Heavy Metals Presence in Aquaculture Ecosystems

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Abstract

In the lists of potentially toxic substances, metals are considered to have a priority role in terms of water quality monitoring. Some heavy metals such as mercury, lead or cadmium are compounds that cannot be degraded naturally, having a long remanencetime in the environment, context in which their dangerous character is highlightedas a consequence oftheir accumulation potential in trophic levels.

Keywords: heavy metals, aquaponic, aquaculture

Introduction

Water is not a commercial product like any other, but an inheritance that must be preserved, protected and treated as such (2000/60 / EC). Water pollution is a process of altering its physical, chemical or biological quality, which is produced by human activity. A body of water can be polluted not only when it shows visible changes (color changes, irises of petroleum products, unpleasant smells) but also when, although apparently good, it contains, even in a small amount, toxic substances. Omar et al. (2013) characterize the aquatic environment as the last "recipient" of natural or anthropogenic pollutants.

The industrial revolution and the technological development are the main events that led to the release of significant quantities of toxic compounds in air, water and soil (Strungaru et al., 2016). Due to the impossibility of heavy metalsdegradation, their negative influence persists over long periods of time, their neutralization taking place only by dilution, association with organic compounds and mineralization.

The domestic and industrialwastewatersgenerate significant pressure on the aquatic environment, due to the organic matter, nutrients and dangerous substances loads. In the rural area 95.9% of the population is not connected to the sewerage systems, so the management of the waste water from the rural area is a main problem until 2018 (ICPDR, 2006).

The aquatic organisms exposed to these contaminants accumulate these elements and, sometimes, the amount of metals related to the body mass of these organisms increases with the evolution of the food chain. In case of fishing activities in the contaminated aquatic area and, subsequently, by the consumption of fish catches, the toxic elements are transferred to the level of human body, where they can cause a series of diseases whose severity depends on the metal type and quantity.

In order to avoid a polluting disaster, such as the one in Minamata - Japan, manifested by chronic mercury and cadmium poisoning of the human population as a result of contaminated fishconsumption, continuous monitoring of environmental pollution is mandatory.

Aquaculture isconsidered a high global priority food production sector that can satisfy the future upward demand for proteins.At the global level, the main entity that monitors the aquaculture sector is FAO (Food and Agriculture Organization of the United Nations). Thus, FAO registered an increase of more than 30% of the production resulting from the aquaculture industrial activity, in the next 10 years. In the same time the total quantity of catches registered a approx. 3% increase (Aquanue, 2013).

Material and Methods

At the level of anthropogenic ecosystems, a number of distinctive features are identified, both in terms of the technical part, which involves their design and functioning, as well as related to the technological part, in conjunction with the ecological one. Thus, the term sustainability becomes more important in the operating framework of industrial aquaculture systems. According to Petrea (2014), production systems can be classified as follows:

- ponds (embankment, excavated, dam);
- "raceways" - elongated growth units, channel type, with intense water circulation (depending on the design, location and mode of water circulation there are the following types: "race-ways" with a single water passage, "race-ways" arranged in series or parallel);
- tanks of different shape (circular, octagonal, rectangular), made of concrete, fiberglass, plastics, metal, etc.;
- net retention structures (suspended / floating cages);
- specific aquaculture facilities for shellfish (floating pontoons, suspended grills, suspended trays, etc.).

The criteria for classification of production systems are numerous and transposed as follows:

- by the type of growth unit used by the production system:
  - pond aquaculture;
  - aquaculture in breeding units type "raceway";
  - aquaculture in recirculating systems;
  - aquaculture in floating cages / housing;
  - aquaculture in reeds.
- in relation to the intensity level:
  - extensive, semi-intensive;
  - intensive;
  - very intensive.
- by the location of the technological facilities:
  - land based;
  - water based;
  - transition systems.
- depending on the complexity of technological management and water quality control, the production systems are:

- open, semi-controlled (ponds, raceways, net retention structures - suspended cages);
- full controlled (systems with serial water reuse, systems with partial water reuse, recirculating systems).

