Impact of Sewage Wastes on the Heavy Metal Content of Water, Soil, Plants and Fish in Wadi Hanifah Stream

Sulieman M. Al-Ogaily*, Ahmed M. Al-Harbi and Amanat Ali

Natural Resources and Environmental Research Institute,
KACST, Riyadh, Saudi Arabia

ABSTRACT. Disposal of sewage waste from the city of Al-Riyadh and adjacent areas is partially carried out through a flood channel known as Wadi Hanifah Stream. It is a permanent stream that flows from north (Badiah) to south (southeast of the city of Al-Hair) covering a distance of about 50 km. It carried only seasonal rainwater before the urbanization of the area. At present the main sources of water are sewage effluent, agricultural runoff, pumped shallow ground water from the city of Al-Riyadh and seasonal rainwater. Samples of water, soil, plants and fish were collected from different locations outside the boundaries of the city of Al-Riyadh. The water quality and the heavy metals (Ag, Ba, Cd, Co, Cr, Cu, Fe, Pb, Ni and Zn) in these samples were studied. The pH of the water was overall alkaline (average 7.38). The water appeared to be very hard (mean value 879 mg/l) with high levels of total dissolved solids (average 1601 mg/l). The levels of dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) on the average were 4.50; 39.33 and 6.62 mg/l respectively. The amount of heavy metals in the water was lower than the amount in soil, plants and fish. The maximum concentration of heavy metals was found in the soil followed by plants and fish. Overall iron was found in the highest concentration, followed by barium, zinc, cobalt, copper, chromium and lead. Silver, cadmium and nickel showed the lowest concentrations. Highly positive correlation for various metals was observed between the water, soil, plants and fish. The results indicated that the heavy metal content of water, soil, plants and fish in the Wadi Hanifah Stream was within the acceptable limits and did not pose a high risk of accumulation at this stage. Based on the physical and chemical water quality parameters and heavy metal content of wastewater, it is concluded that it may be used for agricultural purposes.

Key Words: Wadi Hanifah, sewage wastes, heavy metals, environmental impact, water, soil, plant, fish.

***Correspondence:** Dr. S. M. Al-Ogaily, Natural Resources and Environmental Research Institute, _KACST, P.O. Box 6086, Riyadh 11442, Saudi Arabia. Tel: 966-1-488 3555; Fax: 966-1-481 3611; Email: alokaly@kacst.edu.sa

Introduction

Industrial and agricultural discharge and sewage effluent are considered to be the primary source of metal poisoning in fish and in aquatic habitats (El-Nabawai et al. 1987, Sorensen 1991, Abdel-Sabour et al. 1995). These environmental contamination sources release a mixture of toxic elements into aquatic ecosystems. Municipal sewage is often accompanied by trade waste; containing heavy metals, hydrocarbons and synthetic detergents. The presence of heavy metals in sewage sludge imposes serious limitations on their disposal practices, particularly their use as fertilizers in agriculture and forestry. Irrigation with sewage waste water has been reported to enrich the heavy metal content of soil, which can lead to increased uptake of these metals by plants and vegetables grown on them (Abasheeva and Revenskii 1995, Gadallah 1994, Szewczuk and Sugier 1996). The uptake of heavy metals is, however, highly variable and can not be predicted simply by measuring their content in the soil alone (Truby and Raba 1990). Monitoring the concentration of these toxic metals in sewage waste and effluent is of great significance in terms of their transfer to soil, plant and animal life with reference to human health problems. Loading of aquatic habitats with heavy metals can result in complex alterations of numerous teleostrophic levels (Sorensen 1991, Pillay 1992) and may adversely affect the physiological condition of fishes and other aquatic animals (Anderlini 1992). Panday *et al.* (1995) observed a significant correlation for various metals between the treated sewage pond water, soil, aquatic weed and fish samples.

Disposal of sewage wastes from the city of Al-Riyadh and adjacent areas is partially carried out through a flood-channel known as Wadi Hanifah Stream. It is a permanent stream that flows from north (Badiah) to south (southeast of the city of Al-Hair) covering a distance of about 50 km and carrying mainly seasonal rainwater prior to urbanization of Al-Riyadh (Fig. 1). At present the main sources of water are sewage effluent, agricultural runoff, pumped shallow ground water from the city of Al-Riyadh and seasonal rainwater. The treatment of water discharge is done from secondary level to raw sewage water disposal. Approximately 100 million m^3 of water is potentially available annually as wastewater (ADA 1990). The amount of wastewater is expected to increase proportionately with the rapid urbanization.

