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Risks and Impacts of Chromium Metals on Human and Ecosystem Health

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Abstract: *This article discusses the harmful effects of chromium metal on human health and the environment. This review aims to provide an in-depth understanding of its negative implications. Analysis of relevant studies provides a comprehensive picture of how Cr (VI) exposure seriously impacts human health and threatens environmental safety. This review method was conducted by identifying and selecting relevant sources through the scientific journal databases PubMed, Google Scholar, and ScienceDirect with the keywords "Cr(VI)," "health risk," "environmental impact," and "chromium metal" then selected and evaluated by considering the quality of the journal, research methodology, and findings. In terms of human health, exposure to Cr(VI) has been shown to increase the risk of death from cardiovascular disease and has significant carcinogenic potential. The impact is not limited to this; Cr(VI) exposure can also cause respiratory problems and skin irritation in industrial workers. In terms of the environment, releasing Cr(VI) into the air, water, and soil threatens living ecosystems. The impact of Cr(VI) pollution on the water and soil environment is of great concern to the quality of water resources and plant growth. In addition, releasing Cr(VI) into the air around industrial plants can also endanger the health of local communities. Therefore, this article highlights the importance of stricter monitoring of chromium-using industries and promoting safer and environmentally friendly alternatives. Implementing preventive and protective measures is essential to minimize the negative impacts of chromium metal on human health and the environment. Using safer alternatives and environmentally friendly production technologies should also be encouraged to create a sustainable and healthy environment for all living beings.*

Keywords *Cr (VI) exposure; environmental impact; environmental resilience; health impact.*

INTRODUCTION

In the era of advanced industry and technology, the use of heavy metals across various sectors has become an integral part of human life. These metals are very diverse, such as Pb (Lead), Cd (Cadmium), Cu (Copper), Hg (Mercury), Cr (Chromium), and several others (Adhani, 2017; Febria, 2016). Heavy metals are utilized in numerous areas of daily life, ranging from the information technology and manufacturing industries to healthcare applications. For instance, lead (Pb) is frequently employed in the paint, battery, and soldering industries, while cadmium (Cd) is commonly found in solar panels, batteries, and certain types of plastics. While the significance of these metals is undeniable, their increasing usage has raised concerns regarding their impact on the environment and human health (Febria, 2023; Putra, 2023). Excessive processing, improper

disposal, and prolonged exposure to heavy metals can lead to ecosystem degradation and pose serious health risks, including poisoning and chronic diseases.

Chromium has become an essential element across various industrial sectors due to its distinctive properties. It possesses unique characteristics making it valuable in industries such as manufacturing, construction, and technology. However, despite its wide-ranging benefits, chromium also presents substantial risks to both human health and the environment (Goyer, 2001; Putra, 2022). As a heavy metal, chromium is naturally abundant in the Earth's crust, and its release into water bodies is primarily driven by soil erosion. The main sources of chromium contamination in air, soil, and water stem from fossil fuel combustion and industrial activities (Elshazly, 2015). Chromium exists in two primary forms: hexavalent chromium (Cr(VI)) and trivalent chromium (Cr(III)). Cr (VI) is highly toxic and water-soluble, whereas Cr(III) is generally less toxic and more stable. Due to its carcinogenic properties, Cr(VI) poses a significant threat to human health, with strong associations with cancers of the kidney, liver, lung, nose, and esophagus. Studies have shown that Cr (VI) can enter the human body through contaminated air, water, and food, with a portion of it accumulating over time. The cancer risk associated with Cr(VI) exposure may be influenced by several factors, including the consumption of Cr(VI)-contaminated sources and the varying concentrations of Cr (VI) in food and drinking water (ATSDR, 2012; IARC, 2012; Putra, 2024; Ukhurebor, 2021).

Recent studies in this research domain, such as the one by Vaiopoulou and Gikas (2020), underscore the growing concern over the impact of chromium metals on human health and the environment. This study highlights the carcinogenic characteristics of Cr(VI) and identifies the risk of lung, nose, and esophageal cancer associated with exposure to this Chromium (Febria, 2023; Vaiopoulou, 2020). However, reports have not shown the need for more effective preventive measures.

