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MONITORING OF HEAVY METAL IMPACTS BY SMALL MAMMALS

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ABSTRACT

Environment is continuously polluted with various environmental chemicals, released by anthropogenic activities. Therefore, many species and human communities are exposed to a different contaminant such as heavy metals which lead to adverse health effects in both human and other animals. Over the last decades the production of heavy metals in the world areas substantially increased and the subsequent release of these metals into the environment is of some concern. Acute and chronic effects of heavy metals have been reported on different ecosystems and organisms. Protection of human health and the environment from different pollutants such as heavy metals will be resulted by performing environmental monitoring. Bio-indicator species can provide useful information to monitor the quality of the environment, in particular polluted environment. The distributions of heavy metals in the polluted areas are well reflected in the body of small mammals living in the contaminated areas. Small mammals like rodents have interesting features make them popular as a bio-indicator species in different studies. Therefore, small mammals are suggested to apply in monitoring of heavy metals due to large population, wide distribution, and similarity to human in terms of habitat and internal organs, short life spans, and many other characteristics.

KEYWORDS: Small mammal, heavy metal, rodent, monitoring, pollution.

BIO-MONITORING FOR ENVIRONMENTAL MANAGEMENT

Different ecosystems or processes can be monitored for a wide range of aims, including establishing health status for temporal or spatial trends, evaluating the effects of particular natural or anthropogenic stressors, and evaluating the efficacy of deliberate anthropogenic measures (Burger and Gochfeld 1994; Azgomi et al. 2018; Artiola and Warrick 2004). Environmental monitoring can be defined as all the processes and activities that need to happen to characterize and monitor the quality of the environment. Environmental monitoring assesses the circumstances of environment by the collection of one or more measurements (Artiola and Warrick 2004). In order to acquire the best environmental monitoring information and robust results, the aims, required materials, sample collection strategies, and methods of analysis used in monitoring should be well defined before starting monitoring programs (Artiola and Warrick 2004). Protection of human health and the environment will be resulted by performing environmental monitoring (Artiola et al. 2019). By performing several monitoring programs, improvement has been made toward improving regulation, reporting, and monitoring on a project basis during last decades. Previous studies listed several reasons for performing a monitoring study. Munn (1973) mentioned that monitoring studies lead to increase quantitative knowledge of human being in the environment. In addition, monitoring programs can enhance the knowledge of dynamic balance in ecosystems and aware people about warning of significant environmental changes (Munn 1973; Moody et al. 2002).

For proper management of environment, knowledge of the transport and fate of pollutants in natural ecosystems is necessary (Wren 1986). To protect our environment from different pollutant, environmental monitoring is required to be able preserve the public and the environment. Based on Connell and Miller 1984 classifications, environmental bio-monitoring can be classified in two categories of factor monitoring (monitoring of various contaminations in the different sections of the environment) and target monitoring (monitoring the impacts of pollutants on the natural environment) which is interested by biologists and toxicologists. There researchers are becoming increasingly concerned with the impact of pollutant substances to natural ecosystems and populations of wild organisms. Every day several harmful environmental chemicals from different sources are daily released to the environment and accumulated in the body of wild animals (Talmage and Walton 1991). Among these xenobiotic, heavy metals have been received increasing attention over last decades for monitoring program.

Heavy Metal Toxicity

Although heavy metals are naturally occurring elements, high concentration of these pollutants are reported in different parts of the environment due to intense anthropogenic activity. Heavy metals are widely using in industrial, domestic, agricultural, medical, and technological applications which raising concerns over their adverse impacts on human health, animals, and the environment (Tchounwou et al. 2012; Rajaei et al. 2013). The toxicity of heavy metals depends on the many factors such as type of metal, dose, pathway of exposure, sex, body size, age, life span, genetics, different tissues, homeostatic mechanisms of the individual, physiological state, differences in population structure, interactions with other species, and interaction between elements (Tchounwou et al. 2012; Alavian et al. 2017; Khazaee et al. 2015). Many heavy metals like cadmium (Cd), chromium (Cr), and lead (Pb) often cause acute and chronic environmental contamination. These metals are considered systemic toxicants and can significantly affect different organism and human even in very low concentrations. In contrast, some heavy metals cobalt (Co), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn) are essential for human and other animals. It was reported that inadequate concentrations of these micronutrients lead to in a variety of deficiency diseases or syndromes (Tchounwou et al. 2012)

