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Effects of Heavy Metals on Fish

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Abstract: Heavy metals are matters that form the most dangerous side of chemical water pollution due to their ability to bioaccumulate and biomagnify and can not be eliminated from the body by metabolic activites. In this study literature is reviewed by examining studies on general characteristics and sources, uptake by fish, concentration evaluations and effects on fish and other aquatic organisms of heavy metals such as cadmium, copper, manganese, nickel, iron and lead. Studies examined showed that heavy metals cause severe damage on fish thus endanger fish health and ecosystem and constitute respectable risks for human health via consumption of heavy metal contaminated fish.

Keywords: Heavy metal, Effect, Fish, Pollution

Ağır Metallerin Balıklar Üzerine Etkisi

Öz: Biyolojik birikim, biyolojik artış kabiliyetleri ve metabolik faaliyetler sonucu vücuttan atılamamaları sebebiyle ağır metaller, kimyasal su kirliliğinin en tehlikeli boyutlarını oluşturan maddelerdir. Bu çalışmada kadmiyum, bakır, çinko, manganez, nikel, demir ve kurşun gibi ağır metallerin genel özellikleri, kaynakları, balıklar tarafından alınımı, ağır metal seviyelerinin belirlenmesi ve balıklar ve diğer sucul organizmalar üzerine olan etkileri ile ilgili çalışmalardan literatür derlemesi yapılmıştır. İncelenen çalışmalar göstermiştir ki ağır metaller balıklarda oldukça şiddetli olumsuz etkiler oluşturmakta, balık sağlığını ve ekosistemi tehlikeye atmakta ve ağır metal içeren balıkların tüketimi sonucu insan sağlığında da ciddi tehlikeler meydana getirebilme potansiyeline sahiptir.

Anahtar Kelimeler: Ağır metal, etki, balık, kirlilik

INTRODUCTION

There are several ways to describe the term "heavy metal" in the literature. It is often used as synonym for trace metals and includes essential and nonessential metals that have high atomic weight and greater density than that of water. Heavy metal is chemically defined as all matter that can become electron donor and valence ion, can switch places with H ions in acids, can form compounds with nonmetals but can not form with each other and has alkaline oxides. In physical terms it is defined as all matter that can conduct heat and electricity well, can be transformed into metal plate and wire, has a metallic colour and lustre and is solid under normal circumstances except mercury (Rainbow, 1995; Sönmez et al., 2012a; Tchounwou et al., 2012). But when it comes to effects of them, regardless of its definition any metal may be called heavy metal if it is toxic to any organism under any circumstances.

Heavy metals naturally exist in various concentrations in earth's crust, soil, air, water and all biological matter and they have been spread widely as a result of anthropogenic activities such as cement production, iron steel industry, steam power plants, glass production, garbage and waste mud incineration facilities, mining activites, smelters and foundries, piping, combustion and traffic (Langston, 1990; Alloway and Ayres, 1993; Bolognesi et al., 1999; Rether, 2002; Sönmez, 2012a). They can also diffuse around by natural events such as wind, soil erosion and volcanic activity (Fergusson, 1990; Gregory et al., 2002; Taylan and Özkoç, 2007; Karayakar et al., 2017).

Pollution and corresponding risks that come into existence by this rapid increase in agricultural activities, population growth, urbanization and industrialization are critical issues about environment (Akbulut et al., 2010; Sönmez et al., 2013a). There is no doubt that the most dangerous chemical pollution in water is heavy metal contamination (Sönmez et al., 2012a). Heavy metals constitute a significant ecological and health concern due to their toxicity and ability to accumulate in living beings. Heavy metals have a strong influence on the stability of ecosystems but also have adverse effects on humans (IARC, 1980; 1987; 1990; Bolognesi et al., 1999).

Even though some of the heavy metals such as zinc, iron, cobalt and copper are essential for enzymatic activity and other biological processes at low levels they become toxic when they exceed certain limit. On the other hand other metals such as lead, cadmium and mercury have no essential role in living organisms and are toxic even at too low concentrations (Bryan, 1976).

Heavy metals do not pend in water and settle down swiftly onto sediment due to their higher density than that of water. This was demonstrated with Cd and Cu exposure, metals showed 72 to 97% decrease from their initial concentration after 96 hours of experiment (Ghosal and Kaviraj, 2002; Ghosh et al., 2016; Ghosh et al., 2018).