• after the relation of the production-environment system, respectively the possibility of controlling the impact of the production system on the environment:
  - open (net retention structures);
  - semi-closed (ponds, race-ways, other growth units such as tanks, etc.);
  - closed (recirculating systems);
• according to water management in a production system:
  - flow-through aquaculture systems (the water is passed once through the rearing units and is completely discharged in the water course from which it was taken);
  - aquaculture systems with partial water reuse - PRAS (part of the effluent of the growth units is retained and recycled in order to reuse the water);
  - recirculating aquaculture systems - RAS (the effluent of the production system is fully recycled and reused).
• according to the salinity of the water:
  - freshwater aquaculture systems / continental aquaculture;
  - aquaculture systems in marine water / marine aquaculture;
  - aquaculture systems in brackish water / brackish aquaculture.
• by the species that is the object of growth:
  - aquaculture of cyprinids;
  - salmonid aquaculture;
  - sturgeon aquaculture; shellfish aquaculture;
  - shellfish aquaculture;
  - aquaculture of algae, etc.
• considerations related to the profitability of aquaculture and / or the reduction of the environmental impact have led to its integration / association in / with different systems of growth of plants and animals (FAO, 2001; Enache, 2012). As such, the following production systems can be identified:
  - aquaponic systems;
  - integrated multi-trophic aquaculture systems;
  - partitioned aquaculture systems;
  - integrated systems of aquaculture and plant culture;
  - integrated aquaculture and animal husbandry systems;
  - substrate-based aquaculture systems;
  - aquaculture systems based on periphyton, etc

The aim of this paper is to identify the heavy metals presence in both extensive pond based and super-intensive (recirculating aquaculture systems - RAS) aquaculture production systems.

Results and Discussions

Heavy metals in pond-based production systems

The ponds are considered the based of systematic cyprinids and salmonids production systems. It is built by the embankment of a flat land and the water supply is made gravitationally or by pumping. Regarding the supply and discharge of technological water, both are performed in a control manner. Pond aquaculture involves maintaining the medial conditions at the level of technological requirements through a judicious balancing of the food inputs, with the assimilative capacity of the pond (Cristea, 2002). As stated by Cristea V. et al. (2002), the natural biological productivity of the pond acts as a biological filter that processes the waste. An extensive aquaculture system, based on pond rearing units, raises a number of issues related to earthworks (pond compartmenting, dam design and construction), design and implementation of feed / drain and drainage channels, maintenance work, required to be carried out on a regular basis (Cristea, 2002). The potential of these systems to develop or increase their attractiveness among investors is low, considering that the current trend is generated by the increase of productivity and the decrease of the space used for the production process (Petrea et al., 2012).

A number of scientific articles have been reviewed regarding the presence of heavy metals in earthen ponds (Onuoha, 2017; Ben Salem et al., 2014; Feldlite et al., 2008; Ju et al., 2017) and the data are represented. in Table 1.

Table 1: The concentrations of metals in water and sediment fractions from earthen ponds, by various authors

