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Research Article

Heavy Metals Concentrations in Drinking Water in Dongola and Merowe, Northern State, Sudan

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Abstract

The contamination of metals is a major environmental problem and, especially in the aquatic environment. Some metals are potentially toxic or carcinogenic even at very low concentration and are, thus, hazardous to human, if they enter the food -chain. This study aims to identify and determine the levels the heavy metals (HMs) in the River Nile in two town in the Northern State, Sudan, and other drinking water source. The water was analyzed in the Central Petroleum Laboratories, Khartoum, Sudan, using Inductively Coupled Plasma-Optical Emission Spectrometer ICP-OES 725 E) instrument to determine Zn, Pb, Cu, Co, Ni, Cd, Mo, Cr, Fe, Li, and Hg levels and compare their concentrations with the permissible levels (PLs), using the Complete Randomized Design (CRD) with three replications. The results from Dongola locality revealed the presence of high concentrations of Pb, Ni, Cd, and Fe in River Nile drinking water (RNW) samples (4.92, 16.535, 0.013 and 0.46 ppm, respectively), which are higher than WHO (2004) acceptable limits. The tap water (TW) samples reflected the presence of Pb, Ni, Cd, Cr, Fe and Hg at 5.985, 22.445, 0.013, 0.06, 0.485 and 0.003 ppm, respectively, which are again higher than the WHO (2004) acceptable limits. However, the underground water (UDW) samples showed the presence of Pb, Co, Ni, Cd, Cr and Hg at 4.145, 4.315, 20.25, 0.007, 0.07 and 0.002 ppm, respectively, which are also high. The results from Merowe Locality followed the same trend. High concentrations of Pb, Ni, Cd and Fe were detected in the RDW samples (4.7, 14.495, 0.0131 and 0.325 ppm, respectively); these levels were higher than those of WHO (2004) limits. The samples of TW in Merowe also showed presence of high levels of Pb, Ni, Cd, Fe and Hg. Their levels were 4.72, 18.33, 0.012, 0.37 and 0.002 ppm, following the same order. The UGW samples reflected the presence of high quantities of Pb, Co, Ni, Cd, Cr and Hg (2.84, 2.360, 18.635, 0.004, 0.055 and 0.002 ppm, respectively). It is concluded that all water sources in Dongola and Merowe Localities are not suitable for drinking and require urgent attention by the authorities.

Keywords: *Heavy Metals; Pollution; Contamination; Drinking Water; Sudan Northern State, Merowe, Dongolay*

Introduction

Heavy metals (HMs) are present in the environment in different forms, e.g. in solid phase, and in solution, as free ions, or absorbed to solid colloidal particles. The HM concentrations in the environment are attributed to natural sources and anthropogenic sources [1].

Currently, HMs are of environmental concern. They are dangerous as they tend to bio-accumulate in the food-chain/web; can be harmful to humans and animals. The HMs risk pose to human and animals health is provoked by their long-term persistence in the environment [2,3]. Since the beginning of human kind, HMs have been emitted and deposited in the environment [1,3]. Currently, anthropogenic inputs of metals are higher than the natural input, and this may pose a great threat to aquatic life in particular, and to the whole ecosystems in general [4]. In natural aquatic ecosystems, HMs occur in low concentrations. HMs contamination of the aquatic environment may lead to deleterious effects, which may be acutely or chronically toxic to aquatic life within the affected area [5].

The term HM is a general collection term applying to the group of metals and metalloids with an atomic density > 6 g/cm^3 [6]. Water pollutants include organic and inorganic chemicals, HMs, petrochemicals and microorganisms and may also occur in the form of thermal pollution and depletion of dissolved oxygen. Water pollution can come from single (point) sources or from larger and dispersed (non-point) sources. Point sources discharge pollutants at specific location through drain-pipes or sewer line into bodies of surface water. Nonpoint sources, e.g. runoff, are diffused and intermittent, and influenced by factors, e.g. land use, climate, hydrology, topography, native vegetation and geology. Common urban nonpoint sources include runoff from streets or fields; such runoff contains all sorts of pollutants, from HMs to chemicals and sediments. Rural source of nonpoint pollution are generally associated with agriculture, mining, or forestry [7].