Uptake of Heavy Metals by Fish

Heavy metals are mostly toxic, can cause severe damage and become lethal for most organisms since they are able to bioaccumulate and biomagnify. Bioaccumulation means an increase in the concentration of a xenobiotic in an organism over time compared with xenobiotic concentration in the environment (Govind and Madhuri, 2014). Biomagnification means transfer of a xenobiotic from food sources to an organism, resulting a higher concentration in the organism than the sources (Connell, 1989; 1990; Rand et al., 1995).

Uptake of heavy metals by fish from the environment primarily occurs through gills, food, skin and in freshwater fish through water taken with food and taken heavy metals are carried to organs by carrier proteins via blood path and can reach high concentrations by bonding to metal binding proteins in these tissues (Sönmez et al., 2016).

The toxic element concentration in fish depends on sex and age of fish, season and place. Pollution of water sources by anthropogenic activities leads to aquatic loss and therefore disrupts the balance of food chain (Afshan et al., 2014).

There have been many determination studies of heavy metals in water, sediment, fish and other aquatic organisms. Some of them are presented in Table 1.

Table 1. Some determiation studies of heavy metals in fish

Fish Species	Investigated Heavy Metals	Organ / Tissue	Are edible parts apporopriate for human consumption ?	Permissible limits determined by	Location	References
Epinephelus areolatus Lutjanus russelli Sparus sarba	Cd, Cr, Cu, Ni, Pb, Zn	Liver, Gonad, Muscle, Skin	Yes	Hong Kong Government		Wong et al. (2001)
Saurida undosquamis Sparus aurata Mullus barbatus	Cd, Fe, Pb, Zn, Cu, Mn, Ni, Cr, Co, Al	Muscle	Yes	Nauen (1983), EPA	İskenderun Bay, Mediterranean, Turkey	Türkmen et al. (2005)
Leuciscus cephalus Lepomis gibbosus	Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn	Muscle, Gill, Liver	Yes	FAO/WHO, EU, TFC	Sarıçay, Turkey	Yılmaz et al. (2007)
Scomber scombrus Merlangius merlangus Mullus barbatus Mugil cephalus Pomatomus saltor Sarda sarda Trachurus trachurus Engraulis encrasicholus Clupea sprattus	Hg, As, Pb, Cd, Fe, Cu, Mn, Zn, Se, Cr, Ni	Muscle	No	FAO, WHO, TFC	Black Sea, Turkey	Tüzen (2009)
Oncorhynchus mykiss Cyprinus carpio Leiciscus cephalus Capoeta tinca Chondrostoma regium	Fe, Zn, Cu, Pb, Mn, Ni, Cd	Muscle	No	FAO/WHO, TFC	Yeşilırmak, Turkey	Mendil et al. (2010)
Puntius ticto Puntius sophore Puntius chola Labeo rohita	Cd, As, Pb, Cr, Ni, Zn, Se, Cu, Mo, Mn, Sb, Ba,V, Ag.	Whole body	No	FAO/WHO	Buriganga river, Bangladesh	Ahmed et al. (2016)

Glossogobius giuris						
Trachurus mediterraneus Engraulis encrasicolus ponticus Sprattus sprattus	As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn	Muscle, Gill, Gonad	No	EC, TFC	Black Sea, Turkey	Alkan et al. (2016)
Merlangius merlangus	Fe, Zn, Mn, Co, Cu, Cr, Pb, Cd, Ni, Al, Hg	Muscle, Gill, Liver	Yes	EFSA, TFC, MAFF	Sinop Coast, Black Sea, Turkey	Bat and Arıcı (2016)
Scomber japonicus Caranx rhoncus Pegusa lascaris	Zn, Cu, Pb, Cd	Gill, Liver, Kidney, Spleen, Muscle	Yes	TFC	Mersin Bay, Mediterranean, Turkey	Karayakar et al. (2017)

EC: European Commission, WHO: World Health Organization, EPA: United States Environmental Protection Agency, FAO: Food and Agriculture Organization, TFC: Turkish Food Codex, EFSA: European Food Safety Authority, MAFF: United Kingdom Ministry of Agriculture, Fisheries and Food

Effects of Heavy Metals on Fish

Some of the aquatic organisms can store heavy metals up to certain amount. Even though these heavy metals are not harmful or toxic, they can reach to humans via food chain and affect human health (Merlini, 1971) As a general rule toxicity occurs when heavy metal concentrations reach above certain levels. Also heavy metals piled in water join to the food chain from many stages and threaten ecosystem safety, fish and human health. (Jain et al., 2008; Sönmez et al., 2013a).