	Water	Sediments	Source
Fe	0.32±0.04 mg ml $^{-1}$	-	Onuoha. 2017
	0.41 ± 0.27 mg L^{-1}	38.067 ± 3166 mg kg^{-1} dw	Ben Salem șicolab.. 2014
Zn	9.90 ± 0.21 mg L^{-1}	371.17 ± 250.24 mg kg^{-1} dw	
	5.39 µg L^{-1}	116.6mg kg^{-1}dw	Ju șicolab., 2017
Cu	1.97µg L^{-1}	39.8mg kg^{-1}dw	
	15.10 ± 1.04 mg L^{-1}	177.21 ± 127.42 mg kg^{-1} dw	Ben Salem șicolab., 2014
Cr	9.70 ± 0.04 mg L^{-1}	70.02 ± 19.11 mg kg^{-1} dw	
	0.2µg L^{-1}	51.4 mg kg^{-1}dw	Ju șicolab., 2017
Mn	0.16 ± 0.11 mg L^{-1}	2877 ± 886 mg kg^{-1} dw	Ben Salem șicolab., 2014
	0.08±0.04 mg ml^{-1}	-	Onuoha, 2017
Ni	10.61 ± 1.84 mg L^{-1}	45.61 ± 9.51 mg kg^{-1} dw	Ben Salem șicolab., 2014
	1.61 in µg L^{-1}	24.1 in mg kg^{-1} dw	Ju șicolab., 2017
As	< 0.015 mg L^{-1}	1.16 mg kg^{-1} dw	Feldliteșicolab., 2008
	0.22µg L^{-1}	5.2 mg kg^{-1}dw	Ju șicolab., 2017
Pb	0.14 ± 0.01 mg L^{-1}	37.29 ± 2.65 mg kg^{-1} dw	Ben Salem șicolab., 2014
	< 0.01 mg L^{-1}	1.45 mg kg^{-1}	Feldliteșicolab., 2008
	0.39µg L^{-1}	18.3mg kg^{-1}dw	Ju șicolab., 2017
Cd	0.0105± 0.0007 mg L^{-1}	1.67 ± 1.49 mg kg^{-1} dw	Ben Salem șicolab., 2014
	< 0.003 mg L^{-1}	< 0.003 mg kg^{-1}	Feldliteșicolab., 2008

**dw - dry weight*

In the water column of the earthen ponds (Table 1), the values of the metal concentrations varied significantly in the studies undertaken by different authors,fact explained by the different methodology for determining the elements in the water fraction.

Considering the concentrations in the sedimentary fraction, the downward trend of metals accumulation is as follows: Mn> Zn> Cu> Cr> Fe> Ni> Pb> As> Cd.

Regarding the concentration of metals in the muscular tissue of the fish biomass reared in earthen ponds, in Rutilusrutilusmuscle tissues, the following concentrations were recorded: Cd, Ni and Pb were below the detection limit, Cr 0.062 ± 0.001 µg g^{-1}DW, Cu 0.95 ± 0.02 µg g^{-1}DW, Fe 16.75 ± 0.82 µg g^{-1}DW, Mn 3.14 ± 0.07 µg g^{-1}DW, Zn 74.11 ± 1.33 µg g^{-1}DW(Ben Salem et al. , 2014).

In common carp (Cyprinus carpio) muscle tissues the following concentrations were recorded: As <0.2 mg kg^{-1} DW, Cd <0.003 mg kg^{-1} DW, Pb <0.1 mg kg^{-1} DW(Feldlite et al., 2008). In the tilapia (Oreochromis niloticus) muscle tissues the following concentrations were recorded: Pb 0.37 ± 0.15 µg g^{-1}DW, Cd 0.05 ± 0.01 µg g^{-1}DW, Cr 1.23 ± 0.66 µg g^{-1}DW, As 0.04 ± 0.03 µg g^{-1}DW, Cu 1.20 ± 0.14 µg g^{-1}DW, Zn 20.0 ± 5.8 µg g^{-1}DW, Ni 0.35 ± 0.29 µg g^{-1}DW(Ju et al., 2017).

In ponds, high water temperatures have a major positive effect on the biological activity and respiration rate of freshwater fish. As the water temperature increases, the intensity of the metabolic rate and feeding activity also increases, thus leading to high accumulation of metals in the tissues (Ben Salem et al., 2014). As a result, the authors observed higher concentrations in the summer season in water, sediments and fish, compared to the autumn season.

Heavy metals in super-intensive and intensive recirculating aquaculture systems (RAS)

The aquaculture recirculating productionsystems are intensive and super-intensive production systems, being categorized as sustainable in relation to the environment (fig.1).

Fig. 1: Recirculating aquaculture industrial production system (FAO, 2015).

