Role of Wastewater in Transportation of Heavy Metals: *A risk assessment to human health*

Sandeep Kumar Soni[1*], Dr. Manoj Kumar Solanki[2],

[1] M.Sc. (Chemistry) & INSPIRE (SHE) Scholar, Department of Chemistry, A.P.S. University Rewa (M.P.) India 486001.*

[2] Associate Professor & HOD, Department of Chemistry, Rewa Engineering College Rewa (M.P.) India 486001.

Abstract - *The worldwide industrialization and the utilization of natural resources for metal mining and industry have an enormous adverse impact on the environment. The poisoning of air, land, and water by heavy metals is one of the most damaging repercussions that the modern world faces. The primary causes of this problem are believed to be the rapid industrialization or urbanization, shifts in land usage, and industrialization, particularly in non-mechanized countries with large populations like India. Since the financial globalization and mechanical revolt, the range of common toxins has greatly increased, seemingly with infinite anthropological resources. As a result, multiple and growing challenges related to food security have gained widespread attention, particularly given their proximity to clinical issues pertaining to humans. This paper highlights the detrimental effects of wastewater, including the function it plays in the transportation of heavy metals, the bioaccumulation of heavy metals in plants, and the toxicological effects these metals have on human health and microorganisms.*

Key Words: Heavy metals, toxicological impacts, toxicity, Contamination, Environment.

1. INTRODUCTION

Water is a vital resource for a variety of human activities as well as for advancement of production, transportation, and agriculture. Water resources are under pressure due to the rapid growth of industries and their resulting increased demand for water. One of the world's least well-managed resources is water [1]. Currently, industrial wastewater generation is estimated to produce 83 million m per day, and over the next 20 years, this amount is predicted to double. Similar to this, India generates roughly 22.9 million MV of domestic wastewater per day, but only about 24% of that wastewater is treated [2].

Wastewater is primarily found in urban areas due to the improper disposal of untreated industrial effluents and other wastes, which significantly degrades the water quality [3]. Certain metals, such as Cd, Pb, Mn, Cr, Fe, and all those considered to be at risk of toxic wastes, may be essential for the proper functioning of living things' cells due to their comparatively long half-lives, which are comparable to those of cadmium. Inside the body's cellular organization. Women are progressively more vulnerable to unfavorable burdens such as cadmium and other heavy metals, which have higher effects on the body because of cadmium's half-life and developed dietetic ingestion. Low intensity cumulative disclosure can be linked to changes in the kidney's biochemical function as well as bone metabolism [4].

The overall solids in wastewater are made up of both soluble compounds dissolved in water and insoluble or suspended solids. On the other hand, proteins, carbohydrates, and fats make up the majority of the organic matter found in wastewater. In an average wastewater, 40–65% of the solids are suspended. Wastewater's genuine composition varies depending on the source and the community, but in general, all wastewater from municipalities is composed of biological material, nutrients (such as nitrogen, phosphorus, and potassium), inorganic substances (dissolved minerals), hazardous chemicals, and infections [4].

2. HARMFUL IMPACTS OF WASTEWATER

In contrast to canal irrigation, wastewater production is continuous, making it a dependable and demand-based source of water that farmers can access whenever needed. Farmers who are confident in their water supply can cultivate high-value crops during the dry season, which makes them financially viable. With wastewater utilization, crops that are more valuable like vegetables can be grown in comparison to lower-value staple crops even though they are more sensitive to water stress.

An additional benefit for farmers saving money on chemical fertilizers and boosting crop yields is the availability of nutrients in wastewater. Because of its nutritional value, farmers prefer to use sewage for farming, even in areas where fresh water is not a constraint. This lowers the need for artificial fertilizers. Another significant land use is the production of green fodder in semi-urban agriculture using wastewater to meet the needs of milch animals [5].

Many countries in the arid and semi-arid regions are forced to use wastewater for irrigation in agricultural fields due to the growing scarcity of freshwater resources. Reusing wastewater for irrigation has an impact on the soil, both positively and negatively. In regions with a shortage of freshwater, wastewater enables low-income farmers to grow crops that they wouldn't be capable of contrary.

