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Chromium Toxicity In Aquatic Ecosystem: A Review

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Abstract

Heavy metal chromium, though a essential elements, becomes highly toxic when present in excess. Chromium is commonly used in chromium-based industries (leather tanning, electroplating, mining and pigment production, etc.). When it enters in aquatic ecosystem, affects behaviour, physiology, biochemistry, reproduction as well as genetic makeup of flora & fauna. Present review deals with the deleterious affect particularly on fishes & crustaceans. Proper remedial measures have been discussed.

Keywords- Chromium, Fishes, Crustacean, Heavy metal

1. Introduction

Increasing concern is arising regarding the rising toxicity of heavy metals (HMs), which are significant pollutants in our environment. HMs refer to elements with metal-like properties and greater atomic weight, and even minute quantities of these toxic substances pose a serious threat to the flora, fauna, and overall life on Earth (Abed-el-Aziz et al., 2017). The contamination resulting from HMs usage has caused severe harm to both the ecosystem and physical health, leading to various diseases such as liver damage, heart damage, cancer, neurological disorders, cardiovascular issues, and disruptions to the central nervous system (CNS) (Sumiahadi and Acar, 2018). Heavy metals are naturally dispersed within rock formations, but due to urbanization and industrialization, human activities have significantly increased the presence of HMs in the ecosystem (Chandrasekaran et al., 2015; Huang et al., 2016). The primary sources of HM pollution in soil, air, and groundwater are mining and manufacturing industries (Yadu et al., (2020). Heavy metals are widely known for their toxicity, bioaccumulation, numerous sources, and persistence, making them typical environmental pollutants (Liu et al., 2014). Among these metals, lead, chromium, arsenic, mercury, and cadmium are of particular concern due to their high toxicity and significant impact on human health (Aslam and Yousafzai, 2017). Heavy metals enter the aquatic system through industrial effluents from various industries such as tanneries, textiles, mining, dyeing, electroplating, photographic printing, printing, stainless steel manufacturing, rubber manufacturing, and pharmaceuticals; (Ahmed et al., 2013). Heavy metals and metalloids are hazardous pollutants found in industrial wastewater that pose threats to human health and the environment (Nakkeeran et al., 2018) Chromium, in particular, is considered highly toxic and is widely used in industrial processes. It can be naturally released from the earth's crust and exists in both trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)] forms (McCartor and Becker, 2010; Stambulska et al., 2018). While trivalent chromium is an essential element for living creatures, its absence or excess can have a drastic impact on their metabolism (RojasRomero et al., 2015). On the other hand, hexavalent chromium is highly soluble, mobile, and more toxic, causing greater harm to animals and humans than the trivalent form (Nakkeeran et al., 2018). Aquaculture, which relies on various water sources such as rivers, coastal areas, and estuaries, is particularly vulnerable to pollutant contamination. This can lead to fish production that poses a health risk if consumed. Attention is increasingly being given to naturally derived compounds as potential adjunctive therapies or standalone solutions (Galal et al., 2018). Fish have been used as test organisms in acute toxicity bioassays due to their numerous advantages. Several studies have explored the biochemical effects of heavy metals on fish and prawns to identify predictive biomarkers for water pollution monitoring (Golovanova, 2008). According to the U.S. Environmental Protection Agency, fish are convenient for laboratory research conditions and are sensitive to various pollutants, making them readily available for study throughout the year from both commercial and natural sources (reference to be provided). In this particular review section, an examination is conducted on the various origins of chromium in diverse settings, alongside an exploration of its detrimental effects on aquatic fauna.

2. **What are Heavy Metals** –

Srivastava and Majumder (2008) classify elements with atomic weights ranging from 63.5 to 200.6 and a specific gravity exceeding 5.0 as heavy metals. The discharge of heavy metal wastewaters into the environment is increasing, particularly in developing countries. Unlike organic contaminants, heavy metals are non-biodegradable and have a tendency to accumulate in living organisms. Many heavy metal ions are known to be toxic or carcinogenic. In the treatment of industrial wastewaters, toxic heavy metals of particular concern include zinc, copper, nickel, mercury, cadmium, lead, and chromium. Copper is essential in animal metabolism, but excessive ingestion can lead to serious toxicological concerns like vomiting, cramps, convulsions, or even death (Paulino et al., 2006). It's worth noting that any toxic metal may be referred to as a heavy metal, regardless of its atomic mass or density (Singh MR 2007).