The globallyuse of these production systemsshows an increasing tendency, thus the fish biomass reared inthese systems also shows an upward trend, which is also generated by the increase of the fish speciesdiversity reared within RAS (Verreth, 1993; Martins et al., 2005). The production technology applied in RAS is based on the use of mechanical and biological filters and can be applied to any aquaculture species (molluscs, crustaceans, fish).

The main objective of RAS systems is to produce considerable fish biomass with low water consumption due to high percentage of water which is continuously recirculated (Eding et al., 2006). The tendency regarding the future of recirculating aquaculture systems is to reduce the rate of water exchange to zero (Martins et al., 2011). For example, a recirculating aquaculture system with a fish production of 500 t/yr will have a water exchange rate of 17 m^3 / hour, as opposed to a flow-through production system, with the same production capacity, which will practice a water exchange rate of 1712 m^3/hour (Cristea, 2002). Also, Cristea (2002) mentions that traditional pond-type aquaculture requires large quantities of water, so a specific production unitwith a stocking density of 3000 kg fish / ha results in a specific water consumption of 10 m^3 water / kg fish produced.

Although from the point of view of environmental protection the RAS systems represent a sustainable model of aquaculture systems, from the point of view of the accumulation of substances in the technological water, such systems raise concerns (Martins et al., 2009).

In such systems, various substances, such as heavy metals, can accumulate in technological water and in the tissues of fish biomass (Martins et al., 2009). In recirculating aquaculture systems, the possible sources of heavy metal contamination are erosion of the component parts and the use of compound feed for fish (Deviller et al., 2005).

In their study, Martins et al., 2011noted that the level of heavy metals in the technological water increases with the decrease of the water exchange rate, so that at a water exchange rate of 30 L / kg food / day, the following concentrations of metals were recorded: Zn 52.9 ± 21.5 μg L^{-1}, Fe 35.42 ± 9.41 μg L^{-1}, 13.5 ± 2.49 μg L^{-1}, Mn 3.88 ± 2.03 μg L^{-1}, Ni 8.73 ± 1.84 μg L^{-1}, As 19.9 ± 1.67 μg L^{-1}, Cd 0.30 ± 0.20 μg L^{-1}, while Pb and Cr were below the detection limit. In the muscle and liver tissue of Orechromisniloticus, the concentrations of heavy metals varied, highest values being observed in the liver (Table 2).

The accumulation of heavy metals in technological water of RAS systems is directly influenced by the water exchange rate, so that, at a rate of 30 L / kg feed / day, the values of metals accumulated in water were higher compared to a water exchange rate of 1500 L / kg feed / day, as follows: As and Cd 2 times higher, Mn 5 times higher, Ni 6 times higher, Zn 10 times higher and Fe 17 times higher. Although there is a clear tendency to accumulate metals in the technological water of RAS systems, this trend does not have any adverse effects on human health.

Table 2: Concentrations of heavy metals in Orecochromisniloticus, reared in RAS

Element (mg kg FW)	Muscle tissue	Liver
Zn	3.23 ± 1.24	3.29 ± 1.30
Fe	ND	3.79 ± 1.79
Cu	ND	28.4 ± 14.7
Cr	0.02 ± 0.02	0.06 ± 0.06
Mn	0.10 ± 0.02	0.17 ± 0.07
Ni	0.01 ± 0.01	0.05 ± 0.07
As	0.85 ± 0.42	0.04 ± 0.02
Cd	0.00 ± 0.00	0.02 ± 0.01
Pb	0.00 ± 0.00	0.01 ± 0.01

**FW – fresh weight*

Conclusions

As a conclusion, recirculating aquaculture systems are a reliable alternative to reduce the risk of consumption of contaminated fish from catches or other production systems exposed to environmental pollution. Also, a proper operational management must be applied in order to limit the presence of heavy metals both in extensive, as well as in intensive and semi-intensive aquaculture production systems.

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