Chapter

Health Risks of Potentially Toxic Metals Contaminated Water

Om Prakash Bansal

Abstract

Groundwater which fulfills globally 50–80% need of drinking water, due to Anthropogenic and geologic activities, has been continuously contaminated by potentially toxic metals, causing a range of effects to animals and citizenry. In the developing countries, about 80% of diseases are waterborne diseases. Bio accumulation of these metals in citizenry due to intake of contaminated vegetables, fruits, fishes, seafood and drinking water and beverages causes a serious threat to citizenry. Toxicity of these metals is due to metabolic interference and mutagenesis, interference in the normal functioning of structural proteins, enzymes, and nucleic acids by binding them, adversely affecting the immune and hematopoietic systems in citizenry and animals. The toxic metals also enrich antibiotic resistant microbes particularly bacteria by Co-selection (occurring by Co-resistance and cross-resistance) as it promotes antibiotic resistance in bacteria even in absence of antibiotics. These metals in living cells cause cytotoxicity, oxidative stress resulting in the damages of antioxidants, enzyme inhibition, loss of DNA repair mechanism, protein dysfunction and damage to lipid per oxidase. Endocrine disruption, neuro-developmental toxicity, biosynthesis of hemoglobin, metabolism of vitamin D, renal toxicity, damage to central nervous system, hearing speech and visual disorders, hypertension, anemia, dementia, hematemesis, bladder, lung, nose, larynx, prostate cancer, and bone diseases are some other health's risks to human.

Keywords: pollution, human, potentially toxic metals, health risks, heavy metals resistance, fishes

1. Introduction

Water the "life-blood of the biosphere" may be an alcahest which dissolves different chemicals and environmental pollutants. Globally, groundwater is the main source of domestic drinking water both in rural and urban areas and fulfills approximately 80% need of drinking water in the rural areas and 50% of urban water need. As surface water infiltrates to unconfined aquifers easily, these aquifers are contaminated very easily. The pollution of groundwater causes significant alteration in the environment. The most sources of lakes, rivers, ponds, and streams are the groundwater. When contaminated groundwater is supplied to those sources, the surface water is additionally contaminated which causes harm to birds, animals, and plants. Because of population growth over the last 50 years, the abstraction of groundwater has increased leading to reduce natural discharge flows and groundwater quality. Groundwater quality is additionally suffering from recharge rate and recharge quality. Existence of human on earth without potentially toxic metals is not possible.

These potentially toxic metals (Cd, Cu, Pb, Zn, Cr (III), Cr (VI), and Hg) have high relative atomic mass and density. Hindu Business on Feb 20, 2019 reported that "more than forty million people in rural India drinks to water contaminated by heavy metals, arsenic, fluoride, etc." The results are devastating. Diarrhea, often caused by exposure to fecal matter, kills 600,000 Indians per annum and waterborne diseases throughout the Ganges basin. In India, 25% of water sources is River Ganga. These metals participate within the redox reactions and are an important part of enzymes. Cobalt is a constituent of vitamin B_{12}, and manganese acts as an activator of the enzymes within the physical body [1]. Copper is important for enzyme ascorbate oxidase, cytochrome oxidase, plastocyanin oxidase, and photosynthesis in plants. As these metals cannot be degraded, they persist in the environment (in soils, industrial effluents, groundwater) for a long period; easily bio accumulated and bio magnify within the food chains poses a significant threat to the consumer and pollution of water sources by potentially toxic metals became a worldwide problem [2]. The toxic effect of these metals could also be because of metabolic interference and mutagenesis. These metals interfere in the normal functioning of structural proteins, enzymes, and nucleic acids by binding them. Even a smaller amount of potentially toxic metals/metalloid arsenic, lead, cadmium, nickel, mercury, chromium, cobalt, and zinc beyond their permissible limit in body became harmful. These metals also enrich antibiotic resistant microbes even in the absence of antibiotics. This study discusses the health risks of potentially toxic metals contaminated water to the citizenry accumulated via intake of contaminated vegetables, fruits, fishes (freshwater or marine), drinking water, and beverages. The consequences of those metals on antibiotic resistant genes and bacteria have also been discussed.

2. Potentially toxic metals

Potentially toxic metals are essential in a small amount for various biochemical and physiological functions within the plants, animals, and humans. These metals participate in the redox reactions and are an important part of enzymes. A number of researchers [3–6] have reported that natural contaminates of natural water are potentially toxic metals and organometallic compounds. Based on their health importance, the potentially toxic elements are classified into four groups, (i) essential: Cu, Zn, Co, Cr, Mn, and Fe. These metals beyond their permissible limit become toxic, (ii) non-essential: Ba, Al, Li, (iii) less toxic: Sn, and (iv) highly toxic: Hg, Cd, Pb, As (metalloid).

2.1 Routes of uptake

Routes of uptake of those toxic metals by human and animals are:

i. Ingestion: it occurs via gastrointestinal route, that is, through the mouth by eating contaminated food, vegetables, fruits, seafood including fish, and by drinking contaminated water and beverages.

ii. Dermal: dermal uptake means absorption through skin/gills, the aquatic animals' bio accumulates these toxic metals via dermal contact.

iii. Inhalation: inhalation uptake occurs via inhalation of the polluted air as dust fumes and through exposure at work place. In the fish, these metals enter the body directly from water or sediments via the gills/skin or via its alimentary tract from the fish food/prey.

3. Sources of potentially toxic element contaminants within the water

Contamination of the environment by potentially toxic metals has increased after war II because of rapid industrialization and urbanization and increased rate of mobilization and transport [7]. The main sources of groundwater of contamination by heavy metals are:

3.1 Natural

Rock weathering, forest fires, volcanic eruptions, biogenic sources, and wind born soil particles are the natural sources of potentially toxic metals within the environment. Within the rocks, these metals are present as hydroxides, sulphides, oxides, silicates, phosphates, and chelated with organic compounds.

3.2 Anthropogenic activities

Industrial manufacturing of products to satisfy with the stress of the massive population like to cement production, iron industry, steam power plants, glass production, paint, and tanning industries is one among the causes of environmental pollution because of human activities. Agricultural activities (use of sewage sludge as manure), irrigation by sewage wastewater, mining, and metallurgical processes, garbage and waste mud incineration facilities, combustion of fuels, surface emission, and traffic and runoffs are other ways to release the pollutants within the different environmental compartments. The main route of the groundwater and aquatic contamination by potentially toxic metals are the leaching from toxic industrial waste dumps and municipal landfills and leaching of agricultural chemicals from soils into the upper aquifers [8].

As the concentration of potentially toxic metals within the environment is continuously increasing, and therefore, the soil retention capacity of those metals is decreasing and the resultant is the leaching of those metals within the groundwater [9]. Fertilizers and pesticides applied within the fields contain these potentially toxic metals (Cr, Cd, Cu, Zn, Ni, Mn, Pb, and As) as impurities [7]. Another source of groundwater contamination by potentially toxic metals is the urban runoffs which contain Pb, Cu, Zn, Fe, Cd, Cr, and Ni. The intrusion of seawater in aquifers also causes a rise in concentration levels of potentially toxic metals in the groundwater. Another anthropogenic source of the heavy metals in the environment is the burning of wastes at residential levels and dumpsites.

4. Potentially toxic metals within the ground, surface water, and sediments

The pollution of water resources by potentially toxic metals affects plants, animals, and human health adversely [10]. These metals even at a low concentration are toxic to aquatic organisms as these metals alter the histopathology of the tissues of the organisms [11, 12]. The one among the main sources of potentially toxic metals within the aquatic environment are the sediments which act as a sink and reservoir of those metals [13].

4.1 Potentially toxic metals within the drinking, ground, and surface water

A review of the literature showed that globally number of groundwater, drinking water, and surface water samples contains the potentially toxic metals beyond their permissible limit which affects adversely the human and ecological health. The arsenic concentration in the groundwater samples ranged from 0.0005 to 1.15 mg/L [14–16]. Author himself [17, 18] studied the concentration of potentially toxic metals in the groundwater samples for 20 years (1986–2005) and found that (i) concentration of those metals are increasing with time, (ii) concentration of those metals decreased with depth, and (iii) the concentration became beyond the permissible limit after the year 2000. The concentration of the toxic metals in the groundwater, drinking water, and surface water samples are recorded in **Table 1**.

4.2 Potentially toxic metals within the sediments

The accumulated amounts of the potentially toxic metals in the sediments are reported in **Table 1**.

5. Bioaccumulation of probably toxic metals in vegetables and fruits irrigated by contaminated ground and surface water

A long-term study made by the author himself [17, 18] found that the concentration of potentially toxic metals in the soils of agricultural fields of Aligarh irrigated by sewage effluent is continuously increasing, and therefore, the concentration of those metals in edible parts of the crops grown such soils were beyond toxic limits, and maximum accumulation was within the potato followed by maize [53]. Bansal [53] during their studies on the concentrations of Pb, Cd, Ni, Cr, Zn, and Cu in the vegetables palak, cabbage, brinjal, lady's finger, tomato, bitter gourd, radish, and cauliflower grown in the soils of periurban areas of Aligarh irrigated by sewage effluent water found that the concentration of the metals Cd, Pb, and Ni in all the studied vegetables were beyond their permissible limits for human consumption. The Target Hazard Quotient (THQ) values also denote that consumption of those vegetables will cause a potential risk for human health risk. Kabir and Bhuyan [54] found that the concentration of Cu in the hen's egg yolk (1.85–3.65 mg/kg) and albumin (0.5–1.15 mg/kg) were beyond permissible limits. The concentrations of these metals in the vegetables grown globally are given in **Table 1**.

6. Bioaccumulation of potentially toxic metals in freshwater fish, marine fish aqueous flora and fauna

Bioaccumulation of the potentially toxic heavy metals within the ecosystem of the Riverine has a negative impact on the ecological health of aquatic animals and causes decrease in their populations [55, 56]. Several researchers have reported fish deformities, decline of fish populations, and reduce in their growth rates if the concentration of potentially toxic metals increased beyond their tolerable limit [57, 58]. The concentrations of those metals in freshwater fish are reported in **Table 2**. The info in **Table 3** denotes the concentration of those metals in marine fish and other organisms.

