Concentration of Heavy Metals in underground water wells in Gharian district, Libya

Emhemmed Alhibshi, Khadija Albriky, and Abulnabi Bushita

Abstract— The study was undertaken to assess the status of water quality in the urban areas of Gharian district, northwestrn Libya. All the samples were analyzed for four physicochemical parameters such as total hardness, pH, nitrate and sulfate and twelve heavy metals, Al, Ba, Se, Hg, Cd, Cu, Cr, Fe, Mn, Ni, Pb, and Zn using standard procedures. The analysis indicated that concentrations of the metal were mostly far below the maximum allawable concentration. However, the concentration of Ni in some of the water samples were relatively high when compared to the Libyan and International standards values. Relatively high concentrations of Se had been detected in all samples. The results showed that other parameters differ form each sample. Total hardness, nitrate and sulfate concentration of all samples were higher than the International standards. The pH of all analyzed samples was within the allowable limit.

Keywords— Groundwater, wells, Heavy metals, Gharian.

I. Introduction

WHEN rain falls to the ground, the water does not stop moving. Some of it flows along the land surface to streams or lakes, some is used by plants, some evaporates and returns to the atmosphere and some seeps underground, into pores between sand, clay and rock formations called aquifers [1]. Water moves through aquifers much like a glass of water poured onto a pile of sand. Many communities obtain their drinking water from aquifers. Water suppliers drill wells through soil and rock into aquifers to reach the ground and supply the public with drinking water. Many homes also have their own private wells drilled on their property to tap this supply [2]. Unfortunately, the ground water can become contaminated by human activity. These chemicals can enter the soil and rock, polluting the aquifer and eventually the well [1].

Due to the importance of water which is the lifeblood of the environment, essential to the survival of all living things : plant, animal and human, it is important to maintain it clean and unpolluted. Water covers 71% of the earth's surface and makes up 65 % of our bodies. water is undoubtedly the most precious natural resource that exists on our planet [3] and [4]. Without the seemingly invaluable compound comprised of hydrogen and oxygen, life on Earth would be non-existent: it is essential for everything on our planet to grow and prosper. Everyone wants clean water-- to drink, for recreation, and just to enjoy looking at [5]. If water becomes polluted, its loses its value to us economically and aesthetically, and can become a threat to our health and to the survival of the fish living in it and the wildlife that depends on it [6] and [7].

A major environmental concern is the depletion of underground water as a result of overuse in agricultural developments, causing salinity and sea-water penetration into the coastal aquifers [8]. The Man-made River Project, currently under development to transport water from large aquifers under the Sahara Desert to coastal cities, is the world's most extensive water supply project. Another significant environmental problem in Libya is water pollution [8] and [9]. The combined impact of sewage, oil byproducts, and industrial waste threatens the nation's coast and the Mediterranean Sea generally. In the past three decades, the water resources in Libya had a high priority in its development. This was necessary to meet the water requirements of the ever increasing population growth, and the huge demands from agricultural, domestic, and industrial sectors [8]. The water we use is taken from lakes and rivers, and from underground (groundwater); and after we have used it-- and contaminated it-- most of it returns to these locations. When toxic substances enter lakes, streams, rivers, oceans, and other water bodies, they get dissolved or lie suspended in water or get deposited on the bed [10]. This results in the pollution of water whereby the quality of the water deteriorates, affecting aquatic ecosystems. Pollutants can also seep down and affect the groundwater deposits [11]. The used water of a community is called wastewater, or sewage. If it is not treated before being discharged into waterways, serious pollution is the result. Historically, it has taken humanity quite a bit of time to come to grips with this problem. Water pollution also occurs when rain water runoff from urban and industrial areas and from agricultural land and mining operations makes its way back to receiving waters (river, lake or ocean) and into the ground [9].

The main goal of this paper is to determine the levels/concentration of some of the physicochemical parameters and heavy metals (As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn) in underground drinking water in different parts of the Gharian district, Northwestern Libya and, to

Emhemmed Alhibshi is with Faculty of Science, Aljabel Algharbi Universty, Libya (corresponding author's phone: +218913706966; e-mail: ehebshi@yahoo.com).

Khadija Albriky is with Faculty of Education, Aljabel Algharbi Universty, Libya (e-mail: khadija_albriky@yahoo.com).