A luxuriant fauna and flora have developed in the main channel and on the banks of Wadi Hanifa Stream. A population of exotic *Tilapia* has also

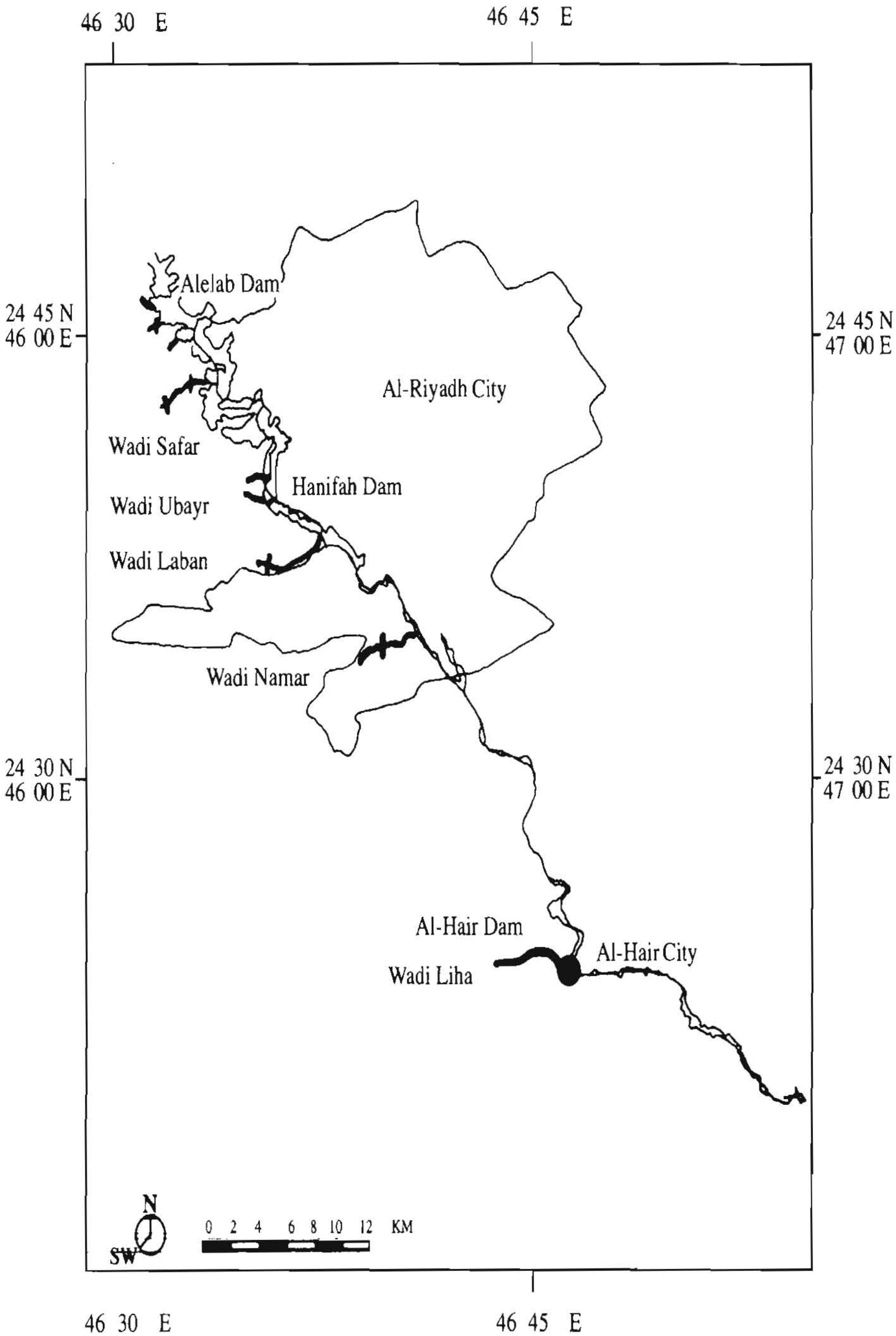

Fig 1 Map of Wadi Hanifah showing the flow of the Wadi Hanifah stream (Wadi means valley)