Heavy metals belong to an ill-defined subset of elements that exhibit metallic properties, encompassing transition metals, some metalloids, lanthanides, and actinides. According to one source, common transition metals like copper, lead, and zinc are considered heavy metals. These metals contribute to environmental pollution from various sources, including leaded petrol, industrial effluents, and leaching of metal ions from soil into lakes and rivers through acid rain.

3. Chromium

Chromium (Cr) exists naturally in the earth's crust and can be found in different oxidation states, ranging from chromium (II) to chromium (VI) (Jacobs JA, Testa SM, 2005). It is a metallic element with an atomic number of 24 and a density of 7.14g/ml, appearing glossy, steel-gray, and crystalline (Oana, 2006). The presence of chromium in the aquatic system mainly originates from industrial discharges, such as tanneries, textiles, mining, dyeing, electroplating, photographic printing, printing, stainless steel manufacturing, rubber manufacturing, and pharmaceuticals (Adhikari et al., 2006; Ahmed et al., 2013). These industries release heavy metals and metalloids into wastewater, posing a serious threat to both human health and the environment (Nakkeeran et al., 2018).Chromium can be released into the environment from natural sources, particularly from the earth's crust, primarily in the form of trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)] (Stambulska et al., 2018). Trivalent chromium [Cr(III)] is essential for living organisms, including humans, as it plays a crucial role in metabolism (RojasRomero et al., 2015). On the other hand, hexavalent chromium [Cr(VI)] is highly toxic and soluble, causing more severe impacts on animals and humans compared to Cr(III) (Nakkeeran et al., 2018). Cr(III) is relatively less poisonous since it is insoluble and primarily found bound to organic matter, making it immobile under ambient conditions (Shankar and Venkateswarlu, 2011).

Most of the environmental chromium releases are attributed to industrial sources, particularly from the processing and manufacturing of chemicals, minerals, steel, metal plating, leather tanning, textile dyeing, electroplating, cement production, metallurgical works, and other industrial processes (Nakkeeran et al., 2018; Lian et al., 2019). These industrial activities generate large amounts of wastewater, including solid sludge and Cr-bearing waste, such as tannery effluents, contributing to significant chromium pollution worldwide (Yoshinaga et al., 2018). Additionally, soil and water pollution can occur due to leaching and weathering of chromite from mines and infiltrated water (Das and Mishra, 2009). Certain regions in India, like Tamil Nadu (e.g., Ranipet), Uttar Pradesh (e.g., Kanpur), Odisha (e.g., Sukinda Valley), and West Bengal (e.g., Ranaghat–Fulia), are particularly at high risk due to elevated concentrations of chromium in soil and water (Shankar and Venkateswarlu, 2011).

For humans, Cr(III) is essential and plays a vital role in glucose, protein, and fat metabolism. However, the Cr(VI) form is known to be hazardous to human health, particularly through acute and chronic inhalation exposures, causing respiratory tract problems, which are the primary target organs for toxicity (Cabral-Pinto and da Silva, 2019; Cabral-Pinto et al., 2020). Studies have also confirmed that exposure to chromium in the aquatic environment can have detrimental effects on aquatic fauna. In this review section, various sources of chromium in different settings are examined, along with an exploration of its harmful impacts on aquatic life.

4. Chromium global production

The concentration of chromium in specific geographical regions, rising demand, emphasis on clean production methods, import reliance, and supply vulnerabilities have collectively elevated chromium's status to that of an indispensable strategic mineral resource, intensifying competition among countries and regions. Many nations, including the United States, Japan, Australia, and China, have identified chromium as a critical mineral, reinforcing its significance on the global economic stage. Consequently, the competition for chromium resources is gaining increasing attention in international trade relations. In light of these developments, formulating a comprehensive international trade policy for chromium resources based on the existing competition topology results becomes crucial to enhance core competitiveness. This matter has been addressed by various researchers (An et al., 2014) as well as in studies related to other natural resources like Natural Gas (Geng et al., 2014; Chen et al., 2016) and fossil energy (Hao et al., 2014). Chromium, widely utilized in various industries such as leather tanning, electroplating, mining, and pigment production, is highly susceptible to Cr(VI) toxicity. The reduction of Cr(VI) to Cr(III) can lead to the production of highly reactive hydroxyl radicals within blood vessels, causing damage to blood cells, organ degradation, and disruption of cellular activity due to metal-DNA bindings (Kim HS et al., 2015). Additionally, there is belief that Cr(VI) is responsible for teratogenic effects in humans, supported by animal model trials (Baruthio F, 1992).