Abulnabi Bushita is with Faculty of Science, Aljabel Algharbi Universty, Libya (e-mail: mhensheri@yahoo.com).

compare the values with the national and international organization (like WHO) recommended drinking water standards.

II. DESCRIPTION OF THE STUDY AREA

The study was carried out in Gharian district. Gharian is located in northwestern Libya about 80 kilometers (50 miles) south of Tripoli in the Nafusa Mountains (Figure 1). With an estimated area of 4,660 square kilometers, this region has an estimated populations of 161,408.

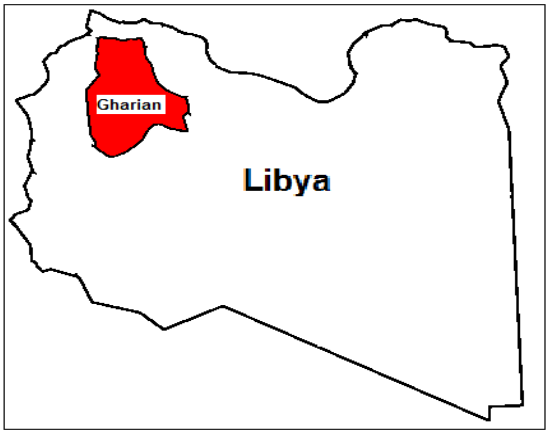


Figure 1: Figure 2. Location of Gharian District

III. MATERIAS AND METHODS

The field work was carried out during autumn 2010 (October-November). Different wells were chosen from different areas from Gharian district: Alfogha (S1), Seedi Intat (S2), Sagaif (S3), Taghasat (S4), Wadi asania (S5), Baderten (S6) and Buzain (S7), two liters samples from each well were taken directly before storage. Groundwater samples were collected from a total number of 7 tube wells. The depth of the tube wells ranged between 160 and 180m. Heavy metals (Al, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se and Zn) analysis was done at analytical laboratory of Libyan Petroleum Institute using ICP Optical emission spectrometry (ICP-OES), Groundwater pH was measured using pH-meter TEMA International. The total hardness is conventionally calculated as calcium carbonate, even if it is due to calcium sulphate, magnesium carbonate or any other polyvalent metal salt, nitrate and sulfate were determined using Portable Datalogging Spectro-photometer/HACGDR/2010, [13] and [14].

IV. RESULTS

The results of heavy metal analysis of Gharian district samples are shown in Table (1). The analysis indicated that concentrations of the elements were mostly far below the maximum allowed concentration. However, the concentration of Ni in some of the water samples were relatively high (largest value, 0.045 mg/L) when compared to the Libyan and International standards values (0.02 mg/L). Relatively high concentrations of Se had been detected in all samples where the highest was in sample 2. The other heavy metals concentrations were found to be within the prescribed International limits. The concentrations of heavy metals: Al, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se and Zn in the drinking water samples analyzed are presented in table 1. Highest heavy metal concentration was found for Zinc (0.173 mg/L) in water sample from Baderten (S6). Levels of Aluminum, Cadmium, Chromium, Copper, Mercury and Lead were below the detection limit in all the samples.

TABLE I
CONCENTRATION OF HEAVY METAL (MG/L) IN DRINKING WATER SAMPLES

Metal	S1	S2	S3	S4	S5	S6	S7
Al	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Ba	0.049	0.100	0.097	0.065	0.132	0.023	<0.0003
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.008
Cu	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Fe	0.089	<0.002	<0.002	0.010	0.003	0.011	0.008
Hg	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mn	0.024	<0.0003	<0.0003	0.001	<0.0003	<0.0003	<0.0003
Ni	0.037	0.045	0.044	0.024	0.035	0.012	<0.010
Pb	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Se	0.038	0.058	0.040	0.032	0.029	0.022	0.042
Zn	0.121	<0.001	<0.001	0.024	0.080	0.173	<0.001

As shown in Table (2), the concentration of nitrate in all samples were higher than Libyan and International standards, where the highest were with S3 and S4 respectively. Sulfate concentration in S1 and S3 were higher than International standards, it was for S1 and S3 1800 and 550 mg/l respectively. The pH of all analyzed samples was within the allowable limit. Total hardness of all samples were higher than International standards.