The critical contribution of this study lies in a deeper understanding of the impact of chromium metal on human health and the environment, as well as providing insights into the hazardous characteristics of Cr (VI) and essential information regarding the health risks inherent in Cr (VI). In addition, this report highlights the threat of environmental pollution stemming from the release of Chromium to aquatic and soil ecosystems. It also emphasizes the need for stricter monitoring and control, an essential part of this research contribution.

The main objective of this review article is to comprehensively collect and analyze information on the impacts of chromium metal on human health and the environment. With a comprehensive approach, this study describes the potential carcinogenicity of Cr(VI) and its detrimental effects on human health. It also examines the environmental pollution from chromium release, emphasizing the need for preventive measures and enhanced regulatory oversight of chromium metal use.

RESEARCH METHODS

The first step was to identify and select relevant research sources through scientific journal databases such as PubMed, Google Scholar, and ScienceDirect using keywords such as "Cr(VI)," "health risk," "environmental impact," and "chromium metal" (ATSDR, 2012; IARC, 2012). Subsequently, the articles were screened and evaluated by considering journal quality, research methodology, and findings. Data collection and interpretation were conducted by identifying critical findings on the impacts of chromium metal on human health and the environment and formulating a comprehensive picture of the health risks and environmental pollution threats associated with Cr(VI) (Ukhurebor, 2021). In managing research sources, Mendeley Desktop version 1.19.8 was used to organize and store references, facilitate citations, and prepare reference lists, as shown in Figure 1.

Figure 1: Stages of the article review method

RESULTS AND DISCUSSION

In this article review, data regarding the harmful effects of chromium metal on human health and the environment was collected and analyzed from various research sources. Through the research conducted by various scientists and researchers, it can be presented a comprehensive picture of the severe impacts caused by chromium metals, mainly focusing on hexavalent Chromium (Cr(VI)) and its implications for human health and environmental sustainability.

Mechanism of Cr(VI) Exposure

Human and environmental exposure to Cr(VI) involves complex mechanisms that can seriously impact human and ecosystem health. The details of the process can provide a deeper understanding of how Cr(VI) interacts with the environment and humans (Figure 2).

Human Exposure

Air Exposure. Cr(VI) particles can be dispersed in the air due to industrial processes or human activities. Industrial workers directly exposed in the workplace may inhale these particles, which then enter their respiratory tract.

Water Exposure. Cr(VI) dissolved in groundwater or surface water can migrate to drinking water sources or water sources used in agriculture. Humans may be exposed to contaminated water or food grown using contaminated water.

Food consumption. Plants growing in Cr(VI) contaminated soil can utilize this metal through their roots. Humans who consume contaminated vegetables, fruits, or animal products may be exposed to Cr(VI) through food.

Skin Contact. Direct contact with materials or products containing Cr(VI) may result in exposure through the skin. Industrial workers or individuals who come into contact with such materials may experience skin irritation or Cr(VI) absorption into the body (ATSDR, 2012; WHO, 2020).

Exposure to the Environment

Industrial Emissions. Industries using or processing Cr(VI) may emit Cr(VI) particles into the air during their production process, causing the dispersion of Cr(VI) in particulate form into the surrounding air.

Deposition in Soil and Water. Cr(VI) particles dispersed in the air may settle on the surface of soil and water through deposition, thus contaminating agricultural soil, surface water, and groundwater.

Accumulation in Organisms. Cr(VI) dissolved in water can infiltrate the aquatic ecosystem and subsequently accumulate in aquatic organisms such as fish and crustaceans, initiating the food chain in the aquatic ecosystem (Goyer, 2001; K. et al., 2020).