5. General effect of Chromium

Despite its essential role in biological systems, excessive amounts of Cr can lead to toxic effects (Bielicka et al., 2005). The biogeochemical cycle of chromium is significantly influenced by its chemical speciation, with Cr (VI) generally being more mobile, soluble, and toxic compared to Cr (III) (Bielicka et al., 2005; Cao et al., 2011; Chattopadhyay et al., 2010). Besides its involvement in the metabolism of glucose, fats, and proteins in animals and humans, Cr (III) exhibits distinct toxicological characteristics (Dayan AD, Paine AJ 2000). High levels of chromium (VI) in drinking water have been associated with the development of stomach tumors in humans and animals (Goyer RA. 2001). However, when Cr (VI) is reduced to Cr (III), its toxicity diminishes as it cannot be transported inside the cells (Cohen MD et al., 1993). Cr (VI) can penetrate various cell types and, under specific physiological conditions, generate reactive intermediates that may disrupt cellular integrity and various functions (De Mattia G et al., 2003).

6. Chromium toxicity on Fishes

Upon initial exposure to chromium, fish undergo various behavioral modifications, including suspended feeding behavior, uneven swimming, and accelerated operculum movement. Additionally, structural changes such as hypertrophy and paraplegia may occur at the gill epithelium, weakening the body's immune system (David IG et al., 2012).(Nisha et al. (2011) studied the impact of chromium trivalent and hexavalent toxicity on zebrafish (Danio rerio) and observed erratic motion, mucus discharge, gasping behavior, color and shade alterations, and irregular swimming. Ali et al. (2017) investigated behavioral changes in goldfish (Carassius auratus) exposed to chemicals, observing that all fingerlings congregated in a corner of the aquarium and exhibited decreased appetite. Similarly, examined Channa punctatus after hexavalent chromium exposure and noted irregular swimming and sluggish behavior, accompanied by gill changes like epithelial hyperplasia, edema, lifting, and necrosis.

Fish blood is a vital diagnostic tool for detecting stress and pathologies resulting from various biotic and abiotic stresses. Several studies (Ashaf-Ud-Doulah et al., 2020) have used fish blood to assess the impact of heavy metal exposure, leading to significant changes in hematological and biochemical parameters (Islam et al., 2020; Suchana et al., 2021).

6.1 Behavior

In the study conducted by Nisha et al. (2016), the impact of chromium trivalent and hexavalent toxicity on the behavior of Danio rerio (zebra fish) was investigated. They observed several behavioral changes in the fish, including erratic motion, mucus discharge, opening mouth for gasping, alterations in color and shade, and irregular swimming.

Similarly, Ali et al. (2017) examined the behavioral changes in goldfish (Carassius auratus) and found that all the fingerlings tended to congregate in the corner of the aquarium, and there was a decrease in appetite due to chemical effects. These effects were also observed in C. punctatus after exposure to Cr, Ni, and Zn.

Moreover, behavioral alterations have been studied in crustaceans after exposure to various toxicants (Sharma and Shukla, 1990). In yet another study, the modification in behavioral patterns of Channa punctatus after exposure to hexavalent chromium was investigated. The exposed fish showed irregular swimming and became sluggish (Mishra & Mohanty B., 2008).

6.2 Physiology

Chromium toxicity in aquatic ecosystems is influenced by various factors, both living (biotic) and non-living (abiotic). Biotic factors include an individual's age, developmental phase, and species type. On the other hand, abiotic factors consist of the concentration and oxidation state of Cr, water temperature, pH, alkalinity, and hardness.

The toxicity of Chromium is closely linked to its concentration and water temperature; as these parameters increase, so does its toxicity. However, it tends to decrease with higher salinity and sulfate concentration (Wang S & Shi X. 2001). The pH of water also plays a crucial role in determining the extent of Chromium toxicity. In environments like seawater, interstitial waters, and estuaries, where pH levels can vary, different levels of chromium toxicity can be observed (Pourahmad Jet al, 2005). The concentration of Chromium in lakes and rivers typically ranges from 1 to 10 ug/L. For the protection of aquatic life and human health, EPA has proposed safe levels of 50 to 100 ug Cr/L.