Fish are at the top of the aquatic food chain, and they can accumulate preexisting metals in various tissues and organs (Mansour and Sidky 2002; Sönmez et al., 2012). Aquatic organisms such as fish and shell fish accumulate metals to concentrations many times higher than present in water or sediment (Olaifa et al, 2004, Gumgum et al., 1994; Al-Weher, 2008). Accumulated metals in fish tissues up to toxic concentrations are based on certain environmental conditions such as food chain, predation competition, water chemistry (salinity, pH, water hardness,) and hydrodynamics in the water (Förstner and Wittmann, 1981; Guven et al., 1999; Akgün et al., 2007; Al-Weher, 2008). Furthermore, interaction between metals may also influence accumulation (Pagenkopf, 1983; Cicik, 2003).

Studies carried out on fish revealed that all heavy metals, despite the fact that some of them are essential for life, have adverse effects on living organisms through metabolic interference and mutagenesis. These adverse effects are decrease in fitness, interference in reproduction that leads to carcinoma and eventually death (Govind and Madhuri, 2014).

In addition to reproduction, hypoxic conditions, excessive stocking and starvation, heavy metal effects also cause stress in fish (Levesque et al., 2002; Arslan et al., 2006). Stress factors including pollution affect growth, development and reproduction adversely by changing metabolic, physiological and biochemical functions (Heath, 1995; Çiftçi et al., 2017).

Adverse impacts on physiological functions and biochemical parameters both in blood and tissue of the fish living in metal contaminated waters have been observed. It has been reported that fish exposed to metals showed immune system malfunction and thus became vulnerable to contagious diseases and had a greater mortaliy risk (Larsson and Haux, 1985; Abel and Papoutsouglou, 1986; Sehgal and Saxena, 1986; Nemesok and Huphes, 1988; Çelik, 2006; Akgün et al., 2007; Al-Weher, 2008).

In despite of carcinogenic effects of heavy metals are not known well, several studies suggest genotoxic effects may exist (Snow, 1992). Heavy metals enhance genotoxicity either directly or indirectly by inducing toxicity of other chemical agents (Bolognesi et al., 1999). Heavy metal exposure reduces estrogenic and androgenic secretion and also causes pathological changesi in fish (Ebrahimi and taherianfard, 2011).

Effects of Cadmium (Cd)

Cadmium exhibits high toxicity at even very low concentrations and has acute and chronic effects on fish and environment. Long exposure of cadmium poses various acute and chronic effects on aquatic living beings (Thomas et al., 1983; Kuroshima, 1992). Such effects are enhancement of humoral immune response (Descotes, 1992; Krumschnabel et al., 2010), inducement of structural and functional changes in gill, intestine, liver and kidney (Kumar and Sing, 2010), pathological alterations in liver such as congestion, necrosis of pancreatic cells and fatty changes in the peripancreatic hepatocytes, congestion and engorgement of blood vessels (Rani and Ramamurthi, 1989; Dangre et al., 2010; Kumar and Sing, 2010). It also causes disruption of calcium metabolism, hypercalciuria and leads kidney stones to form. Toxicity varies in fish, salmonids are highly susceptible to cadmium exposure and sublethal effects such as obvious spine malformation were reported. According to Kumar and Sing it alters antioxidant defense system and production of free radicals

Çiftçi et al. (2017) observed a decrease in hepatosomatic index in north african catfish (*Clarias lazera*) after Cd exposure. In rosy barb (*Puntius conchonius*) short term effect of high concentrations of Cd caused hyperglycemia, whereas long term effect of low concentrations of Cd caused hypoglycaemia and liver glycogen concentrations were enhanced in both situations (Çelik et al., 2008).