TABLE II
ANALYSIS OF WELL WATER (MG/L) IN GHARIAN DISTRICT

Parameter	S1	S2	S3	S4	S5	S6	S7
Total hardnes	1620	636	692	760	696	687	711
Nitrate	111.6	129.2	114.3	198.5	138.4	103.7	122.9
Sulfate	1800	252	550	380	290	323	296
PH	7.763	7.703	7.293	7.363	7.293	8.083	7.603

The other analyzed ions agreed with Libyan and International standards. Total hardness of all samples were higher than International standards.

V. DISCUSSIONS

Ground water usually affected by the nature of the rocks, industrial and mining activities and underground reservoir, [15]. The heavy metals are common air pollutants, being

emitted mainly as a result of various industrial activities. Although the atmospheric levels are low, they contribute to the deposition and build-up in soils. Heavy metals are persistent in the environment and are subject to bioaccumulation in food-chains. Table (3) shows Libyan and International standards for the analyzed parameters.

TABLE III
LIBYAN AND INTERNATIONAL STANDARDSVFOR THE ANALYZED PARAMETERS

Parameter	International Standards	Libyan Standards
pH	6.5– 8.5	6.5– 8.5
Total hardness	500	500
Sulfate	250	400
Nitrate	50	45
Al	0.2	0.2
Ba	1.0	1.0
Cd	0.005	0.005
Cr	0.05	0.05
Cu	2.0	1.0
Fe	0.2	0.1
Hg	0.001	0.001
Mn	0.05	0.05
Ni	0.02	0.02
Pb	0.05	0.05
Se	0.01	0.01
Zn	5.0	5.0

Because aluminium competes with calcium for absorption, increased amounts of dietary aluminium may contribute to the reduced skeletal mineralization (osteopenia) observed in preterm infants and infants with growth retardation. In very high doses, aluminium can cause neurotoxicity, and is associated with altered function of the blood–brain barrier. Cadmium is highly toxic and responsible for several cases of poisoning through food. Small quantities of cadmium cause adverse changes in the arteries of human kidney. It replaces zinc biochemically and causes high blood pressures, kidney damage etc [16]. It interferes with enzymes and causes a painful disease called Itai-itai. Contamination of drinking water with high level of copper may lead to chronic anemia [17]. Elemental (metallic) mercury and its compounds are toxic and exposure to excessive levels can permanently damage or fatally injure the brain and kidneys. Elemental mercury can also be absorbed through the skin and cause allergic reactions. Ingestion of inorganic mercury compounds can cause severe renal and gastrointestinal toxicity. Water-soluble barium compounds are poisonous. Lead enters the human body in many ways. It can be inhaled in dust from lead paints, or waste gases from leaded gasoline. It is found in trace amounts in various foods, notably in fish, which are heavily subjected to industrial pollution. In this study, copper, aluminum, cadmium, mercury and lead were not detected in all the sampling areas, presumably due to the low related industrial and mining activities in the sampling areas. Since the Libyan and International standards maximum admissible limit of those metals in drinking water was well above the method detection limit; there was no health related risk due to the presence of mentioned metals in drinking water of the study areas [17] and [18].

In this study, all samples contain lower barium than Libyan and International standards maximum admissible limit (1.0 mg/L). At low doses, barium ions act as a muscle stimulant, whereas higher doses affect the nervous system, causing cardiac irregularities, tremors, weakness, anxiety, dyspnea and paralysis. Lead is the most significant of all the heavy metals because it is toxic, very common [19] and harmful even in small amounts.

Chromium is an essential micronutrient for animals and plants, and is considered as a biological and pollution significant element. Generally the natural content of chromium in drinking water is very low ranging from 0.01 to 0.05 mg/L except for the regions with substantial chromium deposits [20]. Chromium in excess amounts can be toxic especially in the hexavalent form. Sub chronic and chronic exposure to chromic acid can cause dermatitis and ulceration of the skin. Long-term exposure can cause kidney, liver, circulatory and nerve tissue damages. Chromium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high level of chromium [21] and [22]. In this study, chromium was not detected in only one of the sampling areas: Buzian (S7). In the other areas, Chromium level was below 0.002 mg/L. Buzian (S7), which are above the National and International maximum admissible limit of Cr in drinking water (0.05 mg/L).

