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DRINKING WATER BIOLOGICAL AND CHEMICAL CONTAMINANTS: A CASE STUDY OF RURAL AREAS OF NORTHWEST SINAI, EGYPT

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ABSTRACT

This study was carried out in the countryside areas of Romana district, Northwest Sinai, Egypt, to assess the biological and chemical quality of the drinking water. Eighty water samples were collected from 13 rural locations and subjected to be analysed for different biological and chemical characteristics. The results showed that coliform bacteria were undetectable reflecting clean water from coli bacteria in all studied samples. However, samples collected from Al Karama and Al Salam Villages showed high amounts of total number of bacteria. Values of water pH, Electrical conductivity and dissolved organic matter showed suitability of the drinking water for human use according to published permissible limits. All water samples were in the safe zone according to the limits of WHO with some exceptions, in term of heavy metals contents. Cd in all samples, Pb in almost 54% of samples exceeded the drinking water limits of WHO. Water quality index showed that all drinking water were excellent for human use except samples taken from Qatia which characterized by a relative lower quality. The author emphasized that Cd was excluded from water quality index assessment as it needs further research work to confirm its high concentration in the drinking water samples.

INTRODUCTION

The need for a clean and safe drinking water supply for urban agglomerates has been recognized for over 2000 years **(Nastic, 2022**). The early Romans recognized that human activities and effluent were a major source of water pollution, and that providing water from relatively unpopulated areas was a solution to the problem. In 312 b.c. the Romans under Appius Claudius began development of an aqueduct system to deliver water taken from the Tiber River upstream of the city, thus improving the quality and quantity of their water supply **(Kulperger *et al.*, 2003**). It has been said that the availability of a good water supply through their extensive aqueduct system enabled the rise of Rome as a center of civilization-and it has also been speculated that the use of lead for water pipes helped lead to its downfall، through slow poisoning of the population. This has been disputed, with evidence that terra-cotta was a preferred piping material, resulting in better-tasting drinking water. Thus, the maintenance of drinking water quality has been a major quest throughout the development of modern civilization **(Hall and Dietrich, 2000**).

Chlorination of drinking water for bacteriological control was begun in the United States in 1908 (in Boonton, New Jersey), although it had been studied extensively before that time in both Europe and United States **(Park *et al.*, 2016**). The

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treatment was quickly demonstrated to make a tremendous difference in disease transmission. The discoveries leading to the technique are considered to be one of the greatest public health breakthroughs of all time, preventing millions of illnesses and deaths.

However, tremendous source of anthropogenic contaminants such as heavy metals represents health risk although chlorination of drinking water has been applied **(Abeysinghe and Sirimuthu, 2019**). In north Sinai, very few studies were under taken on health risk assessment **(Abdel-Shafy *et al.*, 2020**) and none in the selected study area such as countryside of Rommana area in the Northwest Sinai, Egypt.

Therefore, investigation of the contamination levels and dispersion patterns of heavy metals in drinking water around agricultural areas in the studied areas, are needed to assess their microbial and chemical characteristics for the residents.

MATERIALS AND METHODS

Study Area

This investigation was carried out in western part of North Sinai region, Egypt. The sampling was performed along the path of the drinking pipeline that transfer drinking water from Eastern part of Qantara city (30°52'45.86" N 32°21'44.21" E) to Ber-Elabd city and its districts as shown in Table 1.

The total domestic water supply for the studied areas is around 60,000 $m^3 day^{-1}$; 40,000 m^3 day^{-1} fresh water for drinking purposes are pumped from the station of drinking water purification in Qantara through a main water line with a diameter of 1000 mm and the other 20,000 m^3 day^{-1} are obtained from water Saline wells (Personal communications).

Sample preparations

Total 80 samples have been studied from the drinking water pipes. Different chemical and microbiological examinations were undertaken. Briefly, desktop analyses were carried out to select the collection points according to the number of resident and the distant from the main water takes in each distract. Different sampling procedures were employed for different types of water analysis (chemical and biological analyses) and all the precautions were occupied.

Tap water was allowed running for, approximately, fifteen minutes before filling the bottle samples. Then, water flow was decreased to permit filling of bottle without splashing. First of all, gases from the bottles were expelled by filling up, then emptying over the tap water, and refilled in the same manner again for microbial analysis. In addition, samples taken for chemical analysis were immediately filtered using < 0.22 µm filter (Millex® Millipore). The three water samples were collected from each sampling point in each location as following: (i) the first one, the bottle was filled with unfiltered non acidified water for microbial analysis and collected in ice box then kept in dark and cold (4°C) to be analyzed within 24 hrs from the collection time. (ii) the second bottle, was filled with filtered water having no acid for pH, EC and dissolved organic carbon (DOC) analysis (iii) the third bottle was filled with filtered water from the same site and acidified to reach 2% of (TAG) HNO_3 by adding one drop of the concentrated acid (70%) to stop the microbial activities and preserve trace metal in the solution phase for multi-elements analysis. After transportation to laboratory the non-acidified samples were kept in -80°C freezer for pH, EC and DOC analyses while acidified samples were sent directly for multi-elements analysis.

For chemical elemental analysis, 20 drinking water samples were selected to represents the whole studied area and sent to chemistry laboratory for elemental analysis. For microbiological analysis, 24 selected samples were studied that represented the whole studied areas.

Table 1. The geographical coordinates of the water samples collected from 80 locations in the study area

Location Name	Number of samples	Coordinates
Al Shaikh Zaied	5	31.017945780488215, 32.53192812958769
Baloza	5	30.680069214188546, 32.64666701069089
Al Ahrar	5	31.097261355106472, 32.59747239795844
Al Shohat	5	30.9850764829926, 32.58540477162798
Al Shohada	5	31.01331864242451, 32.641194677249885
Romana	5	31.01257593865223, 32.65741260189939
6 October	5	30.994475729778138, 32.69080477299753
AlKarama (Al Ganain)	5	31.002194160858743, 32.73267894976515
Rabaa	10	30.999688830094488, 32.740917981995835
Qatia	10	30.95244184280441, 32.74641068225036
Om Oqba	5	30.98863631638034, 32.771379789632135
Al Salam	5	30.986262076799314, 32.76000704893091
Negila	10	31.00323790484873, 32.8266088716568

Microbiological Analysis

Most Probable Number (MPN) method and Total Viable Count (TVC) were used for the microbiological analysis within 24 hours of sampling as recommended by **Federation and Association (2005**). The procedure for testing drinking water was done aseptically. MPN method was conducted in three steps **(Koneman *et al.*, 1997**); (i) Presumptive test, (ii) Confirmed test and (iii) Completed test. Presumptive test functions as the primary presumption for the presence of Gram-negative coliform bacteria in the samples. The water source will be considered microbiologically safe in case of negative presumptive test. But showing acid and gas indicate the positive reaction and considered unsafe tube in the series. The confirmed and completed tests were not performed because of negatively of presumptive test. MacConkey broth medium (Strength, G. MacConkey Broth (DM150H)) **(PUBL, 1968**) was used for lactose fermentation for the presence of the indicator Bromo-cresol purple in the presumptive test. The inverted Durham's tube was used for the detection of gas formation by Gram-negative coliform bacteria. The color changed of media into yellow and on the collection of gas in Durham's tube assumed that coliform bacteria were present in the samples **(Phyo and San, 2019**). Three of 5ml of water samples were inoculated into each of 5ml of presumptive broth (double strength). Three of 1ml water sample were added to a tube containing 5ml of presumptive broth (single strength). Three of 0.1ml water sample were added to a tube containing 5ml of presumptive broth (single strength). After 48 hr., incubation at 37ºC, the number of positive tubes was recorded from each set and compared with the standard chart to give presumptive coliform count per 100 ml water sample. One contaminated sample was prepared to be a model for making sure of the truly of the current methods that were used as a quality assurance of the method.