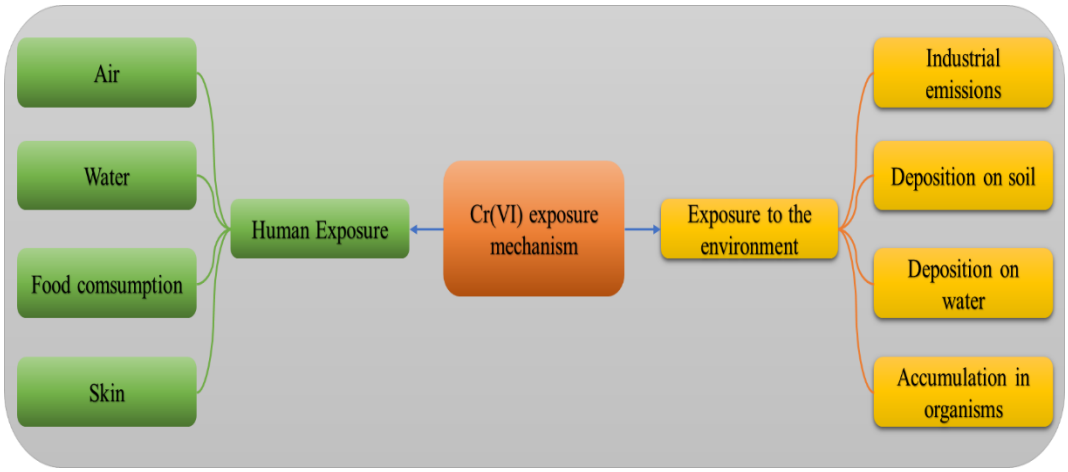

Figure 2. Cr(VI) Exposure Mechanism

Human and environmental exposure to Cr(VI) involves complex mechanisms that pose severe risks to human health and ecosystem. Cr(VI) can be dispersed into the air through industrial processes or human activities, where industrial workers directly exposed in the workplace may inhale these particles, leading to their deposition in the respiratory system. When Cr(VI) dissolves in groundwater or surface water, it can migrate to drinking water sources or agricultural water supplies, exposing humans to contaminated water or food cultivated using such water. Cr(VI) can bioaccumulate in aquatic organisms, such as fish and crustaceans, initiating its entry into the aquatic food chain. The environmental impact of Cr(VI) includes contamination of agricultural soil, surface water, and groundwater, potentially disrupting the ecological balance. Consequently, reducing Cr(VI) exposure through personal protective equipment, ensuring access to clean water, and substituting Cr(VI)-free materials in industrial processes is essential.

Impact on Human Health

Cr(VI) has been shown to impact human health seriously. The International Agency for Research on Cancer (IARC) has classified Cr(VI) as potentially carcinogenic to humans (IARC, 2012). Epidemiological studies have linked Cr(VI) exposure to an increased risk of death from cardiovascular disease (ATSDR, 2012). In addition, exposure to Cr(VI) can also cause skin and respiratory tract irritation, potentially resulting in respiratory disorders and contact dermatitis in humans. Chromium VI, in the form of particles or dispersed compounds, can be easily inhaled or absorbed through the skin, adversely affecting human health (Georgaki, 2023). Scientific studies have linked Cr(VI) exposure to a variety of severe health problems, one of the main impacts being the risk of cancer, especially lung, liver, and kidney cancer. In addition, exposure to Cr(VI) can also cause respiratory distress, skin irritation, impaired liver function, and circulatory system disorders (Deng, 2019; Shin, 2023). An illustration of the presence of Chromium in the environment is shown in Figure 3.

Respiratory and Cardiovascular System

Cr(VI) can have detrimental effects on the human respiratory system. It can enter the body through inhalation or ingestion and spread via the bloodstream. Once in the respiratory system, Cr(VI) can irritate the respiratory tract, including the nose, throat, and lungs, leading to symptoms such as coughing, shortness of breath, and sore throat. Moreover, exposure to Cr(VI) has been

associated with an increased risk of respiratory infections, such as pneumonia (Deng, 2019; Georgaki, 2023).

Numerous studies have demonstrated that the mechanism of Cr(VI) impacting the respiratory system involves cellular damage within the respiratory tract and the subsequent triggering of an inflammatory response. Cr(VI) can stimulate the production of free radicals, which further contribute to cellular damage and exacerbate inflammation, impairing the human immune system's ability to combat infections and thereby increasing the risk of respiratory infections (Chakraborty, 2022; Ukhurebor, 2021). Furthermore, additional research has indicated that exposure to Cr(VI) may elevate the risk of cardiovascular diseases, including coronary heart disease and hypertension (Yatera, 2018).