Arsenic (As) is a known human carcinogen by both the inhalation and oral exposure routes. In humans exposed chronically by the oral route, skin tumors are the most common type of cancer. Ingestion also increases the risk of internal tumors, mainly of bladder and lung, and to a lesser extent, liver, kidney, and prostate [8]. Cu is toxic when concentrations exceed that of natural concentrations (< 0.05 µmol/L; [9,10]. Acute poisoning results from ingestion of excessive amount of Cu salt can lead to nausea, vomiting, stomachache and diarrhea and may produce death. At low concentration, Cu can result in anemia, gastrointestinal (GIT) disturbances, bone development abnormalities and death [11]. The effects of Pb are the same, whether it enters the body through breathing or swallowing. The main target for Pb toxicity is the nervous system (NS). Long-term exposure of adults to Pb at work has resulted in decreased performance in some tests that measure functions of the NS; may also cause weakness in fingers, wrists, or ankles. Pb exposure also causes small increases in blood pressure, particularly in middle-aged and older people, and may also cause anemia. At high levels of exposure, Pb can severely damage the brain and kidneys and ultimately Pb and Pb- compounds are reasonably anticipated to be human carcinogens, based on limited evidence from studies in humans and sufficient evidence from animal studies, and the US EPA has determined that lead is a probable human carcinogen [8]. Ni is moderately toxic to most species of aquatic plants, though it is one of the least toxic inorganic agents to invertebrates and fish. The major source of discharge to natural waters is municipal wastewater, followed by smelting and the refining of nonferrous metals. Drainage effluents are major contributors, due to high concentrations of Ni found in the discharges [12]. The most commonly reported adverse health effect associated with Ni exposure is contact dermatitis. After an individual becomes sensitized to Ni, dermal contact with a small amount of Ni or oral exposure to low doses of Ni can result in dermatitis [13]. Chronic exposure to Zn results in extensive deterioration of liver, kidneys, heart, and muscle. Chronic sub-lethal Zn concentration can also delay or inhibit the growth, sexual maturity and reproduction of the fish, and can also induce pathological and morphological abnormality in adult fish [14]. Taking too much Zn into the body through food, water, or dietary supplements can also affect health. The levels of Zn that produce adverse health effects are much higher than the Recommended Dietary Allowances (RDAs; 11 mg/day for men and 8 mg/day for women). Doses 10 - 15x higher than the RDA taken by mouth even for a short time, can cause stomach cramps, nausea, and vomiting. Ingesting high levels for several months may cause anemia, damage the pancreas, and decrease levels of HDL cholesterol [15]. When, too much Co is taken into the body harmful health effects can occur. Serious effects on the lungs, including asthma, pneumonia, and wheezing, been found in people exposed to 0.005 mg Co/m^3, while working with hard metal, a cobalt-tungsten carbide alloy [16]. Cr is carcinogenic to humans. Long-term exposure has been associated with lung cancer in workers exposed to levels in air that in the order of 100 to 1000 x higher than usually found in the environment [12]. The major effects of Cd -poisoning are experienced in the lungs, kidneys and bones. Acute effects of inhalation are bronchitis and toxemia in the liver [17,18]. Studies using animals indicate that long-term oral exposure to inorganic Hg salts causes kidney damage, effects on blood pressure and heart rate, and effects on the stomach. Results of several studies also suggest that reactions involving the immune system may occur in sensitive populations after swallowing inorganic Hg salts. Some animal studies report that NS damage occurs after long-term exposure to high levels of inorganic Hg [19,20]. Excess Fe in the body causes liver and kidney damage (hemochromatosis). Some Fe-compounds are suspect carcinogens [21]. Mo is generally considered to be of low human toxicity, and clinical or epidemiologic evidence of adverse effects is limited. Chronic exposure to very high levels may result in higher serum uric acid levels and a gout-like illness [22]. Along term inhalation, bioassay of molybdenum trioxide in mice yielded "some evidence" of carcinogenicity. One case-control study suggested a possible link between occupational exposure to Mo and lung cancer [22]. Although individual metals exhibit specific signs of their toxicity, the following have been reported as general signs associated with Cd, Pb, As, Hg, Zn, Cu and Al poisoning: GIT disorders, diarrhea, stomatitis, tremor, hemoglobinuria causing a rust-red color to stool, ataxia, paralysis, vomiting and convulsion, depression, and pneumonia, when volatile vapors and fumes are inhaled [23].