In order to release nutrients, organic residues must be broken down, assimilate nitrogen, and be fixed by microorganisms in the soil. As a result, when they decline, soil fertility declines and this natural resource is destroyed. However, an unrestricted ban on the use of wastewater is not the answer, even though the uncontrolled use of untreated wastewater cannot be encouraged due to the risks to the environment and public health [6].

Urban food security and nutrition can also be greatly enhanced by wastewater irrigation. Even with the aforementioned information, using untreated wastewater has a number of drawbacks. Yet, because wastewater is a byproduct of human activity, including various developmental activities, it typically contains elevated concentrations of potentially toxic substances, such as trace metals. This could limit the long-term use of effluents for agricultural purposes because of the risk of phytotoxicity, illness, and negative environmental effects [7].

In addition to being a significant source of income, wastewater use in agriculture may benefit farming families in a number of ways, including better nutrition, access to healthcare, and education. Utilizing wastewater lessens the need for freshwater irrigation, which is beneficial in regions with limited water resources [8].

The use of a lot of wastewater in agriculture reduces the amount of pollutants that would otherwise end up in rivers, canals, and other surface water resources. Those who use these water resources for domestic and drinking water purposes downstream will benefit from this in terms of their health. Another issue with wastewater application on agricultural land is the potentially phytotoxic nature of organic wastes, which can be caused by a variety of factors like high salinity, an excess of ammonium ions, organic compounds, or low molecular weight fatty acids. These factors, for example, may inhibit seed germination. vectors, including mosquitoes and snails [9].

In addition to causing nitrates and chemical pollutants, such as heavy metals (such as cadmium, lead, chromium, and nickel), the use of wastewater irrigation can have a major negative impact on the environment, particularly if the wastewater contains industrial wastes. Numerous studies indicate that a variety of practices, such as irrigation with wastewater, have contaminated soil ecosystems worldwide with heavy metals [10]. Continued wastewater usage is the cause of the excessive buildup of heavy metals in agricultural soils. This can lead to contaminated soil as well as crop absorption of heavy metals, which can have a negative impact on food quality and public health [11].

Vegetables grown in soil that is irrigated with wastewater accumulate heavy metals to a degree that poses a risk to consumer health. Wastewater application may also have a negative impact on soil fertility. Farmers' options for crops are limited when it comes to certain nutrients, like nitrogen, which can be found in higher concentrations linked to the use of wastewater [12].

Higher concentrations of heavy metals, pesticides, BHC, and other contaminants in grasses, forages, milk, and animal serum were found in several studies carried out in areas where wastewater was used as an irrigation source. The ingestion of milk, milk products, eggs, and meat carries a constant risk of getting into the human system [13].

3. WASTEWATER AND HEAVY METALS

Numerous intricate chemical and biological processes are known to be involving heavy metals and metallic compounds. Sorption/desorption interactions, chemical association involving inorganic and organic ligands, and redox reactions—both biotic and abiotic—in soil environments all play a significant role in regulating the oral absorption of metals. The physical-chemical characteristics of the soil affect the chemistry, speciation, and bioavailability of metals.

Because of their strong binding to soil particles and low solubility in water, certain metals are less accessible. Potential targets for promoting metal accumulation include both the discharge of carbohydrates and the acidification of the rhizosphere [14]. Higher plants' capacity to absorb metals is contingent upon their quantity in the soil and bioavailability, which are influenced by organic matter content, pH, redox potential, temperature, and elemental concentrations. A simple rise in the content of metals in the soil is not enough to have negative consequences. Plant cell membranes are crucial for maintaining metal homeostasis because they limit or prohibit metal entry into the cell. It has been shown that although metal ions move differently in plants, roots often contain more metal than above-ground tissues [15]. The soil's pH, sorbent quality, the presence and quantity of organic and inorganic ligands, such as fulvic and humic acids, exudates from roots, and soil nutrients are the main variables that influence their mobility. Moreover, redox reactions—both biotic and abiotic—are crucial in regulating the oxidation state and, consequently, the mobility and toxicity of numerous elements, including Cr, Se, Co, Pb, As, Ni, and Cu [16]. Metals' chemical form and soil binding behavior determine their mobility, accessibility, and cytotoxicity [17].