High levels of both toxic and essentials metals can damage different internal tissues as well as cellular organelles and components such as cell membrane, mitochondrial, lysosome, endoplasmic reticulum, DNA damage, and conformational changes (Moein Rajaei et al. 2015; Tchounwou et al. 2012. Previous studies reported the adverse effects of heavy metals on plant (Alloway 1995), oyster (Alavian et al. 2017), fish (Rajeshkumar and Li 2018), mammals (Piskorová, Vasilková, and Krupicer 2003), and human (Espinosa-Reyes et al. 2014). Due to significant functional and trophic roles in terrestrial ecosystems, small mammals have been shown to accumulate high levels of heavy metals (Damek-Poprawa and Sawicka-Kapusta 2003). Therefore, small mammals living in polluted regions such as industrial areas are proper tools to evaluate the presence of different contaminates such as heavy metals.

Monitoring of heavy metals by different species

All species tolerate a limited range of chemical, physical, and biological conditions, which we can use to evaluate environmental quality. Various species of biota can be potentially used or were used as bio-indicator organisms for measuring diversified types of pollutants at different situations. In this aspect, many organisms and plants are widely used as bio-indicators for heavy metals pollution in different environment.

Animals as Bio-indicators

Zooplankton, invertebrate and vertebrate mostly use as bio-indicators. Among of zooplanktons, *Daphnia magna* as bio-indicator species was influenced by several advantageous characteristics. Compared to mollusks, freshwater organisms, or macro-crustaceans, it has a small size and is relatively sensitive to chemicals. The ecology of *Daphnia* has been widely studied; thus, there are background information on its biology and ecology. Therefore, *Daphnia magna* is the most investigated freshwater species to determine the toxicity of heavy metals such as Cu, Cd, Zn, and Se (Lam and Wang 2008).

The earthworm *Eisenia fetida* is one of the mostly used organism for investigation of heavy metals toxicity in terrestrial ecosystems. Mollusks play substantial ecological roles in the different aquatic and terrestrial ecosystems due to their ubiquitous distribution and enormous species number. Although mollusks are basically a marine group of animals, gastropods and bivalves have also extended their distribution to various freshwater systems (Moloukhia and Sleem 2011). Gastropods have additionally penetrated into a huge variety of terrestrial habitats so that mollusks can be found today sea, lakes, rivers, forests, mountains, as well as deserts. Thus, mollusks have been successfully used to obtain information on the quality of terrestrial, marine and freshwater ecosystems and to evaluate contaminants in their environment (Oehlmann and Schulte-Oehlmann 2002). Compared with vertebrates, mollusks demonstrate only a limited ability to excrete pollutants directly via their kidneys or other excretory organs. Therefore, mollusks show higher bioaccumulation or bio-concentration factors for many pollutants than other groups. Most gastropod and bivalve species used for bio-monitoring and bio-indication purposes are relatively large and easy to handle. Consequently, they can be applied both under laboratory and field circumstances, for active and passive bio-monitoring.

Fish are well recognized bio-indicators of environmental changes, including metals pollution, and are adequate for waters monitoring programs. In fishes some trace metals, such as Mn, Co, Fe, V, Cu, Zn and Se, are necessary in small levels for metabolic processes being naturally absorbed by fish. Other metals, such as Ni, Pb, Cr, Cd, and Hg are non-essential elements which have no biological roles and become toxic above certain concentrations (Hauser-Davis et al. 2012). The mobility of many fish species makes difficult to identify not only the exact source of pollution, but also the time and duration of pollution exposure.

A few groups of birds are well studied in the literature investigated the contaminants in various environment, particularly raptors, waterfowl, and seabirds. Birds can play a significant role as bio-indicators in their habitats. The general biology and ecology of birds are well known and birds are easy to identify (Zamani et al., 2015). However, despite their undoubted benefits as bio-indicators, birds are not being used in bio-monitoring studies. Since many bird species are migratory, it is difficult to determine where exposure occurred (Burger and Gochfeld 2004). Birds have been successfully used to indicate temporal and spatial trends in toxic metal pollutions in terrestrial and aquatic ecosystems (Zhang and Ma 2011; Kitowski et al. 2012). Birds have been proposed as useful bio-monitoring species of pollutants from the year 1993. Until than focus have been on waterfowl or raptors, terrestrial passerines, such as great tit (*Parus major*), coal tit (*Periparus ater*), blue tit (*Cyanistes caeruleus*), pied flycatcher (*Ficedula hypoleuca*) and collared flycatcher (*Ficedula albicollis*) (Berglund et al. 2011). They have successfully been used to monitor the environment close to a variety of different metal industries.

