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ASSESSMENT OF GROUNDWATER QUALITY USING RS AND GIS TECHNIQUES BASED ON MICROBIOLOGICAL AND CHEMICAL MEASUREMENTS IN EL-ARISH AREA, NORTH SINAI, EGYPT

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ABSTRACT

Groundwater quality evaluation in developing countries has become a critical issue due to fresh water scarcity. Groundwater is a valuable resource in Egypt, including Sinai, and it is a vital source for drinking water. It is necessary to consider the effects of land use change on groundwater resources when making land use decisions. Landsat-8 was used to generate land use/land cover map using ENVI 5.1 program using 20 well water samples collected from El-Arish area, North Sinai. Four classes were identified: barren land, vegetation, sand dunes and built up area. A GIS-based model was developed to assess groundwater contamination in the study area and its hazard on health and irrigation. A spatial prediction maps showing the potential hazard areas and area at risk due to contaminations was developed using kriging method on Arc GIS 10.2 program. The results show that some of wells were at risk and contaminated with *E. coli* and heavy metals. In microbiological examinations (*E. coli* examination as indicator on coliform contamination) well number 3 and 13 recorded high contamination, Well No. 1, 7 and 12 recorded moderate, two wells (9 and 16) have low contamination, while the rest wells have no *E. coli* detection. Moreover, the result were compared with World Health Organization and Food and Agriculture Organization standards; Pb, U, Mn and Cr were above the WHO limits for drinking, Se was above FAO limits for irrigation purposes. Therefore, more precaution should be considered in order to use this particular water in specified area for both drinking and irrigation purposes.

Key words: Groundwater, *E. coli*, Heavy metals, RS, GIS, Kriging.

INTRODUCTION

Groundwater is an important source of water in North Sinai. It is used in domestic, agricultural, and industrial purposes, so a potential hazards obtained from various natural and anthropogenic contaminations should be considered. Moreover, currently, most countries in the world suffer from severe water shortages, especially arid and semi-arid areas so they resorted to alternative sources of water such as groundwater **(Abou Rayan *et al.,* 2000; Allam and Allam, 2007)**. This because groundwater contamination is a major national-wide socioeconomic problem now **(Arnous and El-Rayes, 2012)**. As a result of rapid urbanization and raising industrial, agricultural activities as well as global climate changes, underground water are

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facing many challenges, the most important being the increase of man-made contamination **(Kondratyev *et al.,* 1998; He *et al.,* 2008)**. Giving the planning authorities guidelines is an important milestone on the way to sustainable planning and conservation the non-contaminated groundwater for a longer period **(El Alfy, 2012)**. Therefore, the monitoring of water quality for both drinking and irrigation purposes is a very necessary task for each country to supply sufficient data for water quality to local authority and the relevant researchers for further use and decision making **(Chen *et al.,* 2007).** The traditional approaches for observing water quality are usually unreliable due to the lake of sample numbers, labor work intense, time consuming and the disability to provide a general image for the water status particularly in developing countries such as Egypt. Remote sensing (RS) satellite data inputs have been playing a key role in the management of natural resources along with geographic information system (GIS) over the past two decades and therefore they may offer an appropriate method to integrate biological and chemical data analyses of underground water collected from limited conventional in situ **(Wu *et al.,* 2009).** Remotely sensed data provide valuable and near real-time spatial information on natural resources and physical terrain parameters. Moreover, GIS is a computer-based system design tool applied to geographical data for integrating, collecting, storing, retrieving, transforming, and displaying spatial data for the planning and management of natural resources. GIS and remote sensing derived information can be well integrated into the conventional database for assessing the actual groundwater contamination scenario and contamination vulnerability **(Arnous and El-Rayes, 2012)**. Therefore, the general objective of this study is to provide current baseline groundwater quality data throughout El-Arish area based on microbiological and chemical analyses to address the potential contamination sources. To achieve this goal, 20 well water samples were carefully selected to represent different land use/cover forms to: (i) determine the status of well water (chemical and biological analyses) contaminations, (ii) evaluate its suitability for drinking and irrigation, and (iii) assess the current land use/land cover situation.

MATERIALS AND METHODS

2.1. Sampling and site descriptions

Twenty well water samples were collected on October 2013 from different locations in El-Arish area according to the surrounded land uses (Fig.1). The study area (75.4 km^2) is located at El-Arish area, North Sinai, Egypt (Fig.1). The area locates within 31° 02′ 11.6″ and 31° 10′ - 18.5″ longitudes 33° 44′ 16.7″ and 33° 53′ 24.1″ latitudes, respectively. Two samples were collected in separate sterilized dark color bottles (200 ml). Different sampling procedures were employed for different types of water analysis (chemical and biological analysis) and all the precautions were occupied. The two well water samples were collected from each well as following: (i) the first one, the bottle was filled with unfiltered non acidified water for microbial analyses and collected in ice box then kept in cold (4°C) to be analyzed within 24 hrs. from the collection time (ii) the second 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 heavy metals (loids) in the solution phase for multi-elements analysis. After transportation to laboratory the acidified samples were sent directly for multi-elements analyses.