4. TRANSPORTATION OF HEAVY METAL BY WASTEWATER

Besides to being generated or treated close to agricultural areas, wastewater is frequently used in agriculture because it includes important minerals needed for plant growth. It has the capacity to provide (inorganic) nutrients and (organic) carbon nutrients that promote crop and plant growth, such as NPK [18].

To some extent, industrial effluent can be a valuable supply of water and nutrients for crops, but it can also harm the quality of the land and water [19]. However, this effluent may also contain harmful heavy metals that are not necessary and, if present in large enough quantities, might enter the food chain and cause a variety of disorders [20]. 90% of industrial wastes, by weight, are thought to be produced as liquids, with 60% of these liquids being organic and 40% being inorganic, according to U.S. EPA data from 1974 [21].

According to studies, there are a number of possible questions connected to using wastewater for irrigation, including degrading aggregate stability, lowering soil hydraulic conductivity, surface sealing, issues with runoff and soil erosion, compaction of the soil, and a loss in soil aeration. Wastewater has both positive and negative effects on the chemical and physical characteristics of soil. In wastewater irrigation areas, their research has looked into a variety of soil physical and chemical aspects [22].

A change in any one of these characteristics could make the soil less fertile. Reusing wastewater for irrigation in agriculture is a rapidly growing practice that is presently being looked into by a number of municipalities [23]. To address the issue of using untreated sewage water. In an arid area, scientists ran an experiment to find out how treated wastewater affected the physical and chemical characteristics of the soil. According to their findings, treated wastewater had no effect on the growth-season increases in Fe, Cd, Ni, Cu, and Zn when compared to untreated wastewater [24]. Wastewater is thought to be an important source of organic matter and plant nutrients that keep the soil fertile and productive [25]. When it comes to disposing of wastewater, irrigation using treated municipal wastewater is thought to be a more environmentally friendly method than dumping it directly into surface or ground water bodies.

In a similar vein, scientists assessed the contaminants found in the wastewater of the Jakara wastewater channel, which provides irrigation for vegetable cultivation. The study found that BOD, COD, TSS, and TDS levels were far beyond the WHO and Nigeria's Federal Environmental Protection Agency (FEPA) acceptable limits, as were excessive quantities of contaminants such as heavy metals. When this water is utilized for irrigation, it pollutes the crops growing in it as well as degrading the soil's quality [26].

5. BIOACCUMULATION OF HEAVY METALS

They are frequently absorbed by plants while in the soil, and over time, they also lessen soil fertility by destroying the microbiota in the soil. Heavy metal concentrations have been the focus of research and documentation about the effects of industrial and municipal wastewater on agricultural soils, as these metals have a number of negative effects while remaining in environmental components [27].

Long-term exposure to heavy metals can cause a number of chronic issues, including skin poisoning, kidney, liver, and gastrointestinal tract malfunctions, detrimental effects on the central nervous system from lead ingestion, and skin poisoning. Metals have a negative impact on soil health in addition to human health. A disturbance of the natural equilibrium of components in the soil typically results in lower soil productivity and lower-quality agricultural output [28].

Additional research on the health of humans and animals revealed that the pattern in the concentration of metals and micronutrients in okra was Ni>Pb>Cr>Cd and Fe>Mn>Cu>Zn for heavy metals. On the other hand, in Spain, the general pattern of abundance was Fe>MN>Cu>Zn for micronutrient and Ni>Pb>Cr>Cd for metals [29].

6. MECHANISM OF BIOACCUMULATION OF HEAVY METALS IN PLANT

One of the primary roles of root systems in terrestrial plants—which have wide-ranging effects on soil—is the accumulation of metal ions. The availability and concentration of heavy metals, as well as the population and species of a given plant, determine how the metals are distributed throughout the body of the plant [30]. The availability of metals in the soil is the primary determinant of their uptake by plants. Metals are present in soils as a range of chemical species in a dynamic equilibrium that is controlled by the soil's biophysical and biological mechanisms [31]. The portion of the total pollutant mass in the soil and sediment that is accessible to plants is referred to as the bioavailability of soil pollutants. Plants absorb metals through the interception and entry of metal ions into the roots, followed by their mass movement and diffusion to the shoot. By using metal-chelating, the absorption is accomplished by freeing metals that are attached to soil particles.