Objective of the Study

The objectives of the present study were to identify and determine the HMs levels in the River Nile and other drinking water sources in North Sudan (viz. Dongola and Merowe Localities) and compare them with the international levels.

Materials and Methods

Site of experiment

The study was carried out in Dongola and Merowe localities, Northern State. The state population is ca. 699,065.

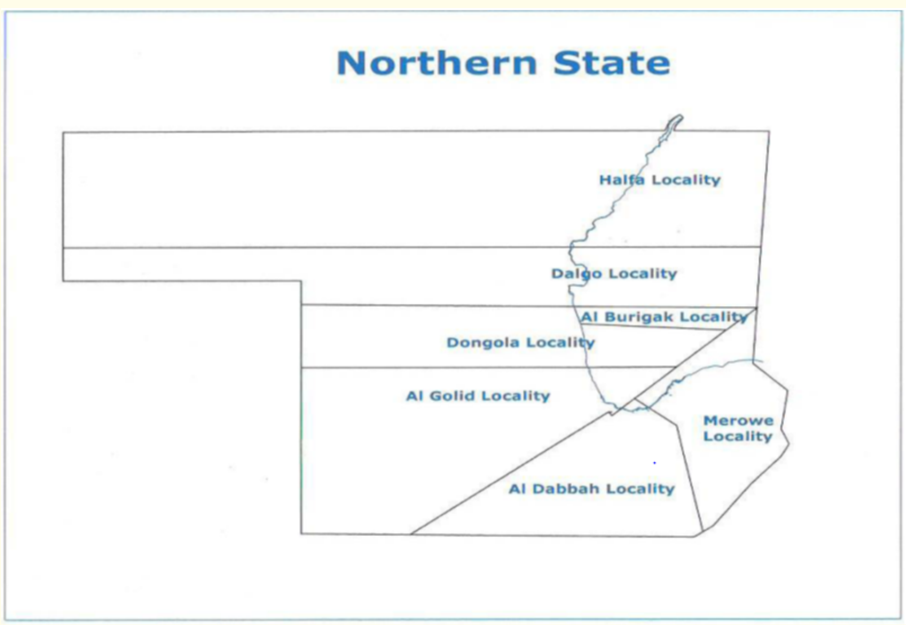

Figure: *Map of the River Nile State showing the River and the two studied localities (Dongola and Merowe).*

Methods

The laboratory work was meant to determine Zn, Pb, Cu, Co, Ni, Cd, Mo, Cr, Fe, Li and Hg levels in all sources of drinking water in Dongola and Merowe localities and compared them with the permissible levels (PL), using the Complete Randomized Designed (CRD) with three replications. The reported data was used to relate the detected concentrations of these HMs to the health conditions of citizens from the two localities.

Samples collection

Samples were collected from tap water (TW), underground water (UGW) and River Nile water (RNW). Three sample of each water source, from both localities, were taken randomly and this was repeated three times during the study period, labeled in plastic containers (total of 81 samples). These samples were analyzed to determine the concentration of the above-mentioned HMs by Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES).

Reagents, Instruments and Glassware

The reagents required for this work were as follows: HNO_3 and deionized water. The materials used were sterile water, measuring cylinders of different sizes, pipettes, test tubes, volumetric flasks and ICP-OES 725 E.