In the areas studied, iron content varies from 0.002 - 0.089mg/L which was within the limit of Libyan and International standards. Iron is the fourth most abundant element by mass in the earth's crust. In water, it occurs mainly in ferrous or ferric state [23]. Iron in surface water generally present is ferric state. It is an essential and non-conservative trace element found in significant concentration in drinking water because of its abundance in the earth's crust. Usually, iron occurring in ground water is in the form of ferric hydroxide, in concentration less than 500 μg/L [24]. The shortage of iron causes disease called "anemia'' and prolonged consumption of drinking water with high concentration of iron may lead to liver disease called as haermosiderosis [16] and [25].

Manganese level varies from below detection in samples from to 0.024mg/L. The maximum allowable limit for manganese is 0.05 mg/L and none of the drinking water samples analyzed show above the limit. Well water rich in manganese can be the cause of excessive manganese intake and can increase bacterial growth in water. Symptoms of toxicity mimic those of Parkinson's disease (tremors, stiff muscles) and excessive manganese intake can cause hypertension in patients older than 40. Significant rises in manganese concentrations have been found in patients with

severe hepatitis and posthepatic cirrhosis, in dialysis patients and in patients suffering heart attacks [26].

Nickel is a silver-white metal found in the earth's crust that is used to produce steel, nickel-cadmium batteries, heating fuel, nickel plating and ceramics. Certain amounts of nickel are useful to the human body, but too much nickel can be toxic. About 10% of women and 2% of men are highly sensitive to nickel. The most serious effects occur when nickel is inhaled. This can lead to increased risk of respiratory infections, asthma and sinus problems [27]. The maximum allowable limit for Ni in drinking water is 0.02 mg/L. In this study, Nickel was detected in six of the sampling areas with concentration range 0.012 mg/L in water samples from Baderten (S6) 0.045 mg/L from Seedi Intat (S2).

In the areas studied, selenium content varies from 0.022 to 0.058 mg/L which was higher than the limit of Libyan and International standards (0.01 mg/L). Selenium, which is nutritionally essential for humans, is a constituent of more than two dozen selenoproteins that play critical roles in reproduction, thyroid hormone metabolism, DNA synthesis, and protection from oxidative damage and infection [28].

Zinc is one of the important trace elements that play a vital role in the physiological and metabolic process of many organisms. Nevertheless, higher concentrations of zinc can be toxic to the organism [29]. It plays an important role in protein synthesis and is a metal which shows fairly low concentration in surface water due to its restricted mobility from the place of rock weathering or from the natural sources [16]. In this study, maximum level of Zinc was found in water sample 6 (S6) with 0.173 mg/L which is below maximum allowable limit.

Analysis showed that the pH of all analyzed samples was within the allowable limit. High concentrations of nitrate were found in most of the samples reaching 198.5mg/l in S4. Nitrate comes into water supplies through the nitrogen cycle rather than via dissolved minerals. It is one of the major ions in natural waters [30]. Most nitrate that occurs in drinking water is the result of contamination of ground water supplies by septic systems, feed lots, and agricultural fertilizers. The concentrations of nitrate in Gharian district samples were High which is due to the nature of the rocks and under ground reservoir which could be contaminated by the several mentioned ways [31]. Sulfate occurs in almost all natural water. In the analyzed samples, most sulfate compounds originate from the oxidation of sulfite ores, the presence of shales, and the existence of industrial wastes. Sulfate is one of the major dissolved constituents in rain [32]. High concentrations of sulfate in drinking water causes a laxative effect when combined with calcium and magnesium, the two most common components of hardness, high sulfate in S1 and S3 mostly due to mentioned causes [32] and [33].

The total hardness of a water represents primarily the total concentration of calcium and magnesium ions expressed as calcium carbonate [34]. Hardness may range from zero to hundreds of parts per million, depending on the origin of the water or the treatment to which the water has been subjected, Senior [35]. The terms "hard water" and "soft" water may be defined within very specific concentration ranges as shown in the following Table IV.

TABLE IV
ASSESSMENT OF WATER

$mg\ l^{-1}\ (CaCO_3)$	Assessment
0-50	soft
50-100	moderately soft
100-150	slightly hard
150-200	moderately hard
200-300	hard

According to this classification, the total hardness of all samples are very hard, total hardness and water quality are connected. Hard water is safe for drinking, cooking, and other household uses, but it can cause problems [11]. Total hardness and water quality are connected in their effect on appliances that use water such as dishwashers and washing machines [18].

