Journal of Natural Science Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol. 3, No.13, 2013
www.iiste.org

Preliminary Assessment of Shatt Al-Arab Riverine Environment, Basra Governorate, Southern Iraq

Balsam Al-Tawash[1] Hadi Salim Al-Lafta[1*] Broder Merkel[2]
1. Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq
2. Head of Geology Department-Chair of Hydrogeology, Gustav Zeuner Str., Freiberg, Germany
[*] E-mail of the corresponding author: haoubid@yahoo.com

Abstract

Environmental investigation has been done for 16 selected sites at Basra Governorate, Southern Iraq (eight sites at Shatt Al-Arab River, four irrigation canals branching from Shatt Al-Arab, three marshlands, and Arabian Gulf). These sites represent distinct land uses: urban, agricultural, marshes, and marine. Water samples have been analyzed for major anions and cations (Na, K, Ca, Mg, Cl, F, Br, NO_3, PO_4, and SO_4) as well as for heavy metals (Li, Be, Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Cd, Pb, and U) in an effort to make a preliminary assessment for Shatt Al-Arab riverine environment (i.e. contaminants' distribution, level, and sourcing) and to examine the water suitability for drinking and irrigation purposes. Analyses revealed that Shatt Al-Arab water quality does not comply with drinking or irrigation standards. High population rate, major oil and gas production plants, power generating plants, and agricultural activities at Basra governorate indicate anthropogenic sources of some pollutants as we evidenced in this study.

Keywords: Environmental Geochemistry, Water Quality, Pollution, Irrigation, Shatt Al-Arab, Basra

1. Introduction

Rapid industrial development and population growth in the last few decades have added huge loads of pollutants to rivers (CPCB, 2004, India). Studies to evaluate the contamination in fresh water bodies are getting a worldwide attention during recent years (Iqbal et al., 2006). Human activities have increased the concentrations of nutrients and metals in many natural water systems which have raised concerns regarding human health (Pan and Brugam, 1977). Nutrients such as Na^+, k^+, Mg^{+2}, and Ca^{+2} are essential for life at certain levels, however, excessive nutrient inputs to the environment can result in many problems. Elevated nutrient inputs to the environment, for example, can cause water pollution making it unsuitable for human and livestock consumption as well as for irrigation; eutrophication of surface water and a decrease in natural diversity; and climate change by increasing greenhouse gas concentrations (e.g. N_2O emission) (Vries et al., 2000). Similarly, while they are crucial for life, heavy metals such as manganese, iron, cobalt, nickel, copper, zinc, vanadium, and molybdenum at high levels can be toxic to humans, animals, as well as plants, and their solubility in water is considered to be one of the major environmental issues (Sial et al., 2006).

In developing and arid regions (e.g. Iraq) where fresh water naturally occurs in low quantities, water scarcity can be greatly exacerbated by poor basin-wide strategic water management legislations as well as by anthropogenic activities (i.e. lack of wastewater treatment and disposal systems and taking surface and ground water faster than the environment can replenish it).

Considered the center of oil industry in Iraq, Basra Governorate, southern Iraq faces many water quantity and quality challenges. Shatt Al-Arab River which originates from the confluence of Tigris and Euphrates rivers is the prime fresh water body in the rather arid surroundings in the governorate. Shatt Al-Arab water is no longer as viable as it was once due to many reasons. First, dam projects by neighboring upstream countries and Iran's diversion of the Karun and Karkha river paths -the two rivers that feed Shatt Al-Arab- to pass through Iran have drastically reduced the flow of Shatt Al-Arab (Niqash, 2009) promoting the saline arm to extend from the Arabian Gulf up to100 km into Shatt Al-Arab during dry years and consequently resulting in high salinity levels in the river (Al-Maliky, 2012) and helping to turn a once-fertile plain into desert. Second, Tigris, Euphrates, and Shatt Al-Arab are usually receiving a huge amount of untreated wastewater from urban areas (Al-Hejuje, 1997) and agricultural runoff from orchards and the surrounding farmlands. Therefore it becomes very important to systematically study the water quality status of Shatt Al-Arab River. Specific research questions addressed here are: What are the levels of nutrients and heavy metals in Shatt Al-Arab and how are they compared to Tigris and Euphrates? Is Shatt Al-Arab water suitable for human consumption? What are the possible sources of contamination? And finally is Shatt Al-Arab River suitable for irrigation purposes?

2. Study Sites

Water samples were collected in May 2010 from 16 sites (Figure 1). Samples 1, 2, and 3 represent Basra marshes, namely Salal, Al-Nakara and Al-Twail marshland respectively. Samples 4, 5, 7, and 8 were collected from irrigation canals called Al-Habab, Abu-Mgera, Khoz, and Gekor respectively, all these irrigation canals that branch from Shatt Al-Arab pass through cultivated farmlands and carry huge amount of agricultural runoff wastes towards Shatt

Al-Arab River. Samples 6, 9, 10, 11, 12, and 13 that collected from different locations at Shatt Al-Arab are; Al-Ashar, Garma-Najebia next to Najebia power station, next to Dakeer island, before Al-Taleemy Hospital, after Al-Taleemy hospital, and Salhiya River, respectively. Sites 14, 15, and 16 are at the lower reaches of Shatt Al-Arab towards the Arabian Gulf with site 14 at the Gulf. Land use across our study sites is notably variable, however, we were able to define 4 land use types (sites 1, 2, and 3 are marshlands (MS); sites 4, 5, 7, and 8 are agricultural (AG); sites 6, 9, 10, 11, 12, 13, 15, and 16 are urban (UR); and finally site 14 is the Arabian Gulf (GU)).

3. Methods

3.1 Solute Analysis

3.1.1 Solute Chemistry Analysis

The water temperature, electrical conductivity (EC) and pH of the water samples were measured on site (except samples 14, 15, and 16). The water samples were kept in polyethylene bottles. One of them was filtered through 200 µm and acidified with suprapur HNO_3 (pH2) on site for heavy metals measurement, and the other unfiltered samples were collected in polyethylene bottles for measuring major contents of anions and cations. We labelled all bottles and stored them in refrigerator at 6° C then sent to the Hydrogeology Department Labs at TU Freiberg for analysis. Metrohm device was used to measure the major contents of anions and cations of 16 water samples. For anion measurements, anion column used of A Supp 15, 150 mm with eluent 3.0 mM caustic soda ($NaHCO_3$) and sodium carbonate (Na_2CO_3), with the flow rate 0.8 ml/min at temperature 45 ° C for cation measurements. The cation column was Metrosep Cu, 150 mm with a fluent of 2 mM nitric acid and 0.7 mM dipicolinic acid flow rate 0.9 ml/min at temperature 30° C and sample volume of 0.5 ml. We prepared standard solution by diluting of individual stock solution at 1000 mg/l with concentration ratios chosen to be similar to those in water samples. Standard solution for calibration was prepared a few minutes before use. Water samples were diluted by 1:20 except sample at site 14 which is diluted to 1:200 (Table 1). We used ICP-MS (Inductively Coupled Plasma Mass Spectrometry) to measure heavy metals in water samples. All the parts of ICP-MS were under software control, provided by the ELAN software on all perkin Elmer SCIEX ICP-MS instrument. Filtered water samples were diluted to 1:4 except sample 14 that was diluted to 1:10 for heavy metals measurement.

Analyses were performed using JMP 8.0 (SAS System) to compare solute concentrations to water quality standards. Furthermore, we compared concentrations in our study sites in order to investigate their distribution across these sites and to examine the relationship between solute concentrations and the land use of these sites.

3.1.2 Solute Statistical Analysis

We correlated solute concentrations across the study sites against chloride, a biologically inert solute commonly used as a conservative hydrologic tracer indicative of solute transport processes (Kirchner et al., 2000; Neal et al., 1988; Rascher et al., 1987; Triska et al., 1989) in order to group the solutes according to their relationship to Cl. Then, to identify the solute patterns, we performed a multivariate analysis on the solute concentrations and generated a correlation matrix of solute concentrations. The correlations were clustered using the 2-way average non-standardized clustering method (Sall et al., 2007) with a minimum distance threshold of 1.5 between clusters. Cluster analysis has proven useful in solving classification problems where the object is to sort variables into groups, or clusters such that the degree of association is strong between members of the same cluster and weak between members of different clusters (Shrestha and Kazama, 2007; Pal, 2011).

3.2 Water suitability for Irrigation Analysis

In this paper we focused on using water analyses to investigate water suitability for irrigated agriculture. Analyses included assessing: salt hazard, sodium hazard, water infiltration hazard, lime deposition hazard, chloride hazard, percent sodium hazard, and magnesium hazard.

4. Results and Discussion

Field parameters (i.e. pH, temperature (T), Oxygen (O2), Electrical Conductivity (EC), ElectroMotive Force (EMF), and EH) as well as cations and anions concentrations for our study sites are displayed in Table 1 and Table 2.

4.1 Solute Analysis

4.1.1 Solute Chemistry Analysis

a) Major Cations and Anions

- Sodium (Na^+)

Sodium concentrations in the current study range from 307.7 mg/l (site 16) to 674.3 mg/l (site 7) with an average of 429.9 mg/l (sites 14 and 15 are excluded as they have exceptionally high values, representing the Arabian Gulf and

Shatt Al-Arab towards the Arabian Gulf respectively) (Table, 2, Appendix 1-A) which are much higher than that of Tigris River (94.8 mg/l, Al-Maliki, 2005) and (122.6 mg/l, Khalaf, 2009) and slightly higher than that of Euphrates River (422 mg/l, Ahmed, 2006). Furthermore, Na^+ concentrations are higher than the maximum admissible limit in drinking water which is 200 mg/l (Ramesh and Elango, 2011).

High Na levels in Shatt al-Arab can be attributed to the sharp decrease in water inputs in the Tigris and Euphrates basins during the past years that promoted the saline arm to extend from the Arabian Gulf up to 100 km into Shatt Al-Arab during dry years (Al-Maliky, 2012). In addition, anthropogenic activities in Basra can represent an additional considerable source of Na.