Witeska and Jezierska (1994) revealed that red blood cell count and haematocrit levels of Cd exposed common carp (*Cyprinus carpio*) increased. Johansson-Sjobeck and Larsson (1978). showed that red blood cell count, haematocrit and haemoglobin levels of european flounder (*Pleuronectes flesus*) decreased significantly after Cd exposure. Also in mozambique tilapia (*Oreochromis mossambicus*) Cd caused decrease in haemoglobin levels and red blood cell count (Ruparella et al., 1990; Çelik, 2006).

Tort et al. (1988) found out that Cd exposure caused leucocyte (WBC) concentration of lesser spotted dogfish (*Scyliorhinus canicula*) to reduce. Similar results were obtained in mozambique tilapia by Ruparella et al. (1990). However Tort and Hernandes-Pascual (1990) observed decrease in WBC count of mozambique tilapia that exposed to Cd (Çelik, 2006).

Cd also effects glucose levels of fish. It has been shown that Cd exposure caused glucose levels in rainbow trout (*Oncorhynchus mykiss*) to increase (Haux and Larsson, 1984), in comon carp (*Cyprinus carpio*) to decrease (Yamawaki et al., 1986). Çelik (2006) showed that Cd in common carp induced glucose levels on 1st and 3rd days whereas glucose levels were not affected on 15th and 30th days after exposure.

Kidney is the main target organ of cadmium toxicity and chronic exposure in almost all animal species and it is characterized by various renal damage degrees (Roméo et al., 2000; Shukla and Gautam, 2004; Kumar et al., 2006; Vesey, 2010; Kumar and Sing, 2010).

Effects of Copper (Cu)

Copper reduces resistance of fish to diseases by disrupting migration; altering swimming; causing oxidative damage; impairing respiration; disrupting osmoregulation structure and pathology of vital organs such as gills, kidney, liver and other stem cells (Hodson et al. 1979, Knittel, 1981, Rougier et al. 1994, Eisler 2000, Craig et al. 2010, Tierney et al. 2010; Woody and O’Neal, 2012).

Cu exposed different fish species posed behavioural changes such as decrease in swimming ability and food intake and increase in operculum movements (Ansari, 1984; Venkataramana and Radhakrishnaiah, 2001; Ali et al., 2003; Arslan et al., 2006). Findings of Arslan et al. revealed that these changes went back to normal with longer exposure durations.

In stinging catfish (*Heteropneustes fossilis*), rainbow trout (*Oncorhynchus mykiss*) and north african catfish (*Clarias lazera*) Cu effect caused muscle and liver glycogen levels to decrease and serum glucose levels to increase (Singh and Reddy, 1990; Dethloff et al., 1999; Arslan et al., 2006). Arslan et al. suggested that such changes might have arised due to adaptation of fish to hypoxic conditions induced by existence of Cu.

Singh and Reddy (1990) and James and Sampth (1995) showed that cu effect on different fish species led a decrease in muscle and liver total protein and an increase in free amino acids concentration and gluconeogenic enzyme activity (Arslan et al., 2006).

Çiftçi et al. (2017) studied the effects of Cu on nile tilapia (*Oreochromis niloticus* in terms of hepatosomatic index (HSI), gonadosomatic index (GSI) and condition factor (CF) and found out that Cu caused HSI to increase and CF to decrease. Çiftçi et al. revealed that although Cu led GSI to increase at the beginning, with longer exposure duration there has been a decrease in GSI.

Fish rely on their sense of smell to migrate, avoid predators and find food. Cu affects sense of smell (olfaction) in fish thus causing alterations in appetite, navigation and awareness of surroundings. It also reduces sperm and egg production, survival rates and increases abnormality incidences (Solomon, 2009).

Effects of Iron (Fe)

Although iron is essential for physiological precesses in animals, it may be detrimental to living organisms at higher concentrations than optimum conditions. (Davies, 1991; Misra and Mani, 1992).

Smith et al. (1973) observed that more than 1.0 mg/l iron concentrations affected feeding of fry and juveniles, caused prolonged stress and reduced growth. Debnath et al. (2012) also showed that behavioural changes, decrease in feeding rate and reduced growth occured in mrigal (C*hirrhinus mrigala*), catla (*Catla catla*) and roho labeo (*Labeo rohita*) larvae after iron exposure and suggested that such alterations might have taken place because of accumulation of iron in gills, therefore disrupting osmoregulation and respiration.