Unfortunately, numerous fish species are highly susceptible to Chromium, experiencing fatal effects such as lymphocytosis, anemia, eosinophilia, bronchial, and renal lesions. Zebrafish swimming near areas with metal product disposal in surface waters may suffer harm to their gills due to high Chromium concentrations (De Mattia G et al, 2004).

6.3 Histology

Mishra & Mohanty (2008). observed significant changes in the gills and trunk kidney of exposed fish. The gills exhibited epithelial hyperplasia, lamellar fusion, oedema, epithelial lifting, necrosis, desquamation, aneurysm, and curling of secondary lamellae. Similarly, the trunk kidney showed hypertrophy of epithelial cells with reduced lumens, renal tubule atrophy, glomeruli contraction in Bowman's capsules, and haematopoietic tissue necrosis.

However, despite the potential risks of chromium toxicity, there is a scarcity of research on histopathological responses in vital organs like gills, kidney, and liver in fish. Limited reports are available on gill histomorphology alterations (Nath et al., 1997; Begum et al., 2006). Hexavalent chromium (Cr VI) in the form of chromate ion is dominant in aqueous solutions and can easily penetrate cellular membranes. Existing studies have focused on the cytotoxic effects of chromium on the histopathology of organs such as kidney, testis, and brain (Oliveira et al., 2006)

7. Chromium toxicity on Crustacean

The absorption rate of inorganic chromium is minimal, ranging from 0.4% to 3%. On the other hand, organic chromium is absorbed much more efficiently, being 20 to 30 times better than its inorganic counterparts. As a result, chelated minerals are considered superior sources of chromium (Starich and Blincoe, 1983). While various studies have explored the impact of dietary organic and inorganic chromium on growth and carbohydrate utilization in fish species, there is a lack of information when it comes to shrimp.

Chromium is an essential nutrient, but all forms, including hexavalent and trivalent chromium, can be toxic and even carcinogenic at high concentrations (Tulatermed si and Rao, 2014). Moreover, chromium is a prevalent environmental pollutant, entering aquatic systems through industrial effluents, and posing a significant threat to aquatic organisms and food safety due to its bioconcentration in the food chain (Velma et al., 2009).

Studies indicate that excess chromium disrupts the body's redox balance, leading to the formation of reactive oxygen species (ROS), a reduction in antioxidant enzyme activity, and alterations in oxidative status (Dazy et al., 2008; Rai et al., 2004). Furthermore, chromium exposure has been associated with cell death through apoptosis in various organisms, including fish (; Singh et al., 1998]).

The adverse effects of chromium on fish include oxidative stress, DNA damage, and apoptosis (Bagchi et al., 2003). The sensitivity to chromium toxicity varies among species, suggesting that the level of toxicity may depend on the species and the dosage of chromium administered (Velma et al., 2009).

7.1 Behaviour

Behavioral toxicology is employed for evaluating water pollution hazards (Beitinger and Freeman, 1983). Changes in animal behavior can indicate disruptions in internal body functions, such as enzyme function inhibition, neural transmission impairment, and metabolic pathway disturbances (Shah, 2002). Mishra et al. (2018) observed behavioral changes in the Crustaceans Simocephalus vetulus (crustacean – Cladocera) due to chromium effects. Cruz-Suarez et al. (1994) reported on Cr supplementation in Pacific white shrimp (Litopenaeus vannamei).

Sharma et al (2008) Subjected a fresh water prawn Macrobrachium Dayanum to static bioassay test in order to determine the LC_{50}Value of potassium dichromate and observed behavioural anomalies such as hyperactivity aggression, loss of balance, erratic swimming, rapid surfacing, profused mucous secretion. Blackening of gills etc.

7.2 Histology

K. Ranga Rao and Daniel G. Doughtie (2003) studied histopathological/ultrastructural changes in various tissues of grass shrimp (Palaemonetes pugio) exposed to hexavalent chromium. The dithiocarbamates and PCP induced severe pathological alterations, primarily evident in the gills, causing the "black gill syndrome," characterized by early melanization and eventual lamellar truncation. In contrast, hexavalent chromium did not induce marked changes in the gills but caused invasive melanized cuticular lesions, particularly at the articulations of the pereiopods, pleopods, and abdominal segments. Additionally, chromium appeared to cause labyrinth hypoactivity in the antennal glands, while dithiocarbamates seemed to induce labyrinth hyperactivity. Arthropod haemolymph contains mesodermal origin haemocytes, basophilic and circulating in blood channels, performing various functions like food transport, phagocytosis, capturing foreign particles, defense, and haemolymph coagulation. Banslal et al. (1979) and Olmedo et al. (2014) also contributed to this field of study.