- Potassium (K^+)

Our data show that K^+ level ranges from 7.5 mg/l (site 4) to 13.7 mg/l (site 7) with an average of 9.2 mg/l (sites 14 and 15 excluded) which is considerably higher than that of Tigris river (2.4 mg/l, Al-Maliki , 2005), Euphrates river (6.7 mg/l, Ahmed, 2006), and average concentration of K^+ in the surface water worldwide (2.3 mg/l, Langmuir, 1997) (Table 2, Appendix 1-A). High K^+ levels in the current study can be ascribed to the agricultural runoff especially at stations 7 and 8 (stations 7 and 8 represent irrigation canals, Table 2).

- Calcium (Ca^{2+})

The concentrations of Ca^{2+} in the current study range from 119.2 mg/l (site 16) to 174.5 mg/l (site 7) with an average of 141.0 mg/l (sites 14 and 15 excluded) which is higher than that of Tigris river (95.8 mg/l, Al-Maliki, 2005); close to that of Euphrates river (135.5 mg/l, Ahmed, 2006); higher than natural occurrence of calcium in surface water (15 mg/l, Langmuir, 1997); and higher than the Maximum Contaminant Level MCL (75 mg/l, National Primary Drinking Water Regulations [NPDWRs], 1999) (Table 2, Appendix 1-A).

- Magnesium (Mg^{2+})

Our data show that magnesium concentrations range from 55.4 mg/l (site 16) to147.2 mg/l (site 7) with an average of 102.5 mg/l (excluding sites 14 and 15) which is higher than that of Tigris river (34.2 mg/l, Al-Maliki, 2005); Euphrates river (50 mg/l, Khwedim, 2010); and higher than MCL (50 mg/l, NPDWRs, 1999) (Table 2, Appendix 1-A). High magnesium levels in our tested water samples might be due to untreated sewage water that discharged directly to the rivers (Mustafa, 2006).

- Chloride (Cl^-)

Concentration of chlorides in water samples in the current study are ranging between 434.8 mg/l (site 16) to 984.4 mg/l (site 7) with an average of 606.0 mg/l (sites 14 and 15 excluded) which is higher than that of Tigris river (110.3 mg/l, Al-Maliki, 2005); Euphrates river (180.7 mg/l, Ahmed, 2006); and MCL (250 mg/l, NPDWRs, 1999) (Table 2, Appendix 1-A).

- Sulfate (SO_4^{2-})

Concentrations of sulfate ion in the current study are ranging from 313.3 mg/l (site 16) to 779.2 mg/l (site 7) with an average of 577.2 mg/l which is higher than that of Tigris river (185.6 mg/l, Al-Maliki, 2005); Euphrates river (417.9 mg/l, Ahmed, 2006); and MCL (500 mg/l, NPDWRs, 1999) (Table 2, Appendix 1-D). Increased levels of sulfate in Basra surface water is due to increased soil salinity and the spreading of sebakha phenomena in the southern region of Iraq. High concentrations of sulfate are also attributed to the contamination by untreated industrial and domestic waste effluents in addition to the agricultural runoff from the surrounding farmland into river courses.

- Nitrate (NO_3^-)

Nitrate concentrations in the current study range 1.42 mg/l (site 2) to 4.86 mg/l (site 16) with an average of 3.21mg/l (excluding site 14 and 15) which is lower than that of Tigris River (4.04 mg/l, Al-Maliki, 2005); higher than that of Euphrates river (2.4 mg/l, Ahmed, 2006); and safely lower than MCL (10 mg/l, NPDWRs, 1999) (Table 2, Appendix 1-D).

During the last two decades Iraq has been affected by climate change which increased the frequency and intensity of drought periods resulting in a decrease in discharges of Iraqi rivers and their tributaries (Al-Maliky, 2012). Andersen et al. (2004) stated that there is evidence that biological uptake increases as river discharge decreases and that can interpret the low nitrate levels in the current study. For example, an increase in the rate of nitrate consumption was observed in the Sein River when river discharge fell below 400 m3/s (Roy et al., 1999). Likewise, Andersen et al. (2004) found that the stagnant river conditions can promote high rates of denitrification resulting in a decrease in nitrate levels. Additionally, algae or aquatic plants in the river can take up nitrate in dry years as was observed in the Thames River (Jarvie et al., 2002).

- Phosphate (PO_4^{3-})

Phosphate concentrations are low in general and detected only in some of the sites (1, 2, 3, 5, and 16). The concentrations are ranging from 0.101 mg/l (site 1) to 1.325 mg/l (site 2) with an average of 0.569 mg/l. Our data indicate that phosphate levels are lower than that of Tigris River (3.5 mg/l, Al-Maliki, 2005) and higher than that of Euphrates River (0.4 mg/l, Ahmed, 2006). Low concentrations of phosphate might be related to the increased biological uptake as discharge decreases knowing that 2010 was a relatively dry year. Possible biological processes in the river include assimilatory uptake, denitrification, and sulfate reduction that can significantly reduce concentration of phosphates (Andersen et al., 2004). In areas that are very shallow and stagnant, drought may increase biological removal of phosphate from river water (Andersen et al., 2004).

b) Heavy Metals

In general the concentrations of heavy metals in the current study are close to those reported by other researchers in the nearby areas (Al-Imarah, 1998; Al-Imarah, 2001; AL-Imarah et al., 2000; Al-Khafji, 2000; Al-Imarah et al., 2006; Al-Hejuje,1997; Al- Imarah et al., 2008); lower than those of Tigris and Euphrates Rivers (Al-Maliki, 2005 and Ahmed, 2006); lower than Iraqi limits; EPA standards; and FAO standards for drinking and irrigation water. We will focus on some of the heavy metals in this study.

- Aluminum (Al)

Aluminum concentrations range from 2.22 µg/l (site 6) to 8.59 µg/l (site 7) with an average of 4.38 µg/l (Table 3, Appendix 1-B). Aluminum concentrations, hence, are much lower than EPA secondary drinking water regulations (0.05 - 0.20 mg/l, EPA, 2010) and FAO maximum limits for irrigation water and livestock drinking water (5.0 mg/l, FAO, 1994). Therefore, Al concentration in the present study makes Shatt Al-Arab safe for drinking and irrigation purposes for Al.

- Vanadium (V)

Vanadium levels in our water samples range from 3.86 µg/l (site 16) to 8.02 µg/l (site 7) with an average of 4.38 µg/l (Table 3, Appendix 1-B). Vanadium concentrations in the current study are less than FAO standards for irrigation water and livestock drinking water (0.1 mg/l, FAO, 1994). Vanadium can be toxic to many plants even at relatively low concentrations, so Basra surface waters are safe for vanadium to be used for irrigation and livestock purposes.

- Chromium (Cr)

Concentration levels of chromium in water samples range from 0.097 µg/l (site 16) to 0.438 µg/l (site 12) with an average of 0.177 µg/l (Table 3, Appendix 1-D). Chromium concentrations in our water samples are less than those of Euphrates River (0.11 mg/l, Ahmed, 2006); less than that of global fresh water (0.02 mg/l) according to EPA (EPA, 2005); less than MCL (0.1 µg/l, NPDWRs, 1999); and less than the limits set by FAO for livestock and irrigation (0.1 and 1.0 mg/l respectively, FAO, 1994). Low levels of chromium in general might be due to the mobility of the metal from water to sediments.

- Manganese (Mn)

The concentrations of manganese in our water samples range from 0.88 µg/l (site 16) to 15.70 µg/l (site 8) with an average of 5.55 µg/l (Table 3, Appendix 1-B), which is less than the permissible limits of EPA (0.05 mg/l, EPA, 2010) for drinking water and less than the maximum recommended limits set by FAO for irrigation and livestock drinking water (0.2 and 0.05 mg/l respectively, FAO, 1994).

- Iron (Fe)

Concentrations of iron in water samples range from 1.44 µg/l (site 16) to 15.47 µg/l (site 7) with an average of 6.26 µg/l (Table 3, Appendix 1-B). Iron concentrations are lower than those recorded by other researchers in nearby areas (0.70 mg/l, Khwedim, 2007); less than that of Tigris and Euphrates Rivers (0.26 and 0.35 mg/l respectively, Al-Maliki, 2005; Ahmed, 2006); less than the Iraqi standards limits in river water (0.30 mg/l); less than EPA secondary limits for drinking water (0.30 mg/l, EPA, 2010); and less than FAO limits for irrigation and livestock's drinking water (5.0, 2.0 mg/l respectively, FAO, 1994).

- Cobalt (Co)

Cobalt concentrations in water samples range from 0.079 µg/l (site 6) to 0.210 µg/l (site 8) with an average of 0.125 µg/l (Table 3, Appendix 1-B), which are less than the acceptable limit of WHO for drinking water (0.05 mg/l, WHO, 1993) and less than the recommended maximum limits of irrigation (0.05 mg/l) and the permissible limits of livestock drinking water (1.00 mg/l) (FAO, 1994).

- Nickel (Ni)

Concentrations of nickel range from 1.61 µg/l (site 16) to 3.34 µg/l (site 7) with an average of 2.65 µg/l (Table 3) which is less than those of Tigris and Euphrates River (0.02 and 0.03 mg/l respectively (Al-Maliki, 2005; Ahmed, 2006); and less than the maximum recommended limits for irrigation (0.20 mg/l, FAO, 1994).

- Copper (Cu)

Copper concentrations in water samples are ranging from 0.72 µg/l (site 16) to 3.01 µg/l (site 13) with an average of 1.86 µg/l (Table 3, Appendix 1-D), which lower than those of Tigris and Euphrates Rivers (0.17 and 1.05 mg/l respectively, Al-Maliki, 2005, and Ahmed, 2006); less than the maximum recommended concentration in irrigation water (0.20 mg/l, FAO, 1994); and less than MCL (1.30 mg/l, NPDWRs, 1999).

