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Copper toxicity in aquatic ecosystem: A Review

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Abstract

Heavy metals, such as copper, are naturally occurring elements with high atomic weight and density, present in trace concentrations in various environmental matrices. However, heavy metal contamination has been on rise in India, affecting industries and agriculture. Copper is one of the most harmful heavy metals, causing adverse effects on human health and aquatic ecosystems. In particular, crustaceans, play crucial roles in aquatic environments but have not been adequately studied. This review aims to explore the impact of copper on aquatic system with special reference to crustaceans and their potential as bioindicators in aquaculture. The origin and sources of heavy metal in water, their toxicity, and effects on fishes and other aquatic organisms are also discussed. Comprehensive research on aquatic bodies and bioindicators is essential to address the challenges posed by heavy metal pollution for sustainable aquatic environments and human well-being.

Keywords: Heavy metals, heavy metal pollution, copper toxicity, fishes, crustaceans

1. Introduction

Heavy metals are naturally occurring elements that have high atomic weight and density, at least 5 times greater than that of water, according to, Tchonwou, *et, al.* (2012) [39]. These metals are also considered as trace elements as they are present in trace concentration, [ppb range to less than 10ppm] in various environmental matrices as mentioned in Bacon Raton's theory in (2001). However, heavy metal contamination issues are on the rise in India, affecting industries such as mining, foundries, smelter, coal-burning power plants and agriculture as documented by, Naga Jyoti, *et al.* (2010) [26]. heavy metals encompass transition metals, metalloids, lanthanides, and actinides as reported by, Singh. R, *et al.* (2011) [32].

A global concern about heavy metals in aquaculture has been raised due to the threat they pose to fish and the associated health risks for consumers, as noted by Lakra and Nagpure in (2009) [15]. Among the toxic elements, copper referred to as a "grey listed metal" by M.O. Obiakor, *et al.* (2011) [27], and has been identified one of the most harmful. High doses of copper can lead to anaemia, liver and kidney damage, and stomach and intestinal irritation in humans and aquatic ecosystem. This metal naturally occurs in rocks, soil, drinking water (via Cu pipes), entering the human body and causing various diseases as mentioned by Mason in (1996) [24].

Studied by, Hodson, *et al.* (1979) [9], have shown that copper cause gill damage in aquatic invertebrates at high concentration and interferes with osmoregulation in fishes. The effects of copper on *Macrobrachium dayanum*, have been tested after acute and sub-acute exposure of lead nitrate, has been mentioned by, Shukla S., *et al.* (2019) [35] Crustaceans such as *M. lamarrei* and *M. dayanum*, play a significant role in respiration, excretion, acid-base balance, and osmotic and ionic regulation, as highlighted by, Tripathi. R., *et al.* (2019) [40]. Despite, their economic value and potential as lab models and bioindicators for aquaculture, smaller freshwater prawns like *M. lamarrei* and *M. dayanum* have not been adequately studied, except in specific cases, according to Verma. D., *et al.* (2010) [41].

In light of growing concerns surrounding heavy metal contamination, particularly copper, and its adverse effects on aquatic ecosystem and human health, it becomes imperative to conduct comprehensive research on aquatic bodies. This review aims to delve into the current state of knowledge regarding the impact of copper on these aquatic animals with special reference to crustaceans, and explore their potential as aquaculture.

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By addressing, these crucial gaps in research, we can better understand and address the challenges posed by heavy metal pollution in the context of sustainable aquatic environment and human well-being.

Heavy metals their pollution and copper toxicity in aquatic ecosystem-As per the proposal in the review by H.B. Bradl, (2005) [4], that the origin of heavy metals in surface and groundwater, as well as in atmospheric and anthropogenic sources, can be traced back to human activities like industrial production and agriculture. According to, Ishrat Bashir, *et al.* (2020) [12], the excessive use of pesticides, fertilisers and sewage from residential and industrial areas ultimately contaminates aquatic environments. Swapnali. Jadhav, *et al.* (2020) [37], found that the toxicity of heavy metal led to a decline in aquaculture population, causing physical deformities in organism and polluting aquatic environment. These heavy metals often result in poisoning and toxicity in animals through exchange and coordination mechanisms, Duruibe, *et al.* (2007) [8]. Paul. B. Tchonwou, *et al.* (2012) [39], highlighted that heavy metal poisoning can occur either through water contamination, or intake via food chain. This exposure can lead to developmental issues, neurotoxicity, kidney damage, various cancers, liver and lung damage, fragile bones, and even death in cases of high level of exposures. Singh. A, *et al.* (2022) [36].