Sample	Source	Concentration of metal (mg/L) or (mg/kg)								Reference
		Cd	Cr	Cu	Zn	Pb	Ni	As	Others	
Drinking water	Lagos state, Nigeria	0.0	0.009–0.021	0.027–0.060	0.11–0.41	0.098–0.14	0.72–1.02			[19]
Drinking water and surface water	Yobe State, Nigeria		0.0074–0.99	0.001–0.12	0.012–0.087	0.024	0.0			[20]
Surface water	Nile River and its canals	0.001–0.048				0.054–0.329				[21]
Drinking water	Egypt	0.002–0.049				0.09–0.41				
Drinking water	Nigeria	0.02–0.124;		0.009–0.057	0.08–20.1	0.04–0.57		0.091–0.485		[22]
Surface water	Pearl River, China	0.0005–0.0075	0.0035–0.011	0.003–0.005	0.0165–0.0607	0.0006–0.0011	0.0014–0.0045			[4]
Surface water	Dares salaam, Tanzania	0.32	0.59	0.03	1.14	0.46–0.55			0.99–1.26 (Fe)	[23]
Surface water	Ganga River, India	0.0–18.55	0.003–6.28	2.25–63.56	4.70	0.166–107.34	0.06–5.9	4.73		[5, 6, 24]
Ground water	Chembarambakkam lake (India)	0.00–1.32	0.00–0.19	0.018–0.088	0.008–2.45,	0.172–0.486	0.00–0.03			[25]
Surface water		0.00–1.5	0.00	0.01–0.03	0.01–0.70	0.16–0.22	0.00			
Surface water	Tamilnadu		0.229–1.484	0.001–0.128	0.001–0.65	0.031–0.781;	0.01–0.695			[26]
Surface water	Solan district (India)	0.00–0.00004			0.0021–0.0072	0.0 0–0.0041,		0.00–0.0014		[27]
Ground water		0.00001–0.00033			0.0006–0.0015	0.0001–0.0029		0.0–0.0009		
Surface water	Bodo Creek water	0.03–0.06				1.03–1.63				[28]
Surface water	Kenya	0.31–0.53		1.37–1.92		0.57–2.43				[29]

Sample	Source	Concentration of metal (mg/L) or (mg/kg)								Reference
		Cd	Cr	Cu	Zn	Pb	Ni	As	Others	
Ground water	Maru Town, Nigeria		0.0–0.99	0.0–0.33	0.012–0.087		0.00–0.0056			[30]
Groundwater	Albania	0.0–0.0006		0.0075–0.078		0.001–0.0058		0.008–0.009		[31]
Groundwater	Iran	0.006				0.09				[32]
Ground water	Singhbhum, India	0.01–0.08	0.04–0.28			0.08–0.42	0.03–0.14		0.07–4.45 (Fe)	[33]
Sediments	River Raohe, Chia	0.00–1.60	13.5–97.1	15.6–793.5	11.2–52.9	16.0–222.2	18.4–66.4	12.9–318.0		[13]
Sediments	Mashavera Basin Georgia	1.5–1.7	26.4–28	347.8–410.7	423.3–458.9	29.6–37.2	22.3–22.5		0.00–0.02 (Hg)	[34]
Sediments	Kabul	4.4–7.1	75.5–92.5	10.9–15.3	8.1–88.3	32.8–54.6	69.1–85.1			[35]
Sediments	River of Philippines		32.8–131.8	29.4–217.1	76.8–263.3		12.1–98.1		4.1–25.3 (Co)	[36]
Sediments	River Gomati	1.9–8.4		9.0–95.4		35.8–90.9		3.7–15.0		[37]
Sediments	River Ghaghara	0.21–0.28	61.3–84.7	2.8–11.7	13.3–17.6	10.7–14.3	15.3–25.6		11.4–18.4 (Co)	[38]
Sediments	River Ganga	1.7	69.9	29.8	67.8	26.7	26.7			[39]
Sediments	Bay of Bengal	0.03–0.06	0.61–0.79	0.38–0.66		0.01–1.42	0.01–0.23			[40]
Vegetables	Bangladesh	0.03–2.4	0.03–22.6	0.4–52.3	0.33–95.5	0.0.02–61.5	0.03–1.02	0.63–1.33	0.02–32 (Mn)	[41–43]
Vegetables	Supermarket of the Florida	0.002–0.040	0.012–0.223	0.13–2.47	1.31–3.95	0.0019–0.065	0.012–0.291	0.002–0.020	0.0005–0.033 (Co)	[44]
Vegetables		0.0006–0.028	0.009–0.126	0.22–2.65	1.12–3.88	0.0005–0.07	0.010–0.096	0.0012–0.016	0.0012–0.0065 (Co)	

Sample	Source	Concentration of metal (mg/L) or (mg/kg)								Reference
		Cd	Cr	Cu	Zn	Pb	Ni	As	Others	
Vegetables	Iran	0.030.55		0.85–4.1		0.5–1.5			0.69 (Co)	[45, 46]
Vegetables	Pakistan	0.045–0.39	2.72–6.62	22.2–65.2	19.5–41		1.8–5.0		18.7–137.3 (Mn)	[47]
Vegetables	Nigeria	0.11–0.43	5.1–9.9	4.7–75	38.1–335.2	2.6–9.2			19.3–33.3 (Mn)	[48]
Vegetables	Local vegetables, Iraq	1.5–6.0	1.02–1.13	7.3–37.2	25.3–43.8	0.5–1.48	6.3–7.9	4.73	2.83–3.09 (Co)	[49]
Vegetables	Imported vegetables, Iraq	1.6–5.8	1.03–1.15	17.3–33.5	17.3–33.5	0.32–1.55	7.1–10.3		3.08–3.10 (Co)	
Vegetables	China	0.004–0.51		0.015–1.31	1.4–24.2	0.004–1.16		0.014–0.66		[50]
Vegetables	Indonesia		0.0–152.8	4.3–150.1	5.1–90.7	11.1–347.5				[51]
Vegetables	Germany	0.01–0.79	0.03–4.69	3.2–23.2	11.7–122.8	0.1–31.3	0.03–1.93			[52]

Table 1.
The concentration of different potentially toxic metals (mg/L) in drinking, ground, and surface water and in sediments and vegetables (mg/kg).

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Cyprinus carpio	Sardaryab, tributary of River Kabul	Gills		0.154	0.024	0.074	0.041			[59]
		Liver		0.188	0.089	0.07	0.142			
		Muscles		0.024	0.016	0.018	0.000			
Labeo rohita	Sardaryab, tributary of River Kabul	Gills		0.133	0.018	0.058	0.024			
		Liver		0.165	0.071	0.088	0.161			
		Muscles		0.019	0.01	0.02	0.000			
Cyprinus carpio	Indus River Mianwali, Pakistan	Gills		2.9–9.4	0.77–1.4	—	0.5–1.87			[60]
		Liver		3–5.4	2.5–3.4	—	0.45–1.1			
		Kidney		1.55–3.5	1.4–2.5	—	0.48–0.9			
		Muscles		1.03–2.63	1.1–1.67	—	0.46–1.9			
Wallago attu	Indus River Mianwali, Pakistan	Gills		4.5–9.5	3–5.9	—	0.45–1.92			
		Liver		12.5–20	11.5–21	—	0.9–1.0			
		Kidney		2.0–6.5	1.4–3.5	—	0.0–0.5			
		Muscles		6.5–15.2	2.9–5.5	—	0.83–2.0			
Labeo rohita	Kolleru Lake, India	Gills	0.38	0.19	0.09	0.19	0.3		0.05	[61]
		Liver	0.62	0.69	1.06	1.04	1.48		0.27	
		Kidney	0.25	0.72	0.23	0.94	0.55		0.07	
		Muscles	0.32	0.02	0.09	0.38	0.22		0.04	
Channa striatus	Kolleru Lake, India	Gills	0.32	0.59	0.03	1.14	1.30		0.12	
		Liver	0.48	0.33	0.99	1.01	1.35		0.20	
		Kidney	0.16	0.47	1.03	1.21	1.33		0.25	
		Muscles	0.45	0.85	0.53	0.46	1.30		0.14	

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Oreochromis niloticus	Burullus Lake, Egypt	Muscles	0.45	0.85	0.39	4.70	0.46			[62]
Finfish	Lower Gangetic Delta, India	Whole Body	0–1.32		1.3–53.1	2.0–111.5	0–3.05			[63]
Shrimp	Lower Gangetic Delta, India	Whole Body	0–1.5		6.2–109.2	11.7–213.7	0–10			
Oyster	Lower Gangetic Delta, India	Whole Body	BDL		8.7–69.1	21.4–202.8	0–8			
Tilapia zillii	Niger River, Nigeria	Gill	0.094			8.92	ND		ND	[64]
		Muscle	0.049			5.42	ND		ND	
		Intestine	0.119			12.20	ND		ND	
Malapterurus electricus	Niger River, Nigeria	Gill	0.056			5.77	ND		ND	
		Muscle	0.032			3.74	ND		ND	
		Intestine	0.049			5.74	ND		ND	
Clarias gariepinus	Niger River, Nigeria	Gill	0.055			5.55	ND		ND	
		Muscle	0.04			3.38	ND		ND	
		Intestine	0.033			6.6	ND		ND	
Clarias batrachus	Local fish ponds of Ludhiana city and Sutlej River	Liver	3.74	3.69	3.48	67.78	11.12	3.13		[58]
		Muscle	0.24	2.10	3.79	29.42	4.48	0.68		
		Kidney	4.45	2.14	4.65	56.83	8.04	3.09		
Barbuss harpeyi	Tigris River in Baghdad	Gills	2.3–2.4	2.2–2.5	1.1–1.2	1.05–1.1	1.5–1.6			[65]
		Liver	1.3–2.9	2.5–2.7	0.5–0.8	0.9	2.05			
		Muscle	0.97–1.2	1.6–1.6	0.6–0.7	0.80	1.05			
Barbus xanthopterus	Bodo Creek, Niger Delta, Nigeria	Gills	2.2–2.5	2.1–2.5	1.2–1.3	1.1–1.2	1.3–1.6			
		Liver	2.7–2.8	2.2–2.6	0.7–0.8	0.7–0.9	1.8–2.1			
		Muscle	0.8	0.5–1.6	0.7–0.8	0.7–0.8	1.1			