Total Bacterial Count

This method was used for a quantitative estimate of the concentration of microorganisms. The count represented the number of colonies forming units (CFU) per g (or per ml) of the sample. Total bacterial count was achieved by plating serial tenfold dilution of the sample; 30 and 300 colonies can be counted on a single plate **(Thomas, 2006; Wise, 2006**). The counted plate was used for the counted number of colonies multiplied by the dilution; the high concentration of micro-organisms was indicated by high TVC counts which indicate low quality for drinking water. According to the method of **Koneman *et al.* (1997**); usually 1 ml and 0.1 ml of the sample are plated on the nutrients agar medium. The plates are incubated either at 20°C for 48 hours or at 35°C for 24 hours; then a colony count is made and the number of bacteria per millilitres of the sample is calculated. Counting the number of colonies on a plate that shows between 30 and 300 colonies and, by knowing the dilution of this plate, it was calculated the number of CFUs per ml in the original sample **(Wise, 2006**).

Chemical Analysis

The pH was measured using a pH meter and a combined glass electrode (Ag/AgCl; PHE 1004); (Model pH-211, PHE 1004, HANNA Instruments, Bedford, UK). Electrical conductivity (EC, dsm^{-1}) was measured a Conductivity meter (Model HI 9033 Multi-rang, Hanna instruments, Bedford, UK). The concentration of dissolved organic carbon (DOC) in water samples was evaluated by spectrophotometer at 360 nm. Samples were diluted where necessary to obtain absorbance values in the range 0.0-1.2 and according to **Moore (1987**). The DOC concentrations were calculated using the following formula:

$$DOC\ (g/m^3) = 160.1A + 6.9$$

Where DOC: is the dissolved organic carbon concentration (g/m^3); A: is the measured absorbance in 1 cm cell.

Multi-element analysis was undertaken by the standard Agilent triple quadruple ICP-MS (ICP-QQQ - 8800, Tokyo, Japan), as described by **(Marzouk *et al.*, 2013**). ICP-MS is a type of mass spectrometry based on coupling together inductively coupled plasma as a method of producing ions (ionizations) with a mass spectrometer as a method of separating and detecting ions. ICP-MS is highly sensitive and capable of determination of a range of metals and several non-metals at concentrations below one part in 10^{12}. In this study, total 19 elements (Al, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Si, Sr, Ti, V and Zn) were determined in water samples.

Water Quality Index (WQI) method

Bordalo *et al.* (2006) reported that WQI is a mechanism to define a certain level of water quality. **Katyal (2011**) classified large amounts of water quality data using WQI to specific degrees (*e.g.*, excellent, good, bad, *etc*.) for reporting to management and the public in a consistent manner. **Birawat *et al.* (2021**) divided WQI methods for three steps which include selection of parameters, determination of quality function for each parameter, and aggregation through a mathematical equation. The index provides a single number that represents overall water quality at a certain location and time based on some water parameters. According to **Birawat *et al.* (2021)** the weighted arithmetic WQI method was applied to assess water suitability for drinking purposes. In this method, water quality rating scale, relative weight, and overall WQI were calculated by the following formula**:**

$$q_i = (C_i/S_i) \times 100$$

Where qi = quality rating scale; C_i = concentration of i parameter; S_i = standard value of i parameter

Relative weight was calculated by the following equation:

$$W_i = 1/S_i$$

Where, i is inversely proportional to the relative weight.

Finally, overall WQI was calculated according to the following expression:

$$WQI = \Sigma q_i W_i \times \Sigma W_i$$

Statistical Analysis

Each treatment was conducted with three replicates (except in the elemental analysis, two replicates were used to minimize the analysis cost using ICP-MS), and the results were presented as mean ± standard deviation (SD). The statistical analysis of experimental data utilized the Paired t-test and Pearson correlation. Each of the experimental values was compared to corresponding control using Minitab ® statistical software Version 17.1.0.

RESULTS AND DISCUSSION

Microbiological Characteristics

The results in Table 2 and Fig.1 show that the highest percentage of total bacterial counts was in Al Karama village (183 $CFUs.ml^{-1}$), followed by Al Salam (160 $CFUs.ml^{-1}$) and Negila 2 (146 $CFUs.ml^{-1}$) neighborhoods, while the lowest percentage of the total number of bacteria was in Al Ahrar (50 $CFUs.ml^{-1}$) and Rabaa 1 area (52 $CFUs.ml^{-1}$). Despite this discrepancy, all the apparent percentages remain within the internationally permitted limits and safe limits for health according to the international standard specifications shown by the World Health Organization ($CFUs.ml^{-1} < 300$). As shown in Fig.1, a remarkable increase in the percentage of bacterial counts recorded in older village. Actually, there is no obvious trend in the total bacterial count and the distribution of the village except to some extend the density of population and local trad markets.

Bacteriological examination of water for total coliform count was done by most probable number (MPN) method for 13 samples as shown in Table 3. The results of the presumptive coliform counts showed that recorded counts in all three different dilutions (3 of 5, 1 and 0.1 ml each). Disappear of yellow color and the absence of gas of Durham's tubes can be assumed that no coliform bacteria presented in these samples **(Phyo and San, 2019**) . These results agree with international standard specifications shown by the **WHO (2011**), the European Union Standards (EUs) **(Carney, 1991**), and the Egyptian Ministry of Health (EGs) **(EMH, 2007**).

Chemical Characteristics

Water pH

Water sample pH presented in Fig. 2. pH is the main indicator that could be relied upon to know the degree of acidity and alkalinity of water **(Dutt and Sharma, 2022**). In addition, pH has an indirect effect on the quality of the water and its suitability for drinking **(Banna *et al.*, 2014**). The global reports published by the WHO, EUs and EGs, stated that the pH is an important factor of water quality parameter, but it usually has no direct impact on consumers. In this study, pH of the samples taken from the study areas was analysed and it was found that the highest value was 7.26 [SD± 0.03] in Al Shohat village followed by OM Oqba village 7.24 [SD± 0.03] while the lowest values were 7.15 and 7.17 in Rabaa and Al Sallam villages, respectively (Fig. 2). In general, the results indicated that the pH of the water samples is within the permissible limits according to the standard specifications which approved by the WHO (7.5), EUs (8.5) and EGs 7.5 as shown in the Fig. 2. In the same context, **Haydar *et al.* (2016**) reported that pH values higher than 8 are not suitable for effective disinfection while values less than 6.5 led to corrosion in water sources and plumbing system.

Table 2. Total bacterial counts in all selected samples (n = 25) in the main entrance of each village

No.	Sample	Total bacterial count (CFUs.ml^{-1})
1	Al Shaikh Zaied	126
2	Baloza 1	114
3	Baloza 2	95
4	Al Ahrar	50
5	Al Shohada 1	75
6	Al Shohada 2	82
7	Romana	64
8	6 October	82
9	Al Karama	183
10	Rabaa 1	52
11	Rabaa 2	61
12	Rabaa 3	84
13	Al ganain	103
14	Eqtaia 1	128
15	Eqtaia 2	115
16	Qatia 1	76
17	Qatia 2	92
18	Al meraih	70
19	Om Oqba 1	122
20	Om Oqba 2	109
21	Al Salam	160
22	Negila 1	96
23	Negila 2	146
24	Negila 3	128
25	Wastewater (control)	300