been established in the channel where the flow of water is moderate. Just before leaving the boundaries of the city of Al-Riyadh, the effluents from the Water Treatment Plant are also added to the mainstream. The main channel at this point is about 5m wide and 1m deep with moderately high rate of water flow that gradually slows down. Here castor oil plants are abundantly available on the sides of the channel. Patches of reed plants and *Typha domingensis* are also present. Filamentous algae are also abundantly available. As the stream flows further through the reed beds, a number of shallow lakes of considerable area with graveled bottoms are formed. Reed plants are established at the margins of the lakes. In pond areas both *Chara sp.* and *Juncus sp.* are abundantly available. *Typha domingensis* and filamentous algae become rare when a lake-like environment has been formed. Siddiqui and Al-Harbi (1995) reported that the effects of sewage pollution were apparent on the ecology of the Wadi Hanifah Stream. No information is, however, available on the heavy metal content of water, soil, plant and fish from Wadi Hanifa Stream as it leaves the boundaries of the city of Al-Riyadh. The present study was therefore conducted to investigate the environmental impact of land disposal of sewage wastes in Wadi Hanifah Stream with particular reference to heavy metal content of water, soil, plants and fish.

Materials and Methods

Triplicate samples of water, soil, plants and fish were collected from different sites of Wadi Hanifah Stream outside the boundary of the city of Al-Riyadh. The sites for sampling were selected between the place where the stream leaves the boundaries of the city of Al-Riyadh and finally ends up in a number of lakes. The samples were collected between 08.00 and 12.00 o'clock. Bottom samples were collected with the help of an Ekman Dredge. Plant samples (*Chara sp.*, *Juncus sp.* and filamentous algae) were collected by hand. Fish samples (*Oreochromis niloticus*) were collected with the help of seines, and cast and hand nets. The samples were analyzed for different parameters. Surface water temperature, pH and dissolved oxygen were determined on the site of the sample collection. For other water quality parameters, the samples were sealed in plastic bags and transported to the laboratory in an icebox and analyzed further using a Hatch DR/3000 Unit.

Mineral Analysis

The heavy metal contents were determined with the help of a SCIEX Elan Inductively Coupled Plasma Mass Spectrometer Model-250 (ICP/MS) using concentration calibration program (concal) for multi-element analysis. The equipment was attached to a 15BC 012B computer, a printer (Epson LQ 1050) and a plotter (Houston Instrument) for data acquisition, manipulation and storage. The samples were introduced using a peristaltic pump (Model Mini-Pulse-2 by Gibson). The operating conditions for the ICP / MS used for the analysis are given in Table 1.

Table 1 Operating conditions of Elan ICP-MS

R.F.- Incident Power	1.25 kW	Sample flow rate	1ml/min.
Plasma gas flow	13 L/min.	Resolution	low
Auxiliary gas pressure	1.4 L/min.	Threshold (Ions/Sec.)	1
Nebulizer gas pressure	39 psi	Counting precision	0.1%
Measurements per peak	5	Repeats per integration	5
Measurements (Lines/Sec.)	0.5		

Procedure

All chemicals used were of analytical grade. Double distilled deionized water was used throughout the experiment. The standard solutions for Ag, Ba, Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn were obtained from Ultra Scientific Company, USA. The working standards containing 0, 50, 100, 200, 300, 400, and 500 ppb were prepared from the stock solutions for constructing the calibration graphs (Fig. 2a and 2b). Samples of water, soil, plants and fish were prepared through the wet ashing process as described by Al-Swaidan (1991, 1994). The blanks were prepared similar to the samples. The blank, sample and standard solutions were aspirated into the Elan ICP / MS using concentration calibration (concal) and quantitative computer programs supplied by SCIEX for measuring element concentrations. The data so collected was subjected to statistical analysis, and correlations between the heavy metal content of water, soil, plants and fish were drawn (Snedecor and Cochran 1989).