VI. CONCLUSION

The main goal of this paper was to assess the status of drinking water quality in urban areas of Gharian district, northwestern Libya, with special emphasis on trace heavy metals. The results show that concentrations of some heavy metals in some of samples are higher than the Libyan and International maximum allowable limit. This is an indication of pollution hazards and weak drinking water treatment practices in these areas which, in turn, have implications on the health of the people. In Gharian district or any where, Groundwater is stored in the voids, spaces and cracks between particles of soil, sand, gravel, rock or other materials. These cracks or space can include fractures, faults, bedding planes, solution channels (limestone formations), dissolution channels associated with more easily weathered material or other structural features such as bed planes or deformation in the bedrock due to folding. These materials form what is sometimes called the groundwater aquifer or reservoir. The study of ground water wells showed high concentration of some parameters such as nitrates, total hardness and sulfate in most of the samples. These concentrations differences between wells is due to the nature and components of the rocks holding water. High water contents of mentioned parameters need to be treated to be completely safe for drinking, cooking and also for other household uses generally.

REFERENCES

[1] Akoto, O & Adiyiah, J. 2007. Chemical analysis of drinking water from some communities in the brong ahafo region. International Journal of Environmental Science and Technology, 4(2):211-214. http://dx.doi.org/10.1007/BF03326276

[2] Gregoriadou, A., Delidou, K., Dermosonoglou, D., Tsoumparis, P., Edipidi, C & Katsougiannopoulos, B. 2001. Heavy metals in drinking water in Thessaloniki area, Greece. Proceedings of the 7th International