Mammals represent useful organisms for bio-monitoring purposes and can be used when both temporal and spatial information is necessary. Among different classes of organisms, free ranging animals or "wildlife" fit best the requirements for a bio-monitor. This is because they depend exclusively on the quality of food, water, and air in their habitat. They consume flora or fauna that reflect the local soil, water, and air contamination. Any contamination present will influence the animal and can have an effect on its health. The metal toxic levels in mammals depend on their diet composition and often influenced by food chain effects.

Plants as Bio-indicators

Many toxic and bio-accumulative pollutants are found in only trace amounts in water, and often at elevated levels in sediments. Data from sediments may not be representative of pollutant concentrations in the overlying water column and cannot give information on patterns of contamination at the higher levels of the food chain. For example, the uptake of toxic metals by phytoplankton is the first step in the bioaccumulation in aquatic food webs. Macro- and microalgae also play an important role in the removal of toxic metals (Torres et al. 2008; Azizi et al. 2012).

In terrestrial environments, bacteria, fungi, algae and other lower plants play the substantial role in the biochemical cycling of heavy metals. In aquatic environments, algae play a key role in biogeochemical cycling of metals and their accumulation in sediments. Metals sequestered by microalgae are a major contributor to the metal load of the water column as well as to the metal content of sediments (Torres et al. 2008).

Some green algae or phytoplankton like *Scenedesmus subspicatus*, Chlorella vulgaris or *Pseudokirchneriella subcapitata* are in use as standard bio-indicators representing primary producers (Ratte et al. 2003). For example, dominated algal mats of the green algae genera *Klebsormidium* are good indicators of high Fe concentration in water, whereas the presence of Fucus vesiculosus suggesting heavy metal pollution in marine environment (Das et al. 2009). At low metal concentration, algae, accumulating metals, pass them to other trophic levels.

Mosses and lichines are particularly used as bio-indicators of aerial heavy metals contamination because of their bio-accumulative properties (Blagnyte and Paliulis 2010). Analysis of indigenous mosses is currently used in international and national monitoring programmers, particularly in Europe (Harmens et al. 2008). Mosses have been applied to measure heavy metal levels and trends within and around urban and industrial areas (Suchara et al. 2011). The use of fungi in the monitoring of heavy metal pollution is limited but some fungal groups are better bio-accumulators than others. Little published literature exists with regard to fungi distribution patterns in response to aerial metal contamination. Also, the use of marine organisms as bio-indicators for trace metal pollution is currently very common. Macroalgae and mollusks are among the organisms most 5 Bio-indicators of Toxic Metals 195 used for this purpose (Joksimovic and Stankovic 2012).

Leaves/needles of spruce, birch, pine, oak, olive, poplar; also a bark of oak, pine, ash tree are the most important sections of plant and trees for bio-monitoring (Serbula et al. 2012). Different plant organs (leaves, flowers, bark or roots) from naturally occurring wild plants and trees, and cultivated plants (vegetables and fruits) were investigated as possible bio-indicators of heavy-metal pollutions in various ecosystems (Filipovic-Trajkovic et al. 2012). The bioavailability of trace elements from aerial sources through leaves also has a considerable effect on plant pollution. Trace elements absorbed by leaves can be translocated to other plant organs according to Filipovic-Trajkovic et al. (2012) and Serbula et al. (2012).

The terrestrial plants are also promising indicators for metal pollution in the soil. It is essential during metal bio-monitoring plans that the background of examined elements concentrations in the soil should be established. The design of a monitoring plan should contain the selection of proper species, sampling locations, sample collection, sampling frequency, various metals, chemical detection technique, and data analysis.

Of all the species studied terrestrial small mammals (shrews, moles, voles, mice) fulfil the basic requirements for use in bio-monitoring and eco-toxicological studies (Sánchez-Chardi and Nadal 2007; Adham et al. 2011; Okati and Rezaee 2013). They have widespread occurrence, a limited home range, generalized food habits, short life span, and high reproductive rates and are easily collected. They are more exposed to environmental contaminants than large mammals due to their small body size and high metabolic rate (Levengood and Heske 2008). Moreover, small mammals can serve as a mammalian replacement or proxy for humans (Damek-Poprawa and Sawicka-Kapusta 2003). Furthermore, small mammals are important prey for birds and mammals and could constitute an important pathway for the entry of metals into their food chains (Sánchez-Chardi and Nadal 2007; Levengood and Heske 2008).