8. Bioaccumulation of Chromium

Chromium bioaccumulation varies depending on size and organs. As the organism's size and dimension increase, the concentration of chromium in soft tissues and the shell decreases substantially. Different tissues show varying levels of chromium accumulation, with the highest concentrations found in gills, kidneys, and liver of fish, while muscular tissues tend to accumulate less chromium. Water's physical and chemical properties, as well as seasonal changes, are the main factors influencing the intensity of heavy metal accumulation in various fish tissues. Sadiq (1992) provided relevant research on this topic. Treated wastewater disposal is a problem in developing countries (Chipo et al., 2011). Anthropogenic activities like rapid industrialization, urbanization, and other human sources can lead to the emission of pollutants into the environment (Telesca and Lovallo, (2011). Main effects of chromium in plants include decreased plant growth, membrane damage, and chlorosis (Gardea-Torresdey et al., 2005; Jada and Fulekar, 2009). The use of wastewater for irrigation in agricultural activities can cause biomagnification and heavy metal accumulation in the food chain (Chipo et al., 2011) However, reusing wastewater can help conserve water in arid and semi-arid conditions (Prabha et al., 2007).

8. Conclusion

In conclusion, this review article highlights the dual nature of chromium as an essential element, yet highly toxic when present in excessive amounts. Its widespread use in chromium-based industries poses significant risks to aquatic ecosystems, affecting the behavior, physiology, biochemistry, reproduction, and genetics of flora and fauna. Fishes and crustaceans, in particular, are highly impacted by the deleterious effects of chromium pollution. However, the review also offers hope by discussing proper remedial measures to mitigate these adverse effects and safeguard aquatic life. Implementing these measures is crucial to protect the delicate balance of aquatic ecosystems and ensure the sustainability of aquatic organisms in the face of chromium contamination.

References

1. Ahmed AS(1998). Farm-made feed in Aquaculture. The technologies to reckon with in rural development,452-460.
2. Fawad M, Yousafzai AM, Haseeb A, Rehman UH, Afridi AJ, Akhtar N et al. Acute toxicity and bioaccumulation of chromium in gills, skin and intestine of goldfish (*Carassius auratus*). Journal of Entomology and Zoology Studies. 2017; 5(1):568-571.
3. Dang, T.A.; Kamali-Bernard, S.; Prince, W.A. Design of new blended cement based on marine dredged sediment. *Constr. Build Mater*. **2013**, *41*, 602–611. [**Google Scholar**] [**CrossRef**]
4. Debasis Bagchi a,∗, Chandan K. Sen b, Sidhartha D. Ray c, Dipak K. Das d, Manashi Bagchi a, Harry G. Preuss e, Joe A (2003). Vinson f Molecular mechanisms of cardioprotection by a novel grape seed proanthocyanidin extract Mutation Research 523–524 87–97
5. Ji, X., Shen, Q., Liu, F., Ma, J., Xu, G., Wang, Y., et al. (2012). Antibiotic resistance gene abundances associated with antibiotics and heavy metals in animal manures and agricultural soils adjacent to feedlots in Shanghai; China. *J. Hazard. Mater.* 235-236, 178–185. doi: 10.1016/j.jhazmat.2012.07.040
6. Emad Farahat Tarek M. Galal **(**2018)Environmental Science and Pollution Research 25(1-4)Trace metal accumulation by Ranunculus sceleratus: implications for phytostabilization
7. Golovanova, I. L. (2008). Effect of Heavy Metals on Physiological and Biochemical Status of Fishes and Aquatic Invertebrates. Inland Water Biology, 1, 99-108.
8. Xin Liu, Delphine Beyrend-Dur, Gae¨l Dur, Syuhei BanEffects of temperature on life history traits of *Eodiaptomus japonicus* (Copepoda: Calanoida) from Lake Biwa (Japan) Limnology (2014) 15:85–97
9. Sonia Aslam and Ali Muhammad Yousafzai (2017) Chromium toxicity in fish Journal of Entomology and Zoology Studies; 5(3): 1483-1488
10. Yang JY, Wang M, Lu J, Yang K, Wang KP, Liu M et al (2020) Fluorine in the environment in an endemic fluorosis area in Southwest, China. Environ Res 184:109300
11. Huang, J., Liu, W., Qi, Y.X., Luo, J., Montell, C. (2016). Neuromodulation of Courtship Drive through Tyramine-Responsive Neurons in the Drosophila Brain. Curr. Biol. 26(17): 2246--2256.
12. Chandrasekaran et al., 2017, Cell Reports 21, 2965–2977