- Zinc (Zn)

Zinc concentrations range from 0.63 µg/l (site 5) to 7.97 µg/l (site 10) with an average of 2.02 µg/l (Table 3, Appendix 1-C). Natural occurrence level of zinc in fresh water is (0.0001-0.05 mg/l) (WHO, 2001). Zinc concentrations in the present study are much lower than that of EPA standards for drinking water (5.0 mg/l) (EPA, 2010). Maximum recommended concentration of zinc for livestock and irrigation set by FAO is 2 mg/l and 24 mg/l respectively (FAO, 1994). So in this case the surface water of present study is considered to be safe for zinc.

- Arsenic (As)

Arsenic concentrations are ranging from 0.94 µg/l at site 16 to 3.35 µg/l at site 7 with an average of (2.44 µg/l) (Table 3, Appendix 1-B), which is safely lower than MCL (0.05 mg/l, NPDWRs, 1999) and lower than FAO arsenic maximum recommended concentration in irrigation water and livestock drinking water (0.2 and 0.1 mg/l respectively, FAO, 1994).

- Selenium (Se)

Concentration levels of selenium in water samples are ranging from 10.79 µg/l at site 6 to 19.24 µg/l at site 7 with an average of 13.77 µg/l (sites 14 and 15 excluded) (Table 3, Appendix 1-A), which are lower than MCL (0.05 mg/l, NPDWRs, 1999). FAO standards for selenium as recommended maximum concentration for livestock drinking water and irrigation are 0.02 and 0.05 mg/l respectively (FAO, 1994). So the concentration levels of selenium in water sample of present study are considered to be safe for humans and animals consumption as well as irrigation purposes.

- Molybdenum (Mo)

Molybdenum concentrations in our water samples are ranging from 5.46 µg/l at site 16 to 9.98 µg/l at site 9, with an average of 8.59 µg/l (Table 3), which is lower than the maximum recommended concentration set by FAO for irrigation water which is 0.01 mg/l (FAO, 1994).

- Cadmium (Cd)

Cadmium concentration in water samples range from (0.002 µg/l) at site 13 to (0.026 µg/l) at site 10 with an average of (0.0117 µg/l) (Table 3, Appendix 1-C), which is safely lower than MCL (0.05 mg/l, NPDWRs, 1999) and lower than FAO standards for livestock drinking water and irrigation which are (0.01 and 0.05 mg/l respectively, FAO, 1994).

- Lead (Pb)

Concentrations of lead in water samples are ranging from 0.004 µg/l at site 5 to 0.254 µg/l at site 10, with an average of 0.0898 µg/l (Table 3, Appendix 1-C). It is clear that it is much less than those of Tigris and Euphrates Rivers 0.02 and 0.04 mg/l respectively (Al-Maliki, 2005; Ahmed, 2006). It is also less than MCL (0.015 mg/l, NPDWRs, 1999) and less than the maximum recommended concentrations of Pb in irrigation water (5.0 mg/l) and livestock drinking water (0.1 mg/l) (FAO, 1994). So this concentration of lead in water courses of the studied area makes the surface water safe for lead to be used for different purposes.

- Uranium (U)

Uranium concentrations in our water samples range from 1.640 µg/l (site 16) to 2.346 µg/l (site 7), with an average of 2.0399 µg/l (Table 3, Appendix 1-D), which is less than the MCL (20 µg/l, NPDWRs, 1999).

The present study indicates that the concentrations of heavy metal, in general, are within the safe limits at the sampling site throughout the study period.

4.1.2 Solute Statistical Analysis

Overall, solute correlations to chloride, a biologically inert solute indicative of hydrologic transport, were mixed (Table 4). Some solutes like As and Cu were negatively correlated to Cl, while others such as Na and K correlated positively and significantly. Despite the high variability of solute patterns, the clustering analysis highlights 4 specific solute response patterns (R1, R2, R3, and R4, Table 4, Figure 2). The degree of relationship between clusters is represented by the distance of the centroid of one cluster to another, where clusters with smaller or shorter distances between them are more similar to each other than clusters with larger or longer distances between.

A large number of solutes that highly correlate to Cl ($r^2 > 0.79$) clustered into pattern R1. Solutes clustering in R1 include Mg, Na, Se, Br, K, Ca, and Li. The concentration patterns of R1 solutes are illustrated in Appendix 1-A. Mn, Co, Al, Fe V, Ni and As did not correlate with Cl, and had the highest concentrations at agricultural sites and clustered together in pattern R2 (Table 4, Figure 2, Appendix 1-B). Solutes clustered in pattern R3 that did not correlate to Cl, had the highest solute concentrations at urban and marshland sites, and included Cd, Zn, and Pb (Table 4, Figure 2, Appendix 1-C). Finally, NO_3, Sn, Cu, Mo, U, SO_4, Be, F, and Cr clustered together in pattern R4, and had the highest concentrations at Arabian Gulf and urban sites (Table 4, Figure 2, Appendix 1-D).

The clustering analysis highlighted differences in transport and sourcing controls on water quality. Because we use Cl as a biologically inert tracer of hydrologic transport (Kirchner et al., 2000; Neal et al., 1988; Rascher et al., 1987; Triska et al., 1989), we can assume that Cl concentrations vary in response to changes in conservative transport processes. All solutes identified in our analysis as R1 are conservative (i.e. Mg, Cl, Na, Se, Br, K, Ca, and Li) and had the highest solute concentrations in Arabian Gulf site. The conservative solutes are all of small charge, so that they are not subject to strong electrostatic attractions that might remove them in the way that scavenged solutes are. Moreover, they are little affected by biological processes, at least in comparison to their overall abundance in nature. Collectively conservative solutes make up more than 99% of the dissolved solids in the oceans (Railsback, 2013) and that can explain their high concentrations in the Arabian Gulf in the current study (Appendix 1-A).

Solutes clustering in R2, such as Mn, Co, Al , Fe, V, Ni and As indicates a possible geologic sourcing as is evidenced by the soil geochemistry of Basra city which is known to be of high As, Al, Fe, Ni, and Co concentrations (Khwedim et al, 2009). Ziemacki et al. (1989) indicated that Arsenic in its natural state appears primarily in association with Co, Fe, Pb, Ni, and Cu in ores. Likewise, the Canadian Ministry of the Environment (2001) stated that Co usually occurs in association with other metals such as Ni, As, Mn, and Cu in most rocks, soil, surface and groundwater. High concentration of these solutes in agricultural sites in the present study (Appendix 1-B) might be attributed to the flushing of soil which is rich in these solutes (Khwedim et al, 2009).

Cd, Zn and Pb that clustered in R3 are associated with anthropogenic sourcing (i.e. residential, industrial, commercial and road land uses). Furthermore, Cd and Zn appear to have the same sources (brake lining abrasion, tire abrasion, roof runoff, motorway abrasion, pesticides, plumping, and cosmetics products) (Omu, 2008), therefore it is not surprising that they clustered together in the present study, and that the highest concentrations were observed at urban land use (Appendix 1-C). Furthermore, we found that Cd, Zn, and Pb have also high concentrations in marshes. High levels of these solutes in marshes can be attributed to the suspended solids transported in surface water runoff to the wetlands (Peltier, 2003). Our data are consistent with Kim et al. (2004) who recorded high concentration of Zn and Pb in the Wolfe Glade and Great marshes in Delaware, US and assigned that to the anthropogenic sources of these solutes that are ultimately trapped into these marshes.

Patterns of solute concentrations were highly variable in R4 (i.e. NO_3, Sn, Cu, Mo, U, SO_4, Be, F, and Cr), however, they tend to have relatively high concentrations at urban sites suggesting anthropogenic sourcing (Appendix 1-D). Moreover, other solutes in R4 like SO_4 and U have relatively high concentrations at Arabian Gulf and marshes highlighting the effects of natural sourcing.

4.2 Water suitability for Irrigation Analysis

Water Quality is a major concern to everyone who uses water. How to manage water in a specific situation can be both a practical and financial challenge. Water originating from an industrial, livestock, or municipal source may require additional analyses and care in order to use it for irrigation (Ramesh and Elango, 2011). The suitability of water for irrigation purposes depends upon the effect of mineral constituents of water on both plants and soils. Some irrigation waters can damage plants directly, while others damage soil structure (Hopkins et al., 2007). In this paper we will focus on using water analyses to investigate Shatt Al-Arab water suitability for irrigated agriculture. Analyses include assessing:

- Salt hazard
- Sodium hazard
- Lime deposition hazard
- Chloride hazard
- Percent sodium hazard
- Magnesium hazard

Water quality analyses can be used as guidelines by farmers for selecting appropriate management practice to overcome potential salinity hazard, if the quality of available water would pose any problem for irrigation to maintain existing soil productivity with the benefit of high crop yield under irrigation.

- Salt Hazard

Salts in water samples are measured by total dissolved solids (TDS) or electrical conductivity (EC). The higher the TDS or EC is, the higher the salt hazard. For example, water with an EC of 1.0 ds/m contains 640 mg/l salt. When irrigating with 1 acre-feet of this water, approximately 0.87 tons of salt per acre are applied every year according to: (640 m/l salt x 2.7 [million lb water per acre-foot] x 1 acre-foot water) / 2000 lb per ton = 0.87 tons salt per acre. Analysis revealed that the water quality is unacceptable for irrigation in five sites and requires careful management in eight sites (Table 5).

- Sodium Hazard

a) Sodium adsorption ratio (SAR)

An equation used to predict irrigation water sodium adsorption ratio (SAR). SAR is the ratio of sodium to calcium and magnesium. The higher the SAR is, the greater the sodium hazard. SAR is calculated as:

$SAR = [Na+]/(0.5([Ca^{2+}]+[Mg^{2+}]))^{0.5}$ Where concentrations are in meq/l

In general, the higher the SAR, the less suitable the water is for irrigation. Irrigation using water with high SAR may require soil amendments to prevent long-term damage to the soil. If irrigation water with a high SAR is applied to a soil for years, the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and a loss of soil structure. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production (Islam and Shamsad, 2009). Results indicated that using Shatt Al-Arab water for irrigation might be restricted in 13 sites and not suitable in 3 sites (Table 6).

b) Water Infiltration Hazard

SAR is an important factor in determining the suitability of water for irrigation; however, it is not enough by itself to predict the water infiltration problems. Using EC along with SAR must be considered in estimating water infiltration hazard (Ramesh and Elango, 2011). In general, risk of water infiltration problems increases as SAR increases and EC decreases. In the current study, fortunately, EC has high values resulting in a minimum or no reduction in water infiltration (Figure 3).