Sample Preparation

The collected water samples were acidified at the time of collection with nitric acid (2 ml of 69 - 72% conc.) to minimize precipitation and adsorption of the HMs cations on the walls of the container (100 ml). Water samples in the container were shaken for thorough mixing, and then 50 ml aliquots were filtered on Whatmann No. 41 filter papers, and quantitatively transferred into 50 ml volumetric flask before aspiring directly into the ICP for analysis of HMs according to USEPA Guideline [24,25] Varian [25]. Time between collection of samples and analysis was about 24 hr.

Results and Discussion

Metals are dangerous as they tend to bio-accumulate in the food-chain/web and, they can be harmful to humans, animals, plants and the environment. The HMs risk to human and animals health is provoked by their long-term persistence in the environment. Since the beginning of human kind, metals had been used for different activities and thus HMs have been emitted and deposited in the environment [1,3]. The records of Dongola Center for Tumor Therapy (DCTT; Table 1) showed that about 32 types of cancer in both sexes were reported in both localities in 2016. The breast cancer was ranked as No. 1 type (both sexes 29.95%), followed by bone cancer (6.68%), the testicular cancer (6.43%), prostate cancer (5.44%), and pancreas cancer ranked 5th (3.46%). Some types were reported in women only (e.g. bone-marrow, ovarian, cervical, liver, mouth, gall-bladder, pancreas, chorionic. esophageal, nasopharynx, colon, skin and bowl). Others were reported in males only (viz. brain, stomach, kidney, prostate, tongue, testicular, cheek, and abdominal). The cases shared between the two sexes were breast cancer, benign tumors, bone-cancer, lymphoma, leukemia, sarcoma, lung, gum and eye cancers.

Serial	Diagnosis	Female (No. and Rank)	Male (No. and Rank)	Total (No. and Rank)	% from state population
1	Breast cancer	221 (I)	21 (IV)	242 (I)	0.035 (29.95%)a
2	Brain cancer	-	2 (XII)	2 (XVII)	0.0003 (0.24%)
3	Stomach cancer	-	27 (III)	27 (VI)	0.0039 (3.34%)
4	Bone marrow cancer	19 (VII)	-	19 (IX)	0.0027 (2.35%)
5	Kidney Cancer		3 (XI)	3 (XVII)	0.0004 (0.37%)
6	Benign tumors	10 (XI)	3 (XI)	13 (XIII)	0.0019 (1.60%)
7	Prostate cancer		44 (II)	44 (IV)	0.0063 (5.44%)
8	Bone Cancer	47 (II)	7 (VIII)	54 (II)	0.0077 (6.68%)
9	Tongue cancer	-	5 (X)	5 (XV)	0.0007 (0.61%)
10	ovarian cancer	21 (VI)	-	21 (VIII)	0.003 (2.56%)
11	Cervical cancer	17 (IX)	-	17 (XI)	0.0024 (2.10%)
12	Lymphoma	7 (XIII)	16 (V)	23 (VII)	0.0033 (2.85%)
13	Thyroid disease	1 (XVI)	3 (XI)	4 (XVI)	0.0006 (0.49%)
14	Liver cancer	1 (XVI)	-	1 (XVIII)	0.0001 (0.12%)
15	Leukemia	2 (XV)	9 (VII)	11 (XIV)	0.0016 (1.36%)
16	Mouth cancer	1 (XVI)	-	1 (XVIII)	0.0001 (0.12%)
17	Gall bladder cancer	4 (XIV)	-	4 (XVI)	0.0006 (0.49%)
18	Pancreas cancer	28 (III)	-	28 (V)	0.004 (3.46%)
19	Testicular Cancer	-	52 (I)	52 (III)	0.007 (6.43%)
20	Cancer chorionic	14 (X)	-	14 (XII)	0.002 (1.73%)
21	Esophageal cancer	21 (VI)	-	21 (VIII)	0.003 (2.59%)
22	Sarcoma	22 (V)	6 (IX)	28 (V)	0.004 (3.46%)
23	Nasopharynx cancer	27 (IV)	-	27 (VI)	0.0039 (3.34%)
24	Lung cancer	9 (XII)	2 (XII)	11 (XIV)	0.0016 (1.36%)
25	Early detection	98	12 (VI)	110	0.0157 (12.37%)
26	Colon cancer	1 (XVI)	-	1 (XVIII)	0.0001 (0.12%)
27	Cheek cancer	-	2 (XII)	2 (XVII)	0.0003 (0.24%)
28	Skin cancer	18 (VIII)	-	18 (X)	0.0026 (2.22%)
29	Abdominal cancer	-	3 (XI)	3 (XVI)	0.0004 (0.36%)
30	Gum cancer	1 (XVI)	1 (XIII)	2 (XVII)	0.0003 (0.24%)
31	Bowel cancer	2 (XV)	-	2 (XVII)	0.0003 (0.24%)
32	Eye cancer	1 (XVI)	1 (XIII)	2 (XVII)	0.0003 (0.24%)
Total		590	218	808	