Gill damage causes a disruption of carbon dioxide and oxygen exchange, hypercapnia, plasmatic acidosis and hypoxia (Playle and Wood, 1989; Exley et al., 1991). Some authors described iron accumulation on gills and detrimental effects (Larson and Olsen, 1950; Kinne and Rosenthal, 1967; Brenner et al., 1976; Dalzell and MacFarlane, 1999) whereas others only reported iron existence without any gill epithelium damage, especially at low pH values (McDonald, 1983; Wood, 1989; Peuranen et al., 1994; Slaninova et al., 2014).

Standal et al. (1997) conducted a study where atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) exposed to radioiron with intraperitoneal injection and found out that iron accumulated primarily in liver and spleen. Hb levels of both fish reduced after a single injection. Even though *O.mykiss* recuperated after 8 days, Hb levels of *S.salar* remained under the normal range. Standal et al. suggested that inverse correlation between iron level and Hb values might indicate a direct effect on erythrocytes. But when it comes to prolonged fall in Hb levels of *S.salar*, Standal et al. concluded that due to species disparity iron might have caused more severe damage to erythrocytes in *S.salar*.

Effects of Manganese (Mn)

Sharma and Langer (2014) studied the haematological effects of Manganese ($MnSO_4$) on sucker head (*Garra gotyla gotyla*) and found out that Mn treated fish had decreased total erythrocyte count (TEC), haemoglobin (Hb) and haematocrit (Hct) levels whereas had increased mean corpuscular volume (MCV) and mean corpuscular haemoglobin (MCH) levels. Sharma and Langer suggested that toxicity of Mn caused haemopoietic organs to be affected and therefore could not release proper red blood cells (RBCs) into the general circulation. Alongside with decrease in numbers of erythrocyte Sharma and Langer also observed that Mn affected the shape and nucleus of RBCs. Sharma and Langer suggested that these changes start the destruction process and eventually lead to complete degeneration of RBCs. Total leucocyte count (TLC) was increased as a result of Mn treatment and Sharma and Langer claimed that this may be a result of stimulation of immune system as a respond to Mn related tissue damage. According to the presented study it can be concluded that Manganese toxicity causes haematological parameters of *G. gotyla gotyla* to be affected adversely.

Vieira et al. (2012) studied the effects of Manganese on goldfish (*Carassius auratus*) in terms of oxidative stress and antioxidant response. Mn treatment caused oxidative damage and enhanced superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx) activities. In the study, lipid peroxidase levels (LPO) were increased in brain, kidney, liver and gills, Vieira et al. concluded that Mn caused a systematic oxidative stress in *C. auratus*. Vieira et al. also evaluated antioxidant enzyme activities in different organs (brain, kidney, gills and liver) and found out that GPx activity was the most widespread. Therefore Vieira et al. suggested GPx may represent first line in defense system against Mn toxicity in *C. auratus*.

Effects of Nickel (Ni)

Ghosh et al. (2018) studied Ni toxicity on common carp (*Cyprinus carpio*) and suggested that Ni does not precipitate in water as fast as other heavy metals and therefore making it more bioavailable to pelagic organisms. Ghosh et al. revealed that Ni primarily accumultes in the gills of *C.carpio* and transportation of Ni from gill to liver, kidney, and muscle tissues is too little to detect within 96 hours of exposure and the Ni amount evaluated in the gut was negligible. Ghosh et al. concluded that Ni toxicity mainly occurs gill-mediated in *C. carpio*.

Hughes et al. (1979) and Pane et al. (2004) suggested that primary effect of Ni is on respiratory system in fish by causing gill lamellae to swell as well as increasing oxygen consumption, ventilatory stroke volume and respiration frequency.

In several studies it has been shown that Ni toxicity causes oxidative stress in goldfish (*Carassius auratus*), streaked prochilod (*Prochilodus lineatus*) and mummichog (*Fundulus heteroclitus*) (Kubrak et al., 2013; Blewett and Wood, 2015; Palermo et al., 2015). And also sensitivity of catalase to Ni exposure was revealed (Rodriguez et al., 1990; Cartana et al., 1992; Kubrak et al., 2013).