Several studies have also illustrated that Cr(VI) can adversely affect blood vessels and cardiac function. Cr(VI) in the body can compromise the integrity of blood vessel walls and elicit an inflammatory response, increasing the likelihood of cardiovascular diseases. Additionally, Cr(VI) exposure has been linked to elevated blood pressure and cholesterol levels, both of which are significant risk factors for cardiovascular conditions. Cr(VI) may also impact the functionality of cardiac cells, including cardiomyocytes and endothelial cells, disrupting the contraction and relaxation of the heart while triggering inflammatory responses and causing damage to cardiac tissues (Mishra, 2016).

Skin and Kidney Health

Cr(VI) exposure can also negatively affect human skin health. Several studies have shown that exposure to Cr(VI) can cause skin irritation, contact dermatitis, and even skin cancer. The mechanism of Cr(VI) impact on skin health shows that Cr(VI) can damage skin cells and trigger an inflammatory response. Cr(VI) can also trigger the production of free radicals, damaging skin cells and exacerbating inflammation. In addition, Cr(VI) can also affect melanin production in the skin. Exposure to Cr(VI) can inhibit melanin production, causing the skin to become more sensitive to sunlight and increasing the risk of skin cancer.

Long-term exposure to Cr(VI) can also cause kidney damage. The metal can interfere with kidney function, reducing their ability to filter toxic substances from the blood (Chakraborty, 2022). Exposure to Cr(VI) can cause damage to the kidneys and increase the risk of kidney disease. The mechanism of Cr(VI)'s impact on kidney health suggests that Cr(VI) can damage kidney cells and trigger an inflammatory response. Cr(VI) can also affect kidney function, such as reducing the ability of the kidneys to filter waste and toxins from the blood. In addition, Cr(VI) can also affect the production of enzymes and hormones in the kidneys. Several studies have shown that exposure to Cr(VI) can interfere with the production of enzymes and hormones necessary for healthy kidney function (Chakraborty, 2022).

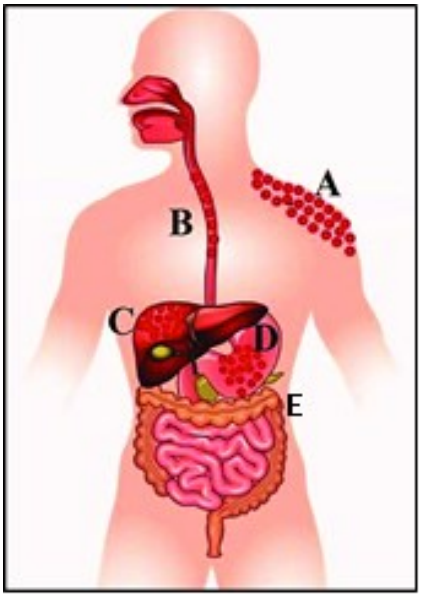

Figure 3. Illustration of the impact of Cr(VI) exposure; a) Skin, b) Respiratory tract, c) Stomach, d) Liver, and e) Kidney

Cr(VI) has severe impacts on human health. The International Agency for Research on Cancer (IARC) has classified Cr(VI) as potentially carcinogenic to humans. Epidemiological studies have linked Cr(VI) exposure to an increased risk of death from cardiovascular disease. Cr(VI) exposure can also cause skin and respiratory tract irritation and potentially cause respiratory distress and contact dermatitis. Cr(VI) can be easily inhaled or absorbed through the skin, adversely affecting human health. The impact of Cr(VI) on the respiratory system can damage cells in the respiratory tract and trigger an inflammatory response, increasing the risk of respiratory infections. In addition, Cr(VI) can also affect blood vessels and heart function, increasing the risk of cardiovascular disease. Cr(VI) exposure can also negatively affect skin health, causing skin irritation, contact dermatitis, and skin cancer. The impact of Cr(VI) on the kidneys can interfere with kidney function, causing kidney damage and increasing the risk of kidney disease. Using personal protective equipment, clean water, and materials not containing Cr(VI) in industry is essential to reduce exposure to Cr(VI) and avoid adverse impacts on human health and the environment.

