrate concentration exceeding the WHO standards. Multivariate statistical techniques (CA and FA) were applied on the hydrochemical parameters of the groundwater in the study area. CA resulted in three clusters which can be differentiated by the total ionic concentration and the nitrate concentration. FA resulted in a three-factor model which accounts for 76.78% of the groundwater chemistry variation. Factor 1 "salinity factor" is responsible for 47.05%of the total variance and has strong positive loadings on electrical conductivity, chloride, sodium and sulfate. Factor 2 "pollution factor" accounts for 16.27% of the total variance and has strong positive loadings on nitrate and potassium. Factor 3 "hardness factor" accounts for 13.46% of the total variance and has strong positive loading on bicarbonate and moderate loadings on calcium and magnesium. To deduce the processes that control the groundwater chemistry, factors' scores were mapped. There are two agents that control the groundwater quality in the study area: human activities and natural processes, as it is pointed by the factor analysis. Human activities which led to modification on the water quality include agricultural activities mainly crop cultivation and application of fertilizers. This is well indicated by the very significant correlation (r = 0.82) between nitrate and potassium. Treated/untreated wastewater is another major source of groundwater pollution, which is indicated by the presence of bacteriological contamination in the wells surrounding Ar Ramtha wastewater treatment plant. Total coliform content up to 1600 MPN/100 ml, and E. coli content of 500 MPN/100 ml were recorded. Rock/soil-water interaction plays an important role in the modification of the groundwater chemistry, especially water hardness.

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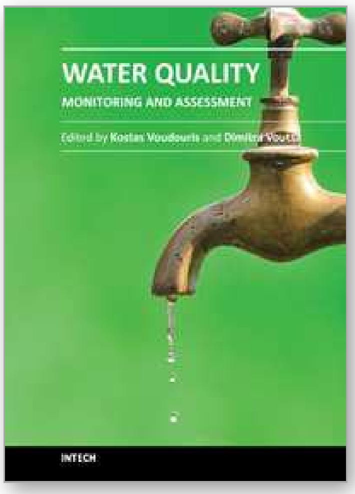

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