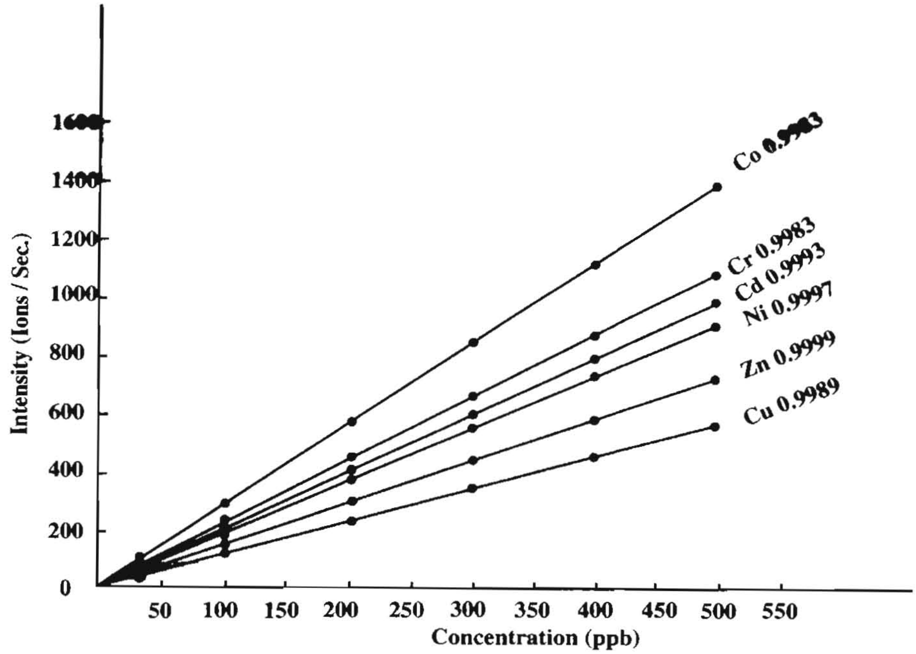

Fig 2a Calibration graph for standard solution

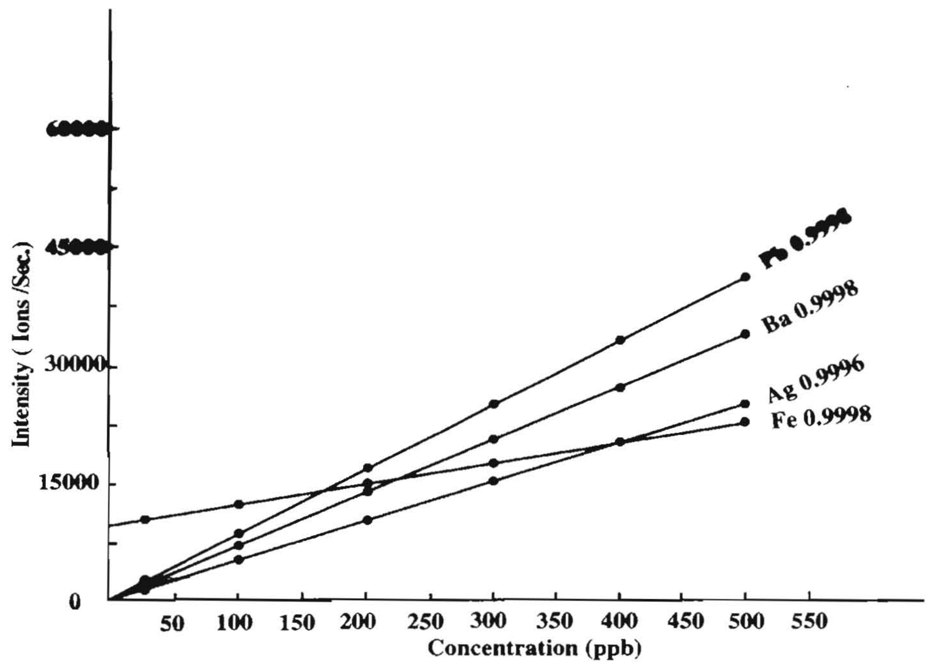

Fig 2b Calibration graph for standard solution

Results

The data on temperature and other water quality parameters of Wadi Hanifah Stream is given in Table 2. The results indicated that some variability existed in the samples collected at various points. The pH of the water was overall alkaline (average 7.38). The total alkalinity on average as $CaCO_3$ was 153.67 mg/l. The stream water appeared to be very hard (average 879 mg/l) with high levels of total dissolved solids (average 1601 mg/l). The values for Na, K, Ca, Mg, Cl and PO_4 also showed a wide range in the results. The levels for dissolved oxygen (DO); biochemical oxygen demand (BOD) and chemical oxygen demand (COD) on average were 4.50; 39.33 and 6.62 mg/l respectively.