Impact on the Environment

The impact of chromium metal is not only limited to human health but also contributes significantly to the environment. Industries that use Chromium in their production process often produce chromium-containing waste. If this waste is not managed correctly, it can contaminate surface water and groundwater, threatening living organisms in aquatic ecosystems (Ukhurebor, 2021). A study conducted by Park et al. (2023) found that releasing Chromium into the air around ferrochrome plants can pose health risks to local communities. The impact can also be felt in terrestrial ecosystems, where Chromium can damage soil and plants, disrupt plant growth, and threaten environmental sustainability (Berryman, 2022; Sun, 2022). An illustration of the presence of Chromium in the environment is shown in Figure 4.

Soil and Water Pollution

Research conducted by Xu et al. (2023) revealed that releasing Cr(VI) from various industrial sources can contaminate soil and water around the plant site. This pollution can damage agricultural soil productivity and contaminate community water sources. Soil contaminated with Cr(VI) can disrupt microbial ecosystems that are important for nutrient balance and plant growth (Xu, 2023)

Impact on Aquatic Ecosystems

A study conducted by Aslam and Yousafzai in 2017 highlighted the impact of Cr(VI) contamination on aquatic ecosystems. The release of Cr(VI) into waters can result in the accumulation in aquatic organisms, such as fish and crustaceans. As a result, the aquatic food chain can be contaminated, and humans who consume these fish and aquatic animals are at risk of exposure to Cr(VI) (Aslam, 2017).

Climate Change and Ecosystem Balance

Recent studies have also shown that releasing Cr(VI) into the environment can contribute to climate change. Airborne Cr(VI) can precipitate in soil and water, affecting biogeochemical cycles and disrupting ecosystem balance. This process also changes water quality and the decomposition rate of organic matter in the soil (Edlira, 2019; Georgaki, 2023).

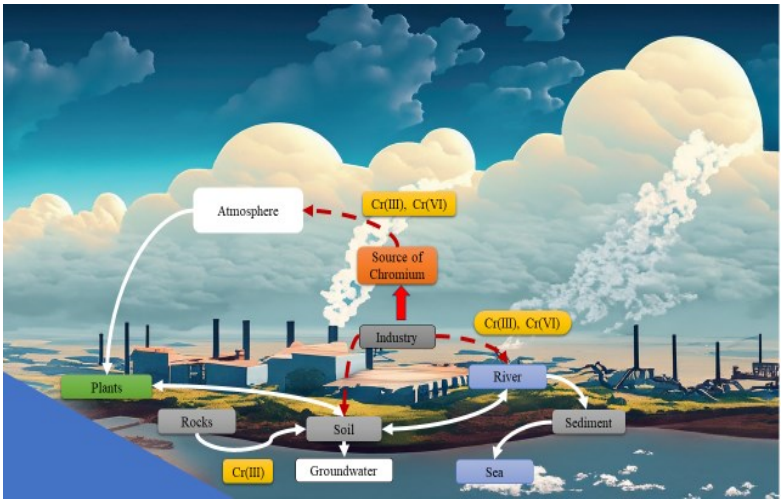

Figure 4. Illustration of the presence of Chromium in the environment (Edlira, 2019)

The impact of chromium metal is not only limited to human health but also contributes significantly to the environment. Industries using chromium in their production process often produce chromium-containing waste. Improper waste management can contaminate surface water and groundwater, posing significant threats to living organisms within aquatic ecosystems. Chromium release into the air surrounding industrial areas presents health risks to local populations, degrades soil quality, damages crops, disrupts plant growth, and jeopardizes environmental sustainability. Soil and water contamination by Cr(VI) can impair agricultural soil productivity and contaminate community water supplies while disrupting microbial ecosystems essential for nutrient cycling and plant growth. The impact of Cr(VI) contamination on aquatic ecosystems can result in accumulation in aquatic organisms, such as fish and crustaceans, and risk exposure to Cr(VI) for humans who consume fish and aquatic animals. In addition, releasing Cr(VI) into the environment can contribute to climate change, disrupt ecosystem balance, and affect biogeochemical cycles.

Comparative Study

In this discussion, a comparative study was conducted on several references that have been reviewed regarding the adverse effects of chromium metal on human health and the environment, as shown in Table 1. By comparing these references, we can learn more about the similarities and differences in the findings of different researchers.