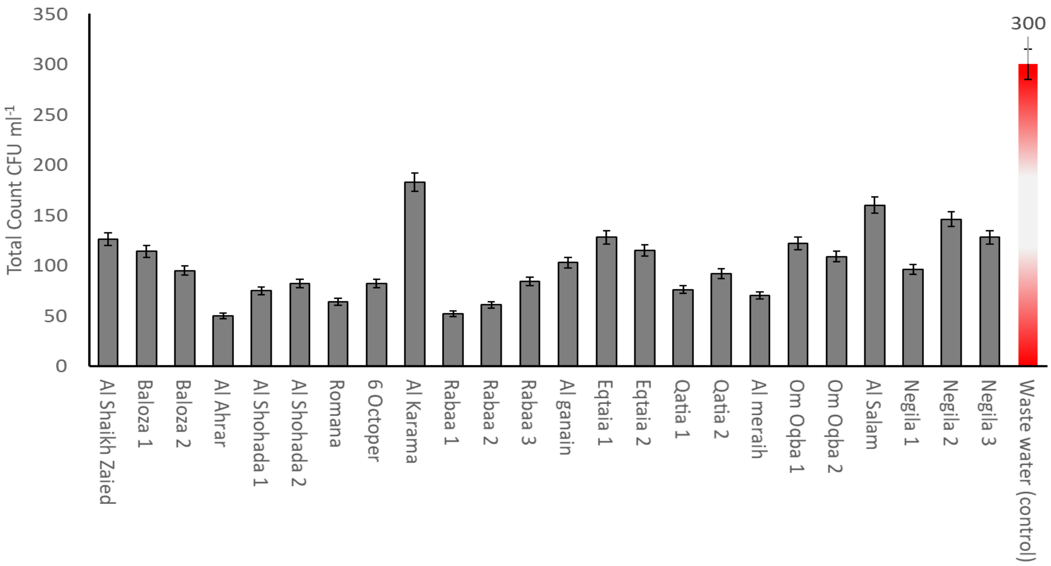

Fig. 1. **Total Bacterial Count (CFUs L^{-1}) determined in all tested samples from the studied locations. Locations were directionally arranged from the west to the east**

Table 3. Results of presumptive test shows most probable number index (n=13)

Sample site	Number of tubes given the positive reaction out of			MPN Index per 100ml
	3 of 5ml Each	3 of 1ml Each	3 of 0.1ml Each	
Al Shaikh Zaied	0	0	0	<3
Baloza	0	0	0	<3
Al Ahrar	0	0	0	<3
Al Shohat	0	0	0	<3
Al Shohada	0	0	0	<3
Romana	0	0	0	<3
6 October	0	0	0	<3
Al Karama	0	0	0	<3
Rabaa	0	0	0	<3
Qatia	0	0	0	<3
Om Oqba	0	0	0	<3
Al Salam	0	0	0	<3
Negila	0	0	0	<3
Indicates	2	1	0	15

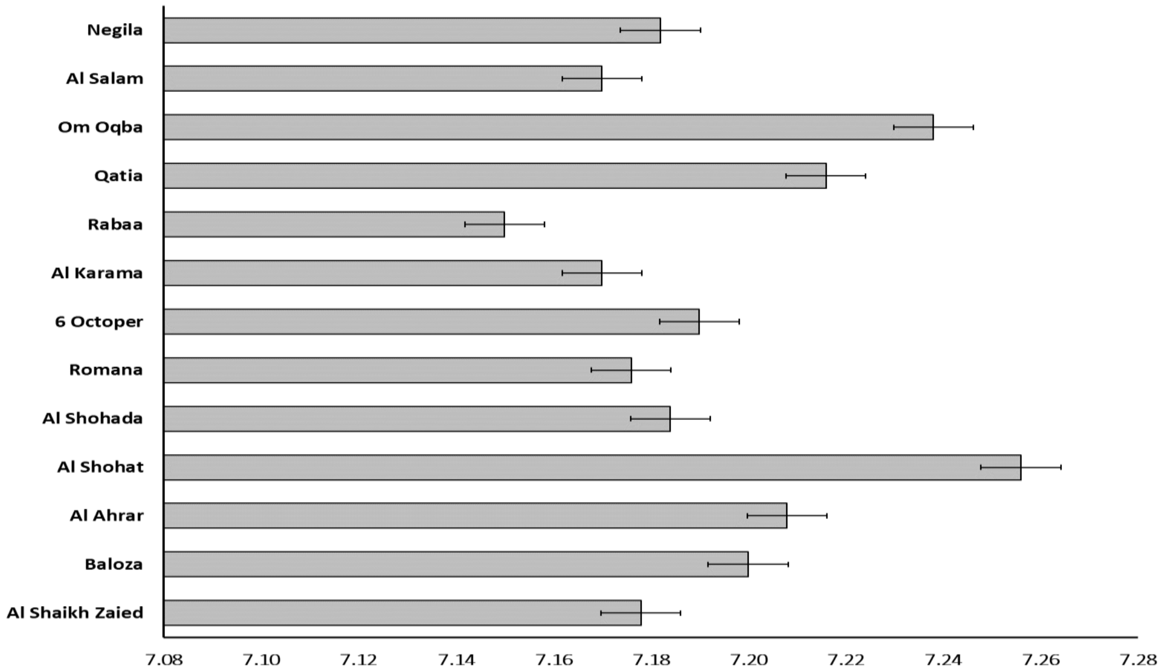

Fig. 2. Average pH value in all tested samples from the studied locations. Error bars represents the standard error of all samples within each collecting site

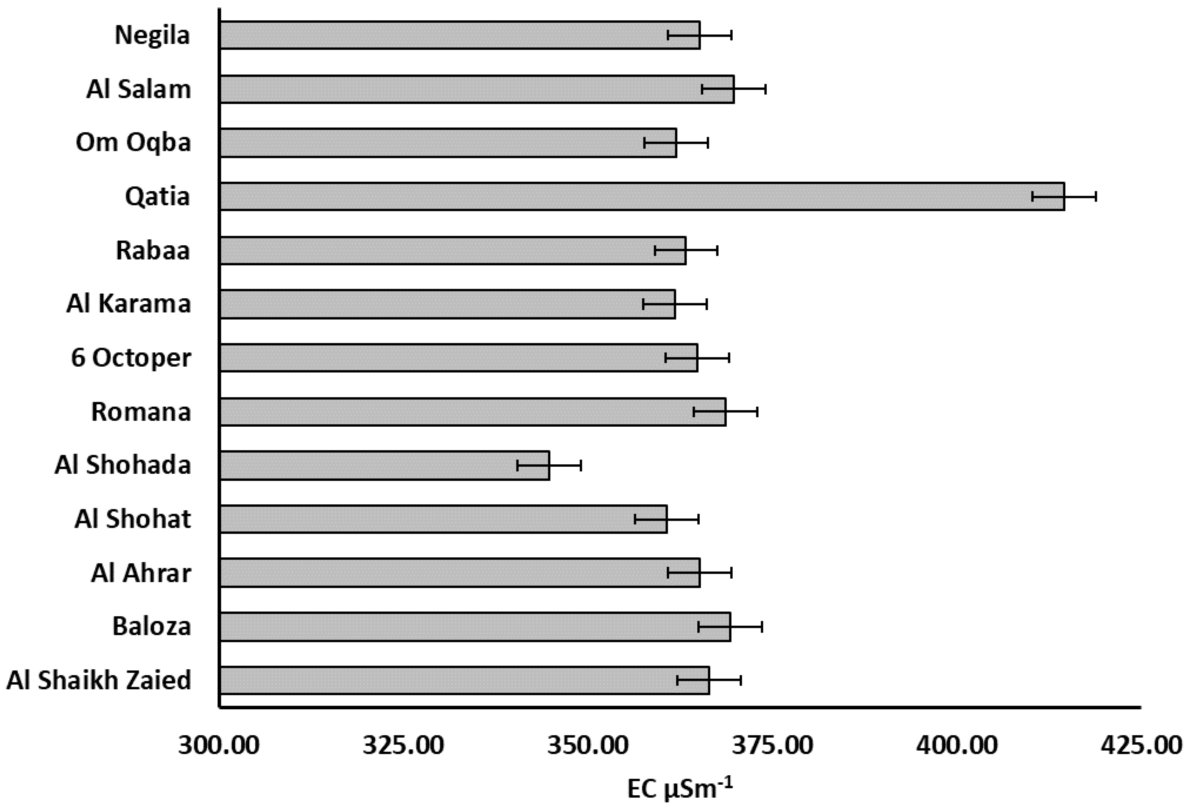

Fig. 3. Average electrolyte Conductivity (EC, μSm^{-1}) of all studied samples. Error bars represents the standard error of all samples within each collecting site