Table 1: *Number of patients diagnosed with cancer in Dongola Centre for tumor therapy during 2016.*
(Source: University of Dongola and Ministry of Health, Northern State, 2016).
a= Value between brackets (%) = cancer type/all cancer cases x 100

Ni is accused of being a causal agent for breast cancer; Cr and Cd are lung - cancer causing agents. Cr is also one of the leading kidney failure causing agents known as carcinogenic. Beryllium, Pb, Hg, Al, titanium, antimony, tungsten, bismuth and Fe are reported as carcinogens or potentially carcinogenic. Some of these metals were not included in the study; e.g. beryllium, tungsten, bismuth, titanium and antimony [13-15,18-22,26,27].

Zn concentrations in all sources in both localities were below the PLs (3 ppm), and the highest was that from the RNW (1.725 ppm) and the lowest was samples taken from the TW in Merowe (0.105 ppm). Pb was very high, ranging between 5.985 and 2.84 ppm. The former value was for the Dongola TW, and levels, i.e. 4.92 ppm for Dongola and 4.7 ppm for Merowe; the PL is 0.05 ppm. Cu in the three sources showed concentration below the PL (2 ppm). The detected concentrations ranged between 1.89 ppm in the UGW of Dongola to 0.62 ppm in RNW of Merowe Locality. The TW in both localities also showed high levels (1.27 and 1.175 ppm, for Dongola and Merowe, respectively; tables 2 and 3). In Dongola, the UGW showed very high level of Co (4.135 ppm; PL = 1 ppm), whereas that of Merowe was 2.36 ppm, i.e. 2.36x that of the PL. The TW in both localities showed higher levels than the RNW, and all of them were lower than the PLs (0.5 - 0.6 ppm). Ni, which is accused of being a major causative agent for breast cancer, was extremely high in all sources. The PLs is 0.02 ppm. The detected levels were from 16.5 to 22.4 ppm in Dongola; the highest was that of TW, which makes it a very serious exposure source in the houses. Regarding Merowe, the range was 14.4 -18.6 ppm; the lowest was that of the RNW and the highest was detected in the UGW. While the TW registered 18.33 ppm, again, it is very important to consider dealing with it seriously. It is worth mentioning that the levels detected in Dongola were higher than those of Merowe. Cd in Dongola showed identical values for RNW and TW (0.013 ppm; PL 0.003 ppm), i.e. 4.3 x the PLs. The UGW showed 0.007ppm (2.3x the PLs). In Merowe the Ni concentration was identical to that of Dongola as to RNW, whereas that of the TW was 0.001 ppm, less than its Dongola counterpart. The UGW reflected the presence of 0.004 ppm, still higher than the PL. Mo in all drinking water sources in both localities was lower than the PL (0.07 ppm), the range was 0.015 - 0.035 ppm; the higher value belongs to Merowe UGW. The PLs for Cr is 0.05 ppm; it is a lung cancer and kidney failure causing agent. Cr concentration in all water sources was ranging from 0.025 to 0.07 ppm. The concentration in the RNW in both localities was lower than the PLs (0.035 ppm in Dongola and 0.025 ppm in Merowe). TW concentrations were 0.06 and 0.045 ppm, respectively. The UGW levels detected were 0.07 and 0.055 ppm, following the same order. This source requires more attention based on the hazards caused by this HM. Fe is a carcinogen and its levels in the water sources in both Localities require more attention and its PL is 0.3 ppm. The detected levels in the RNW were 0.46 and 0.325 ppm for Dongola and Merowe, respectively. The TW in Dongola contained even a higher level (0.485 ppm), whereas that of Merowe was 0.37p pm. Regarding the UGW, Dongola showed 0.42 ppm, and Merowe 0.265 ppm. The famous carcinogen Hg showed very low concentrations in the RNW (0.001 and 0.0005 ppm, for Dongola and Merowe, respectively; PL = 0.001 ppm). Surprisingly, TW and UGW in Dongola Locality showed 0.003 and 0.002 ppm, following the same order. For Merowe Locality, the value was 0.002 ppm for both sources, i.e. double the PL.