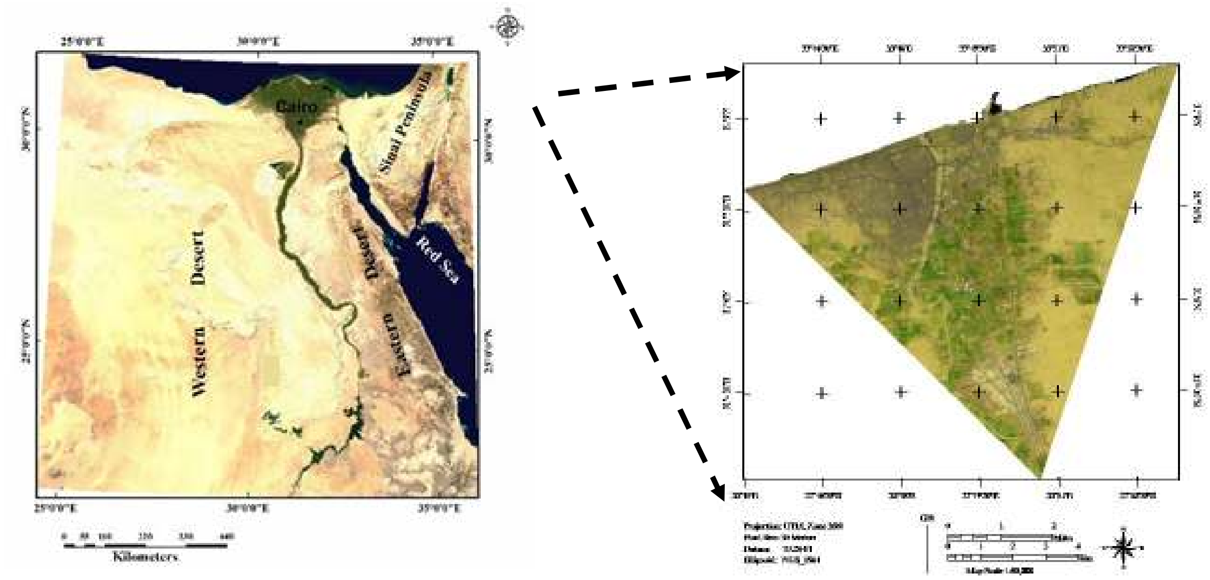

Figure (1): Location map of the study area, El-Arish city, North SINAI.

2.2. Microbiological analyses

The microbiological analyses were carried out according to standard method **(APHA, 1995)**. The analysis of water for the presence of E.coli bacteria was carried out in three steps: (i) The Presumptive Test (using the multiple-tube fermentation technique method and lactose broth media); (ii) The Confirmed Test (using sterile glass petri dishes containing 15 ml medium of EMB 'Eosin Methylene Blue Agar'); and (iii) The Completed Test (using EMP and Endo Agar, inoculated petri dishes and tubes).

2.3. Chemical analyses

Multi-element analyses were undertaken by the standard Agilent triple quadrupole ICP-MS (ICP-QQQ - 8800, Tokyo, Japan) in helium gas mode to reduce polyatomic interferences as described by **Marzouk *et al.* (2013)**.

2.4. RS and GIS data analyses

Remote sensing (RS) and digital image processing techniques has been proven to be very useful tools for surveying natural resources and mapping and monitoring the environmental impacts, particularly when rapid and repetitive observations are required. The most obvious tool to correlate the spatial extent of contamination with other resources features both concisely and rapidly is the Landsat Satellite image **(Arnous and El-Rayes, 2012)**, for this study Landsat-8 was used to generate land use/land cover map using ENVI 5.1 program and classification techniques to discriminate and construct various land use/land cover classes. Geographic Information System (GIS) is a system that deals with information related to spatial distribution of features on the earth’s surface and is designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information **(Omran, 2012a)**. A GIS-based model was developed to assess groundwater contamination in the study area and its hazard on health and irrigation. A spatial prediction map showing the potential hazard areas and area at risk due to contaminations was developed using kriging method on Arc GIS 10.2 program, Ordinary Kriging (OK) provides the `best' optimal and unbiased linear technique for estimation of unknown values from sample data. The estimate is obtained by weighting each of several sample data that are proximate to the estimate. OK has played a major role in predicting the variable and maps of properties **(Lopez-Granados *et al.*, 2005)**.

2.5. Statistical analyses

Geostatistical analysis such as principal component analysis or factor analysis and cluster analyses of the multivariable are carried out based on the data matrix of the chemical parameters of groundwater in order to differentiate between the different types of contamination and confirm the hydrogeochemical database layers which are integrated in the GIS using Minitab 7 and SPSS software.

RESULTS AND DISCUSSION

3.1. Land use pattern and urbanization

Land use activities have direct impacts on water quality, while water quality greatly influences the siting of land use activities. Inappropriate land use, particularly poor land management, causes chronic groundwater quality problems. Acute groundwater quality problems are common and arise from unsuitable land use **(Lerner and Harris, 2009)**. Different types of land-uses are recognized within the study area. The northern part is represented by El-Arish city (urban built-up and rural areas), while the central and southern parts are prevailed by agricultural development **(Gehad, 2003)**. The land use/land cover map for the study area was generated using ENVI 5.1 program. For data processing, analyzing and classification neural network and maximum likelihood methods have a good result on out coming maps. The overall accuracy and Kappa coefficient of these methods are quite higher than the other algorithms such as minimum distance and parallelepiped classifiers, Table (1) show the accuracy of different classification methods and algorithms.

Omran (2012b) have emphasized on the priority of maximum likelihood algorithm in compared to minimum distance and parallelepiped classifiers. For the 2014 dated image, overall classification accuracy for the land use classes was established as 95.80% and the Kappa coefficient was computed as 0.9324. The first result of the accuracy assessment was an overall accuracy of 75% with Kappa Coefficient = 0.71. That is way below the “85%" cutoff level between acceptable and unacceptable result, users’ accuracies were good (above 85%). After spatial reclassification and accuracy assessment of the land use classification the overall accuracy improved to 96%, with Kappa coefficient of 0.93.

Our analysis in these study showed however that a map with reasonable overall accuracy produced from this image interpretation could only have about 4 classes (Fig. 2).

Groundwater quality and its suitability for irrigation and domestic purposes were evaluated by various microbial and chemical parameters. This has been done by comparing the results in the current study with different water standards, tracing the source of contaminant using statistical analysis. Different water parameters will be discussed and point out the suitability of water samples from the study area for both irrigation and drinking purposes.