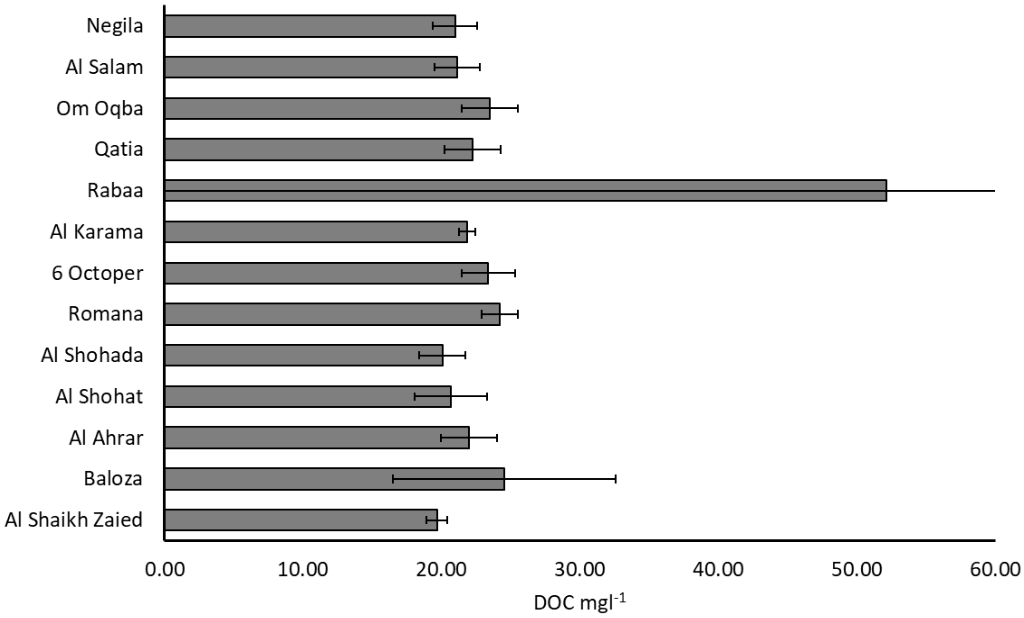

Fig. 4. Average dissolved organic carbon (DOC, mgl^{-1}). Error bars represents the standard deviation of all samples within each collecting site

Water EC

The electrical conductivity (EC) method is considered an acceptable indicator of water quality monitoring **(Sargaonkar and Deshpande, 2003**) where it is a measurement of the dissolved materials in an aqueous solution, which relates to the materials ability to conduct electrical current. There is a direct relationship between the amount of dissolved substances in the aqueous solution and the electrical conductivity. Although, this parameter does not provide information about specific chemicals in water, it acts as a good indicator of water-quality problems, particularly when changes occur in time. As shown in Figure 3, the current study showed that EC values were ranged from 345 to 415 μSm^{-1}. The global reports of WHO and the standard specifications of EUs and EGs referred that the values of the electrical conductivity should not exceed 1400 - 2500 μSm^{-1}. The previous research works confirmed the same specifications **(Mohsin *et al.*, 2013; Sehar *et al.*, 2013**).

Dissolved Organic Carbon (DOC)

According to the studies conducted by several researchers **(Peacock *et al.*, 2014; Pifer and Fairey, 2014; Cooray *et al.*, 2019; Bianco *et al.*, 2022**), the values of dissolved organic carbon (DOC) are considered a reliable indicator in assessing the quality, properties and suitability of drinking water for use, and its non-harm to human health. In this study, all the obtained results were relatively higher, while DOC results in Rabaa village were the most concentrated (52.1 ± 54.8 mg L^{-1}). The high SD value promoted from extremally shifted 3 values taken from different three locations connected to main storage tank (142, 133 and 115 mgl^{-1}). Rabaa village is high populated village compare with the other village in Romana Region. It seems that the main tank in this area is not cleaned, and some DOC could be concentrated as a results of growing water algae. The dissolved organic carbon values achieved the lowest value in Al Shaikh Zaied village (20 mgL^{-1}). However, in term of highly populated area, Baloza area followed Rabaa village in the high value of DOC as seen in Fig. 4.

Fig. 5 shows that by studying the correlation between the values of dissolved organic carbon (DOC) and total bacterial count (TBC), it became clear that there is a positive relationship where TBC got increase with the increase in the percentage of DOC in samples **(Williams *et al.*, 2010**) and this indicates the need to prevent the formation of the causes of the increase in organic carbon as well as provide suitable conditions for pumping and delivering drinking water that reduce the presence of high levels of organic carbon may lead to an increase in the total numbers of bacteria and pathogens in the drinking water **(Bi *et al.*, 2022**).

Multi-element analysis

Multi element analysis have been undertaken for 19 elements. In the current work some elements were selected to discuss the results and the whole were used for multivariable analysis. In the following part the common analysed heavy metals were presented and discussed.

Iron

Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Essential for good health, iron helps transport oxygen in the blood. **WHO (1993**) reported that concentrations of iron in drinking-water are normally less than 0.3 mgL^{-1} but may be higher in countries where various iron salts are used as coagulating agents in water-treatment plants and where cast iron, steel, and galvanized iron pipes are used for water distribution. The results obtained from this study showed that the highest iron values were in the Al Ganain district (0.74 mg. L^{-1}), followed by Al Shaikh Zaied (0.46 mg. L^{-1}), while the lowest iron concentrations were in the water samples in Al Ahrar (0.001 mg. L^{-1}). All results obtained were below the maximum permissible limits as shown in Fig. 6 except for the area of Al Shaikh Zaied and Al Ganain. This finding could be related to the steel pipe rusted in the study area.

Cadmium

Cadmium is one of the important elements in drinking water that has a direct impact on human health. Excess cadmium concentrations in excess of the permissible limits cause many diseases to the human body. According to **Khan *et al.* (2013**) Cd exposure can cause health problems such as nausea, vomiting, diarrhea, muscle cramps, sensory disturbances, liver injury convulsions, shocks and renal failure. Also, **Fatima *et al.* (2019**) mentioned that long term Cd exposure can cause certain effects such as kidney, liver, bone and blood damages. The results showed high levels of Cd concentrations in all study areas compare with the permissible limits of WHO, EUs, and EGs (0.005 mgL^{-1} for each). All of the study areas Cd results concentrations ranged from 0.002 to 0.42 which means high risk to people's health. As shown in Fig. 7. The author hesitated to publish these results because of the high level of Cd in the studied samples. Only two locations are free of Cd; Al Salam and Al Shohada villages. More research works are needed to confirm this finding. Some sources of Cd could be attributed from the agricultural fertilizers and pesticides.

Zinc

Kirchmann *et al.* (2017) published that Zn may be released from phosphate fertilizers, sewage sludge and corrosion of some galvanized plumbing and water pipe materials. In this study, the levels of Zinc were within the permissible limits set by the standards of WHO, EUs and EGs (3 mgL^{-1} for each). As shown in Fig. 8, the highest concentrations of zinc were in Qatia districts (0.178 mgL^{-1}), followed by 6 October (0.135 mgL^{-1}) and Om Oqba (0.108 mgL^{-1}), respectively, while it was the least concentrated in the rest of locations with a range of 0.006 to 0.09 mgL^{-1}.