This process has been linked to low concentrations of chelators like citrate and free histidine, which are abundant in Alyssum lesbiacum. Data on the accumulation and mobility of heavy metals, including Cd, Co, Cu, Fe, Ni, Pb, and Zn, from soil to leaves via roots and stems was discovered, and it was suggested that all of the metals were quite mobile [33]. The metal-ion mobility in plants may also be influenced by other binding substances such as malate, citrate, and histidine [34].

It is believed that membrane transport mechanisms are essential to the relocation process. There are numerous gene families known to be associated with metal transfer. NRAMPs (natural resistance-associated macrophage proteins), cation diffusion facilitators, the Zrt- and Irt-like protein family, cation antiporters, and heavy-metal ATPases are a few of them [35]. A study was carried out in Malaysia to ascertain and contrast the amounts of heavy metals in the soil surrounding the root zone with those in the grains, husks, and other parts of the rice crop [36].

7. HEAVY METALS CONTAMINATION AND HUMAN HEALTH RISK

As a result of the body's abnormal buildup of heavy metals from food, including Ni, Cd, Cr, and Pb. It has been noted that if nickel levels in food beyond the advised levels, it might be lethal. In a similar vein, prolonged exposure to cadmium in food and water can cause kidney accumulation that can result in serious health issues [37]. Lead buildup in many plants can surpass several hundred times the upper limit that is considered safe for humans [38]. When researching how lead affects human health, the majority of lead that accumulates is stored in the bones and teeth while researching the effects of lead on human health. Brittle bones and weakness in the wrists and fingers result from this. Reduced hemoglobin synthesis, abnormal kidney, joint, reproductive, and cardiovascular system function, as well as long-term harm to the central and peripheral neurological systems are all results of lead poisoning [39].

In a similar vein, cadmium is extremely poisonous; prolonged exposure to low concentrations can cause kidney accumulation, which may result in renal disease, lung damage, and brittle bones. Some strange long-term effects include headaches, osteoporosis, diabetes, anemia, cancer, cardiovascular disease, cirrhosis, hypertension, headaches, hypoglycemia, anemia, and strokes. It has been noted that plants grown in uncontaminated soil accumulate far more heavy metals than those that do not. Although vegetables are a wonderful source of nutrients, they can also represent a risk of numerous ailments if they are contaminated with contaminants such as heavy metals [40, 41].

Table 1: Maximum concentration in Water as prescribed by WHO and USEPA.

Metals	WHO $\mu g/L^{-1}$	USEPA $\mu g/L^{-1}$
Cd	3	5
Pb	10	15
Cr	50	100
Hg	1	2
Zn	1000	1000
Cu	2000	1300
Ni	20	-
Al	200	200
Mn	100	50
Fe	300	300
As	10	10

Excessive amounts of contact with heavy metals can seriously harm the kidneys and brain, which can lead to death. Prolonged exposure also causes anemia, small increases in blood pressure, deficits in the fingertips, wrists, or ankles, and decreased performance on certain tests measuring how well the nervous system functions. Additional conditions include tooth decay, anemia, arthritis, attention deficit disorder, back issues, cancer, constipation, headaches, anxiety, diabetes, migraine headaches, and stomach pain [40–42]. Although plants can accumulate significant amounts of lead without obvious changes to their appearance or yield, lead is toxic to plants and can be harmful to them. Vegetables high in chromium can have negative effects on one's health, such as kidney and liver damage, skin rashes, stomach upset and ulcers, respiratory issues, lung cancer, and changes to one's genetic makeup [43].