3.2. Microbial well contamination

One type of microorganism, coliform bacteria, such as *E. coli*, is the primary microbiological parameter used to evaluate water quality and is considered to be a human health concern **(Tuthil *et al.*, 1998).** From all the twenty wells tested for E.coli presence, well number (3, 13, Fig 3) recorded high contamination, well No. (1, 7, 12) recorded moderate, two wells (9, 16) have low contamination, while the rest wells have no E.coli detection (Fig. 3).

Table (1): Accuracy of different classification methods and algorithms

Classification Methods	Overall Accuracy, %	Kappa Coefficient, %
Parallelepiped	80.41	65.43
Minimum Distance	73.12	61.00
Maximum Likelihood	95.80	93.24
Mahal distance	87.98	81.08
Neural Network	95.31	92.38

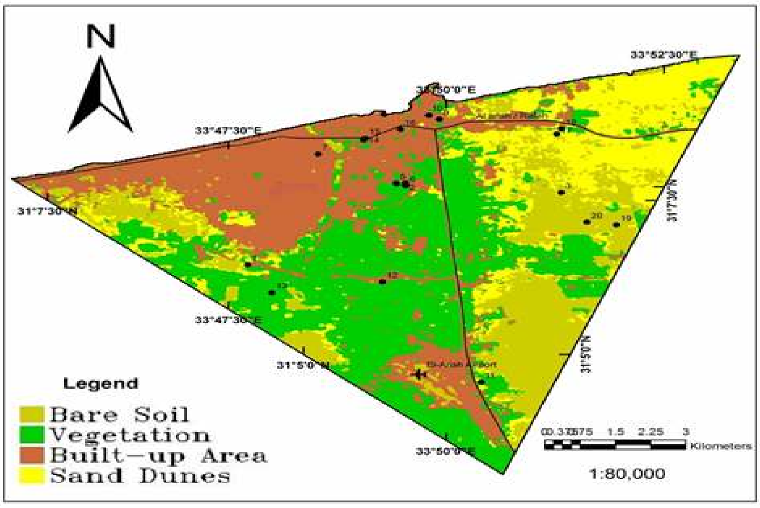

Figure (2): Final land use map of El-Arish study area, North Sinai; dote symbols represent the sampling sites and numbers.

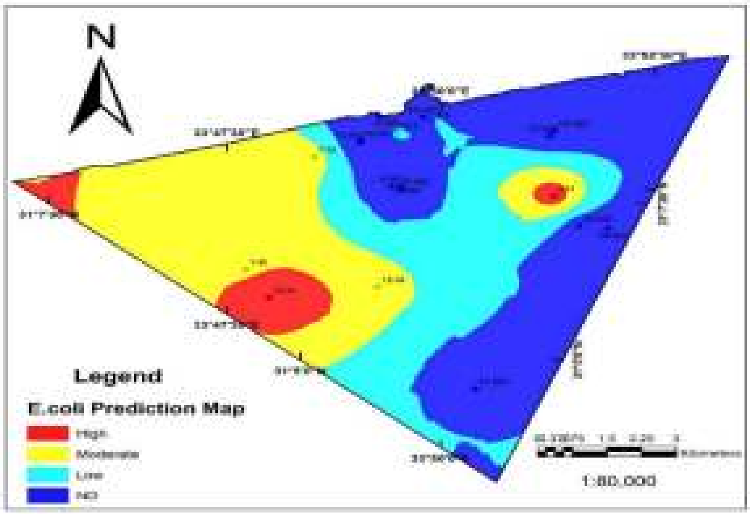

Figure (3): *E. coli* hazard map in the El-Arish study area, North Sinai.

3.3. Multi-element analyses

Groundwater is considered as a vital substance in the environment **(Shah *et al.*, 2012)**, and its contamination with heavy metals such as cadmium, chromium, copper, manganese, nickel, lead and zinc is a worldwide environmental problem **(Muhammad *et al.*, 2011)**. Generally, heavy metals are released from different natural (*i.e.,* weathering, erosion of bed rocks, ore deposits and volcanic activities) and anthropogenic (*i.e.,* mining, smelting, industrial influx and agricultural activities) sources **(Ettler *et al.*, 2012; Krishna *et al.*, 2009; Khan *et al.*, 2008)**.

Sixteen elements were analyzed from which, in average, 21% of the wells exceeded drinking water standard for Pb, Mn, Cr and U **(WHO, 2011)** while only 45 % of the wells exceeded irrigation standard for Se **(FAO, 1994)**. The rest of elements were either below or in the margin line of the WHO and FAO standards. (Fig. 4) shows Pb concentration with permissible limits for irrigation and drinking water.

Lead (Pb)

Lead concentrations, in all water samples, ranged from 0.0301 to 0.0078 mg l^{-1} with an average of 0.014 ± 0.0068 mg Pb l^{-1} (± Standard deviation, SD). The maximum Pb concentration was observed in W9 which shows about two folds the permissible limits for WHO while lowest value was observed in W14 (about half the permissible limits of WHO).Obtained data clear that about 25% of tested samples were higher than the WHO standard, (Fig. 4). Figures 5 and 6 show the spatial distribution of Pb and area at risk in study area. Well No. 9, which shows the highest Pb concentration, is very close to El-Arish trade harbor and the surrounding area is affected by fuel residual discharged from trade ships, it has been reported that petrol (fuel) is enriched with Pb to increase engine efficiency **(WHO, 2011)**. Moreover, high Pb levels may be related to the use of lead solder used in older piping systems near to the harbor. In addition, the second last high Pb concentration was determined in W8 by which anthropogenic source is expected due to military activates in Egyptian Navy camp exists in this site. Both wells are used for domestic and drinking purpose suggesting that it may pose a significant risk to the well consumers.