- Lime Deposition Hazard

Lime deposition occurs when calcium or magnesium carbonates (lime) precipitate out of irrigation water, leaving white residues or deposit. Lime deposition can cause many problems, for example, the presence of high concentrations of lime in irrigation water can precipitate phosphorous or micronutrient fertilizers that are injected into the water. Moreover, the presence of significant concentrations of lime in soil can reduce the solubility of some plant nutrients such as P, Zn, Mn, and Fe (Hopkins et al., 2007). For crops like fruits and vegetables the presence of lime residue can reduce their marketability as the consumers associate white residues with pesticide contamination. The lime deposition potential is calculated as the lesser of carbonate (carbonate + bicarbonate) or divalent cations (calcium + magnesium) in water. Lime deposition potential for the current study is shown in table 7.

- Chloride Hazard

Excess chloride deposited on leaves causes foliar burn and some plants are more susceptible to chloride than others (Hopkins et al., 2007). Damage caused by high-chloride irrigation water can be minimized by planting a less-sensitive crop; avoiding foliar contact by using furrow, flood, or drip irrigation; and rinsing the plants at the end of each irrigation event if a source of high-quality water is available (Hopkins et al., 2007). Chloride concentrations above 350 mg/l can cause severe problems (Ramesh and Elango, 2011). Chloride concentrations in the current study range from 434 to 984 mg/l with an average of 606 mg/l (sites 14 and 15 excluded) (Table 2). Water with this chloride level (i.e. of the current study which is higher than 350 mg/l) is unsuitable for irrigating many plants such as berries, beans, onion, mint, carrot, lettuce, pepper, grape, potato, squash, wheat, corn, tomato, sugarbeet, and cauliflower (HopKins et al., 2007).

- Percent Sodium Hazard (Na^+ %)

The Na^+ in irrigation water is usually denoted as Na^+ % and can be determined using the formula (Wilcox, 1955) given below, where the concentrations are expressed in meq/l.

Percent Sodium = $Na^+ / (Ca^{2+} + Mg^{2+} + Na^+ + K^+) \times 100$

The classification of our water samples with respect to the Na^+ % is shown in Table 8. The Na^+ % in the study area ranged between 52 % and 73 %, with an average of 57 %. It is observed that most of our samples fall within the category of permissible and only two samples fall under doubtful category.

Classifying water based on Na % and EC following Wilcox (1955), however, shows that water samples in 9 sites fall in the fields of doubtful to unsuitable for irrigation and unsuitable in other 4 sites (Figure 4). The agricultural yields are observed to be generally low in fields irrigated with water belonging to doubtful to unsuitable. This is probably due to the presence of Na salts, which cause osmotic effects in soil plant system. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Saleh et al, 1999).

- Magnesium hazard (MH)

Generally, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in water. More Mg^{2+} present in waters affects the soil quality converting it to alkaline and decreases crop yield. Szabolcs and Darab (1964) proposed Magnesium hazard (MH) value for irrigation water as given by the following formula:

MH = $Mg/(Ca^{2+}+Mg^{2+}) \times 100$, where the concentrations are expressed in meq/l

MH values > 50 are considered harmful and unsuitable for irrigation purposes. In the analyzed water samples, the MH ranges from 52.7 to 58.2 (Arabian Gulf site excluded) with an average of 55.5, therefore, our water samples are considered harmful and unsuitable for irrigation purposes.

Conclusions

- The mean concentration of cations in the analyzed water samples is in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, while for the anions it is $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^- > Br^- > PO_4^{3-} > F^-$.
- Cations and anions such as Na^+, K^+, Ca^{2+}, Cl^-, SO_4^{2-} have considerably higher levels than the maximum contaminant level for drinking water, whereas NO_3^- and PO_4^{3-} concentrations fall within permissible limits.
- The mean concentration of heavy metals is in the order of Li > Se > Mo > V > Fe > Mn > Al > Ni > As > U > Zn > Cu > Sn > Cr > Co > Pb > Be > Cd. Fortunately, heavy metal levels are within the safe limits at the sampling site throughout the study period making water safe for drinking and other purposes for heavy metals.
- The concentrations of most solutes are higher than those of Tigris and Euphrates Rivers. High solutes levels in Shatt Al-Arab River can be attributed to the sharp decrease in the water inputs into the Tigris and Euphrates basins during the past years promoting the saline arm to extend from the Arabian Gulf up to 100 km into Shatt Al-Arab during dry years. In addition to the drought condition, discharging of oil production waste, untreated sewage, agricultural runoff, and industrial waste directly into water courses in Basra can contribute to increase the contaminant levels in water bodies.
- Statistical analysis applied defined the possible sources of contaminants; most contaminants are of anthropogenic sources while others are of natural sources.
- Investigation of Shatt Al-Arab water suitability for irrigated agriculture revealed that TDS of collected irrigation water samples falls in the classes of unacceptable and marginal. SAR falls in restricted and unsuitable use class. Lime deposition analysis falls in restricted to not recommended use classes. Chloride analysis indicated that chloride concentrations in all sites can cause severe problems. Percent sodium shows that the water samples are permissible to doubtful for irrigation. Magnesium hazard values are considered harmful and unsuitable for irrigation. Therefore, Shatt Al-Arab River, in general, is considered unsuitable to marginal for irrigation purposes for most crops.

Acknowledgments

I would like to present my appreciation to Technical University Bergakademie Freiberg institute of Hydrogeology, hydrology Labs for their great cooperation in analyzing water samples. I would like to present my sincere gratuity to the German Academic Exchange Service (DAAD) for supporting my proposal. Finally, I am grateful to Dr. Wisal, Dr. Badr, and Mr. Osama at the Marine Science Center, University of Basra who enthusiastically supported me.

References

Ahmed, L.M.R. (2006), “Assessment of environmental monitoring program of the rivers: case of Euphrates Rivers”, dissertation (unpublished), University of Baghdad, College of Science, Department of Geology, 200 p

Al-Hejuje, M.M. (1997), “Distribution of heavy elements in water and sediments from Al-Ashar and Al-Khandak canals connected with Shatt Al-Arab River and their effects on algae”, thesis, University of Basra, 104 p

Al-Imarah, F.J.M. (2001), “Levels of trace metals in water of Shatt Al-Arab at Basrah city”, Marine Mesopotamica, 16 (1):257-265

Al-Imarah, F.J.M., Al-Khafaji, B.Y., & Mahmood, A.M. (1998), “Trace metals in water, sediments and fishes from north west Arabian Gulf”, Bull. Nat. Inst. of Oceanography and Fish, A.R.E., 24:403-416

Al-Imarah, F.J.M., Al-Ta'an, S.M., & Majeed, G.H. (2006), “Pollution in the effluents of Diary and Soft Drinks Industries in Basrah City: Their effect upon water quality of Shatt Al-Arab and removal by column filled with sand and charcoal”, Proceedings of the 4th symposium on Scientific Research Outlook and Technology Development in the Arab World, Damascus, 11-14 Dec. 2006, p.1267-1271

Al-Imarah, F.J.M., Ghadban, R.A., & Al-Shawy, S.F. (2000), “Levels of trace metals in water of southern part of Iraq”, Marine Mesopotamica, 15(2):365-372

Al-Imarah, F.J.M., Mahmood, A.A., & Humadi, M.S. (2008), “Levels of trace metals in Shatt Al-Arab branches during spring and summer seasons, 2006”, Marina Mesopotamiea, 23(1):9-17

Al-Khafaji, B.Y. (2000), “Perliminary survey of selected heavy metals in Al-Jubayla creek connected with Shatt Al-Arab River”, Marine Mesopotamica, 15(1):69-80

Al-Maliki, M.A. (2005), “Assessment of water and soil in Baghdad city using GIS”, dissertation, University of Baghdad, College of Science, Dept. of Geology, 171 p

Al-Maliky, J.H.A. (2012), “Analysis of water quality and the impact of the salt wedge from the Arabian Gulf on the Shatt Al-Arab River, Iraq”, thesis, The University of Queenland, Australia, 81 p

Andersen, C.B., Lewis, G.P., & Sargent, K.A. (2004), “Influence of wastewater treatment effluent on concentrations and fluxes of solutes in the Bush River, South Carolina, during extreme drought conditions”, Environmental Geoscience, 1(1):28-41

Central pollution Control Board (CPCB) (2004), “Status of Water Quality in India, New Delhi, India”

Environmental Protection Agency (EPA), United State (2010), “Drinking water Contaminants”, pp:1-9

Environmental Protection Agency (EPA), US (2005), “Current National Recommended Water Quality Criteria”, pp:1-18

Food and Agriculture Organization (FAO) (1994), “Guidelines for Levels of Toxic Substances in Livestock Drinking Water”

Food and Agriculture Organization (FAO) (1994), “Guidelines Recommended Maximum Concentration of Trace Element in Irrigation Water”

Kim, G., Alleman, L.Y., & Church, T.M. (2004), “Accumulation records of radionuclides and trace metals in two contrasting Delaware salt marshes”, Marine Chemistry 87: 87-96

Hopkins, B.G., Ellsworth, J.W., Horneck, D.A., Stevens, R.G., & Sullivan, D.M. (2007), “Managing irrigation water quality for crop production in the Pacific Northwest”, Oregon State University. Corvallis OR

Iqbal, F., Raza, N., Ali, M., & Athar, M. (2006), “Contamination of Kallar Kahar lake by inorganic elements and heavy metals and their temporal variations”, J. appl. Sci. Environ. Mgt, 10(2):95-98

Islam, M.S., & Shamsad, S.Z. (2009), “Assessment of irrigation water quality of Bogra district in Bangladesh”, Bangladesh Journal of Agricultural Research, 34:597- 608