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Callinectes amnicola	Bodo Creek, Niger Delta, Nigeria	Leg	0.43–3.78				0.3–1.13			[27]
		Gill	0.38–2.02				0.01–0.42			
		Muscle	0.00–1.13				0.01–0.62			
		carapace	2.4–5.43				0.00–0.47			
Chrysichthys nigrodigitatus	Densu River, Ghana	Muscles			0.59	2.34		0.19	0.37	[11]
Alosa immaculata	Danube River	Whole Body	0.09		5.34		0.65			[66]
Cyprinus carpio	Danube River	Whole Body	0.084		5.10		0.58			
Cyprinus carpio	Danube River, Belgrade, Siberia	Whole Body	0.014		0.207		0.036			[67]
Silurus glanis	Danube River, Belgrade, Siberia	Whole Body	0.08		0.235		0.014			
Silurus glanis	Danube River	Whole Body	0.09		0.07		0.17	0.33		[68]
Sander lucioperca	Danube River	Whole Body	0.04		0.11		0.23	0.3		
Tilapia mossambica	Water bodies of Aurangabad, India	Gill		3.66–4.58	0.32–0.46					[69]
		Skin		1.80–2.74	0.19–0.26					
		Liver		1.56–2.16	0.29–0.36					
		Muscle		2.98–4.23	0.26–0.32					
Oreochromis niloticus	Lakes of Coimbatore, India	Muscle	1.26–1.59		8.49–9.69	18.38–25.94	5.91–9.69			[70]
		Gill	1.47–1.85		9.9–11.3	21.05–29.71	6.89–11.30			
		Liver	1.76–2.22		11.74–13.42	25.08–35.4	8.07–13.24			
Lutjanus griseus	Pearl Delta river China	Whole Body	0.03				0.03	0.39		[71]
Lutjanus stellatus	Pearl Delta river China	Whole Body	0.07				0.04	1.53		
Thunnus albacares	Egypt	Whole Body	0.06				0.32			[72]

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Oncorhynchus mykiss	Hamadan Province, Iran	Whole Body	0.17–13.74				0.34–70.17			[73]
		Muscle	0.17–11.88				0.34–35.19			
		Liver	0.17–13.74				1.29–70.17			

Table 2.
The concentration of different potentially toxic metals in different parts of freshwater fish.

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Mullet	Southeast Coast of Indian Ocean	Gills	0.013		0.092	0.087	0.043			[74]
		Gonad	0.001		0.192	0.284	0.302			
		Muscle	0.013		0.034	0.074	0.009			
		Skin	0.010		0.016	0.018	0.000			
		Whole Body	0.005		0.085	0.176	0.026			
Crab	Southeast Coast of Indian Ocean	Muscle	0.027		0.243	0.228	0.237			
		Gonad	0.060		0.330	0.244	0.150			
		Whole Body	0.004		0.061	0.259	0.013			
Shrimp	Southeast Coast of Indian Ocean	Skin	0.001		0.082	0.233	0.268			
		Whole Body	0.001		0.2	0.088	0.007			
Euthynnus affinis	Tok Bali Port, Malaysia	Whole Body	0.007		0.70	62.4	0.3			[57]
Pampus argenteus	Tok Bali Port, Malaysia	Whole Body	0.004		0.038	4.83	0.024			
Decapterus macrosoma	Tok Bali Port, Malaysia	Whole Body	0.003		0.064	5.29	0.001			
Leiognathus daura	Tok Bali Port, Malaysia	Whole Body	0.004		0.018	5.45	0.003			
Fenneropenaeus indicus	Tok Bali Port, Malaysia	Whole Body	0.04		0.34	14.4	0.008			
Lates calcarifer		Whole Body	0.007		0.49	6.5	0.20			[75]
Johnius belangerii	Red Sea, Jeddah Coast, Saudi Arabia	Whole Body			1.35	23.33	1.45			[76]
Chirocentrus dorab		Whole Body			1.45	22.91	1.0			
Arius maculatus		Whole Body			1.15	25.95	0.85			
Parastromateus niger		Whole Body			2.55	22.29	1.0			
Oyster	Gulf of Chabahar	Soft tissue	0.08–0.45	12.7–38.0	59.2–133.5	87–191	2.36–17.5			[77]

DOI: http://dx.doi.org/10.5772/intechopen.92141

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Liocarcinus depurator	Samsun coasts of the Black Sea Turkey	Soft tissue	0.07		7.7	19	0.48			[78]
Rapana venosa		Soft tissue	0.085		4.3	9	0.12			
Mytilus galloprovincialis		Soft tissue	0.08		9.2	14	0.50			
Otolithes ruber	Persian Gulf, Iran	Soft tissue	0.21–0.47				1.98–2.98			[79]
Lutjanus johnii	Persian Gulf, Iran	Soft tissue	0.17–0.38				2.53–3.12			
Lagocephalus sceleratus	North-eastern Mediterranean part of Turkey	Muscle	0.045–0.139	0.20–0.36	0.276–0.518	51.4–86.63	1.46–2.56			[80]
		Skin	0.113–0.217	0.10–0.15	0.168–0.209	3.34–6.45	0.34–0.58			
Hirundichthys coromandelensis	Southeast coast of India	Soft tissue	0.02		0.26–0.28	3–3.28	0.20–0.24			[81]
Cypselurus spilopterus	Southeast coast of India	Soft tissue	0.02		0.26–0.33	2.15–3.30	017–0.19			
Sardina	Algerian coasts, Algeria	Soft tissue	0.55			2.13	0.62			[82]
Xiphias gladius	Algerian coast, Algeria	Soft tissue	0.57			3.90	0.56			
Brachydeuterus auritus	Fishing Habour Ghana,	Muscle			0.42	2.28		0.2	0.31	[11]
Pennahia anea	Coastal Waters, Malaysia	Muscle	0.03–0.21		0.94–4.38	17.7–26.3	0.14–0.41			[83]
		Liver	0.44–0.69		6.7–19.8	7–114.4	0.96–1.26			
		Gill	0.02–0.21		1.08–6.52	48.2–115.7	0.45–1.96			
Arius maculatus		Muscle	0.04–0.09		0.83–3.68	23–48.6	0.15–0.36			
		Liver	0.23–0.98		17.94–55	356–558	0.1–1.16			
		Gill	0.02–0.19		1.65–6.95	282–528	0.24–0.5			
Decapterus maraudsi	Terengganu Coastal Area, Malaysia	Soft tissue	0.2		0.64	7.97	0.17			[84]
Megalaspis cordyla	Terengganu Coastal Area, Malaysia	Soft tissue	0.31		1.16	10.42	0.02			
Bramidae	Terengganu Coastal Area, Malaysia	Soft tissue	1.53		0.98	15.14	0.09			

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
Selaroides leptolepis	Terengganu Coastal Area, Malaysia	Soft tissue	0.66		0.68	11.28	0.14			
Epinephelus lanceolatus	Terengganu Coastal Area, Malaysia	Soft tissue	0.64		0.83	12.51	0.11			
Rastrellige	Terengganu Coastal Area, Malaysia	Soft tissue	0.25		0.5	9.39	0.73			
Nibea soldado	Terengganu Coastal Area, Malaysia	Soft tissue	0.12		0.29	5.91	ND			
Pristipomoides filamentosus	Terengganu Coastal Area, Malaysia	Soft tissue	0.08		0.25	4.88	ND			
Priacanthus tayenus	Terengganu Coastal Area, Malaysia	Soft tissue	0.08		0.42	6.63	0.13			
Siganus canaliculatus	Terengganu Coastal Area, Malaysia	Soft tissue	0.10		0.68	11.60	0.15			
Thunnus obesus	Western and Central pacific ocean	Soft tissue							0.929	
Trichiurus lepturus	Coastal Waters of Ondo State, Nigeria	Muscle	0.0	0.0	0.0	0.34	0.09			[85]
		Head	0.21	0.32	0.0	0.38	0.20			
		Eye	0.37	0.35	0.0	0.38	0.20			
		Gill	0.48	0.49	0.87	0.51	0.15			
		Bone	0.32	0.35	0.59	0.10	0.12			
Pentanmius guigarius		Muscle	0.0	0.0	0.58	0.35	0.1			
		Head	0.26	0.37	0.0	0.36	0.34			
		Eye	0.49	0.62	0.0	0.65	0.14			
		Gill	1.14	1.28	1.88	1.29	0.40			
		Bone	0.32	0.38	0.59	0.39	0.11			
Pseudotolithus senegalensis		Muscle	0.0	0.0	0.46	0.36	0.10			
		Head	0.27	0.26	0.38	0.38	0.71			
		Eye	0.29	0.32	0.39	0.39	0.04			

DOI: http://dx.doi.org/10.5772/intechopen.92141

Fish species	Source	Tissue	Concentration of metal (mg/kg)							Reference
			Cd	Cr	Cu	Zn	Pb	As	Hg	
		Gill	0.81	0.86	0.94	0.94	0.27			
		Bone	0.31	0.38	0.39	0.39	0.12			
Pseudotolithus typus		Muscle	0.31	0.36	0.0	0.36	0.07			
		Head	0.28	0.23	0.0	0.38	0.16			
		Eye	0.30	0.37	0.0	0.39	0.01			
		Gill	0.32	0.37	0.62	0.42	0.12			
		Bone	0.32	0.37	0.59	0.38	0.11			
Cyprinus carpio L,	Ala gul wetland (Iran)	Muscle	0.0–0.140		1.23–39.4	1.15–47.7	0–21.86			[86]
Cyprinus carpio L,	Alma gul wetland (Iran)		0.0–0.02		1.23–4.4	19.15–117.4	2.1–8.7			

Table 3.
The concentration of different potentially toxic metals in different tissues of marine organisms.