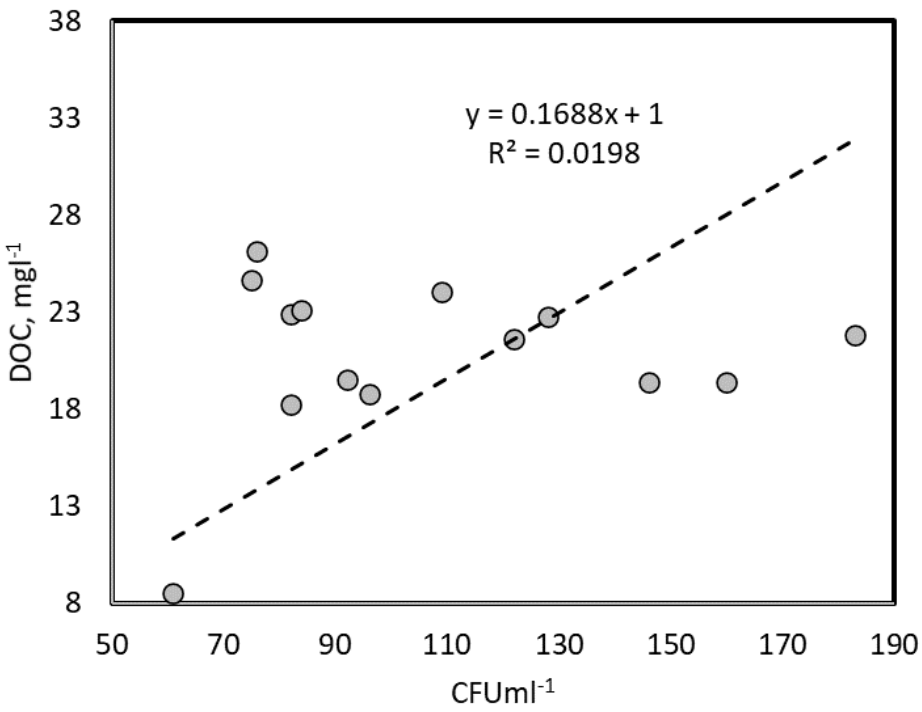

Fig. 5. The correlation relationship between dissolved organic carbon (DOC, mgL^{-1}) and Total Bacterial Count (CFU mL^{-1}). Equation of trending line and R-squared value were shown

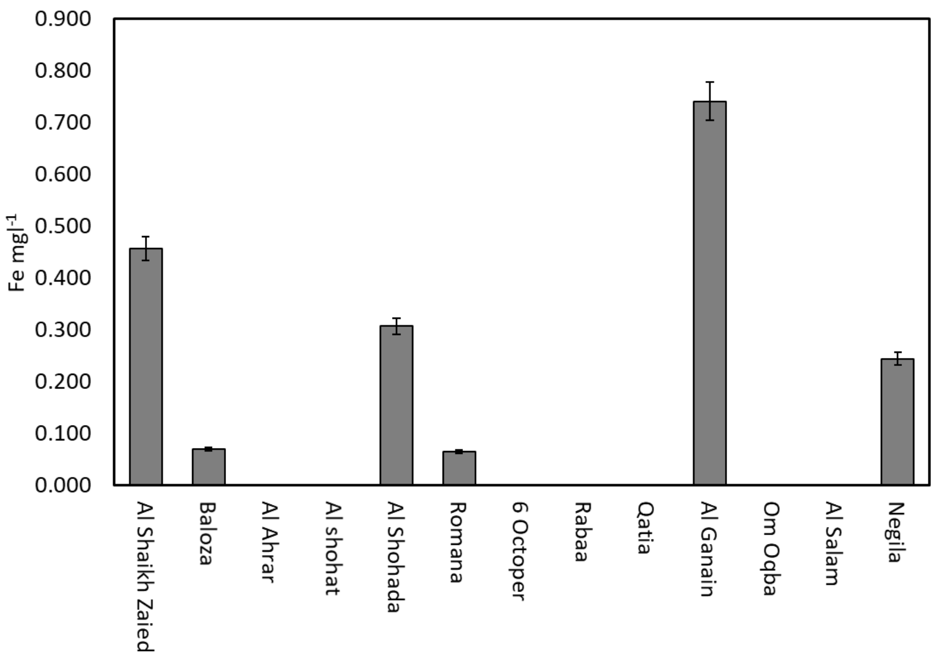

Fig.6. Iron concentration in all tested samples from the studied locations. Locations were directionally arranged from the west to the east. Error bars represents the standard error of all samples within each collecting site

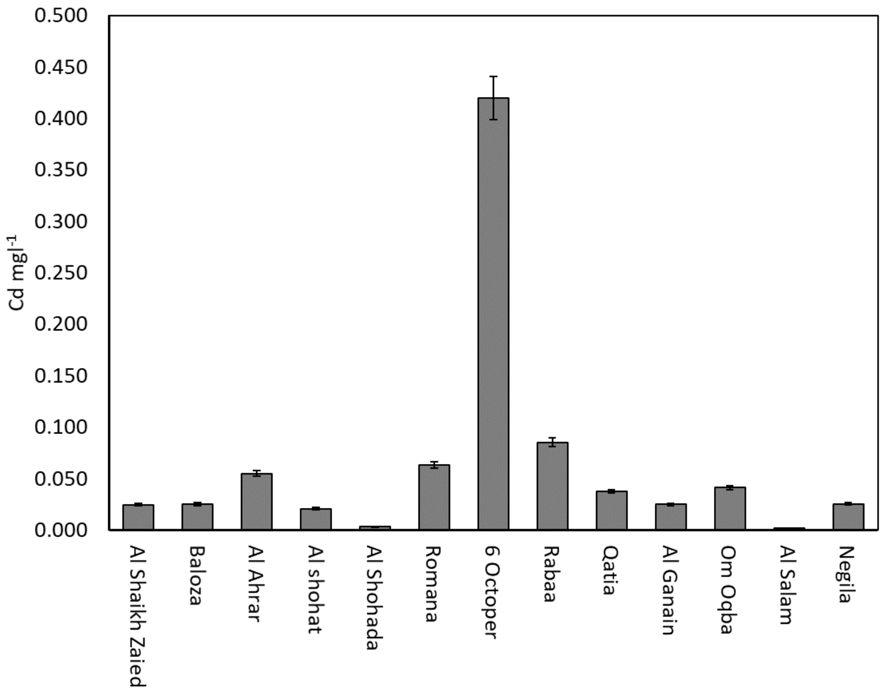

Fig. 7. Cadmium concentration in all tested samples from the studied locations. Locations were directionally arranged from the west to the east. Error bars represents the standard error of all samples within each collecting site

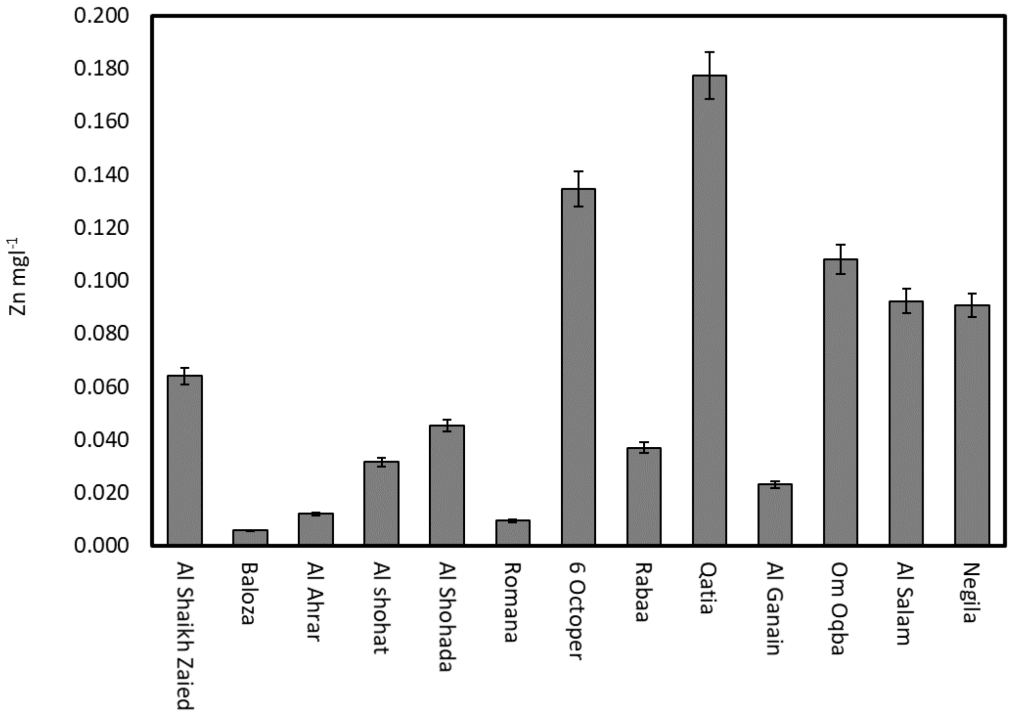

Fig. 8. Zinc concentration in all tested samples from the studied locations. Locations were directionally arranged from the west to the east. Error bars represents the standard error of all samples within each collecting site