Jarvie, H. P., Lycett, E., Neal, C., & Love, A. (2002), “Patterns in nutrient concentrations and biological quality indices across the upper Thames River Basin”, The Science of the Total Environment, 282: 263-294

Khalaf, A. (2009), “Study of Water quality of main rivers in Iraq for the year 2008, preliminary report”, Ministry of Water Resources, General Directorate of Water Resources Management, Department of Environmental Studies, pp:1-27, (In Arabic)

Khwedim, K. H. & Schneider, M. (2010), “Assessment of major contents and born in the water of small streams in Basra City- South of Iraq”, Proceeding of Second International Conference of Environmenal Management (ICEM), Hayderabad, India, (Eds.) Reddy, M. A., Lakshmi, T. V., 1:565-576

Khwedim, K.H. (2007), “Study in the Environmental Situation for Al-Basrah Governorate”, dissertation, University of Baghdad, College of Science, Department of Geology, 180 p

Khwedim, K.H., Al-Anssari, H.R., & Al- Bassam K. (2009), “Study of distribution of some heavy metals in the soil of Basra city- south of Iraq”, Iraqi Journal of Science, 50(4):533-542

Kirchner, J.W., Feng, X.H., & Neal, C. (2000), “Fractal stream chemistry and its implications for contaminant transport in catchments”, Nature, 403:524-527

Langmuir, D. (1997), “Aqueous Environmental Geochemistry”, prentice Hall, USA, 600 p

Ministry of the Environment (2001), Cobalt in the environment, Ontario, Canada

Mustafa, O.M. (2006), “Impact of Sewage wastewater on the Environment of Tanjero River and Basin within Sulaimani City/NE-Iraq”, thesis, University of Baghdad, College of Science, Department of Geology, 111 p

National Primary Drinking Water Regulations (1999), http://www.epa.gov/ogwdw000/wot/appa.html

Neal, C., Christophersen, N., Neale, R., Smith, C.J., Whitehead, P.J., Reynolds, B. (1988), “Chloride in Precipitation and Streamwater for the Upland Catchment of River Severn, MidWales – Some Consequences for Hydrochemical Models”, Hydrological Processes, 2:155-165

Niqash (2009), http://www.niqash.org/articles/print.php?id=2517&lang=en

Omu Akomeno (2008), “Identification of the Sources of Heavy Metal in Urban Wastewater Centre for Environmental Policy”, Imperial College London

Pal, S., Adhikari, K., Ghosh, S., & Mukherjee, S. (2011), “Characterization of Subsurface Water near an Industrial Wastewater Disposal Site”, International Journal of Earth Sciences and Engineering, 4(6):429-433

Pan, Y. & Brugam, R.B. (1997), “Human disturbance and tropic status changes in Crystal Lake, Mcltenry County, Illinois, USA”, J. palaeoliminology,17:369-376

Peltier, E.F., Webb, S.M., & Gaillard, J.F. (2003), “Zinc and lead sequestration in an impacted wetland system”, Advances in Environmental Research 8:103-112

Railsback, B. (2013), “Some Fundamentals of Mineralogy and Geochemistry”, (e-book) available at http://www.gly.uga.edu/railsback/FundamentalsIndex.html

Ramesh, K. & Elango, L. (2011), “Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India”, Environ Monit Assess, DOI 10.1007/s10661-011-2231-3

Rascher, C.M., Driscoll, C.T., & Peters, N.E. (1987), “Concentration and Flux of Solutes from Snow and Forest Floor During Snowmelt in the West-Central Adirondack Region of New-York”, Biogeochemistry, 3:209-224

Roy, S., Gaillardet J., & Allegre, C.J. (1999), “Geochemistry of dissolved and suspended loads of the Seine River, France: Anthropogenic impact, carbonate and silicate weathering”, Geochimica et Cosmochimica Acta, 63:1277-1292

Saleh, A., Al-Ruwaih, F., & Shehata, M. (1999), “Hydrogeochemical processes operating within the main aquifers of Kuwait”, Journal of Arid Environments, 42:19-209

Sall, J.L., Creighton, & Lehman, A. (2007), “JMP start statistics a guide to statistics and dataanalysis using JMP”, SAS Institute, Cary, NC

Shrestha, S., & Kazama, F. (2007), “Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan”, Environ. Modelling and Software 22:464-475

Sial, R.A., Chaudhary, M.F., Abass, S.T., Latif, M.I. & Khan, A.G. (2006), “Quality of effluents from Hatter industrial estate”, Journal of Zhejiang University Science. B (JZUS) B, pp 974-980

Szabolcs, I., Darab, C. (1964), “The influence of irrigation water of high sodium carbonate content on soils”, Proc 8th International Congress Soil Science Sodics Soils, Res Inst Soil Sci Agric Chem Hungarian Acad Sci, ISSS Trans II, 1964, 802–812

Triska, F.J., Kennedy, V.C., Avanzino, R.J., Zellweger, G.W., & Bencala, K.E. (1989), “Retention and Transport of Nutrients in a 3rd-Order Stream in Northwestern California -Hyporheic Processes”, Ecology, 70:1893-1905

Vries, W., Romkens, P., & Kros, H, (2000), “Critical heavy metal and nutrient fluxes for Dutch agricultural soils in view of adverse impacts on food, soil and water quality”, Alterra Wageningen Ur

Wilcox, L.V. (1955) “Classification and use of irrigation waters”, USDA, circular 969, Washington, DC, USA

World Health Organization (WHO) (1993), “Guidelines for drinking water Quality”, 2nd ed., Vol.1, Geneva, 188 p

World Health Organization (WHO) (2001), “Zinc. Environmental health Criteria”, Geneva, 383 p

World Health Organization (WHO) (2006), “Guidelines for drinking water Quality”, 3rd ed., Vol. 1 Recommendation Geneva, 51 p

Ziemacki, G., Viviano, G., & Merli, F. (1989), “Heavy metals: sources and environmental presence”, Ann. 1st. Super Sanita, 25(3):531-536

Table 1 Field Parameters

Site No.	Name	pH	O_2 (mg/l)	O_2 (%)	Temp °C	EC ds/m	EMF (mV)	EH (mV)
1	Salal (Basra Marshland)	8.16	9.83	123.0	26.3	3.42	89.0	298.0
2	Alnakara (Basra Marshland)	7.96	7.86	100.4	26.8	3.58	86.0	295.0
3	Al Twail (Basra Marshland)	7.90	7.25	90.3	25.8	2.95	57.1	266.1
4	Al Habab irrigation canal	7.69	5.46	66.4	24.8	2.67	59.2	268.2
5	Abu Mgera irrigation canal	7.73	5.16	62.7	24.7	2.71	63.9	272.9
6	Shatt Al-Arab (Al-Ashar)	7.67	4.90	59.7	24.8	2.61	55.0	264.0
7	Khoz irrigation canal	7.42	0.95	12.2	27.0	4.63	-32.5	176.5
8	Gekor irrigation canal	7.94	8.75	112.6	27.3	4.00	-63.5	145.5
9	Shatt Al-Arab Najebia power station	7.87	7.29	96.3	27.0	2.99	-59.5	149.5
10	Shatt Al-Arab Daker Jazera	7.73	5.62	70.4	25.6	2.86	-51.1	157.9
11	Shatt Al-Arab before Taleamy hospital	7.86	5.26	65.5	25.5	2.86	-48.1	160.9
12	Shatt Al-Arab after Taleamy hospital	7.71	5.67	70.5	25.6	2.85	-51.5	158.5
13	Shatt Al-Arab Salhiya river	7.74	6.24	77.4	25.9	2.96	-52.3	159.1
14	Arabian Gulf [a]							
15	Shatt Al-Arab (toward Arabian Gulf) [a]							
16	Shatt Al-Arab [a]							

[a] Data not available due to a field problem

Table 2 Cation and anion concentrations (mg/l)

Site No.	Name	F	Cl	Br	NO_3	PO_4	SO_4	Na	K	Ca	Mg	HCO_3[a]
1	Salal (Basra Marshland)	0.33	728	1.35	1.88	0.10	650	491	9.7	140	115	209
2	Alnakara (Basra Marshland)	0.32	763	1.97	1.42	1.33	645	532	11.1	143	120	212
3	Al Twail (Basra Marshland)	0.32	553	1.10	2.00	0.43	591	386	8.7	137	98	212
4	Al Habab irrigation canal	0.30	509	1.06	3.86	ND[b]	486	368	7.5	123	88	225
5	Abu Mgera irrigation canal	0.29	523	1.21	4.07	0.56	483	375	7.9	127	90	228
6	Shatt Al-Arab (Al-Ashar)	0.31	493	0.93	2.93	ND[b]	506	347	6.9	124	87	219
7	Khoz irrigation canal	0.38	984	1.93	2.95	ND[b]	779	674	13.7	174	147	397
8	Gekor irrigation canal	0.35	827	1.67	3.43	ND[b]	662	570	13.5	159	127	327
9	Shatt Al-Arab Najebia power station	0.33	564	1.09	2.91	ND[b]	657	410	8.3	156	107	316
10	Shatt Al-Arab Daker Jazera	0.31	506	0.94	3.49	ND[b]	568	383	7.9	145	99	319
11	Shatt Al-Arab before Taleamy hospital	0.31	527	0.98	3.11	ND[b]	577	387	7.6	143	99	320
12	Shatt Al-Arab after Taleamy hospital	0.31	524	1.08	4.10	ND[b]	571	386	8.8	140	99	322
13	Shatt Al-Arab Salhiya river	0.32	552	1.15	3.97	ND[b]	592	402	9.0	144	103	316
14	Arabian Gulf	-	5058	16.3	3.74	ND[b]	874	3109	112	239	456	211
15	Shatt Al-Arab (toward Arabian Gulf)	0.43	1333	3.49	5.17	ND[b]	440	833	28.3	136	116	215
16	Shatt Al-Arab	0.40	435	0.63	4.86	0.43	313	308	8.2	119	55	211
	Mean	0.33	606[c]	2.30	3.21[c]	0.57	587	429[c]	9.2[c]	141[c]	102[c]	266