Copper, a "Grey listed" metal is a reddish metal that occur naturally in rocks, soil, water and air. Copper, derived from a Latin word "cuprum" with the symbol- Cu, is a chemical element Imar. M, *et al.*, (1999) [11]. Metallic copper exhibits, numerous distinctive characteristics as explored in research. According to a study conducted by, Jim Clark, in (2009) [13], the majority of copper is presently mined, refined and utilized in electrical industries. Notably, alloys like bronze and brass exemplify its application and recognition. According to study conducted by, Chopra, *et al.* (2003) [25], the continuous exposure to heavy metals such as Cd (Cadmium), Ni (Nickle), Cu (Copper), Lead (Pb), Zinc (Zn) has been identified as the significant cause of adverse effects in human and aquatic organisms. In crustaceans, Cu is a natural component of haemocyanin, the respiratory pigment used in Oxygen transport (Taylor and Anstiss, 1999) [38]. Extensive pollution of various environments has been observed, leading to detrimental effects on the survival and physiological activities of target organisms, as indicated in an investigation conducted by B. Raj, *et al*, (2010) [1].

2. Copper global production

Copper production has significant implications for both electricity supply and infrastructure development. Consequently, it exerts substantial impacts on freshwater systems and well-being of local populations, as explored and evaluated in the study by Benjamin S, (2019) [2].

As stated by, Melissa Pistilli, (2023) [31], Chile stands as the world's leading copper producer, contributing 27% to global production. The Democratic Republic of Congo (DRC) and China jointly occupy the third position, each contributing 8% of global production. Contrary to popular belief, Bruno Venditte's estimation in 2022, attributes 10% of global production to Peru, a South-American country, rather than Chile.

Comparing copper production of six other metals, as highlighted by Benjamin S., in (2019) [2], it becomes evident that copper's environmental impacts per kg of production are higher. When combined with projected drastic increases in usage by 2060, this trend results in substantial environmental consequences across regions and various environmental domains, as depicted in graph below:

A comparison of copper's level of environmental impact to the average among other metals

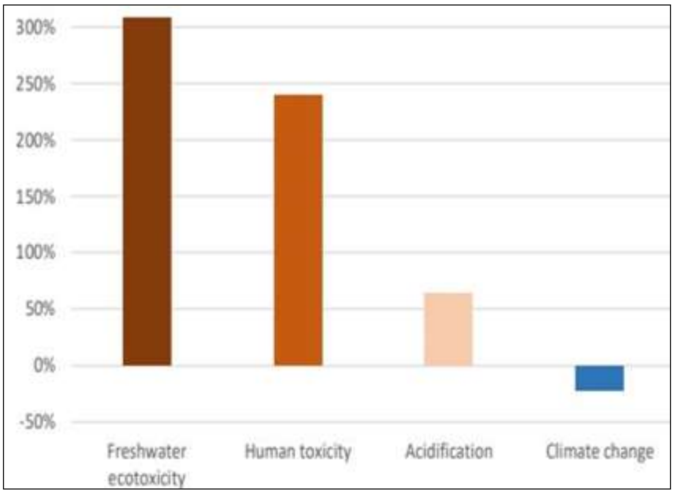

Fig 1: Environmental impacts are calculated between seven metals in 2015, and an average is taken between them and compared to copper's value per kg of production. Source: OECD (2019), Global Material Resources Outlook to 2060

General effects of copper

According to review conducted by, M Tredwell, *et., al*, (2014), it is estimated that the high level of copper imparts a bitter taste in drinking water. Copper has been recognised for over three decades as a crucial factor in the physiology and activity of methanotrophs, which are responsible for methane consumption. However, it is only recently that we have started to comprehend how these cells collect copper and the specific role of copper in CH_4 oxidation through the particulate CH_4 monooxygenase.