HM	RNW (Mean ± SE) (ppm)	C.V. (%)	TW (Mean ± SE) (ppm)	C.V. (%)	UGW (Mean ± SE) (ppm)	C.V. (%)	PL (ppm) WHO (2004)
Zn	1.695 ± 0.045	3.77	0.120 ± 0.010	1.660	0.325 ± 0.005	2.15	3.000
Pb	4.920 ± 0.010	0.28	5.985 ± 0.005	0.110	4.145 ± 0.005	0.16	0.050
Cu	0.720 ± 0.010	1.94	1.270 ± 0.010	1.100	1.890 ± 0.000	0.00	2.000
Co	0.545 ± 0.015	3.85	0.665 ± 0.015	3.150	4.315 ± 0.005	0.16	1.000
Ni	16.535 ± 0.015	0.12	22.445 ± 0.015	0.093	20.250 ± 0.010	0.06	0.020
Cd	0.013 ± 0.000	7.64	0.013 ± 0.001	7.690	0.007 ± 0.001	1.43	0.003
Mo	0.015 ± 0.005	4.66	0.025 ± 0.005	28.000	0.015 ± 0.005	4.66	0.070
Cr	0.035 ± 0.005	2.00	0.060 ± 0.000	0.000	0.070 ± 0.010	3.33	0.050
Fe	0.460 ± 0.010	3.04	0.485 ± 0.005	1.440	0.420 ± 0.010	3.33	0.300
Li	0.020 ± 0.010	7.00	0.015 ± 0.005	4.660	0.035 ± 0.005	2.00	NF
Hg	0.0005 ± 0.000	0.00	0.003 ± 0.000	3.330	0.002 ± 0.001	5.00	0.001

***Table 2:** Concentration (ppm) of heavy metals in the drinking water from Dongola Locality, Sudan, determined by ICP method.*

Metal	RNW (Mean ± SE) (ppm)	C.V. (%)	TW (Mean ± SE) (ppm)	C.V. (%)	UGW (Mean ± SE) (ppm)	C.V. (%)	PL (ppm) WHO (2004)
Zn	1.725 ± 0.005	0.40	0.105 ± 0.005	6.66	0.275 ± 0.005	2.54	3.00
Pb	4.700 ± 0.010	0.29	4.720 ± 0.010	0.29	2.840 ± 0.010	0.49	0.05
Cu	0.620 ± 0.010	2.25	1.175 ± 0.005	0.59	0.960 ± 0.010	1.45	2.00
Co	0.415 ± 0.015	5.06	0.550 ± 0.010	2.54	2.360 ± 0.020	1.18	1.00
Ni	14.495 ± 0.065	0.63	18.330 ±0.010	0.07	18.635 ± 0.035	0.26	0.02
Cd	0.013 ± 0.001	7.69	0.012 ± 0.001	8.33	0.004 ± 0.001	2.50	0.003
Mo	0.015 ± 0.005	4.66	0.015 ± 0.005	4.66	0.035 ± 0.005	2.00	0.07
Cr	0.025 ± 0.005	2.80	0.045 ± 0.005	1.55	0.055 ± 0.005	1.27	0.05
Fe	0.325 ± 0.005	2.15	0.370 ± 0.010	3.78	0.265 ± 0.005	2.64	0.30
Li	0.015 ± 0.005	4.66	0.015 ± 0.005	4.66	0.025 ± 0.005	2.80	NF
Hg	0.001 ± 0.000	0	0.002 ± 0.001	5.00	0.002 ± 0.001	5.00	0.001