[a] HCO_3 concentrations were estimated using Phreeqc software

[b] ND: Not Detectable

[c] Concentrations of sites 14 and 15 were excluded from the mean calculation as they are exceptionally high (marine)

Table 3 Heavy metal concentrations in water samples (µg/l)

Site No.	Name	7Li	9Be	27A -2V	51V -2V	52Cr -2V	55Mn -2V	56Fe -3V	59Co -2V	60Ni -2V	63Cu -2V	66Zn -2V	75As -2V	80Se -2V	95Mo	114Cd -2V	118Sn	208Pb	238U
1	Salal (Basra Marshland)	28.51	0.038	4.454	5.964	0.168	3.928	3.934	0.138	2.851	1.748	0.746	2.771	11.88	9.547	0.019	0.381	0.104	2.313
2	Alnakara (Basra Marshland)	29.28	0.065	4.489	5.515	0.154	4.366	4.32	0.166	3.069	1.789	0.833	2.667	13.09	9.598	0.014	0.316	0.138	2.303
3	Al Twail (Basra Marshland)	23.68	0.066	5.76	6.111	0.138	2.184	3.859	0.093	2.606	2.053	1.839	2.282	10.81	9.123	0.022	0.293	0.201	2.137
4	Al Habab irrigation canal	25.38	0.051	4.66	6.567	0.164	3.702	10.66	0.16	2.506	1.039	1.909	2.467	11.69	7.74	0.006	0.221	0.039	1.752
5	Abu Mgera irrigation canal	25.79	0.049	2.591	6.382	0.126	2.823	2.749	0.086	2.422	1.078	0.628	2.3	12.87	7.507	0.005	0.181	-0.004	1.737
6	Shatt Al-Arab (Al-Ashar)	24.02	0.052	2.215	6.675	0.127	2.119	2.802	0.079	2.371	2.565	1.878	2.579	10.79	8.232	0.011	0.161	0.037	1.796
7	Khoz irrigation canal	33.73	0.065	8.591	8.026	0.239	14.08	15.47	0.208	3.34	1.889	2.113	3.347	19.24	8.927	0.01	0.166	0.078	2.346
8	Gekor irrigation canal	30.67	0.064	4.413	7.069	0.148	15.7	5.796	0.21	2.847	1.194	1.432	3.043	16.3	8.253	0.011	0.149	0.041	1.981
9	Shatt Al-Arab Najebia power station	23.66	0.051	4.204	6.584	0.149	4.536	7.495	0.114	2.724	2.281	1.778	2.175	13.79	9.978	0.011	0.13	0.035	2.327
10	Shatt Al-Arab Daker Jazera	24.13	0.046	4.937	6.985	0.187	5.26	9.233	0.095	2.81	2.176	7.97	2.352	14.11	8.997	0.026	0.125	0.254	2.071
11	Shatt Al-Arab before Taleamy hospital	24.14	0.054	5.738	6.873	0.15	5.848	7.88	0.094	2.538	2.565	2.774	2.423	15.91	9.052	0.006	0.118	0.186	2.069
12	Shatt Al-Arab after Taleamy hospital	23.61	0.062	4.143	6.694	0.438	5.322	5.726	0.091	2.812	1.894	1.515	2.423	15.67	8.85	0.006	0.164	0.061	2.03
13	Shatt Al-Arab Salhiya river	23.86	0.049	2.891	6.559	0.196	7.046	6.278	0.113	2.598	3.008	2.009	2.341	14.29	9.048	0.002	0.09	0.066	2.057
14	Arabian Gulf	59.13	0.081	3.074	5.65	0.218	0.867	2.373	0.141	1.667	0.607	0.49	1.313	110.4	8.632	0.006	0.183	-0.015	2.102
15	Shatt Al-Arab (toward Arabian Gulf)	25.11	0.032	1.777	4.188	0.105	0.844	1.439	0.117	1.70	0.835	1.089	1.113	27.57	6.408	0.011	0.084	0.033	1.739
16	Shatt Al-Arab	16.87	0.022	2.236	3.862	0.097	0.875	1.448	0.094	1.605	0.722	0.802	0.941	12.34	5.459	0.005	0.059	0.022	1.64
	Mean	25.22[a]	0.053	4.136	6.232	0.175	4.969	5.716	0.125	2.529	1.715	1.863	2.284	13.91[a]	8.459	0.011	0.176	0.080	2.025

[a] Concentrations of sites 14 and 15 were excluded from the mean calculation as they are exceptionally high (marine)

Table 4 Correlation of solutes to Cl

Solute	Correlation to Cl (R^2)	Cluster	Sourcing
Cl	1.00	R1	Transport control and solute flushing
Mg	0.97		
Na	0.99		
Se	0.99		
Br	0.99		
K	0.99		
Ca	0.79		
Li	0.88		
Mn	-0.039	R2	Geologic sourcing
Co	0.042		
Al	-0.020		
Fe	-0.051		
V	-0.033		
Ni	-0.209		
As	-0.150	R3	Anthropogenic sourcing
Zn	-0.062		
Cd	-0.026		
Pb	-0.122		
NO_3	0.013		
Sn	0.0003		
Cu	-0.211	R4	Anthropogenic and natural sourcing
Mo	5E-05		
U	0.012		
SO_4	0.360		
Be	0.240		
F	0.004		
Cr	0.014		

Table 5 General hazards from salinity of irrigation water

Site No.	EC (ds/m)	TDS (mg/l)	Amount of salt (ton/acre.year) when water used for irrigation	Salinity Hazard
1	3.42	2189	2.95	High hazard. Unacceptable for irrigation, except for very salt-tolerant plants
2	3.58	2291	3.09	High hazard. Unacceptable for irrigation, except for very salt-tolerant plants
3	2.95	1888	2.55	Medium-high hazard, Require careful management to raise most crops
4	2.67	1709	2.31	Medium-high hazard, Require careful management to raise most crops
5	2.71	1734	2.34	Medium-high hazard, Require careful management to raise most crops
6	2.61	1670	2.26	Medium-high hazard, Require careful management to raise most crops
7	4.63	2963	4.00	High hazard. Unacceptable for irrigation, except for very salt-tolerant plants
8	4.00	2560	3.46	High hazard. Unacceptable for irrigation, except for very salt-tolerant plants
9	2.99	1914	2.58	High hazard. Unacceptable for irrigation, except for very salt-tolerant plants
10	2.86	1830	2.47	Medium-high hazard, Require careful management to raise most crops
11	2.86	1830	2.47	Medium-high hazard, Require careful management to raise most crops
12	2.85	1824	2.46	Medium-high hazard, Require careful management to raise most crops
13	2.96	1894	2.56	Medium-high hazard, Require careful management to raise most crops

Table 6 SAR hazards

Site No.	SAR	Hazard	Site No.	SAR	Hazard
1	7.45	Use may be restricted	9	6.20	Use may be restricted
2	7.92	Use may be restricted	10	6.01	Use may be restricted
3	6.15	Use may be restricted	11	6.10	Use may be restricted
4	6.19	Use may be restricted	12	6.09	Use may be restricted
5	6.23	Use may be restricted	13	6.25	Use may be restricted
6	5.85	Use may be restricted	14	27.22	Severe damage. Unsuitable
7	9.09	Severe damage. Unsuitable	15	12.70	Severe damage. Unsuitable
8	8.18	Use may be restricted	16	5.84	Use may be restricted

Table 7 Lime deposition levels for the studied sites

Site No.	Lime deposition Hazard	Irrigation rate in/hr	Site No.	Lime deposition Hazard	Irrigation rate in/hr
1	3.43	> 0.2 irrigate at night or on cloudy days	9	5.17	Not recommended
2	3.48	> 0.2 irrigate at night or on cloudy days	10	5.23	Not recommended
3	3.48	> 0.2 irrigate at night or on cloudy days	11	5.25	Not recommended
4	3.68	> 0.2 irrigate at night or on cloudy days	12	5.28	Not recommended
5	3.74	> 0.2 irrigate at night or on cloudy days	13	5.17	Not recommended
6	3.58	> 0.2 irrigate at night or on cloudy days	14	3.46	> 0.2 irrigate at night or on cloudy days
7	6.50	Not recommended	15	3.53	> 0.2 irrigate at night or on cloudy days
8	5.36	Not recommended	16	3.46	> 0.2 irrigate at night or on cloudy days

Table 8 Classification of water based on Na%

% Na^+	Category	Sites
< 20	Excellent	-
20-40	Good	-
40-60	Permissible	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16
60 -80	Doubtful	14, 15
> 80	Unsuitable	-