While trace amounts of heavy metals are thought to be micronutrients that are necessary for certain metabolic processes in living cells, high concentrations can be hazardous to the environment and the health of aquatic and terrestrial life forms because they increase morbidity and mortality [44, 45]. By entering living cells through the air, water, or food chains, heavy metals can change the chemical and physical characteristics of the item they are carrying. Because pollution from heavy metals reduces the microbial population in the soil, which aids in the breakdown of the organic material used in crop growth, it disrupts the ecosystem's equilibrium and indirectly affects other living organisms' food chains. For this reason, the USEPA and WHO have set acceptable limits for various heavy metals in water. Certain metals, like mercury, lead, cadmium, and zinc, have the direct ability to destroy live cells; other metals, like zinc, which is corrosive, and mercury, which contaminates catalysts, have indirect impacts [46]. The main symptom of an infected body is organ malfunction; zinc, for instance, can seriously harm the kidneys, brain, heart, lungs, and digestive tract [47]. In addition to hypophosphatemia, cadmium damages the central nervous system and has the same impact [48]. Mercury and arsenic induce hypophosphatemia, cancer, and harm to the liver, heart, and central nervous system [47, 48].

8. TOXICITY OF HEAVY METALS TO THE MICROORGANISMS

Depending on the type or concentration of the contaminated source, heavy metals can also have a significant effect on the growth of microorganisms. The toxic effect of heavy metals has been linked to a number of different processes, including disruption of enzymatic reactions, generation of unstable oxygen species, which serve as soluble electron carriers, and stimulation of oxidative harm, which can alter the formation of proteins and DNA [49, 50]. Additionally, heavy metal toxicity disrupts DNA translation and transcription by employing electrostatic attraction to negatively charge the group of phosphates, which can lead to mutagenesis and immediate harm to the cytoplasmic particles and cell membrane [50]. Therefore, morphological, chemically, and physiological features can all be impacted by heavy metal contact [50, 51]. If water is not available in the proper ranges as recommended by the WHO and BIS, it may have negative effects on people's lives. As a result, aquatic organisms may also be impacted by toxicants in the water [52]. There is a significant increase in heavy metal residues in dairy products, which can be toxic to humans directly or indirectly. Humans suffer grave health problems when they consume milk and milk products that contain a comparatively high density of traces of heavy metals like Zn, Cd, Cu, As, Cr, Pb, Fe, etc [53].

9. CONCLUSIONS

In conclusion, the analysis clarifies the crucial role that wastewater plays in carrying heavy metals, which poses serious hazards to human health and agricultural ecosystems. The comprehensive review of the literature highlights the complex dynamics that underlie the spread of heavy metals, which can originate from a variety of sources, including urban runoff and industrial discharges. The ensuing contamination of farming areas and the possibility of bioaccumulation in food systems highlight how urgently a thorough risk assessment framework is needed.

The findings presented here emphasizes the need for preventative actions, such as strict regulatory frameworks, sophisticated treatment technology, and reliable monitoring techniques. Due to the complex nature of heavy metal transportation, an all-encompassing strategy combining knowledge from public health, agriculture, and environmental science is required. This comprehensive viewpoint is essential for developing effective plans that not only lessen the negative effects but also lay the groundwork for long-term environmental management.

This review not only clarifies the need for cooperative action, but it also advances scientific understanding of the complex interactions between wastewater and heavy metal transport. To encourage the adoption of sustainable solutions, industries, researchers, and politicians must work together. By working together, we may hope to create a future in which the harmful impacts of heavy metals on agriculture and human health are reduced, creating a resilient and sustainable ecosystem for future generations.

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BIOGRAPHIES

Sandeep Kumar Soni is a M.Sc. (Chemistry) scholar from Department of Chemistry, A.P.S. University, Rewa (M.P.) India. He is also an INSPIRE (SHE) scholar, under Department of Science & Technology, New Delhi, India. His research interest includes water quality assessment, heavy metal assessment, and chemical kinetics, catalysis, etc.

He has published more than 10 research article in Peer-reviewed International Journals. His researchgate profile link is: https://www.researchgate.net/profile/Sandeep-Soni-18

Associate Professor (Dr.) Manoj Kumar Solanki is a distinguished academician and researcher, currently serving as the Associate Professor & Head of the Department of Chemistry at Rewa Engineering College in Rewa, (M.P.) India. His expertise spans across several key areas, including chemical kinetics, catalysis, water analysis, bioenergy, heavy metal analysis, and soil analysis.

He has published more than 40 research article in International Journal, 5 articles in National Journals and also owns 7 conference papers. He has also authored a book entitled **"Engineering Chemistry Laboratory Manual"** which is very useful for students.