7. Potentially toxic metals-resistance

The potentially toxic metals (Cd, Cu, Pb, Zn, Cr (III), Cr (VI), and Hg) aren't only toxic to human health but also enrich antibiotic resistant microbes particularly bacteria. Co-selection of an antibiotic and metal resistance in bacteria is extremely important because it promotes antibiotic resistance in bacteria even in the absence of antibiotics. Co-selection occurs by two mechanisms:

i. Co-resistance: when antibiotics and these metals co-exist within the same environment, these metals influence some antibiotic resistant bacteria to survive in more polluted environment. Co-resistance occurs when two or more different resistant genes are present on the same genetic elements (plasmid, transposon, Integron) or are present within the same bacterial strain which provides resistant to different compounds. The rise of antibiotic resistant genes is directly correlated with the concentration of those metals [87].

ii. Cross-resistance: cross resistance occurs when antibiotics and potentially toxic metals target the same microbes leading to generic detoxification of genes by reducing intracellular concentration of antibiotics and metals, and enhanced efflux occurs during cross-resistance [87].

Besides these two mechanisms, co-selection is additionally promoted by co-regulatory mechanism which occurs when different resistant genes is controlled by one regulator gene [88]. The impact of the potentially toxic metals on the antibiotic resistant bacterial strain is a given in **Table 4**.

8. Toxicity of potentially toxic metals

World Health Organization has reported that globally in the year 2015 approximately 8.8 million deaths were due to cancer, presence of potentially toxic metals beyond permissible limits within the environment is one among the main factors of the death because the endocrine system is disrupted by these metals. When the food or drinking water containing potentially toxic metals beyond their maximum tolerance concentration is ingested, the metabolism of living cells in the body is negatively affected [122]. The immune and hematopoietic systems in human and animals also are adversely affected on exposure to the mixtures of those metals [122]. Li et al. [123] reported that the main cause for human bone diseases is the presence of the potentially toxic metals beyond their permissible limit within the aquatic environment. Potentially toxic metals Pb, Hg, Cd, As, and Cr in living cells causes cytotoxicity [124] and oxidative stress [124], leading to the damages of antioxidants, enzyme inhibition, apoptosis (programmed cell death), loss of DNA repair mechanism, protein dysfunction, and damage to lipid peroxidase and of the membrane.

8.1 Cadmium

Cadmium in human causes Itai-Itai disease, liver/kidney lesions, hepato-colic effects [125], carcinoma, prostatic adenocarcinoma, osteoporosis, hypertension, disorder, and kidney lesions including enlargement, nuclear, and mitochondrial damages, and histological changes; decreased antioxidant power of kidney also

Toxic metal	Mechanism of action	Mechanism of resistance	Antibiotic categories / generic names	Pathogen(s)
Cu	Produces hyperoxide radicals by interaction with cell membrane. Enzymatic activities are inhibited and cellular functions are disrupted.	Resistant genes are located on plasmids and transposons and transfers in between bacterial species.	Tetracycline	*Klebsiella* spp. [89, 90]; *Fecal Enterococci* [91]; *E. coli* [92]; *E. faecium* [93]
			Carbapenem	*Pseudomonas aeruginosa* [94]
			Vancomycin, Amphenicol	*Enterococcus faecium* [93, 95]
			Chloramphenicol	*Bacillus* spp. isolated from ship [96]
			Erythromycin	soil bacteria of Scotland [90]; *Enterococcus faecium* [95]
			Fluoroquinolone	*E. coli* [92]; *E. faecium* [93]
			Quinolone; Sulphonamide	*E. coli* [92]
			Cephalosporin	*Fecal Enterococci* [91]
			Penicillin; Cephalosporin; Nitrofuran	*Enterobacter* spp.; *P. aeruginosa* [97]
			Macrolide	*E. faecium* [98]
Hg	Hg inactivates the enzymatic activities, interferes in the protein synthesis and DNA function, and disrupts cell membrane. Destroys the biological membranes as the mercuric ions are lipid soluble so easily passed through biological membranes.	Hg resistant genes are located on plasmids and transposons. The resistance mechanism involves the reduction of Hg^{2+} ions to Hg in the cytoplasm of the bacteria by the enzyme mercuric reductase which is encoded with the merA gene.	Sulphonamide, Chloramphenicol, Ampicillin, Streptomycetin, Augmentin	*Salmonella enterica* [99]; Fecal Gram-negative bacteria [100]
			Fluoroquinolone, Quinolone	*E. coli*, *Citrobacter* spp., Klebsiella spp. [101]
			Penicillin	*Salmonella* spp. [102]; *Serratia* spp. [103]
			Tetracycline	*E. coli*; *Citrobacter* spp.; *Klebsiella* spp. [104]; *E. faecium* [105]
			Teicoplanin	*Salmonella* spp. [102]
			Sulphonamide; Cephalosporin; Macrolide	*E. coli*; *Citrobacter* spp.; *Enterobacter* spp.; *Klebsiella* spp.; *Proteus* spp. [106]
			Cephalosporin	*E. coli* [107]; *Citrobacter* spp.; *Enterobacter* spp.; *Klebsiella* spp.; *Proteus* spp. [106]

Toxic metal	Mechanism of action	Mechanism of resistance	Antibiotic categories / generic names	Pathogen(s)
			Aminoglycoside	*E. coli*; *Citrobacter* spp.; *Enterobacter* spp.; *Klebsiella* spp.; *Salmonella* spp.; *P. aeruginosa* [108]
			Vancomycin	*E. faecium* [100]
Zn	Due to affinity of Zn to thiol group, the Zn metal is toxic to bacteria, retards glycolysis, transmembrane proton translocation and acid tolerance in the bacterial cell. Also decreases the biomass causing growth inhibition.	Resistance to Zn is found in Gram negative and gram positive bacteria and resistance is mainly via *czr*C gene	Norfloxacin, Augmentin, Gentamicin, Ampicillin	Bacteria isolated from the soil of Kenya [109]
			Carbapenem	*Pseudomonas aeruginosa* [94]
			Penicillin, Teicoplanin	*Salmonella* spp. [102]
			Fluoroquinolone, quinolone	*E. coli*; *Citrobacter* spp. [101]
			Methicillin	*Staphylococcus aureus* [110]
Cr	Due to strong oxidizing potential the metal Cr damages the cells of the microbes,inhibits the oxygen uptake, growth and elongation of lag phase.	Cr in microbes affects basal energy metabolism, protein oxidative stress protection, DNA repair, detoxification of enzymes, efflux pumps, homeoostasis	Tetracycline, Carbapenem	Soil bacteria of Scotland [90]
			Penicillin	*Enterobacter* spp. [97]
			Cephalosporin, Tetracycline	*P. aeruginosa* [97]
			Nitrofuran, Teicoplanin	*Salmonella* spp. [102]
			Quinolone, Vancomycin	*E. coli* [111]
			Sulfonamide	*Klebsiella* spp. [112]
Cd	Cd in bacteria denatures the protein, interacts with calcium metabolism, damages the cell membrane, hinders cell division and transcription, and also affects the nucleic acid.	Resistance to Cd in Gram negative bacteria affects Czc and Ncc genes and encoding dsbA gene needed for disulphite formation while in Gram positive bacteria resistance to Cd is with the CdA pump	Augmentin, Ampicillin	Bacteria isolated from the soil of Kenya [109]
			Ampicillin	Bacteria isolated from ship [96]
			Fluoroquinolone, Quinolone	*E. coli*; *Citrobacter* spp.; *Klebsiella* spp. [101]
			Penicillin, Tetracycline	*P. aeruginosa* [113]
			Amphenicol, Cephalosporin Methicillin, Sulfonamide, Aminoglycoside	*E. coli*; *Citrobacter* spp.; *Klebsiella* spp. [112]
			Macrolide	*E. faecium* [98]

Toxic metal	Mechanism of action	Mechanism of resistance	Antibiotic categories / generic names	Pathogen(s)
Pb	Lead induces mutagenicity, inhibits enzyme activities and transcription. Pb in the bacteria destroys the nucleic acid.	Resistance mechanism is due to adsorption of lead by extracellular polysaccharides, cell exclusion and ion efflux to the cell exterior.	Aminoglycoside	*Citrobacter* spp. [104]
			Macrolide, Quinolone	*E. coli* [111]
			Penicillin	*Enterobacter* spp. [107]
			Teicoplanin	*E. faecium* [105]
			Quinolone	*Klebsiella* spp. [106]
			Sulphonamide	*Proteus* spp. [106]
			Vancomycin	*Enterobacter* spp.; *Klebsiella* spp. [106]
			Amphenicol	*Salmonella* Spp. [114]
			Fluoroquinolone	*P. aeruginosa* [115]
			Tetracycline	*Shigella* spp. [116]
Ni	Ni replaces the essential metals from metalloprotein. The activity of the enzymes is retarded as Ni binds the catalytic site of the enzyme. Ni causes oxidative stress which results in the enhanced DNA damage, protein impairment, and lipid peroxidation.	The resistance mechanism is due to energy-dependent Ni efflux pump induced by cnr which is promoted by a chemo-osmotic proton-antiporter system.	Quinolone	*E. coli* [111]
			Tetracycline	Soil bacteria of Scotland [90]
			Penicillin	*Salmonella* spp. [102]
			Amphenicol	*E. faecium* [105]
			Sulfonamide	*Citrobacter* spp. [112]
As	Disrupts enzymatic functions in the cell and interferes in the phosphate uptake and utilization.	Activation of efflux pumps due to cross resistance between arsenic and antibiotics is the main mechanism	Penicillin	*E. coli* [107]
			Sulfonamide	*Salmonella* spp. [117]
			Tetracycline	*E. coli* [118]
			Amphenicol	*Salmonella* spp. [119]
Co	Produces non B_{12} cobalt protein.	The gene Czc, affects the inner and outer membranes and removes the cobalt from the cytoplasm	Aminoglycoside	*Citrobacter* spp. [106]
			Macrolide	*Enterobacter* spp. [120]
			Penicillin	*Salmonella* spp. [102]
			Quinolone	*E. coli* [111]
			Sulfamethoxazole	*P. aeruginosa* [121]
			Vancomycin	*Enterobacter* spp.; *Klebsiella* spp. [106]

Table 4.
Impact of potentially toxic metals on some bacterial strain resistant to antibiotics.

disrupts mineral balance within the body, causing dysfunctions of sexual glands and skeltel diseases. A psychomotor function of the brain is bogged down in the presence of Cd. The toxicity of cadmium to cell is because Cd can displace vitamin C and E from their metabolically active sites, decrease in absorption of calcium by intestine and enhanced dissolution of bone calcium causing disorder in the normal bone metabolism processes. Cd an endocrine disrupter causes neuro-developmental toxicity. Toxicity of Cd in fishes includes immune suppression and immune dysfunction.