13. Sharma UD, Shukla S. SEM Studies of the architecture of the thoracic chelates appendages of freshwater prawn,*Macrobrachium lamarrei* (Decapoda- Palaemonidae).Proc-XII ICEM International Congress for Electron Microscopy, Seattle USA 1990;3:508-509.
14. De Mattia G, Bravi MC, Laurenti O, De Luca O, Palmeri A, Sabatucci A et al. Impairment of cell and plasma redox state in subjects professionally exposed to chromium. American Journal of Industrial Medicine. 2004; 46(2):120-125
15. Wang S, Shi X. Molecular mechanisms of metal toxicity and carcinogenesis Molecular and Cellular Biochemistry. 2001; 222:3-9.
16. Nath K, Kumar N. Hexavalent chromium: Toxicity and its impact on certain aspects of carbohydrate metabolism of the Freshwater teleost, Colisa fasciatu. Science and the Total Environment. 1988; 72:175-81.
17. Mishra AK, Mohanty B. Acute toxicity impacts of hexavalent chromium on behavior and histopathology of gill, kidney and liver of the fresh water, Channa punctatus (Bloch). Environmental toxicology and Pharmacology. 2008; 26(2):136-141.
18. Shukla S & Sharma UD. Smaller fresh water prawns: Their aquaculture potential and suitability as good laboratory model In: Bioresources for food security and rural livelihood Edited by:Kulkarni G.K.and Pandey P.N. 2010; 189-204
19. Aslam, S., Yousafzai, A.M. (2017) Chromium toxicity in fish: A review article. Journal of Entomology and Zoology Studies, 5(3), 1483-1488
20. E. Nakkeeran , Chandi Patra Tasrin Shahnaz , S. Rangabhashiyam, N(2018). Selvaraju Volume 3, September, Pages 256-260
21. Paulino, A.T., Minasse, F.A.S., Guilherme, M.R., Reis, A.V., Muniz, E.C., Nozaki, J., 2006. Novel adsorbent based on silkworm chrysalides for removal of heavy metals from wastewaters. J. Colloid Interface Sci. 301, 479e487
22. Singh MR. Impurities-heavy metals: IR prespective. 2007. [Last cited on 2009 Aug 10]. Available from:
23. . Chowdhury S, Khan N, Kim GH, Harris J, Longhurst P, Bolan NS. Zeolite for nutrient stripping from farm effluents. In: Environmental Materials and Waste. Amsterdam, The Netherlands: Elsevier; 2016. p. 569-89.
24. Hao, Z. & AghaKouchak, A. A multivariate multi-index drought modeling framework. *J. Hydrometeor.* **15**, 89–101 (2014).
25. Alfadaly RA, Elsayed A, Hassan RY, Noureldeen A, Darwish H, Gebreil AS. Microbial sensing and removal of heavy metals: Bioelectrochemical detection and removal of chromium (VI) and cadmium (II). Molecules 2021;26:2549
26. De Mattia G, Bravi MC, Laurenti O, De Luca O, Palmeri A, Sabatucci A et al. Impairment of cell and plasma redox state in subjects professionally exposed to chromium. American Journal of Industrial Medicine. 2004; 46(2):120-125
27. Srivastava, N.K., Majumder, C.B., 2008. Novel biofiltration methods for the treatment of heavy metals from industrial wastewater. J. Hazard. Mater. 151, 1e8.
28. Uliana Ya. Stambulska Maria Bayliak Volodymyr Lushchak (2018) Chromium(VI) Toxicity in Legume Plants: Modulation Effects of Rhizobial Symbiosis
29. Chipo M, Loveness M, Stenly M,et al 2011. Journal of Sustainable development,1-6
30. Sharma U.D, Khan M.A., Lodhi H.S., Tiwari K.J. and Shukla S. (2008). Acute Toxicity and Behavioural anomalies in freshwater prawn, *Macrobrachium dayanum* (Crustacea- Decapoda) exposed to chromium. Aquacult, Vol 9(1), 1-6.
31. Abdal Raouf Al Sinnawi, (2023) Mahmoud Fayyad Land use Policy Vol 131, August,106727
32. Sharma UD, Shukla S. SEM Studies of the architecture of the thoracic chelates appendages of freshwater prawn, *Macrobrachium lamarrei* (Decapoda- Palaemonidae).Proc-XII ICEM International Congress for Electron Microscopy, Seattle USA 1990;3:508-509.
33. Shin, M.; Besser, L.M.; Kucik, J.E.; Lu, C.; Siffel, C.; Correa, A. Prevalence of Down syndrome among children and adolescents in 10 regions of the United States. *Pediatrics* 2009,
34. Hassan Abed, Majed Obaid, Khalid Al-Johani The Saudi Dental JournalVolume 33, Issue 7, November 2021, Pages 731-737
35. Ade Sumiahadi, Ramazan Acar **(2018)** A review of phytoremediation technology: heavy metals uptake by plants **142(1):012023**
36. M. Ahemad, M.S. Khan Biochem. Mol. Biol., 1 (2013), pp. 63-75
37. Marina M. S. Cabral-Pinto, Manuela Inácio, Orquídia Neves, Agostinho A. Almeida, Edgar Pinto, Bárbara Oliveiros & Eduardo A. Ferreira da Silva (2020) *Exposure and Health* **volume 12**, pages629–640
38. Shukla S & Sharma UD. Smaller fresh water prawns: Their aquaculture potential and suitability as good laboratory model In: Bioresources for food security and rural livelihood Edited by:Kulkarni G.K.and Pandey P.N. 2010; 189-204 Delhi: Narendra Publications isbn:8131300439.
39. Shukla S, Tiwari KJ, Lodhi HS, Shukla S, Mishra A & Sharma UD. Histopathological alterations in gills of freshwater prawn, *Macrobrachium dayanum* (Crustacea - Decapoda) after acute and sub-acute exposure of lead nitrate. J. Appl. Nat. Sci. 2019;11(02):568-574. DOI:10.31018/jans.v11i2.2118