Small mammals as bio-indicator species

Free living wild animals are often used to monitor the effects of heavy metal pollutions on environment. Small mammals (voles, mice, and shrews) play a substantial role in terrestrial food webs by acting at different trophic levels (Damek-Poprawa and Sawicka-Kapusta 2003). To evaluate the levels of different contaminants, wild mammals, in particular small mammals are interested in recent studies. Due to wide distribution of small mammals around the world, monitoring of different pollutants can be performed in many regions by applying small mammals (Sierra-Marquez et al. 2018). Based on previous studies, the distribution and concentration pattern of heavy metals in different organs of small mammals are similar to those reported in humans. Therefore, small mammals as a proper mammalian surrogate for human have frequently been applied to monitor the presence of heavy metals and other contaminants in the different ecosystems. These bio-monitoring studies are essential for determining bioavailability of heavy metals and resultant biological effects under natural conditions. Rodents as small mammals have been extensively used in previous studies as bio-indicator species (biota that are developed as indicators of the quality of the environment, the biotic component, or humans within an ecosystem) to monitor heavy metals pollution (Khazaee et al. 2016). Table 1 shows different studies around the world used small mammals to evaluate the concentration of heavy metals in different polluted areas. As the Table 1 represents different small mammals as bio-indicator are applied to monitor the adverse effects of heavy metals in various polluted areas around the world.

Table 1: Small mammals used as bio-indicator species of environmental gradients of metal concentrations.

Species	Area	Tissue	Metals	References
Bank and common voles	Polluted biotopes	Bone	Pb, Zn, Cu, Ni, Cd, Fe	(Martiniaková et al. 2011)
Persian jird	Copper mine	Femur, liver, Hair, and lung	Ti, Mn, Cu, Sr, Ni, Fe, Cr,	(M. Khazaee et al. 2016)
Microtus agrestis	Metalliferous mine site	Liver, Kidney, heart, femur, skull, teeth, muscle	Cd	(Andrews et al. 1984)
Sorex araneus	Metalliferous mine site	Liver, Kidney, heart, femur, skull, teeth, muscle	Cd	(Andrews et al. 1984)
Javan mongoos and Amami rabbit	Amamioshima Island	Liver, kidney, brain	Mg, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Ag, Cd, Sb, Cs, Ba, Tl	(Horai et al. 2006 n.d.)
Talpa europaea	Contaminated and rural areas	Liver, kidney	Cu, Ni, Zn, Cd, Cr, Hg, Pb	(Pankakoski et al. 2019 n.d.)
Bank voles	forests at east and south of Kraków	Liver, kidney, spleen	Cu, Fe, Zn	(Topolska, Sawicka-Kapusta, and Cieślik 2004)
Subterranean rodent	Cultivated area and military area	Liver, muscle	Pb, Zn, Fe, Cu	(Schleich, Beltrame, and Antenucci 2010)
Golden jackal	on the roads along the Caspian Sea	Liver, hair	Hg	(Malvandi et al. 2010)
Red Fox	Province of Siena	Liver	Hg, Pb, Cd	(Corsolini et al. 1999)
Red Fox	Central Zemplín region	Liver, kidney, muscle	Hg, Pb, Cd, Cr	(Piskorová, Vasilková, and Krupicer 2003)
Wood mice	Garraf landfill	Liver	Pb, Hg, Cd, Fe,	(Sánchez-Chardi

	site		Mg, Zn, Cu, Mn, Mo, Cr	and Nadal 2007)
Black-striped field mice	two localities in Serbia	Skulls	Cd, Zn, Ni, Pb Cu, Fe, Mn, Co	(Lagojević, J., Jovanović, V., Stamenković, G., Jojić, V., Bugarski-Stanojević, V., Adnađević and and Vujošević 2012)

CONCLUSION

To evaluate the transfer potential of a various pollutants in details, it is necessary to monitor different physical, chemical and biological parts of environment. Biological monitoring of heavy metal levels in small mammals can play a significant role in environment investigations. Various interesting characteristics of small mammals lead to widely used in many studies. Large population, small home range, wide distribution, high metabolic rate, similarity to human, short life spans, similar habitat relative to human, and easily aged and sexed. Long-term environmental monitoring programs are a big challenge in many countries. Monitoring the polluted areas with different contaminations like heavy metals by small mammals lead to significantly reducing time and cost in future studies. As many previous studies showed, small mammals especially rodents can be used as a proper bio-indicator species in long term monitoring studies for heavy metal pollution in various contaminated area. Thus, small mammals can be valuable biological monitors of environmental gradients of metal levels.

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