3. Copper effect in aquatic ecosystem

Mal. KT, *et al.* (2002), examined the potential of *Elodea canadensis* as biomonitor for pollutant accumulation in aquatic ecosystems due to its widespread distribution. They specifically investigated the impact of copper sulphate on the growth of *Elodea canadensis.*

In a study conducted by, Li. M, *et, al*. (2012), the researchers explored how phosphorous and copper interacted with *Hyalella Azteca* through periphyton in aquatic ecosystems. Their findings indicated that eutrophic conditions led to greater Cu toxicity to benthic macroinvertebrates at lower metal concentrations. This effect was attributed to the higher assimilation efficiency of dietary copper from periphyton incubated under eutrophic conditions.

Xing. W, *et, al.* (2010) [44], used *Spirodela polyrhiza* (L) Schield to assess the physiological responses to excess iron (Fe) and copper (Cu). Their study revealed that both iron and copper accumulation reached a maximum excess of 100mg L-1 during 24h of short-term stress. Additionally, significant differences in chlorophyll fluorescence were observed at 1-100 mg L-1 iron and copper.

4. Copper effects in fishes (changes in behaviour, physiological changes, histology (before and after affecting

of copper), histopathology)

Malhotra. N, (2020) [22], conducted a comprehensive review that analysed the toxicity of copper and copper nanoparticles on various fish species, examining the effects on their organs under different physiochemical parameters in diverse waterbodies. The study critically evaluated, the availability of the toxicological profiles of copper metal ions and CuNPs for different fishes aiming to elucidate the mechanism of copper and CuNPs toxicity.

In investigation conducted by, Verma *et al.* (2010) [41], on CuSO4 changes induces in scaphognathite oscillations of freshwater prawn *Macrobrachium lamarrei* following on with its acute concentration for evaluating the oscillations. An initial increase was been shown in the oscillations after 24hr. in significance to increase and decrease in the oscillations after 96hr; oscillations were below the controls.

MN. Fernandes and CS Carvalho, (2006) [6], investigated the impact of temperature and copper toxicity on haematological responses of neotropical fish *Prochilodus scrofa* at low and high pH levels. They found that CuSO4, commonly used to control algae and pathogens in fish culture ponds, induced changes in haematological parameters in fish, regardless of pH and water temperatures. A Maharajan *et al*. (2016) [19], investigated the histopathological effects of Cu exposure on, *Lates calcarifer* (Bloch). The study revealed the reduced hepatocytes size, vacuolization and hypertrophy in experimental tissue, as well as the fused microvilli in the intestine. Various changes were observed in various fish organs, making *Lates calcarifer*, a potential model organism for toxicological studies due to its significant sensitivity to Cu toxicity, especially in the liver.

The study conducted on *Macrobrachium lamarrei*, by, Verma. *et al.* (2010) [41], for subjection to CuSO4 acute concentration for evaluating the oxygen consumption rate. The review showed, the continuity in decreasing of oxygen consumption rate up to 96 hr; higher than control ones.

5. Copper toxicity in Crustaceans

The extrapolation from fish to invertebrates relies on general assumptions that the mechanism of toxicity induced by Cu in sensitive invertebrates is similar to that observed in the less sensitive teleost fish, as indicated by, Baian Chini, *et, al* (2004).

Recent studies have shown that in low salinities, the mechanism of acute toxicity in euryhaline crustaceans sensitive to Cu is comparable to that observed in freshwater fish and crustaceans. This involves an iono-and osmoregulatory imbalance induced by Na+, K+-ATP ase inhibition. MAPF Santos, *et, al.* (2008) [34], investigated the effects of humic substances on Cu toxicity to the crustaceans *Ceriodaphnia silvestrii.* They found that *C. silvestrii* regulated its body copper content up to 3.0*10^-8mol l-1 free Cu2+ ions in media, but the organisms struggled to cope with lower concentrations of free Cu2+ ions.