Conference on Environmental Science and technology, Aristotle University, Ermoupolis.
[3] Raiswell, R.W. e.a., (1980) Environmental Chemistry – The Earth-Air-Water Factory. London, Edward Arnold (Publishers) Ltd.
[4] NOHA NEWS; (1995) contaminated drinking water. Vol. XX, No. 3, pages 1-4.
[5] EPA Handbook, vol. 1 (1990) Ground Water and Contamination. USEPA, Office of Research and Development, Washington DC.
[6] Cox, P.A., (1991) The Elements – Their origin, abundance and distribution. Oxford, Oxford University Press.
[7] Emsley, J., (2003) Nature's Building Blocks – An A-Z guide to the elements. Reprinted with corrections. Oxford, Oxford University Press.
[8] Bakhbakhi and Salem (1999) Why the Great Manmade River Project? Conference proceeding, Managing non-renewable resources conference. Tripoli, Libya.
[9] Enghag, P., (2004) Encyclopedia of the Elements – Technical Data, History, Processing, Applications. Weinheim, WILEY-VCH Verlag GmbH & Co. KgaA.
[10] Rail, Chester D. (1989) Groundwater Contamination: Sources, Control, and Preventative Measures. Technomic Publishing Company, Inc., Lancaster,PA. pp.37-40
[11] Susan D. Richardson and Thomas A. Ternes (2005) Water Analysis: Emerging Contaminants and Current Issues, Anal. Chem. 77, 3807-3838. http://dx.doi.org/10.1021/ac058022x
[12] E. Greenberg ; L. S. Clesceri and A. D. Eaton (1992) Standard Methods for the Examination of Water and Waste water APHA,AWWA, and WEF. Washington.
[13] Clesceri, Lenore S., Arnold E. Greenberg, and Andrew D. Eaton, eds. (1998) Standard Methods For The Examination of Water and Wastewater, 20th ed. New York: American Public Health Association, American Water Works Association, and Water Environment Federation.
[14] Senior, L.A., (2009) Groundwater-quality Assessment, Pike County, Pennsylvania, U.S. Geological Survey Scientific Investigations Report 2009-5129.
[15] Mason, Chr., (2002) Biology of Freshwater Pollution. Fourth edition. Essex, Pearson Education Limited.
[16] Rajappa, B., Manjappa, S & Puttaiah, E.T. 2010. Monitoring of heavy metal concentration in groundwater of Hakinaka Taluk, India. Contemporary Engineering Sciences, 3(4):183-190.
[17] Acharya, G.D., Hathi, M.V., Patel, A.D & Parmar, K.C. 2008. Chemical properties of groundwater in Bailoda Taluka region, north Gujarat, India, viewed 23 June, 2010, <http://www.e-ournals.in/PDF/V5N4/792-796.pdf>.
[18] Greenwood, N.N. en Earnshaw, A., (2002) Chemistry of the Elements. Second edition. Oxford, Butterworth-Heinemann .
[19] Gregoriadou, A., Delidou, K., Dermosonoglou, D., Tsoumparis, P., Edipidi, C & Katsougiannopoulos, B. 2001. Heavy metals in drinking water in Thessaloniki area, Greece. Proceedings of the 7th International Conference on Environmental Science and technology, Aristotle University, Ermoupolis.
[20] Jayana, B.L., Prasai, T., Singh, A & Yami, K.D. 2009. Assessment of drinking water quality of madhyapur-thimi and study of antibiotic sensitivity against bacterial isolates. Nepal Journal of Science and Technology, 10:167-172.
[21] Hanaa, M., Eweida, A & Farag, A. 2000. Heavy metals in drinking water and their environmental impact on human health. International Conference on Environmental Hazards Mitigation, Cairo University, Egypt, pp. 542-556.
[22] Pandey, J., Shubhashish, K & Pandey, R. 2010. Heavy metal contamination of Ganga river at Varanasi in relation to atmospheric deposition. Tropical Ecology, 51(2):365-373.
[23] Ghulman, B.A., EL-Bisy, M.S & Ali, H. 2008. Ground water assessement of makkah al-mokarama. Proceedings of the 12th International Water Technology Conference, Umm Al-Qura University, Makkah, pp. 1515-1527.
[24] Oyeku, O.T & Eludoyin, A.O. 2010. Heavy metal contamination of ground water resources in a Nigerian urban settlement. African Journal of Environmental Science and Technology, 4(4):201-214.
[25] Bhaskar, C.V., Kumar, K & Nagendrappa, G. 2010. Assessment of heavy metals in water samples of certain locations situated around Tumkur, Karnataka, India', viewed 12 June, 2010, <http://www.indiaenvironmentportal.org.in/. /Assessment %20 of %20 heavy %20 metals %20 in %20 water %20 samples.
[26] Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile for Manganese (Update).* Draft for Public Comment. U.S. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1997.
[27] Aremu DA, Olawuyi J, Meshitsuka S, et al. 2002. Heavy metal analysis of groundwater from Warri, Nigeria. Int J Environ Health Res 12:261-267. http://dx.doi.org/10.1080/0960312021000001014
[28] Sunde RA. Selenium. In: Ross AC, Caballero B, Cousins RJ, Tucker KL, Ziegler TR, eds. Modern Nutrition in Health and Disease. 11th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2012:225-37
[29] Rajkovic, M.B., Lacnjevac, C.M., Ralevic, N.R., Stojanovic, M.D., Toskovic, D.V., Pantelic, G.K., Ristic, N.M & Jovanic, S. 2008. Identification of metals (heavy and radioactive) in drinking water by indirect analysis method based on scale tests. Sensors, 8:2188-2207. http://dx.doi.org/10.3390/s8042188
[30] WHO, (1998) Nitrate and nitrite in Drinking-water .Originally published in Guidelines for drinking-Water Quality" – Vol.2 .Geneva.
[31] Spalding, R.F., and M.E. Exner, (1993) Occurrence of Nitrate in Groundwater—A Review," Journal of Environmental Quality, 22, pp. 392-402. http://dx.doi.org/10.2134/jeq1993.00472425002200030002x
[32] Ramade, F., (1987) Ecotoxicology. Third edition. Chichester, John Wiley & Sons.
[33] Tchobanoglous, G. e.a., (2003) Wastewater Engineering – Treatment and Reuse, Metcalf & Eddy. Fourth edition, revised. New York, The McGraw-Hill Companies.
[34] William A. Wurts, (2005) Understanding Water Hardness, World Aquaculture, 24(1): 18.
[35] Kerister, T., (2010) "Marcellus Hydrofracture Flowback and Production Wastewater Treatment, Recycle, and Disposal Technologies", The Science of Marcellus Shale Conference at Lycoming College, Williamsport, PA.