Lead

Lead concentration, in all water samples, ranged from 0.0001 to 0.25 mg Pb L^{-1} with an average of 0.091 mg Pb L^{-1}. The maximum Pb concentration was observed in Baloza while lowest value was observed in Om Oqba village (Fig. 9). Almost 54% of tested samples were below the WHO standard (0.01 to 0.015 mgL^{-1}). Baloza village was subjected to several military activities which shows the highest Pb concentration including military machine fuel. It has been reported that petrol (fuel) is enriched with Pb to increase engine efficiency **(Saxena and Sonwani, 2019**). Moreover, high Pb levels may be related to the use of lead solder used in older piping systems **(Ng *et al.*, 2020**). In addition, the second and third last high Pb concentration were determined in Romana and Al Ganain villages by which anthropogenic source is expected due to military activities near this site during the study period. This kind of drinking water may pose a significant risk to the drinking consumers if they mainly depend on it **(Triantafyllidou *et al.*, 2009**).

Chromium

Chromium (Cr) has been found in several groundwater locations due to industrial discharge from leather tanning **(Ullah *et al.*, 2009**) along with other anthropogenic activities such as mining and electroplating *etc.* **(Alvarez-Ayuso *et al.*, 2003**). Chromium also increased in areas which exposed to high human activities such as waste disposal **(Mohanty and Patra, 2011**). In the current study, Cr concentration ranged from 0.0001 to 0.006 mg Cr L^{-1} with an average value of 0.002 mg Cr L^{-1}. Around 100% (Fig. 10) of the tested wells were below the WHO standard. Actually, Cr existance in drinking water can cause many harmful diseases in humans **(Emmanuel and Emmanuel, 2021**).

Strontium

The scientific literature shows that Sr is one of the heavy metals that has been documented as a potential human toxin with reports of many diseases, such as brain damages and mental disorder **(McIntyre, 2003**). Strontium concentrations results indicate that all the studied analyzed samples are in the range of 0.28 to 0.35 mg L^{-1} (Fig. 11); the reference dose is 4 mg L^{-1}, therefore, 100% of the tested samples are accepted as drinking water **(El-Sayed and Salem, 2015**). According to **(Agency, 2012**), Sr^{2+} is not likely to be carcinogenic to humans.

Multivariate Analysis

Principal component analysis (PCA)

To study the relationship between a large number of variables which may have a wide numerical range, Principal Component Analysis (PCA) is often used **(ElKashouty *et al.*, 2012**). PCA can show the number of factors affecting a dataset using scree plots as well as identifying relationship between elements through cluster analysis and dendrograms. Elemental associations in all datasets were further examined by principal component analysis (PCA). Scree plots and loading plots were used to assess the number of factors affecting the data. Eigen values above 2 in scree plot were considered to be significant **(Jackson, 1993**) and the scree plot based on the water samples dataset suggests that PC associations were not really meaningful beyond PC3 (Fig. 12). In fact, the first 2 components are considerably more important, with much weaker influences from the third components. Figure 12 shows a very even distribution of score values for the first two components. It was considered that discussion of only the first two components was suitable for examining the water characteristics (Dataset n=19), as found for other geochemical datasets **(Xue *et al.*, 2011**).

All the elements were reasonably well represented by these two principal components (Fig. 13). Loading plots showed a positive value of PC1 probably identifies the influence of similar chemistry behavior of elements (indicated by the dominant Pb, Ni,

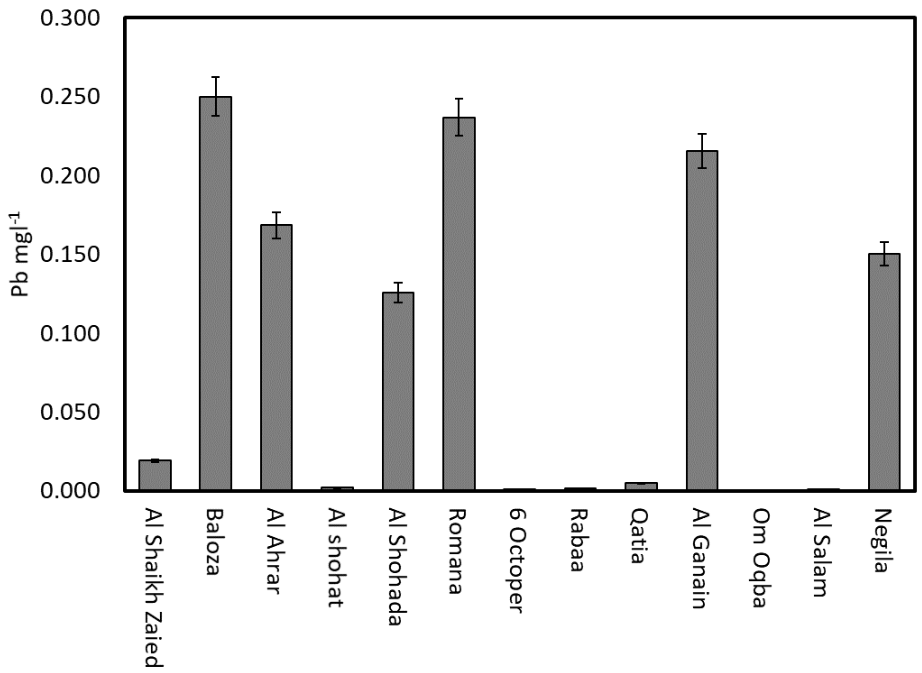

Fig. 9. Lead concentration in all tested samples from the studied locations. Locations were directionally arranged from the west to the east. Error bars represents the standard error of all samples within each collecting site

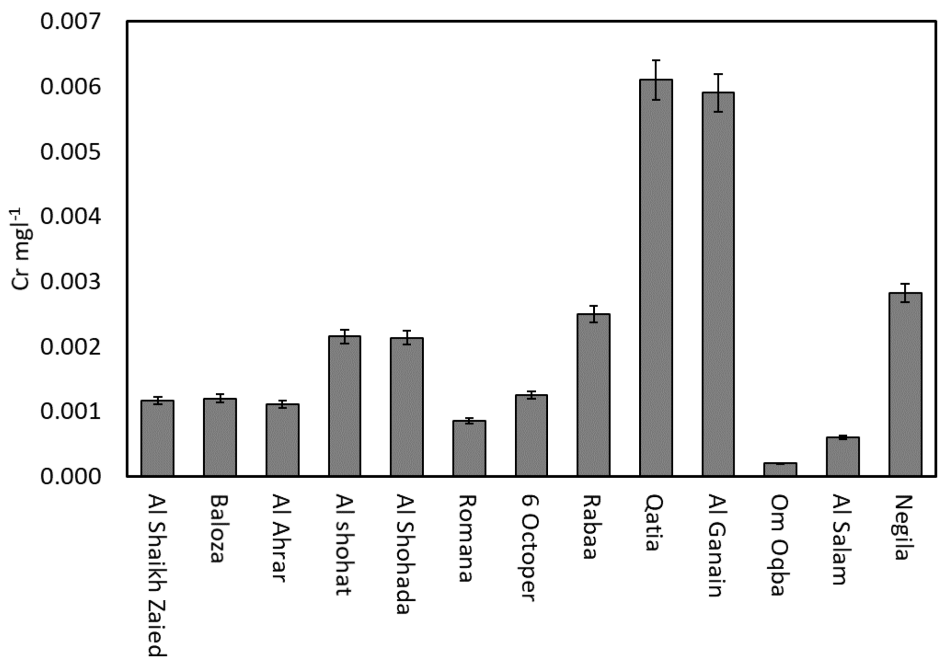

Fig. 10. Chromium concentration in all tested samples from the studied locations. Locations were directionally arranged from the west to the east. Error bars represents the standard error of all samples within each collecting site