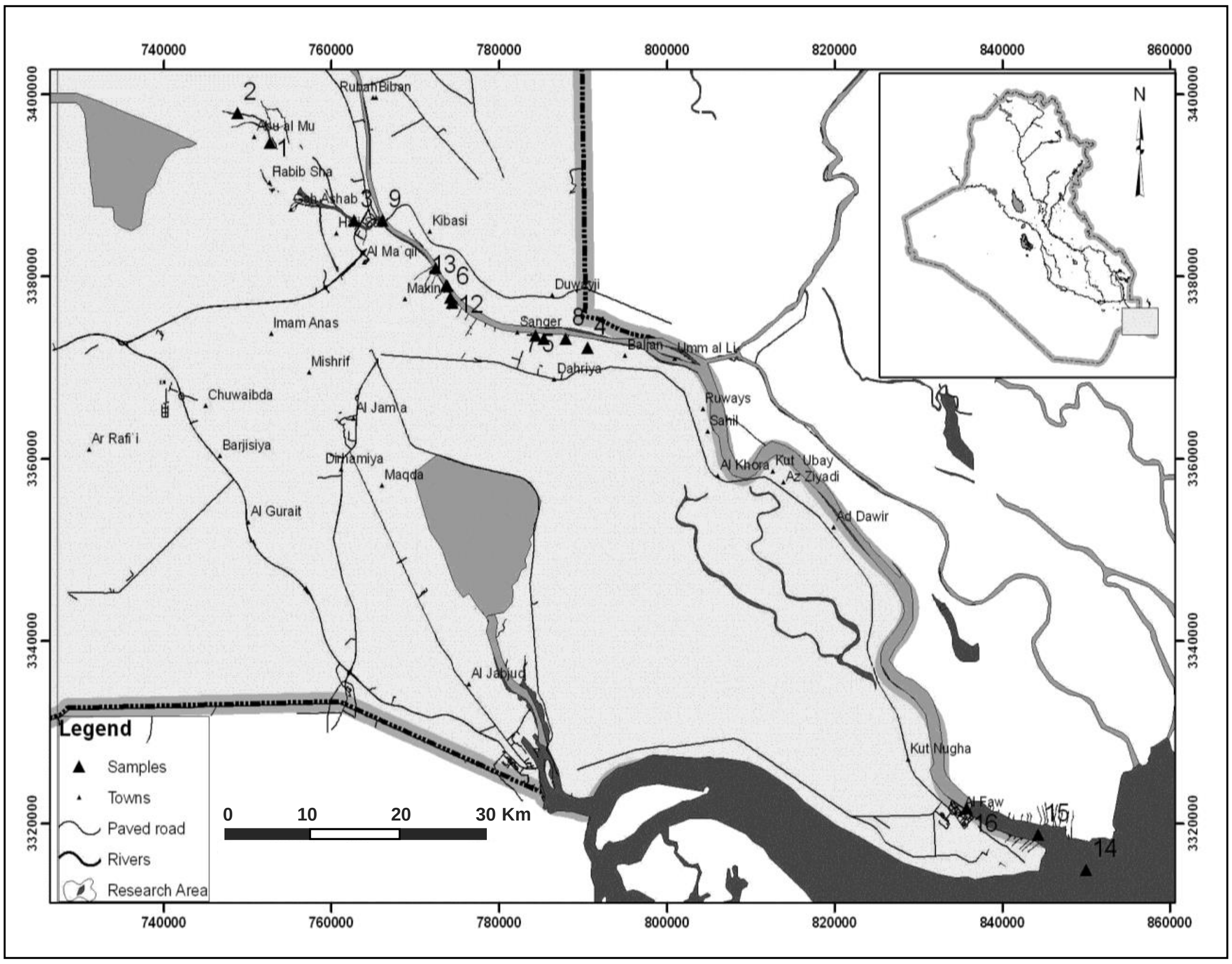


Figure 1 Study Sites

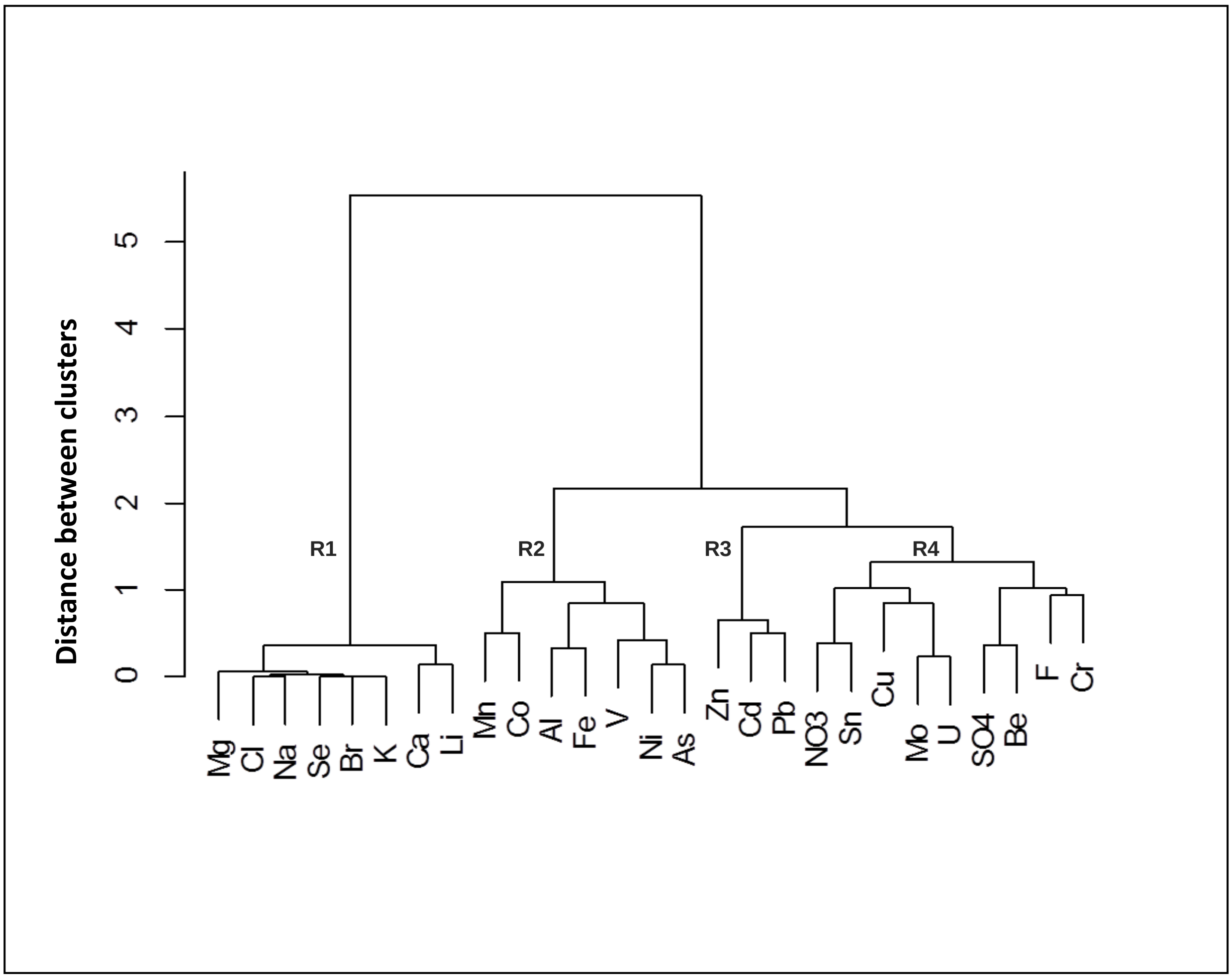


Figure 2 Dendrogram of cluster analysis based on the correlation of solutes among each other. The 4 clusters selected had an average distance between clusters 1.5 and provide the most information regarding water quality patterns

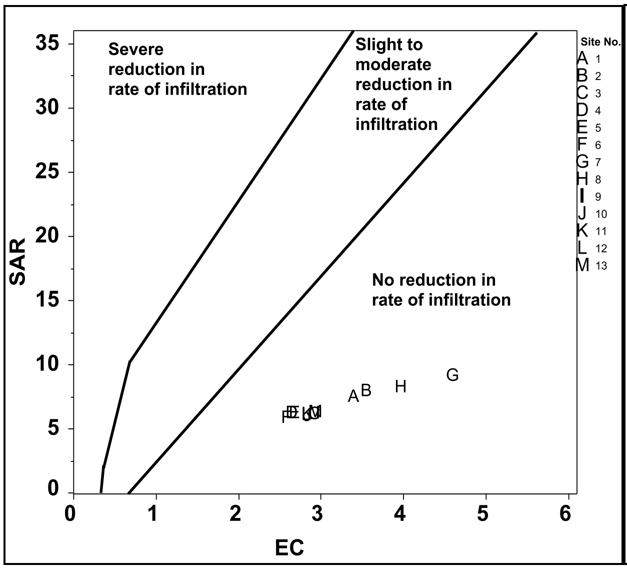


Figure 3 Water Infiltration Hazard

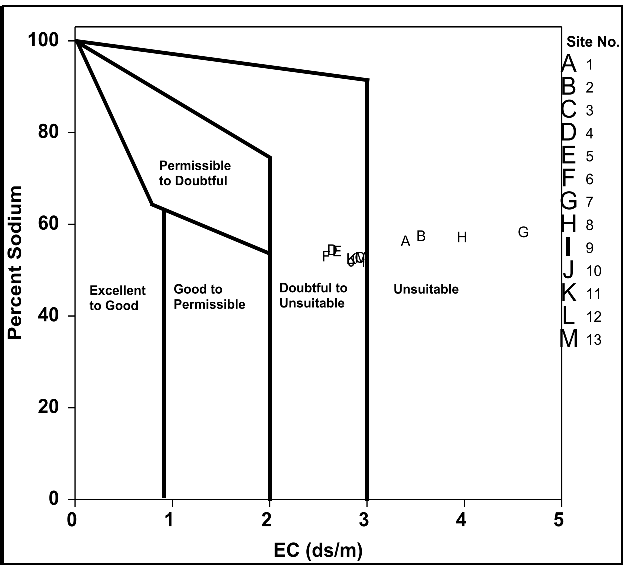
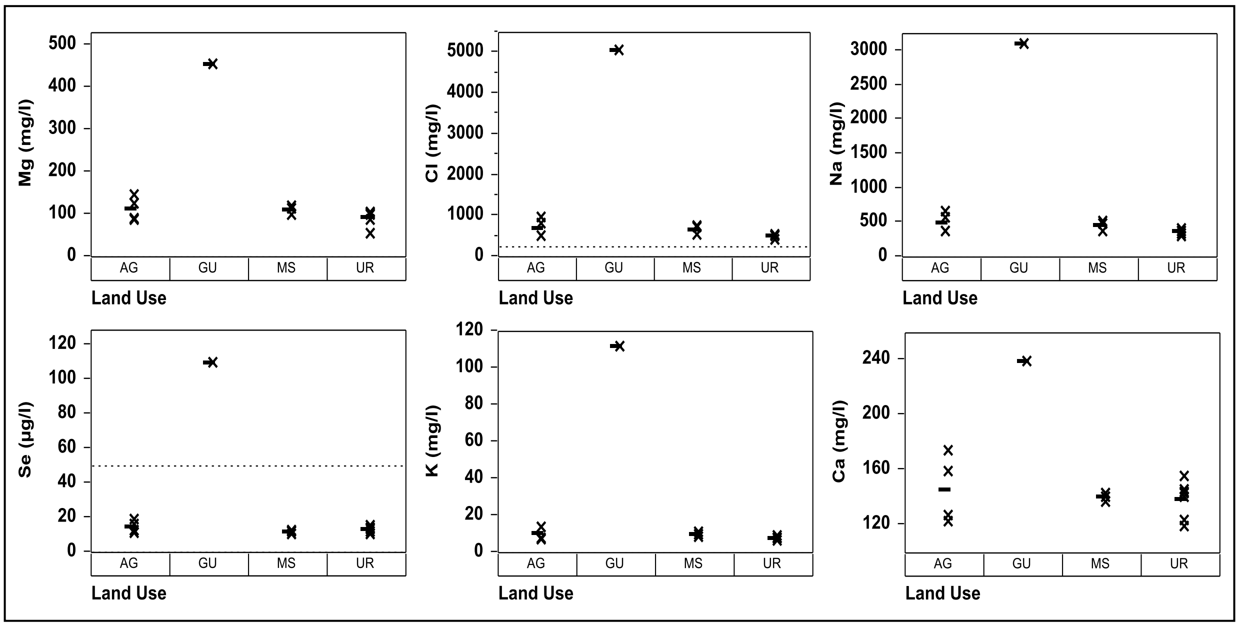