8.2 Lead

Out of about four million tons of lead used per annum globally about three million tons is discharged within the environment. In the physical body, 90–95% of the intruding lead is accumulated within the bones which combine with bone minerals and organic matter causes rise in the blood lead level. Accumulation of lead within the bones affects the acid-base equilibrium causing calcium deficiency. Pb within the body lowers the active vitamin D_3 level and parathyroid level within the plasma affecting somatic cell function viz., decrease in the secretion of γ-carboxyglutamic acid containing protein. Clinical studies have shown that if the extent of Pb in the drinking water is 50 μg/L, the blood lead level within the human is going to be about 30 μg/L; if the extent increased further, the lead level within the breast fed babies are enhanced causing hindrance within the bone development. If the blood lead level in children exceeds 75 μg/L, it causes coma, convulsions, and eventually death. Pb also affects central systema nervosum, renal, cardiovascular, neurological, and musculoskeletal systems. Pb influences the heme synthesizing enzymes by replacing Zn within the heme synthesis. Lead disrupts biosynthesis of hemoglobin, metabolism of Fe, Zn, and Cu, and of vitamin D within the body, and also causes cognitive impairment. Pb in physical body also acts as nephrotoxicants. Lead in fish's body also affects immune system [122]. Long-term exposure to the low concentration of a mix of Cd, As, and Pb in human and other animal cause hepatotoxic (damage to the liver) effects [123].

8.3 Chromium

The annual output of Cr globally is approximately 7.5 million tons. The secretion of Collagen-Type I which helps in the bone fracture healing is suppressed in the presence of chromium ion. Chromium in human causes nose ulcers, asthma, DNA damage, hemolysis, damage to liver, kidney, and carcinoma.

8.4 Arsenic

Smith et al. [126] after their research studies reported that if the person get 50 μg/L of arsenic (daily) then 13 out of 1000 individuals will suffer with lung, liver, kidney or bladder cancer. Skin lesions are by the uptake of 0.0012 mg/kg/day of arsenic. Bhattacharya et al. [125] found that low concentration of arsenic for long period damages liver in human and other animals. Enlargement of kidney, nuclear, and mitochondrial damages, histological changes, and decreased antioxidant power of kidney is additionally caused by arsenic in human. Arsenic also causes neurotoxic effects in human with the assembly of the reactive oxygen species which incorporates death of neuronal cells, cognitive dysfunction, and Alzheimer's disease. Cognitive impairment, deafness, hypertension, anemia dementia, hematemesis, and bladder cancer also is caused by As. The prolonged exposure to arsenic also affects central systema nervosum.

8.5 Mercury

Mercury is the third top hazardous substance. Aquatic organisms convert inorganic mercury to methyl mercury which inactivates Na+/K+ ATPase. Hg with the production of reactive oxygen causes neurotoxic effects in human including death of neuronal cells, cognitive dysfunction, and Alzheimer's disease. As Hg is an endocrine disrupter, during pregnancy exposure to metal causes long-term damages to new born as mercury disrupts the influences the maternal-fetal balance. Minamata disease, renal toxicity, skin, nose irritation, damage to central systema nervosum, hearing speech, and visual disorders are another health risks to human.

8.6 Copper

Copper an integral part of several enzymes in small amount (0.9 mg daily uptake) is an essential metal for animals and plants. Deficiency of copper in human causes anemia, a low number of leucocytes, defects in animal tissue, and osteoporosis in infants. The copper within the body beyond its permissible limit causes hematemesis, jaundice, melena, damage to central nervous system, liver, and kidney problems. Wilson's disease a genetic disease is additionally caused by copper.

8.7 Nickel

Nickel, a natural occurring metal, exists in a number of mineral forms and is an ingredient of chocolate, steel, and other metal products, pigments, valves and of batteries. Excess uptake of nickel by human causes asthma, pneumonia, allergies, heart disorder, skin rashes, and miscarriage. Chances of development of carcinoma, nose cancer, larynx cancer, and prostatic adenocarcinoma also are enhanced.

8.8 Cobalt

Cobalt is an essential metal for the life as it is the integral part of vitamin B_{12} (cobalamin). Human when exposed to the higher concentration of cobalt causes decreased pulmonary function, asthma, interstitial lung disease, wheezing, and dyspnoea and reduces pulmonary function. Respiratory tract hyperplasia, pulmonary fibrosis, increase in number of red blood cells, emphysema, paralysis of the systema nervosum, seizures, growth retardation, and thyroid deficiency are diseases occurs in human at a really high concentration of the metal.

8.9 Zinc

As zinc plays a crucial role in number of metallo enzymes viz., dehydrogenase, alkaline phosphatase, carbonic anhydrase, leucine amino peptidase, superoxide dismutase, and deoxyribosenucleic acid (DNA) and ribosenucleic acid (RNA) polymerase is an essential metal in humans and animals. Over exposures to zinc in human causes dry or pharyngitis, chest tightness, headache, increased indices of pulmonary inflammation, nausea, decrease in the activity of copper metallo enzyme, decreased HDL-cholesterol level, immuno toxicity, and gastrointestinal effects.

9. Conclusions

- Contamination of ground and surface water by potentially toxic metals is a worldwide problem.
- The major route of the groundwater and aquatic contamination by potentially toxic metals are the leaching from toxic industrial waste dumps, municipal landfills, and leaching of agricultural chemicals from soils into the upper aquifers.
- Potentially toxic metals contaminated vegetables and fruits; fishes, seafood, and drinking water are the most sources of the ingestion of those metals by the citizenry.
- A number of biological and biochemical processes are disrupted in the physical body by accumulation of those metals. These metals also cause developmental abnormalities in the children.
- These potentially toxic metals promote the spread of antibiotic resistant genes which causes the ineffectiveness of broad- spectrum antibiotics.

Declaration

No original data is utilized in this review; all information is accessed from published work.

Author details

Om Prakash Bansal
Chemistry Department, D.S. College, Aligarh, India

*Address all correspondence to: drop1955@gmail.com

References

[1] Li L, Yang X. The essential element manganese, oxidative stress, and metabolic diseases: Links and interactions. Oxidative Medicine and Cellular Longevity. 2018;**2018**:7580707. DOI: 10.1155/2018/.580707

[2] Zwolak A, Sarzyńska M, Szpyrka E, Stawarczyk K. Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. Water, Air, and Soil Pollution. 2019;**230**:164. DOI: 10.1007/s11270-019-4221-y

[3] Ali H, Khan E, Ilahi I. Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry. 2019;**2019**:6730305. DOI: 10.1155/2019/6730305

[4] Jiao Z, Li H, Song M, Wang L. Ecological risk assessment of heavy metals in water and sediment of the Pearl River estuary, China. Materials Science and Engineering. 2018;**394**: 052055. DOI: 10.1088/1757-899X/394/5/052055

[5] Nizami G, Rehman S. Assessment of heavy metals and their effects on quality of water of rivers of Uttar Pradesh, India: A review. Environmental Toxicology and Chemistry. 2018;**2**:65-71

[6] Paul D. Research on heavy metal pollution of river ganga: A review. Annals of Agrarian Science. 2017;**15**: 278-286

[7] Toth G, Hermann T, Da Silva MR, Montanerella L. Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International. 2016;**88**: 299-309

[8] Sharma B, Sarkar A, Singh P, Singh RP. Agricultural utilization of biosolids: A review on potential effects on soil and plant grown. Waste Management. 2017;**64**:117-132. DOI: 10.1016/j.wasman.2017.03.002

[9] Galitskaya IV, Rama Mohan K, Keshav Krishna A, Batral GI, Eremina ON, Putilina VS, et al. Assessment of soil and groundwater contamination by heavy metals and metalloids in Russian and Indian megacities. Procedia Earth and Planetary Science. 2017;**17**:674-677

[10] Rezania S, Taib SM, Md Din MF, Dahalan FA, Kamyab H. Comprehensive review on phytotechnology: Heavy metals removal by diverse aquatic plants species from wastewater. Journal of Hazardous Materials. 2016;**318**:587-599

[11] Gbogbo F, Arthur-Yartel A, Bondzie JA, Dorleku WP, Dadzie S, Kwansa-Bentum B, et al. Risk of heavy metal ingestion from the consumption of two commercially valuable species of fish from the fresh and coastal waters of Ghana. PLoS One. 2018;**13**(3):e0194682. DOI: 10.1371/journal.pone.0194682

[12] Ahmed MK, Parvin E, Islam MM, Akter MS, Khan S, Al-Mamun MH. Lead- and cadmium-induced histopathological changes in gill, kidney and liver tissue of freshwater climbing perch *Anabas testudineus* (Bloch, 1792). Chemistry and Ecology. 2014;**30**: 532-540

[13] Wei J, Duan M, Li Y, et al. Concentration and pollution assessment of heavy metals within surface sediments of the Raohe Basin, China. The Scientific Reporters. 2019;**9**:13100. DOI: 10.1038/s 415 98-019-49724-7

[14] Kulkarni HV, Mladenov N, Datta S, Chatterjee D. Influence of monsoonal recharge on arsenic and dissolved organic matter in the Holocene and Pleistocene aquifers of the Bengal Basin.