Uranium (U)

Uranium was detected at levels over the WHO standard limit of 0.02 mg l^{-1} in 3 wells (W16, 3 and 15; as shown in Fig. 7). Figures 8 and 9 show the spatial distribution of U and area at risk in study area. Uranium is present in the environment as a result of leaching from natural deposits, release from mine tailings, emissions from the nuclear industry, the combustion of coal and other fuels and the use of phosphate fertilizers that contain the metal **(WHO, 2004)**. There is insufficient scientific information about the possible carcinogenicity of uranium in humans or experimental animals. Usually, nephritis is the primary chemically induced effect of uranium in humans **(WHO, 2004)**. Phosphate fertilizers is more likely the main source of U in the studied two wells, No. 3 and No. 13 were used for irrigation purposes while well No. 16 was close to El-Salam Suburb Wastewater Plant (Fig. 2).

Selenium (Se)

Selenium is one of the most widely distributed elements of the Earth's crust (**Mateja *et al.*, 2007**). Much of it occurs associated with sulphide minerals **(Shamberger, 1981; Shardendu *et al.*, 2003)**. The widespread occurrence of Se in waters results from a variety of both natural and anthropogenic sources. Selenium accumulation in soils and waters is associated with agricultural irrigation, geochemical processes, mining, and a variety of other industrial sources

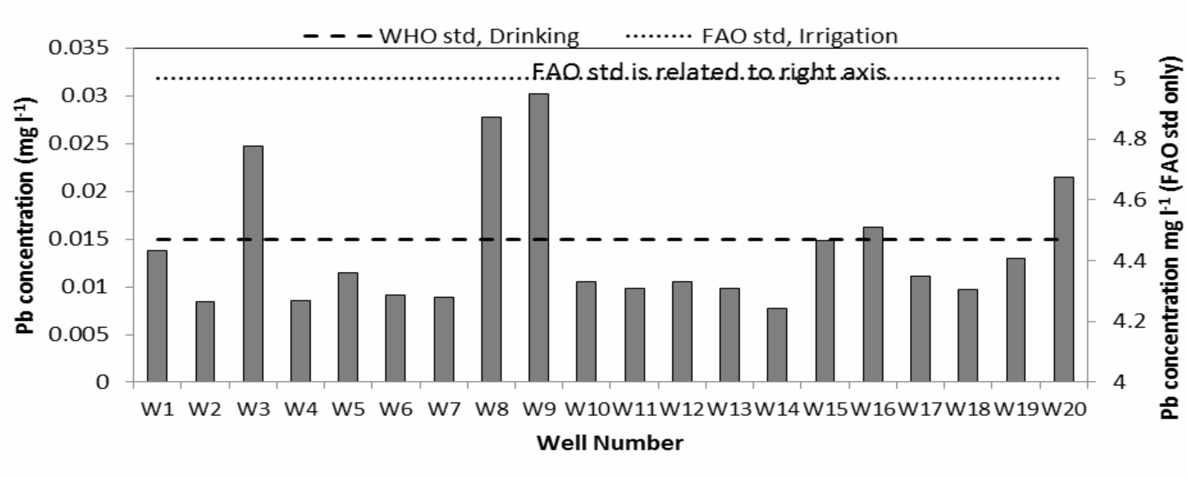

Figure (4): Lead (Pb) concentrations (mg l^{-1}) of all studied samples (n = 20). The fine and course broken lines represent the permissible limits established by the FAO (FAO, 1994; FAO std, Irrigation) and the WHO (WHO, 2011; WHO std, Drinking), respectively.

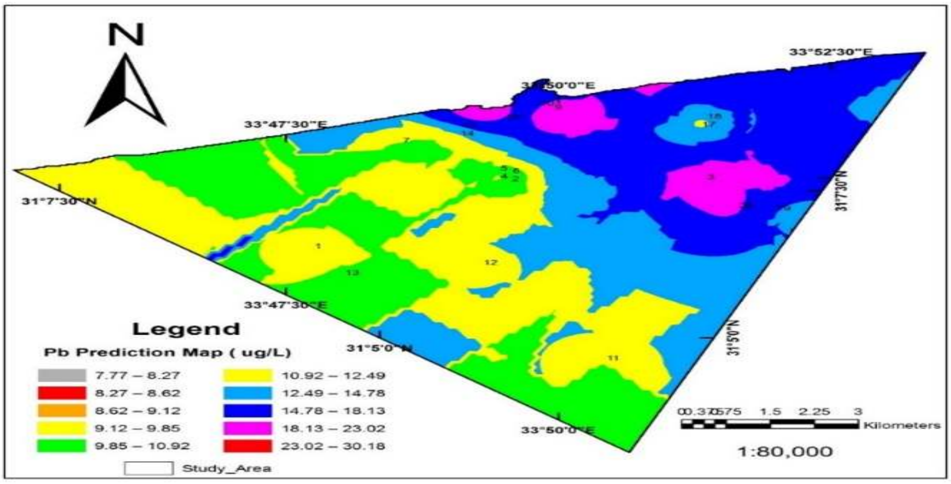

Figure (5): The spatial distribution of Pb in El-Arish study area, North Sinai.

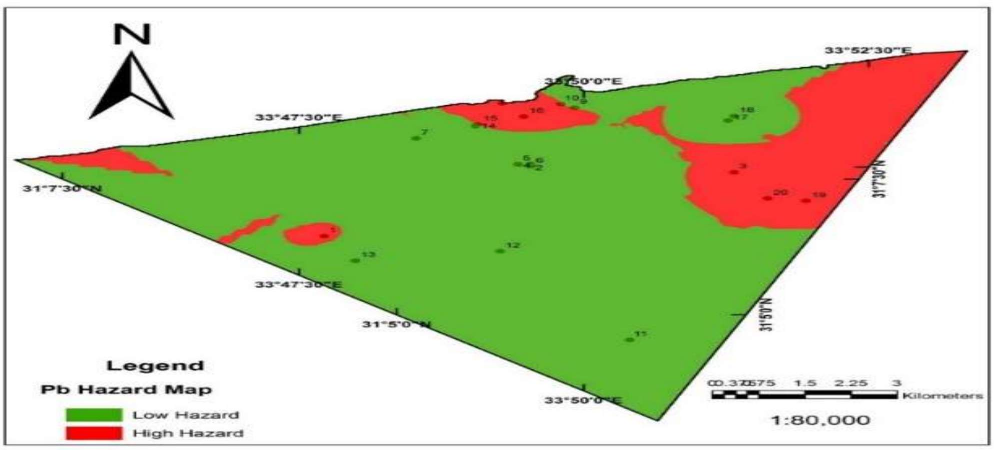

Figure (6): The Pb hazard for drinking in El-Arish study area according WHO std.