40. Shukla S., Sharma UD. Apocrine secretion inhepatopancrease of Indian freshwater prawn, *Macrobrachium lamarrei* (Decapoda- Palaemonidae) J.Adv. Zool 1992;13(1&2):60-62.
41. Silver MK, Meeker JD. Endocrine disruption of developmental pathways and children's health. In: Endocrine Disruption and Human Health. Amsterdam, The Netherlands: Elsevier; 2022. p. 291-320.
42. Singh MR (2007). Impurities-heavy metals: IR prespective..
43. Shukla S & Sharma UD. Smaller fresh water prawns: Their aquaculture potential and suitability as good laboratory model In: Bioresources for food security and rural livelihood Edited by:Kulkarni G.K.and Pandey P.N. 2010; 189-204 Delhi: Narendra Publications isbn:8131300439.
44. Lodhi HS & Shukla S. Morphological and histochemical characterization of haemocytes of fresh water prawn, *Macrobrachium dayanum* Tiwari et al.; UPJOZ, 43(13): 80-87, 2022 86 (Crustacea-Decapoda). Uttar Pradesh J. Zoology. 2020;41(10):109-120.
45. Lodhi HS(2002). Studies on haemocytes and haemolymph of fresh water prawns of Lucknow with special reference to effects of heavy metal.; Ph.D. Thesis, Lucknow University, Lucknow.
46. Tiwari KJ, Lodhi HS, Tripathi R, Shukla S & Sharma UD. Effects of lead on heart beat rate of freshwater prawn, *Machrobrachium dayanum* (Crustacea-Decapoda). Environ. & Ecol. 2008;26(2):807-810.
47. K. Shanker and B(2011). Venkateswarlu, "Abiotic Stress in Plants—Mechanisms and Adaptations," InTech Open Access Publisher, Croatia,
48. Bielicka, I. Bojanowska, A. Wiśniewski (2005). Two Faces of Chromium - Pollutant and Bioelement Polish Journal of Environmental Studies Vol. 14, No. 1, 5-10