Science of the Total Environment. 2018; **637–638**:588-599. DOI: 10.1016/j.scitonev.2018.05.009

[15] Fatima S, Hussain I, Rasool A, Xiao T, Farooqi A. Comparison of two alluvial aquifers shows the probable role of river sediments on the release of arsenic in the groundwater of district Vehari, Punjab, Pakistan. Environmental Earth Sciences. 2018;**77**: 382. DOI: 10.1007/s12665-018-7542-z

[16] Jiang Z, Li P, Tu J, Wei D, Zhang R, Wang Y, et al. Arsenic in geothermal systems of Tengchong, China: Potential contamination on freshwater resources. International Biodeterioration & Biodegradation. 2018;**128**:28-35. DOI: 10.1016/j.ibiod.2016.05.013

[17] Bansal OP. Groundwater quality of Aligarh district of Uttar Pradesh, India, a 11 year study. Pollution Research. 2008;**27**:721-724

[18] Bansal OP. Heavy metals in soil, plants as influenced by irrigation with sewage effluents: A 20 year study. Journal of Indian Association for Environmental Management. 2008;**35**: 143-148

[19] Chika OC, Prince EA. Comparative assessment of trace and heavy metals in available drinking water from different sources in the Centre of Lagos and off town (Ikorodu LGA) of Lagos state, Nigeria. Advanced Journal of Chemistry, Section A. 2020;**3**(1):94-104

[20] Kwaya MY, Hamidu H, Kachalla M, Abdullahi IM. Preliminary ground and surface water resources trace elements concentration, toxicity and statistical evaluation in part of Yobe State, North Eastern Nigeria. Geosciences. 2017;**7**:117-128. DOI: 10.5923/j.geo.20170704.02

[21] Salman SA, Zeid SAM, Seleem EMM, Abdel-Hafiz MA. Soil characterization and heavy metal pollution assessment in Orabi farms, El Obour, Egypt. Bulletin of the National Research Centre. 2019;**43**:42. DOI: 10.1186/s42269-019-0082-1

[22] Aloke C, Uzuegbu IE, Ogbu PN, Ugwuja EL, Orinya OF, Obasi IO. Comparative assessment of heavy metals in drinking water sources from Enyigba Community in Abakaliki Local Government Area, Ebonyi state, Nigeria. African Journal of Environmental Science and Technology. 2019;**13**:149-154

[23] Kacholi DS, Sahu M. Levels and health risk assessment of heavy metals in soil, water, and vegetables of Dar es Salaam, Tanzania. Journal of Chemistry. 2018;**2018**:1402674. DOI: 10.1155/2018/1402674

[24] Chakraborti D, Singh S, Rahman M, Dutta R, Mukherjee S, Pati S, et al. Groundwater arsenic contamination in the Ganga River basin: A future health danger. International Journal of Environmental Research and Public Health. 2018;**15**:180. DOI: 10.3390/ijerph15020180

[25] Ramachandran A, Krishnamurthy RR. Jayaprakash M, Balasubramanian M: Concentration of heavy metal in surface water and groundwater Adyar River basin, Chennai, Tamilnadu, India. IOSR Journal of Applied Geology and Geophysics. 2018; **6**:29-35

[26] Sridhar SGD, Sakthivel AM, Sangunathan U, Jenefer S, Mohamed Rafik M, Kanagaraj G. Heavy metal concentration in groundwater from Besant Nagar to Sathankuppam, South Chennai, Tamil Nadu, India. Applied Water Science. 2017;**7**:4651-4662

[27] Rana A, Bhardwaj SK, Thakur M, Verma S. Assessment of heavy metals in surface and ground water sources under different land uses in mid-hills of Himachal Pradesh. International Journal of Bio-resource and Stress Management.

2016;**7**(3):461-465. DOI: 10.5958/0976-4038.2016.00074.9

[28] Godwin AOM, Chinenye NG. Bioaccumulation of selected heavy metals in water, sediment and blue crab (*Callinectes amnicola*) from Bodo Creek, Niger Delta, Nigeria. Journal of Fisheries Science. 2016;**10**(3):77-83

[29] Wasike PW, Nawiri MP, Wanyonyi AA. Levels of heavy metals (Pb, Mn, Cu and Cd) in water from river Kuywa and the adjacent wells. Environment and Ecology Research. 2019;**7**:135-138. DOI: 10.13189/eer.2019.070303

[30] Kwaya MY, Hamidu H, Mohammed I, Abdulmumini N, Adamu IH, Grema M, et al. Heavy metals pollution indices and multivariate statistical evaluation of groundwater quality of Maru town and environs. Journal of Materials and Environmental Science. 2019;**10**:32-44

[31] Deda A, Alushllari M, Mico S. Measurement of heavy metals in ground water. AIP Conference Proceedings. 2019;**2109**:100001-100004. DOI: 10.1063/1.5110136

[32] Vatandoosta M, Naghipoura D, Omidia S, Ashrafia SD. Survey and mapping of heavy metals in groundwater resources around the region of the Anzali international wetland; a dataset. Data in Brief. 2018;**18**:463-469

[33] Singh UK, Ramanathan AL, Subramanian V. Groundwater chemistry and human health risk assessment in the mining region of east Singhbhum Jharkhand, India. Chemosphere. 2018;**204**:501-513. DOI: 10.1016/j.chemosphere.2018.04.060

[34] Withanachchi SS, Ghambashidze G, Kunchulia I, Urushadze T, Ploeger A. Water quality in surface water: A preliminary assessment of heavy metal contamination of the Mashavera River, Georgia. International Journal of Environmental Research and Public Health. 2018;**15**(4):621. DOI: 10.3390/ijerph15040621

[35] Khan MI, Khisroon M, Khan A, Gulfam N, Siraj M, Zaidi F, et al. Bioaccumulation of heavy metals in water, sediments, and tissues and their histopathological effects on Anodonta cygnea (Linea, 1876) in Kabul River, Khyber Pakhtunkhwa, Pakistan. BioMed Research International. 2018;**2018**:1910274. DOI: 10.1155/2018/1910274

[36] Decena SCP, Arguilles MS, Robel LL. Assessing heavy metal contamination in surface sediments in an Urban River in the Philippines. Polish Journal of Environmental Studies. 2018;**27**(5):1983-1995. DOI: 10.15244/pjoes/75204

[37] Neha Kumar D, Shukla P, Kumar S, Bauddh K, Tiwari J, Dwivedi N, et al. Metal distribution in the sediments, water and naturally occurring macrophytes in the river Gomti, Lucknow, Uttar Pradesh, India. Current Science. 2017;**113**:1578-1585

[38] Singh H, Pandey R, Singh SK, Shukla DN. Assessment of heavy metal contamination in the sediment of the river Ghaghara, a major tributary of the river ganga in northern India. Applied Water Science. 2017;**7**:4133-4149

[39] Pandey J, Singh R. Heavy metals in sediments of Ganga River: Up- and downstream urban influences. Applied Water Science. 2017;**7**:1669-1678

[40] Khan MZH, Hasan MR, Khan M, Aktar S, Fatema K. Distribution of heavy metals in surface sediments of the Bay of Bengal coast. Journal of Toxicology. 2017;**2017**:9235764. DOI: 10.1155/2017/9235764

[41] Uddin MN, Hasan MK, Dhar PK. Contamination status of heavy metals in vegetables and soil in Satkhira,

Bangladesh. Journal of Materials and Environmental Science. 2019;**10**:543-552

[42] Ratul AK, Hassan M, Uddin MK, Sultana MS, Akbor MA, Ahsan MA. Potential health risk of heavy metals accumulation in vegetables irrigated with polluted river water. International Food Research Journal. 2018;**25**(1):329-338

[43] Sultana MS, Rana S, Yamazaki S, Aono T, Yoshida S. Sofian Kanan (reviewing editor): Health risk assessment for carcinogenic and non-carcinogenic heavy metal exposures from vegetables and fruits of Bangladesh. Cogent Environmental Science. 2017;**3**:1. DOI: 10.1080/23311843.2017.1291107

[44] Hadayat N, De Oliveria L, Silva ED, Han L, Hussain M, Liu X, et al. Assessment of trace metals in five most-consumed vegetables in the US: Conventional vs. organic. Environmental Pollution. 2018;**243**:292-300

[45] Naghipour D, Chenari MA, Taheri N, Naghipour F, Mehrabian F, Attarchi MA, et al. The concentration data of heavy metals in vegetables of Guilan province, Iran. Data in Brief. 2018;**21**:1704-1708

[46] Zafarzadeh A, Rahimzadeh H, Mahvi AH. Health risk assessment of heavy metals in vegetables in an endemic esophageal cancer region in Iran. Health Scope. 2018;**7**(3):e12340. DOI: 10.5812/jhealthscope.12340

[47] Latif A, Bilal M, Asghar W, Azeem M, Ahmad IM, Abbas A, et al. Heavy metal accumulation in vegetables and assessment of their potential health risk. International Journal of Environmental Analytical Chemistry. 2018;**5**(1):234-245. DOI: 10.4172/2380-2391.1000234

[48] Hong AH, Umaru AB. Heavy metals concentration levels in vegetables irrigated from Lake Geriyo area of Adamawa state, Nigeria. International Journal of Engineering and Science Invention. 2018;**7**:39-42

[49] Hassoon HA. Heavy metals contamination assessment for some imported and local vegetables. Iraqi Journal of Agricultural Sciences. 2018;**49**(5):794-802

[50] Zhou H, Yang WT, Zhou X, Liu L, Gu JF, Wang WL, et al. Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. International Journal of Environmental Research and Public Health. 2016;**13**:289-296. DOI: 10.3390/ijerph13030289

[51] Siaka IM, Utama IMS, Manuaba IBP, Adnyana M. Heavy metals contents in the edible parts of some vegetables grown in Candi Kuning, Bali and their predicted pollution in the cultivated soil. Journal of Environment and Earth Science. 2014;**4**:78-83

[52] Säumel I, Kotsyuk I, Hölscher M, Lenkereit C, Weber F, Kowarik I. How healthy is urban horticulture in high traffic areas? Trace metal concentrations in vegetable crops from plantings within inner city neighborhoods in Berlin, Germany. Environmental Pollution. 2012;**165**:124-132. DOI: 10.1016/j.envpol.2012.02.019

[53] Bansal OP. Heavy metals in sewage effluent water irrigated vegetables and their potential health risks to consumers of Aligarh, India. Chemical Science Review and Letters. 2014;**3**:589-596

[54] Kabir A, Bhuyan MS. Heavy metals in egg contents of hens (Gallus gallus domesticus) and ducks (Anas platyrhynchos) from Chittagong region. Bangladesh Journal Pollution Effective Control. 2019;**7**:232-237