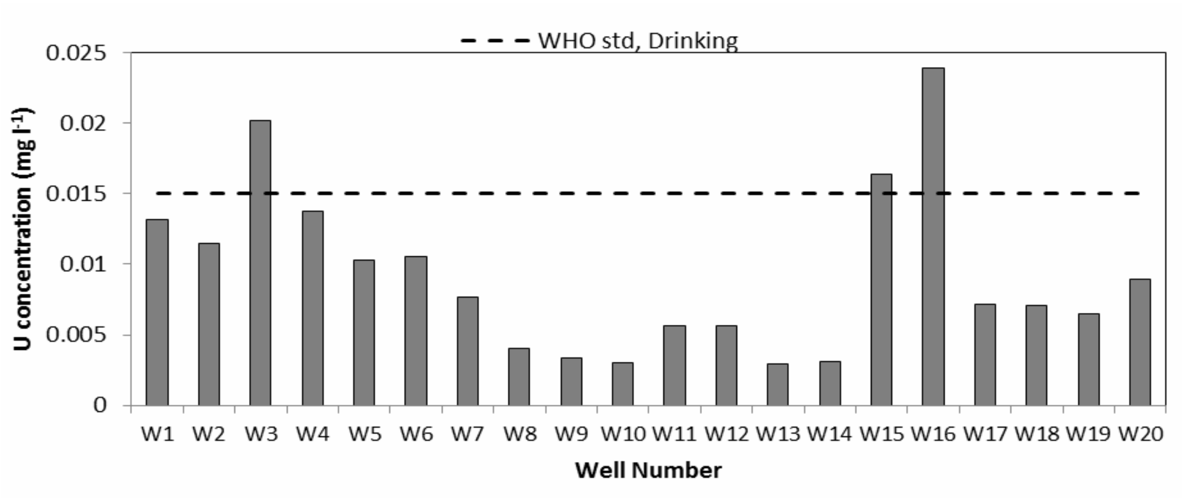

Figure (7): Uranium (U) concentrations (mg l^{-1}) of all studied samples (n = 20). The broken lines represent the permissible limits established by the WHO (WHO, 2011; WHO std, Drinking).

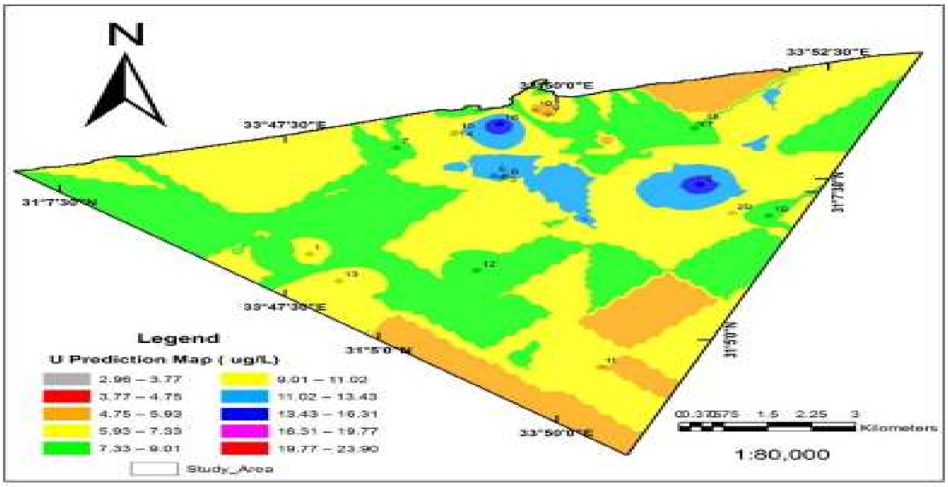

Figure (8): The spatial distribution of U in El-Arish study area, North Sinai.

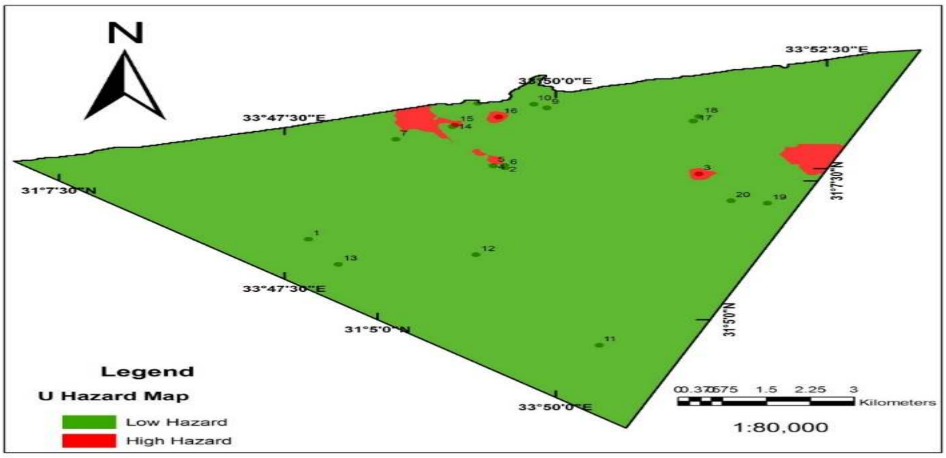

Figure (9): The U hazard for drinking in El-Arish study area according WHO std.