Table 2 Water quality parameters of Wadi Hanifah stream (mg/l)

Parameters	Min. Max.	Mean ± S.E.
Temperature (°C)	18.4 - 26.6	21.43 ± 1.19
pH	7.2 - 2.6	7.38 ± 0.06
Alkalinity (as $CaCO_3$)	136.6 - 164.7	151.67 ± 4.94
Bicarbonates (HCO_3)	166.5 - 198.1	182.17 ± 5.08
Hardness	79.0 - 1120	879.0 ± 69.10
Total Dissolved Solids (TDS)	1146.0 - 2169	1601.0 ± 152.0
NH_3-N (Ammonia Nitrogen)	0.18 - 9.73	0.17 ± 0.09
NO_2-N (Nitrite Nitrogen)	0.13 - 0.41	0.15 ± 0.04
NO_3-N (Nitrate Nitrogen)	6.20 - 21.00	11.68 ± 2.49
Phosphate (PO_4)	0.10 - 9.50	4.79 ± 0.96
Chloride (Cl)	160.0 - 426.0	282.17 ± 37.0
Sodium (Na^+)	180.0 - 378.0	281.5 ± 27.5
Potassium (K^+)	11.0 - 16.0	13.50 ± 0.26
Calcium (Ca^{++})	160.0 - 345.3	133.30 ± 30.10
Magnesium (Mg^{++})	63.0 - 87.5	72.17 ± 3.29
Biological Oxygen Demand (BOD)	4.48 - 7.80	6.62 ± 0.44
Chemical Oxygen Demand (COD)	25.00 - 57.03	39.33 ± 4.70
Dissolved Oxygen (DO)	2.2 - 6.4	4.50 ± 0.64

The data on the heavy metal content of water, soil, plant and fish is given in Table 3. A large variability existed in the amount of metals present in soil, plant and fish samples. Overall the amount of metals in water was lower than the amounts in soil, plants and fish. In soil, iron was found in the highest concentration followed by barium, zinc, cobalt, copper, chromium and lead. Silver, cadmium and nickel showed the lowest concentrations. The highest concentration of barium was found in plant samples followed by soil and fish. The lead and nickel content in plant samples was higher than that found in soil and fish. The maximum amount of copper was found in soil samples, followed by fish. The copper content in plant samples was much less as compared to soil and fish. The maximum level of zinc was found in fish samples. Almost similar levels of cadmium were found in soil, plant and fish sample. The concentration of chromium was found to be the highest in plants, followed by soil and fish. Fig. 3 shows the concentration of various metals in water, soil, plant and fish samples. Highly positive correlation was observed for the heavy metal contents of water, soil, plant and fish samples (Table 4).

Table 3 Heavy metal content of water, soil, plants and fish (µmg/g)

Metal	Water $\overline{X} \pm$ S.E.	Soil $\overline{X} \pm$ S.E.	Plant $\overline{X} \pm$ S.E.	Fish $\overline{X} \pm$ S.E.
Ag	0.006 ± 0.001	0.370 ± 0.027	0.554 ± 0.046	0.590 ± 0.143
Ba	0.050 ± 0.011	21.70 ± 3.920	66.79 ± 1320	16.92 ± 1.09
Cd	0.003 ±0.001	0.094 ± 0.011	0.096 ± 0.022	0.108 ± 0.019
Co	0.012 ± 0.004	5.970 ± 0.772	5.967 ± 0.467	1.727 ± 0.157
Cr	0.010 ± 0.003	2.433 ± 0.522	2.640 ± 0.380	1.621 ± 0.230
Cu	0.008 ± 0.002	5.580 ± 0.617	0.544 ± 0.198	1.179 ± 0.295
Fe	0.212 ± 0.013	103.30 ± 14.80	51.82 ± 8.870	21.58 ± 4.87
Pb	0.003 ± 0.001	1.583 ± 0.291	2.399 ± 0.440	1.431 ± 0.092
Ni	0.006 ± 0.002	0.218 ± 0.090	2.657 ± 0.361	0.335 ± 0.023
Zn	0.114 ± 0.013	6.660 ± 1.760	8.022 ± 0.604	12.606 ± 0.629