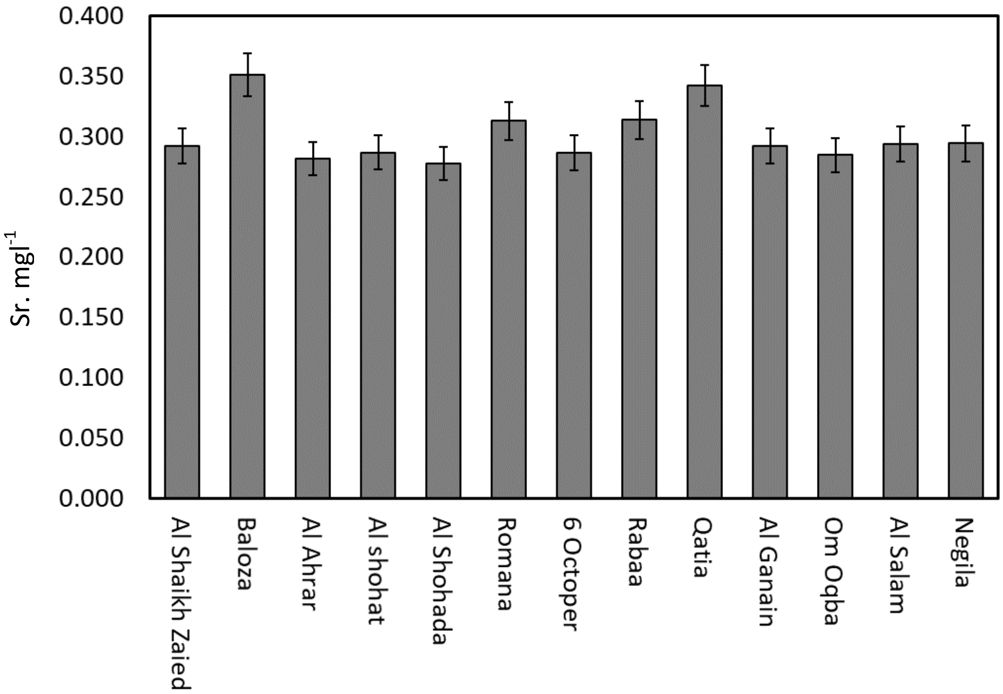

Fig. 11. Strontium concentration in all tested samples from the studied locations. Locations were directionally arranged from the west to the east. Error bars represents the standard error of all samples within each collecting site

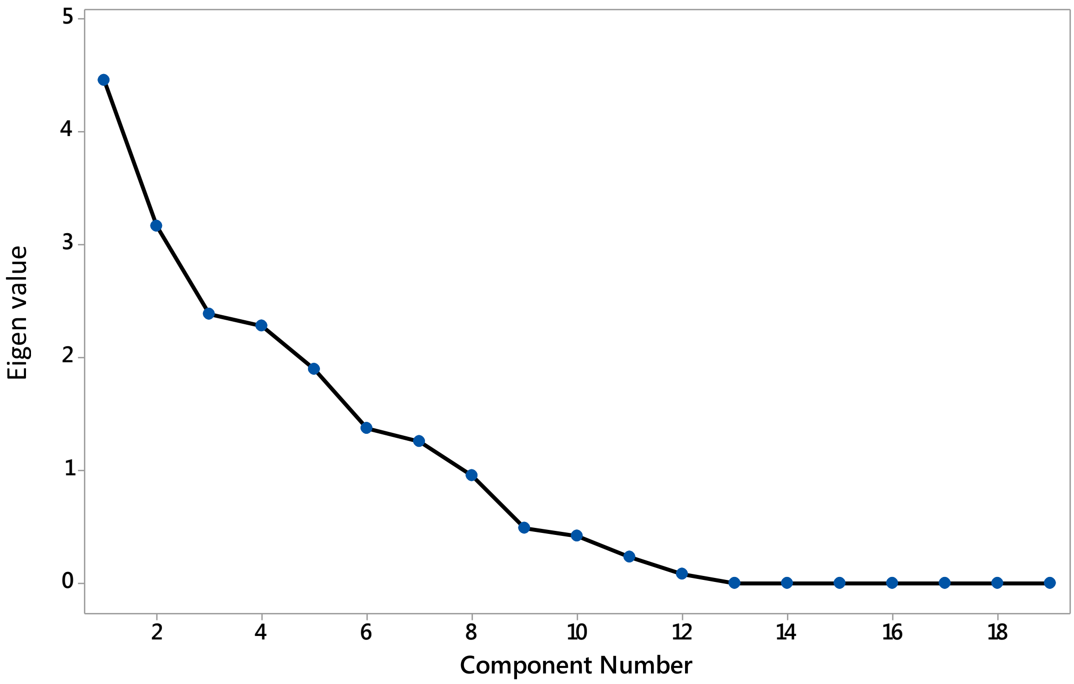

Fig. 12. Principal component analysis scree plot for elemental analysis (mg L^{-1}) of water samples from El-Arish region (n = 19)

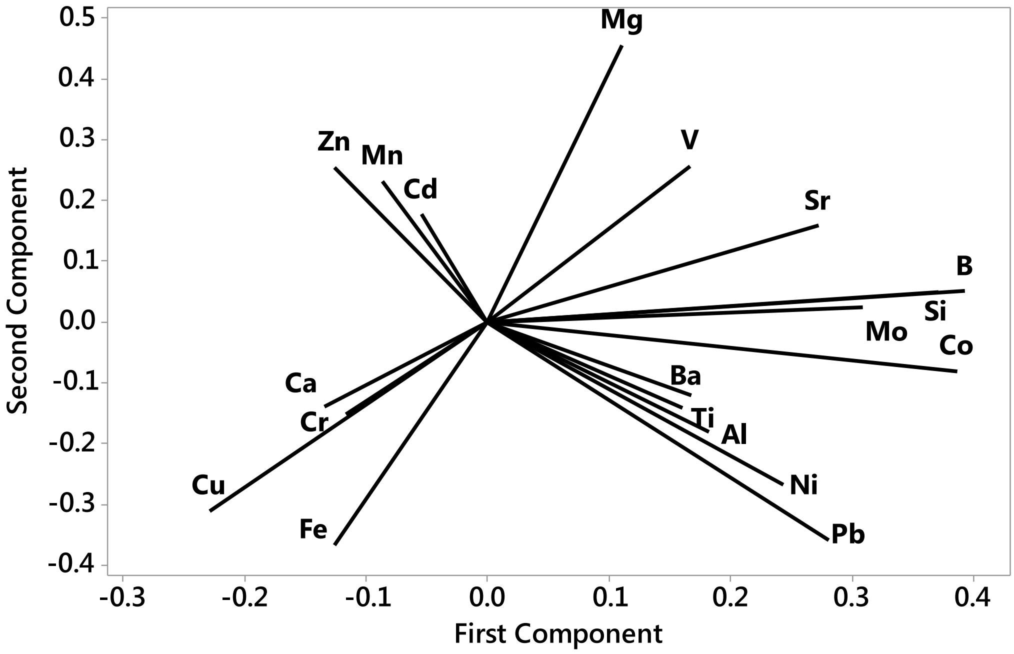

Fig. 13. Principal component analysis loading plots for elemental analysis (mg l^{-1}) of water samples from El-Arish region (n = 19)

Al, Ti and Ba concentrations, Fig. 13) and an association with key trace metals (Co, Si, Mo and B) **(Pant *et al.*, 2020**). In PC2, specific mineral association metals (Cr, Cu, Fe, and Ca) appear to be associated with negative values of PC2, which probably indicates the presence of suspended mineral particulates in water (as they all mineralogy associated) **(Santana *et al.*, 2020**). This may suggest that suspended mineral particulate govern the source of measured elements in drinking water. It seems also that suspended oxide of Mn has effect in adsorbing Cd and Zn in the second components (Fig. 13) **(Ji *et al.*, 2016**).