(Shardendu *et al.,* 2003). Cultivation of plants enriched with Se could be an effective way of producing Se-rich food stuffs, with benefits to health **(Ip and Lisk 1994; Lyons *et al.,* 2005)**. Environmental toxicity of Se in animals and humans is rare. However, about 45%, (Fig. 10) of tested well waters in the current study were above the FAO standard for water irrigation. Figures 11 and 12 show the spatial distribution of Se and area at risk in study area. The highest Se value was observed in the water of Well No. 2 which is a governmental well located in residential area (Atef El-Sadat suburb). Selenium concentration is the only element that pose a significant risk to the grown plant according to the FAO standard. The essentiality of Se to plants remains unclear, even though there is some evidence for its positive effect on many plant processes. On the other hand, Se is toxic to plants and other biota when it is present at high concentrations. Further research is needed to establish the essentiality of Se for higher plants **(Germ *et al.,* 2007)**.

Chromium (Cr)

Chromium has been found in several groundwater locations due to industrial discharge from leather tanning **(Shakir *et al.,* 2012; Daud *et al.,* 2014)** along with other anthropogenic activities such as mining and electroplating, etc… **(Oliveira, 2012; Yadav and Singh, 2013)**. Chromium also increased in areas which exposed to high human activities such as waste disposal **(El-Alfy, 2010)**. In the current study, Cr concentration ranged from 0.059 to 2.05 mg Cr l^{-1} with an average value of 0.036 ± 0.027 mg Cr l^{-1}. About 25%, (Fig. 13) of the tested well waters were above the WHO standard; inculding well No. 6, 17, 18, 19, 20. Only well No. 6 was using for domastic and drinking purposes which can cause many harmful diseases in humans **(Iyer and Mastorakis, 2010)**.

Manganese (Mn)

Manganese, (Fig. 14) exceeded the WHO standard in 6 wells (30% of the total studied wells). The highest level of Mn was detected in a well No. 13 (0.13 mgl^{-1}). The concentration of Mn in fresh water typically ranges from 0.001 to 0.2 mgl^{-1} **(WHO, 2011)**. In addition, levels as high as 10 mgl^{-1} have been reported in acidic groundwater **(WHO, 2004)**. Epidemiological studies have reported adverse neurological effects following extended exposures to very high levels of Mn in drinking water **(WHO, 2004)**.

3.4. Cluster analysis

To examine the strength of multiple elemental associations from the raw dataset for the sixteen measured elements, cluster analysis was undertaken. (Fig. 15) shows a dendrogram illustrating possible associations within which it is possible to visually identify several clusters. Cluster (i) (B, Na, Cr and Cu) could (probably) be indicative of seawater intrusion. Cluster (ii) (Ca, Sr, Se and U) suggests an association with suspended calcareous minerals ($CaCO_3$) or apatites (Ca (PO_4)CO_3); for example, possible co-association of Sr^{2+} and $U^{VI}O_2^{2+}$ with suspended calcareous minerals may also occur. Cluster (iii) (Mg, Ni and Pb) could be anthropogenic sources. Cluster (iv) (Mn, As and Fe) strongly suggests a link through oxide mineralogy (Fe and Mn) associated with adsorption/substitution of As. Cluster (v) (Zn and Cd) Strong geochemical association (Cd occurs as a guest element in Zn sulphides, **Marzouk *et al.,* 2013**); possibly partly an anthropogenic source.

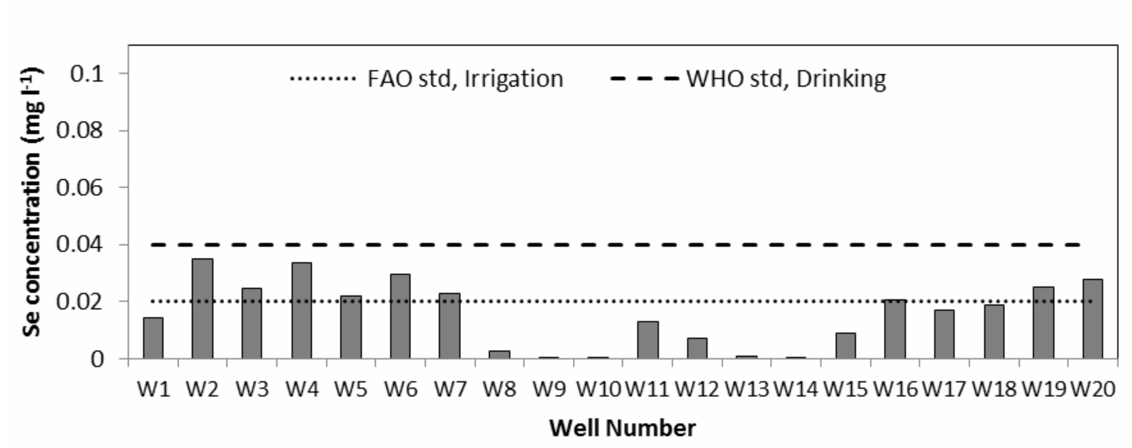

Figure (10): Selenium (Se) concentrations (mg l^{-1}) of all studied samples (n = 20). The fine and course broken lines represent the permissible limits established by the FAO (FAO, 1994; FAO std, Irrigation) and the WHO (WHO, 2011; WHO std, Drinking), respectively.