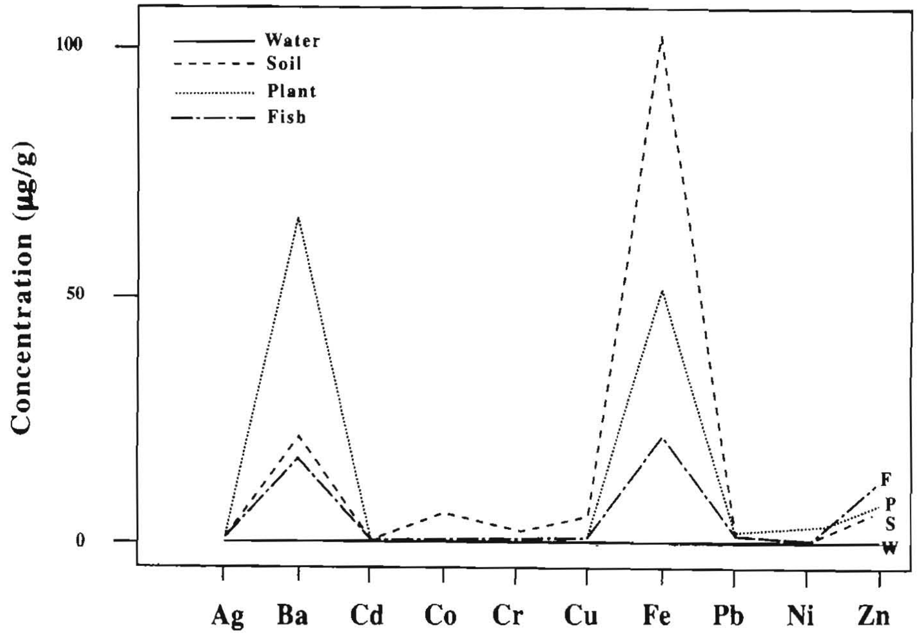

Fig 3 Heavy metals of water, soil, plants and fish

Table 4 Correlation between heavy metal content of water, soil, plants and fish

Parameters	Water	Soil	Plant
Soil	0.894	-	-
Plant	0.625	0.696	-
Fish	0.891	0.802	0.883

Discussion

The major parameters in assessing the impact of environmental factors on water quality are numerous, such as hardness, dissolved oxygen, pH, ammonia, nitrites, nitrates, pesticides, heavy metals etc. The levels of ammonia nitrogen, nitrite nitrogen and nitrate nitrogen showed a wide range between the minimum and maximum values. The un-ionized ammonia is toxic to fish, but the ammonium ion (NH_4^+) is not toxic

(Boyd 1981). The toxic level of ammonia for short term exposure usually lies between 0.6 to 2.0 mg/l (EIFAC 1973). The maximum preferred tolerable concentration is however considered to be lower than 0.1 mg/l (Tiews 1981). The suggested maximum levels for nitrite (NO_2^-) and nitrate (NO_3^-) for prolonged exposure in hard fresh water are 0.1 mg/l and below 100 mg/l respectively. In some of the water samples from Wadi Hanifah Stream higher levels of ammonia and nitrite nitrogen levels were observed, which could be detrimental for fish health and may reduce their growth and productivity. The limits of water quality, however, depend very much on the species cultivated. The levels of dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) on average were within tolerable limits. According to Swingle (1969) and Boyd (1981), warm water fishes can survive at dissolved oxygen levels as low as 1mg/l, but the growth is slowed down by prolonged exposure. Eels, carps and tilapia can tolerate lower concentrations of dissolved oxygen ranging from 3-4 mg/l. The optimum level, however, is higher than 5mg/l.