Behavioural effects of Ni exposure were studied and found out that Ni affects locomotor activity in fish, thus causing hypoactivity in goldfish (*Carassius auratus*) and round goby (*Neogobius melanostomus*) (Ellgaard et al., 1995; Leonard et al., 2014; Blewett and Leonard, 2017).

Effects of Lead (Pb)

Increase of lead levels in water may cause adverse effects in some aquatic living beings and may lead alterations of blood parameters and nervous system in fish and other animals**.** Pb is a dangerous environmental pollutant and it has become much thought of due to its considerable danger risks for human health (Afshan et al., 2014).
It has been detected that Pb inhibits Na+/K+-ATPase enzyme and d-aminolevulinic acid dehydratase enzyme that participates in growth and hem synthesis in erythrocytes and affects lipid peroxidation enzyme**.** It has been shown that Pb also has influence on intercellular communication by changing alanine aminotransferase (ALT) and aspartate aminotransferase (AST) concentrations in tissues and organs (Çoğun and Şahin, 2012).
Çiftçi et al. (2017) studied the effects of Pb on nile tilapia (*Oreochromis niloticus*) in terms of HSI and GSI. Çiftçi et al. found out that Pb caused a decrease in HSI of fish whereas it had no effect on GSI. Çiftçi et al. suggested that the decrease in HSI might have occured due to consumption of energy reserves in hepatocytes.

Effects of Zinc (Zn)

Zinc is an essential element but at greater concentrations it may be toxic to fish as indicated previously. Zn accumulates in the gills of fish and creates adverse effects on fish by causing structural damages that affects growth, development and survival. It also alters fish behaviour, hatchability, hematological parameters, balance, swimming ability (Afshan et al., 2014).
Cicik (2003) studied the effects of Zn on common carp (*Cyprinus carpio*) and found out that most accumulation took place in gill tissue. Cicik suggested that high concentrations of Zn might have occured due to mucus secretion and structural alterations in gill tissue caused by contamination.
In another study Buthelezi et al. (2000) examined effects of Zn exposure in mozambique tilapia (*Oreochromis mossambicus*). Zn caused sublethal stress and increased RBC count in fish. Buthelezi et al. suggested that such increases led enhancement in oxygen carrying capacity of the blood as against altered respiratory homeostasis took place by Zn exposure. Thus, Buthelezi et al. concluded that mentioned reaction might be considered as secondary reaction to the pollutant instead of direct stimulation of haemopoietic tissues by Zn. Buthelezi et al. also revealed that blood Hb concentrations, MCHC values and Hct were increased whereas cell Hb concentrations (MCH) were decreased. Buthelezi et al. propounded that these findings indicate cellular swelling occured according to Soivio and Nikinmaa (1981). Zn also stimulated immune system by enhancing WBC count and Buthelezi et al. suggested that therefore fish are protected against possible infections due to gill damage caused by metals.

CONCLUSION

Heavy metals are highly toxic, harmful and hazardous environmental pollutants. In this study effects of heavy metals on fish were examined and literature review was performed. Factors influence mentioned effects can be listed as species, age, sex, size, dietary habit and preferred habitat of fish; physical and chemical properties of water; and heavy metal interactions with each other and bioavailability. Heavy metals cause damage to ability of growth, development, reproduction, nourishment and survival of fish by affecting physiological, biochemical, metabolic, systemic and genetic functions. Since heavy metals are biologically indestructible and both humans and fish can not metabolise them, even if they do not exceed toxic concentrations in fish, they may reach up to humans via consumption of fish and cause severe health problems.
Although this article mentions the adverse effects of heavy metals, mankind probably represents the most toxic species lived on earth, causing these and other contaminants to interfere with nature. According to the studies examined in this article, the amount of heavy metals in edible parts of fish in some regions exceeds the limits specified in current regulations. If environmental pollution continues to increase at the current rate, unwanted consequences should be expected to happen in the near future. It is essential for related national or international organizations to take precautions about environmental pollutants, prepare necessary regulations and use advanced technologies to reduce aforementioned pollution. Accordingly, studies on detection of heavy metals, investigation of heavy metal effects on living creatures and reduction of environmental pollution should be conducted.

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