[55] Malik DS, Maurya PK. Heavy metal concentration in water, sediment, and tissues of fish species (Heteropneustis

fossilis and Puntius ticto) from Kali River, India. Toxicological & Environmental Chemistry. 2014;**96**: 1195-1206

[56] Luo J, Ye Y, Gao Z, Wang W. Essential and nonessential elements in the red-crowned crane *Grus japonensis* of Zhalong wetland, North-Eastern China. Toxicological & Environmental Chemistry. 2014;**96**:1096-1105

[57] Salam MA, Paul SC, Noor SNBM, Siddiqua SA, Aka TD, Wahab R, et al. Contamination profile of heavy metals in marine fish and shellfish. Global Journal of Environmental Science and Management. 2019;**5**:225-236

[58] Kaur S, Khera KS, Kondal JK. Effect of water contaminated with heavy metals on histopathology of freshwater catfish, *Clarias batrachus*. International Journal of Chemical Studies. 2018;**6**(4): 3103-3108

[59] Yousafzai AM, Ullah F, Bari F, Raziq S, Riaz M, Khan K, et al. Bioaccumulation of some heavy metals: Analysis and comparison of *Cyprinus carpio* and *Labeo rohita* from Sardaryab, Khyber Pakhtunkhwa. BioMed Research International. 2017;**2017**:5801432. DOI: 10.1155/2017/5801432

[60] Mahoob S, Kausar S, Jabeen F, Sultana S, Sultana T, Al-Ghanim KA, et al. Effect of heavy metals on liver, kidney, gills and muscles of *Cyprinus carpio* and *Wallago attu* inhabited in the Indus. Brazilian Archives of Biology and Technology. 2016;**59**:1-10. DOI: 10.1590/1678-4324-20161502

[61] Harsimran Kaur B. Accumulation of heavy metals in fishes of freshwater [Thesis]. Department of Zoology, University of Delhi; 2016. p. 44

[62] El-Batrawy OA, El-Gammal MI, Mohamadein LI, Darwish DH, El-Moselhy M. Impact assessment of some heavy metals on tilapia fish, *Oreochromis niloticus*, in Burullus Lake, Egypt. The Journal of Basic and Applied Zoology. 2018;**79**:13. DOI: 10.1186/s41936-018-0028-4

[63] Ray Chaudhuri T, Dutta P, Zaman S, Mitra A. Status of edible fishes of lower gangetic delta in terms of heavy metals. International Journal of Environmental Sciences & Natural Resources. 2017;**5**(3):555661. DOI: 10.19080/IJESNR.2017.05.555661

[64] Ibemenuga KN, Ezike F, Nwosu MC, Anyaegbunam LC, Okoye EI, Eyo JE. Bioaccumulation of some heavy metals in some organs of three selected fish of commercial importance from Niger River, Onitsha shelf, Anambra state, Nigeria. Journal of Fisheries Science. 2019;**13**:001-012

[65] Mensoor M, Said A. Determination of heavy metals in freshwater fishes of the Tigris River in Baghdad. Fishes. 2018;**3**:23. DOI: 10.3390/fishes3020023

[66] Ionita C, Mititelu M, Morosan E. Analysis of heavy metals and organic pollutants from some Danube River fishes. Farmácia. 2014;**62**(2):299-305

[67] Milanov DR, Krstic M, Markovic R, Jovanovic AD, Baltic MB, Ivanovic SJ, et al. Analysis of heavy metals concentration in tissues of three different fish species included in human diet from Danube River, in the Belgrad region, Serbia. Acta Veterinaria Belgrade. 2016;**66**:89-102

[68] Miloskovic A, Dojcinovic B, Kovacevic S, Radojkovic N, Radenkovic M, Milosevic D, et al. Spatial monitoring of heavy metals in the inland waters of Serbia: A multispecies approach based on commercial fish. Environmental Science and Pollution Research. 2016;**23**(10):9918-9933

[69] Khillare K, Khillare YK, Wagh U. Bioaccumulation of heavy metals in freshwater fishes from Aurangabad

district Maharashtra. World Journal of Pharmacy and Pharmaceutical Sciences. 2015;**4**:511-520

[70] Mercy M, Dhanalakshmi B. Toxicological evaluation of heavy metals in tissues of freshwater fish *Oreochromis niloticus* collected from lakes of Coimbatore district, Tamilnadu, India. International Research Journal of Pharmacy. 2017;**8**(1):41-45. DOI: 10.7897/2230-8407.08018

[71] Leung HM, Leung AO, Wang HS, Ma KK, Liang Y, Ho KC, et al. Assessment of heavy metals/metalloid (As, Pb, Cd, Ni, Zn, Cr, Cu, Mn) concentrations in edible fish species tissue in the Pearl River Delta (PRD), China. Marine Pollution Bulletin. 2014; **78**(1–2):235-245. DOI: 10.1016/j. marpolbul.2013.10.028

[72] El-Moselhy KM, Othman AI, El-Azem A, El-Metwally MEA. Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. Egyptian Journal of Basic and Applied Sciences. 2014;**1**:97-105

[73] Reyahi-Khoram M, Setayesh-Shiri F, Cheraghi M. Study of the heavy metals (Cd and Pb) content in the tissues of rainbow trouts from Hamedan Coldwater fish farms. Iranian Journal of Fisheries Sciences. 2016;**15**(2):858-869

[74] Sulieman HMA, Suliman EAM. Appraisal of heavy metal levels in some marine organisms gathered from the Vellar and Uppanar estuaries southeast coast of Indian Ocean. Journal of Taibah University for Science. 2019;**13**: 338-343

[75] Nasyitah SN, Ahmad ZA, Khairul NM, Ley JL, Kyoung-Woong K. Bioaccumulation of heavy metals in Maricultured fish, *Lates calcarifer* (Barramudi), *Lutjanus campechanus* (red snapper) and *Lutjanus griseus* (Grey snapper). Chemosphere. 2018;**197**: 318-324. DOI: 10.1016/j. chemosphere. 2017.12.187

[76] Younis AM, Amin HF, Alkaladi A, Mosleh YYI. Bioaccumulation of heavy metals in fish, squids and crustaceans from the Red Sea, Jeddah coast, Saudi Arabia. Open Journal of Marine Science. 2015;**5**:369-378. DOI: 10.4236/ ojms.2015.54030

[77] Bazzi AO. Heavy metal in sea water, sediment and marine organism in the gulf of Chabahar, Oman Sea. Journal of Oceanography and Marine Science. 2014;**5**:20-29

[78] Bat L, Arici E, Sezgin M, Sahin F. Heavy metals in edible tissues of benthic organisms from Samsun coasts, south Black Sea Turkey and their potential risk to human health. Journal of Food and Health Science. 2016;**2**:57-66. DOI: 10.3153/JFHS16006

[79] Sadeghi E, Pirsaheb M, Mohammadi M, Salti AP, Sharafi H, Mirzaei N, et al. Evaluation of cadmium and lead levels in fillet marine fish (*Otolithes ruber and Lutjanus johni*) from Persian gulf. Annals of Tropical Medicine & Public Health. 2017;**10**: 1015-1018

[80] Eken M, Aydin F, Turan F, Uyan A. Bioaccumulation of some heavy metals on silver-cheeked toadfish (*Lagocephalus sceleratus*) from Antalya Bay, Turkey. Natural and Engineering Sciences. 2017;**2**(3):12-21

[81] Jayaprabha N, Balakrishnan S, Purusothaman S, Indira K, Srinivasan M, Anantharaman P. Bioaccumulation of heavy metals in flying fishes along southeast coast of India. International Food Research Journal. 2014;**21**(4):1381-1386

[82] Mehouel F, Bouayad L, Hammoudi AH, Ayadi Q, Regad F. Evaluation of the heavy metals (mercury, lead, and cadmium)

contamination of sardine (*Sardina pilchardus*) and swordfish (*Xiphias gladius*) fished in three Algerian coasts. Veterinary World. 2019;**12**(1):7-11. DOI: 10.14202/vetworld.2019.7-11

[83] Bashir FA, Alhemmali EM. Analysis of some heavy metal in marine fish in muscle, liver and gill tissue in two marine fish spices from Kapar coastal waters, Malaysia. In: The Second Symposium on Theories and Applications of Basic and Biosciences. Misrata, Libya; 2015

[84] Rosli MNR, Samat SB, Yasir MS, Yusof MFM. Analysis of heavy metal accumulation in fish at Terengganu coastal area, Malaysia. Sains Malaysiana. 2018;**47**(6):1277-1283. DOI: 10.17576/jsm-2018-4706-24

[85] Olusola JO, Festus AA. Assessment of heavy metals in some marine fish species relevant to their concentration in water and sediment from coastal waters of Ondo state, Nigeria. Journal of Marine Science: Research & Development. 2015;**5**:163. DOI: 10.4172/2155-9910.1000163

[86] Bandpei AM, Bay A, Zafarzadeh A, Hassanzadeh V. Bioaccumulation of heavy metals muscle of common carp fish (Cyprinus carpio L, 1758) from Ala gul and Alma gul wetlands of Golestan and consumption risk assessment. International Journal of Medical Research & Health Science. 2016;**5**:267-273

[87] Tugui C, Szekeres E, Baricz A. Sources and mechanisms of combined heavy-metal and antibiotic resistance traits in bacteria. Studia Universitatis Babeș-Bolyai Biologia. 2017;**LXII**: 101-114

[88] Pal C, Asiani K, Arya S, Rensing C, Stek DJ, DGJ L, et al. Metal resistance and its association with antibiotic resistance. Advances in Microbial Physiology. 2017;**70**:261-301. DOI: 10.1016/bs.ampbs.2017.02.001

[89] Knapp CW, Callan AC, Aitken B, Shearn R, Koenders A, Hinwood A. Relationship between antibiotic resistance genes and metals in residential soil samples from Western Australia. Environmental Science and Pollution Research International. 2017;**24**(3):2484-2494. DOI: 10.1007/s11356-016-7997-y

[90] Knapp CW, McCluskey SM, Singh BK, Campbell CD, Hudson G, Graham DW. Antibiotic resistance gene abundances correlate with metal and geochemical conditions in archived scottish soils. PLoS One. 2011;**6**:e27300. DOI: 10.1371/journal.pone.0027300