In a systematic review by, Paloma AR, *et, al.* (2021) [30], crustaceans were used as bioindicators for metals dynamics and marine toxicity risk assessment. Among crustaceans, crabs were considered excellent bioindicator organisms, particularly their hepatopancreas, which acted as main bio-accumulator organ. The review highlighted the health risk to human consuming sea food, affected similarly to crustaceans, with potential impact on the respiratory, nervous, and reproductive system. HS Lodhi. *et, al*. (2006) [43], conducted experiments to determine the acute toxicity of CuSO4 on freshwater prawns *M. lamarri* and *M. dayanum*. The results indicated that *M. lamarri* exhibited greater sensitivity to CuSo4 than M. dayanum based on bio-individual responses and LC50 values.

In earlier study, Patwardhan, (1937) examined the heart structure of the freshwater prawn and found similarities with the hearts of Palaeamon, *Panulirus internulus*, *Dendrobranchiate*, *Peneaus setiferus* and crayfishes like *Ascatus* and Cambarus. I. Mosunde, *et al*. (2004) [10], investigated the acute toxicity of Cu to juvenile freshwater prawns, *Macrobrachium rosenbergii*, in a high calcium and alkalinity ponds environment. Their findings indicated that CuSO4 treatments with concentration of 0.6, 0.8 and 1.0mg/L led to a significant decrease in prawn survival, with some treatments resulting in 0% survival. Therefore, the study recommended against using CuSO4 treatments in prawn productive ponds.

L. Wang, *et al.* (2022) [42], studied the effects of Cu on gill function of juvenile oriental river prawn, Macrobrachium nipponense. Their research demonstrated that copper exposure adversely respiratory and metabolic activities in *M. nipponense,* leading to damage to mitochondrial membrane of gill cells and inhibition of mitochondrial respiratory chain activity. The study provided important insights into the impact of copper on gill function in aquatic organism's potential mechanisms of Cu toxicity.

The monitored study, conducted on tailless water fleas, *Simocephalus vetulus* by Mishra, *et al*. (2018) [25] showed that the acute, sub-acute, and chronic values, via different metals copper sulphate and potassium chromate each having their executive values. On addition of these metals, the various behavioural changes occurred in *Simocephalus vetulus* like, initial hyperactivity, fast movements of appendages and in phototaxis, geotaxis and avoidance indices various changes were observed.

Additionally, some of the major effects were also observed at the later stage such as, spinning, erratic swimming, activity been decreased, losing balance, loss in feeding and darkening of cuticular coloration, decreased phototactic, geotaxis. In a study conducted by, C. Martinez, *et, al*. (2011), they performed *in vivo* and *in vitro* studies to evaluate acute toxicity, organ- specific distribution, and tissue accumulation of Cu in *Callinectes sapidus* (blue crab). The blue crabs were found to be quite tolerant to Cu, and the differences in salinities were completely explained based on water chemistry. The gills were identified as key target organ for Cu accumulation and an important biological barrier against the excessive uptake of Cu into haemolymph and its subsequent distribution metal to internal organs of the blue crab.

Christianne, (2009), evaluated the accumulation and toxicity in isolated cell from the posterior gills and hepatopancreas of blue crab (*Callinectes sapidus*). Their findings suggested that these cells could serve as model for the development of an invitro BLM version for marine conditions. They also tested cells that were isolated from hepatopancreas of blue crab, as a means to better understand mechanism of Cu tolerance in crustaceans.

In Maharajan, *et, al.* (2011) [20] study, they conducted Cu toxicity tests on juvenile lobsters, examining histopathological changes in various organs such as – muscles, hepatopancreas, midgut, gills, thoracic ganglion, and heart. Through light microscope studies, they observed disruptions and congestion in muscle tissues, blackened haemocytes, disrupted lumen and necrosis of hepatopancreas tubules and midgut muscles cells. The result suggested that Cu exposure caused structural alterations in these organs, potentially impacting the survival and growth of Lobster.

6. Conclusion

The conclusion of the review article emphasizes the growing concern about heavy metal contamination, particularly copper, in aquatic environments. It highlights the adverse effects of copper on aquatic organisms, with a specific focus on fishes and crustaceans. The review emphasizes the need for comprehensive research on the impact of copper in order to better understand and address the challenges posed by heavy metal pollution in the context of sustainable aquatic environments and humanbeings. Implementing effective pollution control measures and sustainable aquaculture practices is crucial for preserving the health of aquatic ecosystems and ensuring the well-being of both aquatic organisms and human populations.

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