Table 1. Comparative study of some health and environmental hazards of chromium metal

No	Findings/Impact	References
1	Increases the risk of death from cardiovascular disease in humans	Pun & Manjouride (2017)
2	Potentially carcinogenic and requires close monitoring of its release	Wang et al. (2021)
3	Cr(VI) near ferrochrome plants carries health risks and affects air quality.	Pappas et al. (2017)
4	The use of Chromium in industry pollutes soil and water, disrupting environmental ecosystems.	Dhankhar & Hooda (2011)
5	Increased risk of respiratory cancer in industrial workers	Wang et al. (2019)
6	Causes skin irritation and respiratory problems in humans	ATSDR, (2012)
7	Lung health risks	ATSDR (2019)
8	Cr(VI) has genotoxic effects and contributes to genetic damage in humans	NTP (2020)
9	Long-term exposure to low Cr(VI) doses may cause renal tubular damage.	Islam & Hartono (2016)
10	Cr(VI) in drinking water can cause health effects in exposed populations.	Montuori et al. (2018)

A comparative review of these articles shows that exposure to Cr(VI) negatively affects human health and the environment. These findings support conclusions regarding the carcinogenic potential of Cr(VI) and its risks to health and the environment.

Importance of Management, Monitoring and Preventive Measures

Cr(VI) has adversely affected human health and the environment. Therefore, it is imperative to implement effective management, strict monitoring, and preventive measures to reduce the negative impacts of Cr(VI) contamination. Based on related research reported in the past five years, we can identify some critical points regarding the importance of such measures.

Industrial Waste Management. Managing industrial effluents containing Cr(VI) is critical in preventing the release of Cr(VI) into the environment. Research conducted by Wang et al. (2022) showed that the use of effective effluent treatment technologies can reduce Cr(VI) emissions to air and water. Treating effluents before they are discharged into the environment can avoid contamination and protect environmental ecosystems (Wang, 2022).

Monitoring and Regulation. Strict supervision of industries that use or treat Cr(VI) is essential. The study by Li et al. (2020) emphasized the need for stricter regulations on releasing Cr(VI) into the environment. The government should implement lower emission standards and monitor industries regularly to ensure they comply with regulations (M. M. Islam, 2023).

Public Education and Awareness. Related research also shows the importance of improving public education and awareness about Cr(VI) risks to health and the environment. Educating industrial workers about personal protection can reduce the risk of Cr(VI) exposure (Kim, 2023). Public awareness can also lead to industries demanding better waste management.

Environmentally Friendly Technology and Use of Alternative Materials. Recent research has also highlighted the importance of developing environmentally friendly technologies, using safer alternative materials in industry, and environmentally friendly and low-cost waste management processes (Fitri, 2021; Putra, 2016, 2019, 2021). Using Cr(VI) substitutes in production can reduce

the risk of contamination and negative impacts on humans and the environment (Febria, 2023; Putra, 2022).

CONCLUSIONS

This review article has comprehensively outlined the harmful effects of chromium metal on human health and the environment. Based on the Indonesian National Standard 6989.20:2009 regulation and Government Regulation No. 22 of 2021, River Water's Cr(VI) threshold is 0.05 mg/L. Cr (VI) concentrations lower than this standard are considered relatively safe in the human body. An in-depth analysis of various studies shows that exposure to Cr(VI) has the potential to adversely affect human health, including increasing the risk of death from cardiovascular disease, respiratory disorders, and carcinogenic potential. In addition, the release of Cr(VI) into the environment has also been shown to threaten water, soil, and air ecosystems. In the face of these challenges, it is advisable to implement strict surveillance measures on industries that use Chromium. This includes close monitoring of effluents generated, use of environmentally friendly effluent treatment technologies, and stricter enforcement of safety regulations. In addition, it encourages the adoption of safer and environmentally friendly alternatives. Technological developments and innovations in chromium metal substitutes must be encouraged to reduce dependence on this hazardous metal. These measures protect human health from the negative impacts of Cr(VI) and preserve the environment. Implementing policies that support the transition to safer substitutes can positively impact the long term, creating a healthier and more sustainable environment. Therefore, authorities, industry, and society must work together to realize safer and responsible metal use and encourage safer and environmentally friendly alternatives to sustain human health and environmental safety.

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