[91] Amachawadi RG, Scott HM, Alvarado CA, et al. Occurrence of the transferable copper resistance gene *tcrB* among fecal enterococci of U.S. feedlot cattle fed copper-supplemented diets. Applied and Environmental Microbiology. 2013;**79**:4369-4375

[92] Becerra-Castro C, Machado RA, Vaz-Moreira I, Manaia CM. Assessment of copper and zinc salts as selectors of antibiotic resistance in gram-negative bacteria. The Science of the Total Environment. 2015;**530-531**:367-372. DOI: 10.1016/j.scitotenv.2015.05.102

[93] Silverira E, Freitas AR, Antunes P, Barros M, Campos J, Coque TM, et al. Co-transfer of resistance to high concentrations of copper and first-line antibiotics among *Enterococcus* from different origins (humans, animals, the environment and foods) and clonal lineages. Journal of Antimicrobial Chemotherapy. 2014;**69**:899-906. DOI: 10.1093/jac/dkt479

[94] Li H, Luo YF, Williams BJ, Blackwell TS, Xie CM. Structure and function of OprD protein in *Pseudomonas aeruginosa*: From antibiotic resistance to novel therapies. International Journal of Medical Microbiology. 2012;**302**:63-68. DOI: 10.1016/j.ijmm.2011.10.001

[95] Wales AD, Davies RH. Co-selection of resistance to antibiotics, biocides and heavy metals, and its relevance to foodborne pathogens. Antibiotics. 2015; **4**(4):567-604

[96] Kacar A, Kocyigit A. Characterization of heavy metal and antibiotic resistant bacteria isolated from Aliaga ship dismantling zone, eastern Aegean Sea, Turkey. International Journal of Environmental Research. 2013;**7**(4):895-902

[97] Heck K, De Marco ÉG, Duarte MW, Salamoni SP, Van Der Sand S. Pattern of multiresistant to antimicrobials and heavy metal tolerance in bacteria isolated from sewage sludge samples from a composting process at a recycling plant in southern Brazil. Environmental Monitoring and Assessment. 2015;**187**: 328. DOI: 10.1007/s10661-015-4575-6

[98] Vignaroli C, Pasquaroli S, Citterio B, Di Cesare A, Mangiaterra G, Fattorini D, et al. Antibiotic and heavy metal resistance in enterococci from coastal marine sediment. Environmental Pollution. 2018;**237**:406-413

[99] Baker-Austin C, Wright MS, Stepanauskas R, McArthur JV. Co-selection of antibiotic and metal resistance. Trends in Microbiology. 2006;**14**(4):176-182

[100] Ji X, Shen Q, Liu F, Ma J, Xu G, Wang Y, et al. Antibiotic resistance gene abundances associated with antibiotics and heavy metals in animal manures and agricultural soils adjacent to feedlots in Shanghai, China. Journal of Hazardous Materials. 2012;**235–236**: 178-185

[101] Anssour L, Messai Y, Estepa V, Torres C, Bakour R. Characteristics of ciprofloxacin-resistant Enterobacteriaceae isolates recovered from wastewater of an Algerian hospital. Journal of Infection in Developing Countries. 2016;**10**(07):728-734

[102] Ali NM, Mazhar SA, Mazhar B, Imtiaz A, Andleeb S. Antibacterial activity of different plant extracts and antibiotics on pathogenic bacterial isolates from wheat field water. Pakistan Journal of Pharmaceutical Sciences. 2017;**30**(4):1321-1325

[103] Mirzaei N, Rastegari H, Kargar M. Antibiotic resistance pattern among gram negative mercury resistant bacteria isolated from contaminated environments. Jundishapur Journal of Microbiology. 2013;**6**(10):634-639

[104] Habi S, Daba H. Plasmid incidence, antibiotic and metal resistance among enterobacteriaceae isolated from Algerian streams. Pakistan Journal of Biological Sciences. 2009;**12**(22): 1474-1482. DOI: 10.3923/pjbs.2009. 1474.1482

[105] De Niederhäusern S, Bondi M, Anacarso I, Iseppi R, Sabia C, Bitonte F, et al. Antibiotics and heavy metals resistance and other biological characters in *Enterococci* isolated from surface water of Monte Cotugno Lake (Italy). Journal of Environmental Science and Health, Part A. 2013;**48**(8): 939-946

[106] Djouadi LN, Selama O, Abderrahmani A, Bouanane-Darenfed A, Abdellaziz L, Amziane M, et al. Multiresistant opportunistic pathogenic bacteria isolated from polluted rivers and first detection of nontuberculous mycobacteria in the Algerian aquatic environment. Journal of Water and Health. 2017;**15**(4):566-579

[107] Verma T, Ramteke PW, Garg SK. Occurrence of chromium resistant thermotolerant coliforms in tannery effluent. Indian Journal of Experimental Biology. 2004;**42**(11):1112-1116

[108] Martins VV, Zanetti MOB, Pitondo-Silva A, Stehling EG. Aquatic environments polluted with antibiotics and heavy metals: A human health

hazard. Environmental Science and Pollution Research International. 2014; **21**(9):5873-5878

[109] Budambula NML, Kinyua DM. Antibiotic resistance of metal tolerant bacteria isolated from soil in Juja, Kenya. In: Conference Paper: JKUAT Scientific, Technological and Industrialization Conference November 2013. Nairobi; 2013

[110] Cavaco LM, Hasman H, Stegger M, Andersen PA, Skov R, Fluit AC, et al. Cloning and occurrence of czrC, a gene conferring cadmium and zinc resistance in methicillin-resistant Staphylococcus aureus CC398 isolates. Antimicrobial Agents and Chemotherapy. 2010;**54**(9): 3605-3608. DOI: 10.1128/AAC.00058-1

[111] Abskharon RN, Hassan SH, Gad El-Rab SM, Shoreit AA. Heavy metal resistant of *E. coli* isolated from wastewater sites in Assiut City, Egypt. Bulletin of Environmental Contamination and Toxicology. 2008; **81**(3):309-315

[112] Sepahy AA, Sharifian S, Zolfaghari MR, Dermany MK, Rashedi H. Study on heavy metal resistant fecal coliforms isolated from industrial, urban wastewater in Arak, Iran. International Journal of Environmental Research. 2015; **9**(4):1217-1224

[113] Deredjian A, Colinon C, Brothier E, Favre-Bonte S, Cournoyer B, Nazaret S. Antibiotic and metal resistance among hospital and outdoor strains *of Pseudomonas aeruginosa*. Research in Microbiology. 2011;**162**(7):689-700. DOI: 10.1016/j.resmic.2011.06.007

[114] Mourão J, Marçal S, Ramos P, Campos J, Machado J, Peixe L, et al. Tolerance to multiple metal stressors in emerging non-typhoidal MDR *Salmonella* serotypes: A relevant role for copper in anaerobic conditions. The Journal of Antimicrobial Chemotherapy. 2016;**71**(8):2147-2157

[115] Soltan MES. Isolation and characterization of antibiotic and heavy metal-resistant *Pseudomonas aeruginosa* from different polluted waters in Sohag district, Egypt. Journal of Microbiology and Biotechnology. 2001;**11**(1):50-55

[116] Manegabe BJ, Marie-Médiatrice NK, Barr Dewar J, Christian SB. Antibiotic resistance and tolerance to heavy metals demonstrated by environmental pathogenic bacteria isolated from the Kahwa River, Bukavu town, Democratic Republic of the Congo. International Journal of Environmental Studies. 2017; **74**(2):290-302

[117] Sandegren L, Linkevicius M, Lytsy B, Melhus A, Andersson DI. Transfer of an *Escherichia coli* ST131 multiresistance cassette has created a *Klebsiella pneumoniae*-specific plasmid associated with a major nosocomial outbreak. Journal of Antimicrobial Chemotherapy. 2012;**67**:74-83. DOI: 10.1093/jac/dkr40.5

[118] Gilmour MW, Thomson NR, Sanders M, Parkhill J, Taylor DE. The complete nucleotide sequence of the resistance plasmid R478: Defining the backbone components of incompatibility group H conjugative plasmids through comparative genomics. Plasmid. 2004;**52**:182-202

[119] Seginkova Z, Kralikova K. Monitoring the contemporary resistance of *Escherichia coli* and *Salmonella* Sp. strains isolated from aquatic environment to antibiotics and ions of heavy-metals. Ekologia Bratislava. 1993; **12**(1):111-118

[120] Hu Q, Dou MN, Qi HY, Xie XM, Zhuang GQ, Yang M. Detection, isolation, and identification of cadmium-resistant bacteria based on PCR-DGGE. Journal of Environmental Sciences. 2007;**19**(9):1114-1119

[121] Oyetibo GO, Ilori MO, Adebusoye SA, Obayori OS,

Amund OO. Bacteria with dual resistance to elevated concentrations of heavy metals and antibiotics in Nigerian contaminated systems. Environmental Monitoring and Assessment. 2010;**168** (1–4):305-314

[122] Ojedokun AT, Bello OS. Sequestering heavy metals from wastewater using cow dung. Water Resources and Industry. 2016;**13**:7-13

[123] Li JJ, Li-Na P, Shan W, Meng-Da Z. Advances in the effect of heavy metals in aquatic environment on the health risks for bone. Earth and Environmental Science. 2018;**186**:012057. DOI: 10.1088/1755-1315/186/3/012057

[124] Hernández-García A, Romero D, Gómez-Ramírez P, María-Mojica P, Martínez-López E, García-Fernández AJ. In vitro evaluation of cell death induced by cadmium, lead and their binary mixtures on erythrocytes of common buzzard (*Buteo buteo*). Toxicology In Vitro. 2014;**28**:300-306. DOI: 10.1016/j.tiv.2013.11.005

[125] Bhattacharya PT, Misra SR, Mohsina Hussain M. Nutritional aspects of essential trace elements in oral health and disease: An extensive review. Scientifica. 2016;**2016**:5464373. DOI: 10.1155/2016/5464373

[126] Smith AH, Lingas EO, Rahman M. Contamination of drinking-water by arsenic in Bangladesh: A public health emergency. Bulletin of the World Health Organization. 2000;**78**(9): 1093-1103