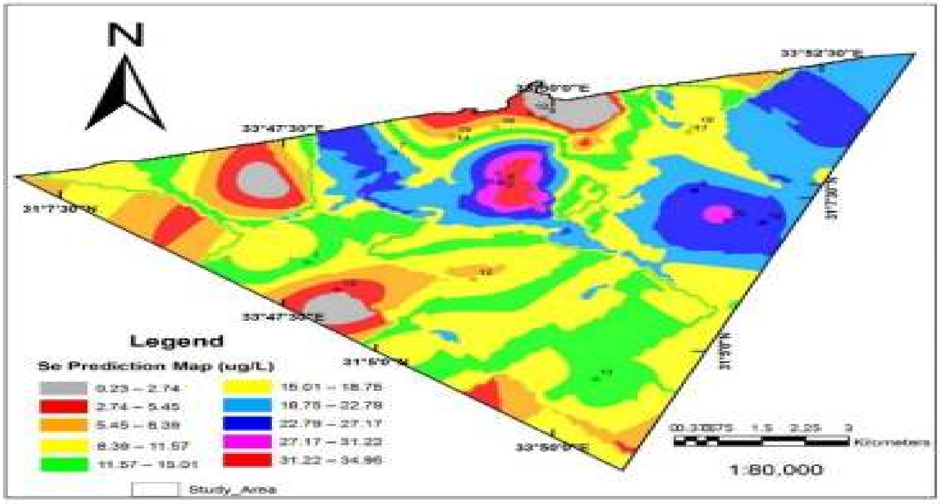

Figure (11): The spatial distribution of Se in El-Arish study area, North Sinai.

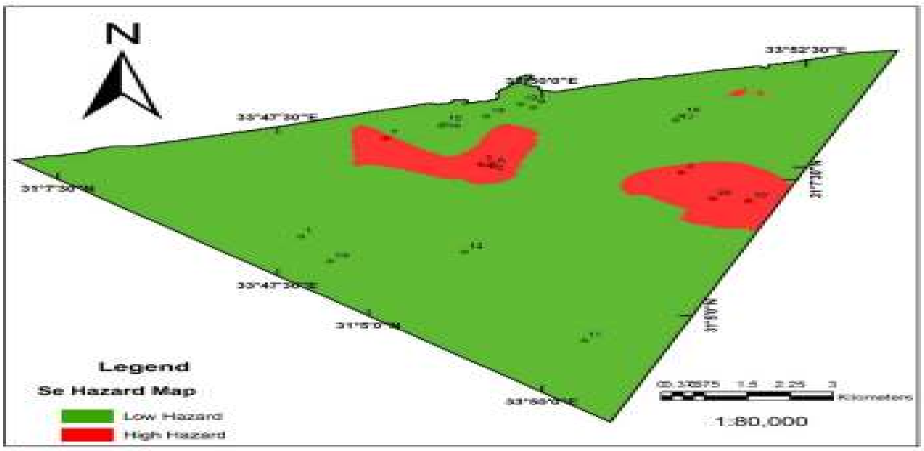

Figure (12): The Se hazard for irrigation in El-Arish study area according FAO.

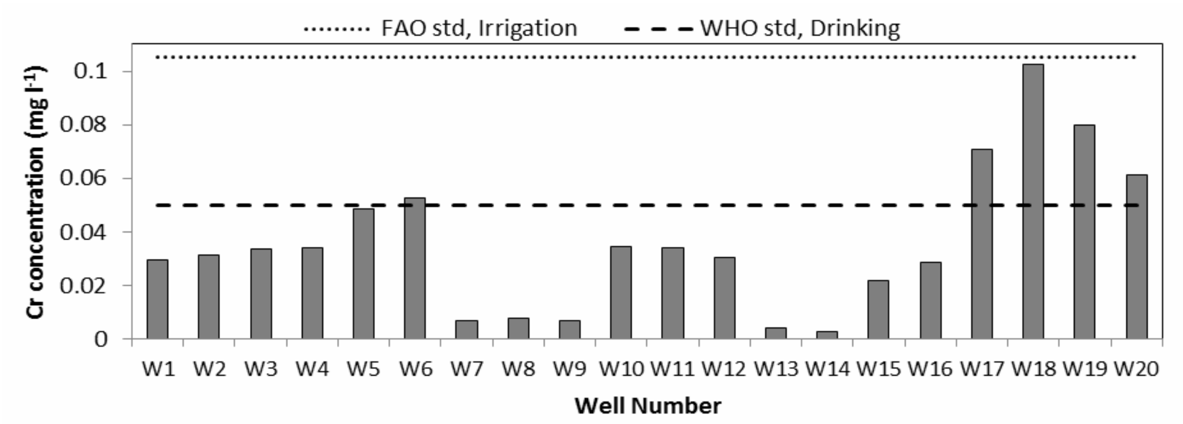

Figure (13): Chromium (Cr) concentrations (mg l^{-1}) of all studied samples (n = 20). The fine and course broken lines represent the permissible limits established by the FAO (FAO, 1994; FAO std, Irrigation) and the WHO (WHO, 2011; WHO std, Drinking), respectively.

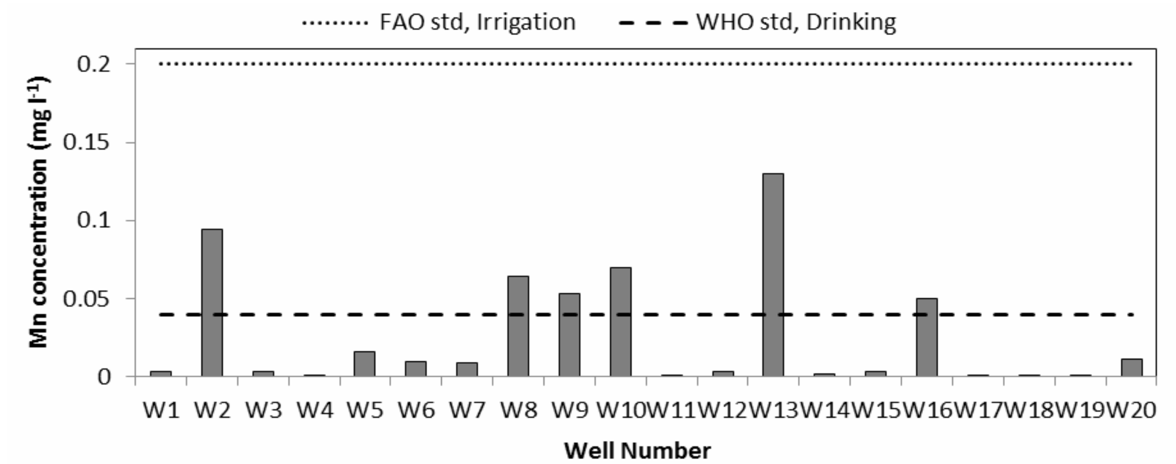

Figure (14): Manganese (Mn) concentrations (mg l^{-1}) of all studied samples (n = 20). The fine and course broken lines represent the permissible limits established by the FAO (FAO, 1994; FAO std, Irrigation) and the WHO (WHO, 2011; WHO std, Drinking), respectively.