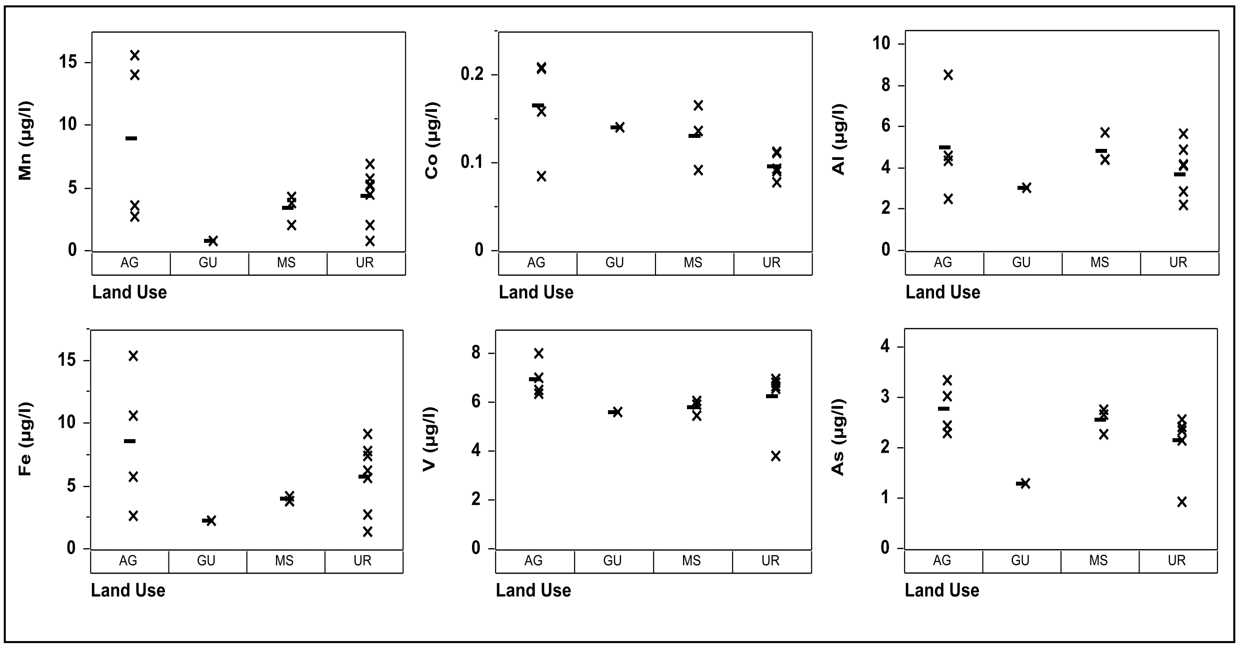
Figure 4 Percent Sodium Hazard

Appendix 1



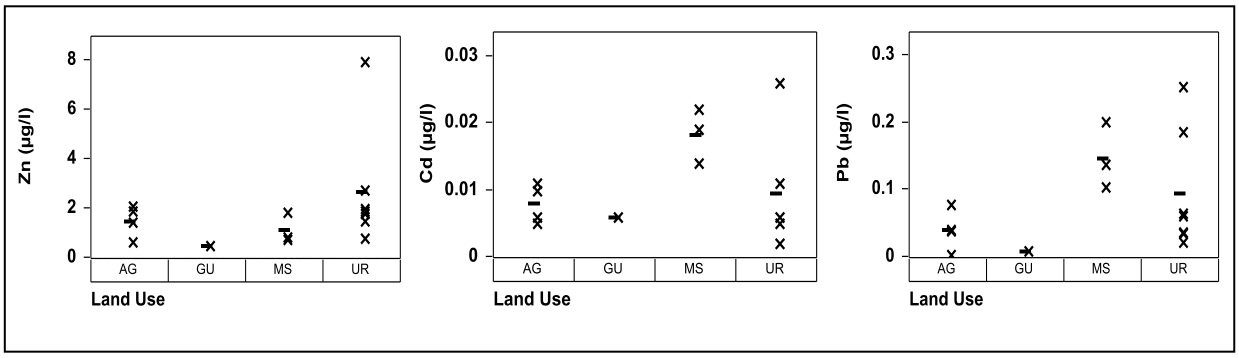
A- Concentration versus land use (cluster R1). The middle horizontal lines represent the mean concentration while the dotted horizontal line represents MCL. Land use: Agricultural (AG), Arabian Gulf (GU), marshlands (MS), and urban (UR)

Appendix 1 (continuation)

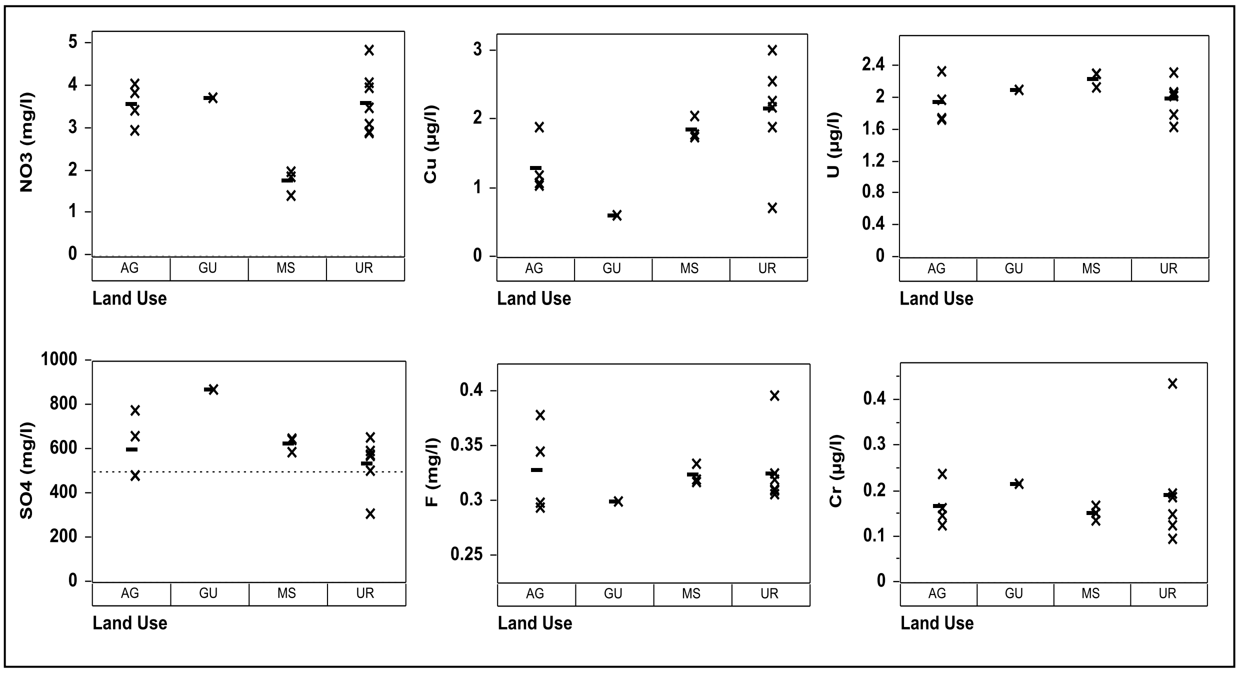


B- Concentration versus land use (cluster R2). The middle horizontal lines represent the mean concentration. Land use: Agricultural (AG), Arabian Gulf (GU), marshlands (MS), and urban (UR)

Appendix 1 (continuation)



C- Concentration versus land use (cluster R3). The middle horizontal lines represent the mean concentration. Land use: Agricultural (AG), Arabian Gulf (GU), marshlands (MS), and urban (UR)



D- Concentration versus land use (cluster R4). The middle horizontal lines represent the mean concentration while the dotted horizontal line represents MCL. Land use: Agricultural (AG), Arabian Gulf (GU), marshlands (MS), and urban (UR)

This academic article was published by The International Institute for Science, Technology and Education (IISTE). The IISTE is a pioneer in the Open Access Publishing service based in the U.S. and Europe. The aim of the institute is Accelerating Global Knowledge Sharing.

More information about the publisher can be found in the IISTE’s homepage:
http://www.iiste.org

CALL FOR JOURNAL PAPERS

The IISTE is currently hosting more than 30 peer-reviewed academic journals and collaborating with academic institutions around the world. There’s no deadline for submission. **Prospective authors of IISTE journals can find the submission instruction on the following page:** http://www.iiste.org/journals/ The IISTE editorial team promises to the review and publish all the qualified submissions in a fast manner. All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Printed version of the journals is also available upon request of readers and authors.

MORE RESOURCES

Book publication information: http://www.iiste.org/book/

Recent conferences: http://www.iiste.org/conference/

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digtial Library , NewJour, Google Scholar