Table 3: *Concentration (ppm) of heavy metal (ppm) in the drinking water from Merowe Locality, Sudan, determined by ICP method.*

The present study agreed with the results of Saeed and Shaker [28], who reported that Fe, Mn, Cd and Pb (in Lake Manzala, Egypt) and Mn and Pb in Lake Borollus (Egypt) from River Nile source recorded levels above the PLs in water. Similar results were obtained by Muiruri., *et al.* [29] done in athi-Galana river in Kenya.

It is, therefore, recommended that the Drinking water in the northern state requires more attention from the health authorities. Although The sources of these HMs must be thoroughly investigated, because the nature of effects could be toxic (acute, chronic or sub-chronic), neurotoxic, carcinogenic, mutagenic or teratogenic. For example, Cd is toxic at extremely low levels. In humans, long- term exposure results in renal dysfunction, characterized by tubular proteinuria. High exposure can lead to obstructive lung disease. Cd is also associated with bone defects, *viz*. osteomalacia, osteoporosis and spontaneous fractures, increased blood pressure and myocardic dysfunctions. Depending on the severity of exposure, the symptoms of effects include nausea, vomiting, abdominal cramps, dyspnea and muscular weakness. Severe exposure may result in pulmonary edema and death [18,23,30,31]. Pb is the most significant toxicant of the HMs, and the inorganic forms are absorbed through ingestion by food and water, and inhalation [32]. A notably serious effect of Pb toxicity is its teratogenic effect. Pb poisoning also causes inhibition of the synthesis of hemoglobin; dysfunctions in the kidneys, joints and reproductive systems, cardiovascular system and acute and chronic damage to the CNS and peripheral nervous system (PNS) [33,34]. Other effects include damage to the GIT and urinary tract resulting in bloody urine, neurological disorder and can cause severe and permanent brain damage [23,30,32,35]. Pb affects children by leading to the poor development of the grey matter of the brain, thereby resulting in poor intelligence quotient (IQ) [36]. Acute and chronic effects of Pb result in psychosis. Zn has been reported to cause the same signs of illness as does Pb, and can easily be mistakenly diagnosed as Pb-poisoning [23]. Zn is considered to be relatively non-toxic, especially if taken orally. However, excess amount can cause system dysfunctions that result in impairment of growth and reproduction [23,30,37]. The clinical signs of Zn toxicosis are vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, kidney failure and anemia [38]. Hg is toxic and has no known function in human biochemistry and physiology. Inorganic forms of Hg cause spontaneous abortion, congenital malformation and GIT disorders [32,33]. Arsenics toxicity symptoms depend on the chemical form ingested, as with Pb and Hg [32,39]. Arsenics acts to coagulate protein, forms complexes with coenzymes and inhibits the production of ATP during respiration [30]. It is possibly carcinogenic in compounds of all its oxidation states and high-level exposure can cause death [40,41]. Arsenic toxicity also presents a disorder, which is similar to, and often confused with Guillain-Barre syndrome, anti-immune disorder that occurs when the body's immune system mistakenly attacks part of the PNS, resulting in nerve inflammation that causes muscle weakness [42,43].

Conclusions

The River Nile water in both localities showed levels higher than WHO (2004) limits, viz. Pb, Ni, Cd and Fe. Tap water Pb, Ni, Cd, Fe, Hg concentration in both localities are by far higher than WHO (2004) limits, in addition to Cr in Dongola locality. High concentrations for Pb, Co, Ni, Cd, Cr, and Hg; greater than 2004 PLs, in particular Ni were detected in underground water in both localities. About 32 types of cancer are reported in the Northern state; around 0.12% of the state population are registered in the State Tumor Therapy Center 2016. Therefore, all water sources in Dongola and Merowe Localities are not safe for drinking and require urgent attention by the authorities.

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Volume 6 Issue 9 September 2018