The amount of heavy metals in wastewater was less than the allowable effluent levels that apply to the wastewater at the end of an outfall and before discharge to coastal waters or to any other channel of wastewater, as given by the Meteorology and Environmental Protection Administration (MEPAS 1981-82). Comparing the metal concentrations in water, soil, plant and fish samples, it appeared that the metal concentration in fish flesh was lower than the concentrations in soil and plants but higher than in water indicating a higher biomagnification rate of heavy metal in fish. Our results agree with the findings of Lasheen (1987), who reported that all metals were more concentrated in fish muscle than in Nile water. Irrigation with sewage waste water has been reported to enrich the heavy metal content of soil, which can lead to increased uptake of these metals by plants grown on them (Abasheeva and Revenskii 1995, Gadallah 1994, Szewczuk and Sugier 1996). The presence of heavy metals also considerably deteriorates the natural biotic communities of the aquatic system (Adams *et al.* 1981). The suspended matter mainly acts as a transport pathway for these metals. The dissolved oxygen content and oxidation-reduction conditions control to a large extent the amount and type of metal ions. Some aquatic weeds, e.g., duckweed, a tiny aquatic plant, have not only shown a greater efficiency in treating domestic wastes but also act as a complete food for fish (Journey *et al.* 1992). The introduction of such aquatic plants will be of great interest in improving the ecology of Wadi Hanifah Stream. Our results are also in line with the findings of Panday *et al.* (1995), who observed a significant correlation of various metals in water, soil, aquatic weed and fish samples, between the treated sewage ponds. The results indicated that the water quality parameters and heavy metal contents in the Wadi Hanifah Stream water were within the permissible safe limits for use of this wastewater for agricultural purposes. The amount of heavy metals found in the soil, plant and fish samples did not pose a high risk of accumulation of these metals at this stage.

Acknowledgements

We wish to express our thanks to King Abdulaziz City for Science and Technology (KACST) for funding this research. We are also thankful to Dr. H. M. Al-Swaidan and his laboratory staff, Department of Chemistry, College of Science, King Saud University, Riyadh, Saudi Arabia for their help and cooperation in the analysis of heavy metals on ICP / MS and for reviewing the manuscript.

References

Abasheeva, N.E. and Revenskii, B.A. (1995) Bio-productivity of sown grasses, contents of biophilic trace elements and lead as a result of irrigation with sewage, *Agroklimiya* **4**: 59-64.

Abdel-Sabour, M.F., Ismail, A.S. and Abu-Naga, H. (1995) Environmental impact of Cairo sewage effluent in El-Gabal El-Asfer Farm, *Egyptian J. Soil Sci.* **35**: 225-237.

ADA (1990) *Draft report of water resources management study,* Wadi Hanifah Development Program, Al-Riyadh Development Authority, 224pp.

Adams, T.G., Atchinson, G.J. and Vetter, R. G. (1981) The impact of an industrially contaminated lake on heavy metals and its effluents stream, *Hydrobiologia* **69**: 187-193.

Al-Swaidan, H.M. (1991) Determination of trace elements in drinking water for Riyadh Metropolitan area by Inductively Coupled Plasma Mass Spectrometry (ICP-MS), *Oriental J. Chem.* **7**: 148-153

Al-Swaidan, H.M. (1994) Determination of trace elements in Saudi Arabian soils by Inductively Coupled Plasma Mass Spectrometry (ICP-MS), *Commun. Soil Sci. Plant Anal.* **25**: 459-467.

Anderlini, V.C. (1992) The effect of sewage on trace metal concentrations and scope for growth in *Mytilus edulis aoteanus* and *Perna canaliculus* from Wellington Harbour, New Zealand, *In:* **Batley, G.E. (ed.).** *Trace Metals in Aquatic Environment* **125**: 263-288.

Boyd (1981) *Water Quality in Warmwater Fish Ponds,* Agricultural Experiment Station, Auburn University, Auburn, Alabama, USA, 359pp.

EIFAC (European Inland Fisheries Commission) (1973) Water quality criteria for European fresh water fish. Report on ammonia and inland fisheries, *Water Res.* **7**: 1011-22.

El-Nabawi, A., Heinzow, B. and Kruse, H. (1987) As, Cd, Cu, Pb, Hg and Zn in fish from Alexandria region, *Egypt. Bull. Environment Contam. Toxicol.* **39**: 889-892.

Gaddallah, M.A.A. (1994) Effects of industrial and sewage waste waters on the concentration of sewage carbon, nitrogen and some mineral elements in sunflower plants, *J. Plant Nutrition* **17**: 1369-1384.

Journey, W.K., Paul, S. and Spira, W. (1992) *Duckweed Aquaculture – A new aquatic farming system for developing countries,* The World Bank Emena Technical Department, Agriculture Division, 85-90 pp.