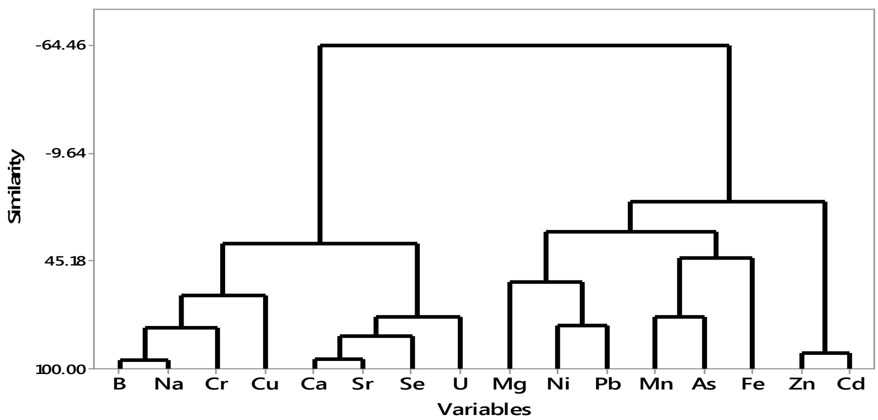

Figure (15): Dendrogram of elemental analysis on water from El-Arish region (n = 20).

Conclusion

Twenty water samples were collected from different water wells located in El-Arish area according to the surrounded land uses, on October 2013. The obtained results can be summarized as follows: Land use/land cover map for the study area shows four classes; barren land, vegetation, sand dunes and built up area. E.coli bacteria has been measured as an indicator of contamination where it showed that from all the twenty wells tested, two wells (well 3 and 13), recorded high degree of contamination. The results also showed that Pb concentrations, in all water samples, the maximum Pb concentration was observed in W9 which is very close to El-Arish trade harbor, while the minimum Pb concentration was observed in W14. Note also the high concentration of U was observed in W16. For Cr concentrations in well water samples, About 25% of the tested well waters were above the WHO standard. Also the highest level of Mn was detected in a well No. 13. The results show that a high concentration of Se in most the samples exceeded the permissible limits for irrigation according to FAO standards for irrigation water. The multivariate analyses including cluster one show variation between natural and anthropogenic sources of contaminates. Moreover, the final maps, used as a visual illustration, showed the spatial distribution of irrigation and drinking water quality in the studied area, it is now much easier for a decision maker to assess the water quality for irrigation and drinking to locate the most suitable site for drilling wells. The present study demonstrates high efficiency for GIS to analyses complex spatial data and groundwater quality mapping.

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الملخص العربى

تقييم جودة المياة الجوفية باستخدام تقنيات نظم المعلومات الجغرافية والاستشعار من بعد بناءً على التقديرات الكيميائية والميكروبيولوجية فى منطقة العريش، شمال سيناء، مصر

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تم جمع عدد ٢٠ عينة مياه من ٢٠ بئرًا في حدود منطقة الدراسة، والنتائج التي تم الحصول عليها يمكن تلخيصها على النحو التالي:

تم التوصل إلى خريطة لأشكال استخدام الأرض الحالية وفيها تم التحقق والتعرف على وجود ٤ درجات مختلفة لاستخدام الأرض بمنطقة الدراسة وهى: أرض قاحلة، وأرض ظهر بها غطاء نباتي بأنواع مختلفة، وأرض مغطاة بالرمال وبعض الكثبان الرملية، وأرض عليها منشآت ومبانٍ. تم الكشف عن وجود بكتيريا الايكولاى كمؤشر على وجود التلوث، حيث أظهرت النتائج أن بئرين فقط (٣،١٣) سجلوا أعل معدل للتلوث بالبكتيريا. اتضح أن أعلى تركيز للرصاص فى جميع عينات المياة لوحظ فى بئر رقم ٩ والذى يقع بالقرب من ميناء العريش البحرى ، بينما لوحظ أقل تركيز له فى بئر رقم ١٤، وكذلك اتضح ارتفاع تركيزات عنصر اليورانيوم فى العينات والذى سجل أعلى تركيز له فى بئر رقم ١٦. أما عن تركيزات عنصر الكروم فوجد ان حوالى ٢٥% من عينات المياة تعدت الحدود المسموح بها لمياة الشرب، وأيضاً اتضح ان اعلى معدل لعنصر المنجنيز سجل فى بئر رقم ١٣. اتضح من النتائج ايضا أن تركيز عنصر السيلينيوم مرتفع فى معظم العينات محل الدراسة، وفى أغلبها تعدى الحدود المسموح بها للرى. التحاليل متعددة المتغيرات بما فيها التحليل العنقودى أظهرت الفرق بين مصادر التلوث الطبيعية والبشرية. علاوة على ذلك تبين الخرائط النهائية- والتى تستخدم كمثال بصرى- التوزيع المكانى لجودة مياة الشرب والرى فى المنطقة ولذلك نجد انه لمن السهل الآن لصانعى القرار تقييم جودة المياه للشرب والري؛ لتحديد الموقع الأمثل لحفر الآبار حسب الغرض من استغلالها، وتوضح الدراسة الحالية الكفاءة العالية لنظم المعلومات الجغرافية لتحليل البيانات المكانية المعقدة، وعمل خرائط جودة المياه الجوفية.

الكلمات الإسترشادية: المياة الجوفية، الايكولاى، العناصر الثقيلة، الاستشعار من بعد، نظم المعلومات الجغرافية.

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