Cluster analysis

To examine the strength of multiple elemental associations from the raw dataset, cluster analysis was undertaken. Figure 14 shows a dendrogram illustrating possible associations within which it is possible to visually identify several clusters. Cluster (i) (Al, Ti) could (probably) be indicative of mineral deposit with anthropogenic intrusion. Cluster (ii) (Ba, Ni, Si, Co and Pb) suggests an association with Si minerals **(Dar *et al.*, 2017**). Cluster (iii) (B, Sr, Mo and V) could be anthropogenic sources intrusion from seawater **(Mora *et al.*, 2020**). Cluster (iv) (Ca, Cu, Cr and Fe) and (Mg and Mn) strongly suggests a link through oxide mineralogy (Fe and Mn oxides) associated with adsorption/substitution Ca as ($CaCO_3$) or apatites (Ca (PO_4) CO_3) **(AbdElHamed *et al.*, 2015**); for example, possible co-association of Cd^{2+} with suspended calcareous minerals may also occur. Cluster (v) (Cd and Zn) possibly partly as natural sources as both metals found together in nature.

Water Quality Index (WQI)

Results of water quality index have been depicted in Table 4. In this assessment, we excluded Cd concentration as it initially made all water unsuitable for drink. So, we suggest to deeply investigate the existence

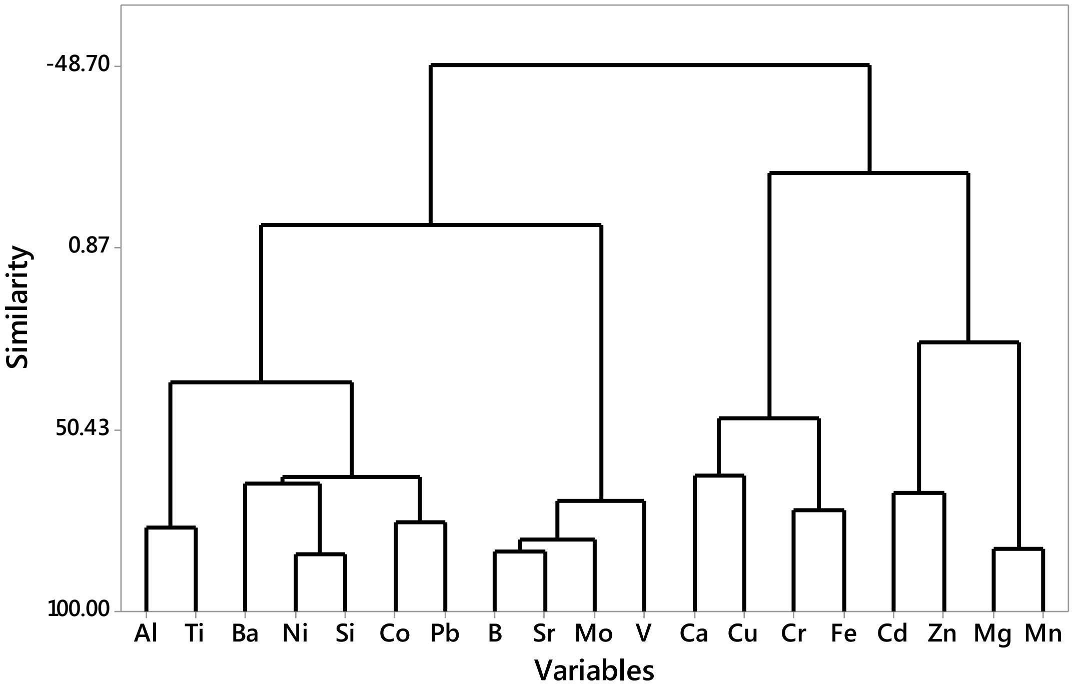

Fig. 14. Dendrogram of elemental analysis on water from El-Arish region (n = 247)

Table 4. Computed water quality values for sample sites

Village name	WQI value	Water quality classification based on computed WQI values in sample sites <50 = excellent; 50–100 = good water; 101–200 = poor water; 201–300 = very poor water, >300 = water unsuitable for drinking
Al Shaikh Zaied	34.2	Excellent water
Baloza	6.93	Excellent water
Al Ahrar	1.99	Excellent water
Al Shohat	2.82	Excellent water
Al Shohada	24.3	Excellent water
Romana	6.36	Excellent water
6 October	2.25	Excellent water
AlKarama(Al Ganain)	1.24	Excellent water
Rabaa	5.80	Excellent water
Qatia	57.5	Good water
Om Oqba	1.39	Excellent water
Al Salam	1.70	Excellent water
Negila	10.1	Excellent water

of Cd in drinking water in Romana Region. It was noted that drinking water obtained from all village intake registered excellent water degree (WQI = less than 50) indicating that the water was most suitable for direct human consumption without treatment but the water samples that were taken from Qatia (WQI= 57.5) recorded good water degree as the least water quality. Generally, the Water quality index showed that water in almost all study areas was classified as an excellent water for drinking.

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الملخص العربي

الملوثات البيولوجية والكيميائية لمياه الشرب: دراسة حالة للمناطق الريفية في شمال غرب سيناء، مصر

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أجريت هذه الدراسة في المناطق الريفية بمنطقة رمانة، شمال غرب سيناء، مصر، لتقييم الجودة البيولوجية والكيميائية لمياه الشرب. تم جمع ثمانون عينة من المياه من 13 موقعاً ريفياً وخضعت تلك العينات لتحليل الخصائص البيولوجية والكيميائية المختلفة بمياه الشرب محل الدراسة. أظهرت النتائج أن البكتيريا القولونية لم تظهر آثارا سلبية بما ينعكس على ان المياه نظيفة من التلوث البكتيري في جميع العينات المدروسة على الرغم من أن قرية الكرامة السلام أظهرتا كميات عالية من عدد البكتيريا الكلى. وأظهرت قيم درجة الحموضة في الماء والتوصيل الكهربى والمواد العضوية الذائبة ملائمة مياه الشرب للاستخدام البشري وفقا للحدود المسموح بها المنشورة. وكانت جميع عينات المياه في المنطقة الآمنة وفقا لحدود منظمة الصحة العالمية مع بعض الاستثناءات، من حيث محتويات المعادن الثقيلة. الكادميوم في جميع العينات، الرصاص فيما يقرب من 54% من العينات تجاوزت حدود مياه الشرب لمنظمة الصحة العالمية. وأظهر مؤشر جودة المياه أن جميع مياه الشرب ممتازة للاستخدام البشري باستثناء العينات المأخوذة من قرية قاطية حيث كانت أقل جودة بدرجة كبيرة. وأكد الباحثين أن الكادميوم استبعد من تقييم مؤشر جودة المياه لأنه يحتاج إلى مزيد من العمل البحثي لتأكيد تركيزه العالي في عينات مياه الشرب.

الكلمات الاسترشادية: مياه الشرب، تقييم المخاطر، المعادن الثقيلة، البكتيريا، التلوث.

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