Lasheen, M.R. (1987) The distribution of trace metals in Aswan High Dam Reservoir and river Nile ecosystems, *In:* **Hutchinson, T.C.** and **Meema, K.M. (eds.)** *Lead, Mercury, Cadmium and Arsenic in the Environment,* Published on behalf of SCOPE and ICSU by John Wiley & Sons, Chichester, New York. 235-254 pp.

MEPA (1981-82) *Environmental Protection Standards (General Standards) Document No. 1409-01,* Meteorology and Environmental Protection Administration (MEPA), Ministry of Defense and Aviation, Kingdom of Saudi Arabia, (1402 H) 17 pp.

Panday, B. K., Sarkar, U.K., Bhownik, M.L. and Tripathi, S.D. (1995) Accumulation of heavy metals in soil, water, aquatic weed and fish samples of sewage fed ponds, *J. Environmental Biology* **16**: 97-103.

Pillay, T.V.R. (1992) *Aquaculture and the Environment,* Fishing News Books, Osney Mead, Oxford OX2 0EL, England, 189 pp.**Siddiqui, A.Q. and Al-Harbi, A.H.** (1995) A preliminary study of the ecology of Wadi Hanifa Stream with reference to animal communities, *Arab Gulf J. Scient. Res.* **13**: 695-717.

Snedecor, G.W. and Cochran, W.G. (1989) *Statistical Methods,* 8th Edition, The Iowa State University Press, Ames, Iowa, USA.

Sorensen, E.M.B. (1991) *Metal Poisoning in Fish,* CRC Press, Boca Raton, USA 364 pp.

Szewczuk, C. and Sugier, D. (1996) Effect of application of different rates of municipal sewage on the microelement content of the above ground parts and roots of fodder cabbage, *Zeszyty- Problemowe-Postepow-Nawk-Rolniczych* **434**: 285-290.

Swingle (1969) *Methods of analysis for waters, organic matter and pond bottom soils used in fisheries research,* Auburn University, Auburn, Alabama, USA, 119pp.

Tiews, K. (1981) *Aquaculture in heated effluents and recirculation systems,* Vol. 1. Schriften der Bundesforschungsanstalt für Fischerei, Hamburg, 59-61.

Truby, P. and Raba, A. (1990) Schwermetalaufnahme von Gartenpflanzen der Freiburger Rieselfelder, *Agribiological Res.* **43**: 139-146.

Received 27/9/1999
in revised form 11/04/2000

Arab Gulf J. Scientific Res., 17 (3), pp 382-395 (1999)

محتويات المعادن الثقيلة في مياه وتربة ونبات وأسماك وادي حنيفة

سليمان بن محمد العقيلي ، أحمد بن حامد الحربي ، آمانت علي.

مدينة الملك عبدالعزيز للعلوم ،التقنية ، معهد بحوث الموارد الطبيعية والبيئة

المستخلص: إن وادي حنيفة الذي يمتد بطول حوالي 50 كلم من منطقة البديعة شمالاً إلى منطقة الحائر جنوباً، يعتبر أساساً مجرى لمياه الأمطار أصبح مجرىً دائماً لكميات كبيرة من المياه نتيجة تعديات وتسربات مياه الصرف الصحي لمدينة الرياض، تسربات مياه الزراعة، ضخ المياه السطحية بالإضافة إلى مياه الأمطار. تم جمع عينات من تلك المياه، التربة، النبات ،السمك من مناطق مختلفة من الوادي وذلك لتحديد جودة المياه، وكذلك لدراسة تراكيز المعادن الثقيلة التالية (الفضة، الباريوم، الكاديوم، الكوبالت، الكروميوم، النحاس، الحديد، الرصاص، النيكل، الزنك).

وأوضحت نتائج الدراسة إن تركيز تلك المعادن في الماء أقل منها في التربة والنبات والسمك. كما وجد أن أعلى التراكيز في التربة، النبات، السمك على التوالي، ،إن الحديد أعلى التراكيز يتبعه على التوالي الباريوم، الزنك، الكوبالت، النحاس، الكروميوم، الرصاص. ،أقلها الفضة الكاديوم والنيكل.

من تلك النتائج يتبين إن تراكيز تلك المعادن الثقيلة في المياه، التربة، النبات، السمك تعتبر ضمن الحدود المسموح بها ولا تشكل ترسباتها خطراً في هذه المرحلة كما إن خواص المياه الكيميائية ،الفيزيائية تعتبر مقبولة للإستخدامات الزراعية.