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A Review on Heavy Metal Contamination in the Groundwater of Panchkula, Haryana, India

Arshpreet Kaur , Simerjit Kaur

University School of Sciences, Rayat Bahra University, Mohali-140104, India.

Abstract: *Groundwater is the primary source of drinking and domestic water in many regions of India, including the district of Panchkula in Haryana. Rapid urbanization, industrial growth, agricultural intensification, and geological factors have contributed to the deterioration of groundwater quality, particularly through heavy metal contamination. Heavy metals such as arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), nickel (Ni), fluoride-associated elements, and uranium have emerged as major environmental and public health concerns. This review paper evaluates the occurrence, sources, distribution, health impacts, analytical assessment, and remediation strategies related to heavy metal contamination in groundwater with special reference to Panchkula and surrounding regions of Haryana. The review highlights that anthropogenic activities including industrial discharge, excessive fertilizer and pesticide use, landfill leachates, and overexploitation of groundwater significantly influence contamination levels. Long-term exposure to heavy metals through drinking water may lead to severe diseases such as cancer, neurological disorders, kidney dysfunction, fluorosis, and cardiovascular diseases. The paper also discusses preventive and remediation to improve the quality of groundwater in Panchkula.*

Keywords: Natural Language Processing, Business, Sustainable Development, Corporate Analysis, Corporate Social Reports (CSRs), Supply Chain, Decision Making, Profit, Customer, Social, Environment, Economic, Challenges

*Corresponding author: Ms.Arshpreet Kaur
e-mail: arshpreet.20529@rayatbharauniversity.edu.in

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1. Introduction

Groundwater is one of the most important freshwater resources used for drinking, agriculture, and industrial purposes. In India, nearly 85% of rural and a substantial urban population depend on groundwater for daily needs. However, increasing industrialization and agricultural activities have severely affected groundwater quality.Heavy metals are non-biodegradable toxic elements that accumulate in water, soil, plants, and living organisms. Even at low concentrations, they can produce serious health hazards due to bioaccumulation and biomagnification. Common groundwater heavy metals include arsenic, lead, chromium, cadmium, mercury, iron, nickel, selenium, and uranium.The district Panchkula, located in the foothills of the Shivalik range in Haryana, has experienced rapid urban growth and agricultural expansion. These developments have increased pressure on groundwater resources. Studies conducted in Haryana indicate rising levels of arsenic, fluoride, nitrate, uranium, and trace metals in groundwater [2].According to a study conducted in the Rohtak district of Haryana, groundwater samples collected from five blocks—Kalanaur, Meham, Lakhan Majra, Rohtak City, and sampleshowed significant contamination of heavy metals during both pre- and post-monsoon seasons. The study revealed that groundwater quality deteriorated further during the post-monsoon period. Water Quality Index (WQI) categorized Kalanaur block under the "very poor" water quality class, while the Heavy Metal Pollution Index (HPI) identified Kalanaur as the most contaminated region among all studied blocks. Principal Component Analysis (PCA) and Pearson's correlation analysis demonstrated strong associations between physicochemical parameters and heavy metal concentrations, particularly cadmium and chromium. Health risk assessment indicated that children were more vulnerable than adults to carcinogenic and non-carcinogenic risks caused by lead and chromium contamination. The study emphasized the urgent need for groundwater monitoring and management strategies to protect public health in Haryana [5].A review study on groundwater quality in North-Eastern Haryana reported that rapid urbanization, industrialization, agricultural activities, landfill leachates, heavy metals, and climatic factors are major causes of groundwater contamination. The study emphasized the need for continuous groundwater monitoring, waste management, water conservation, and proper treatment measures to protect groundwater quality and public health in Haryana [6].A study conducted across 22 districts of Haryana analysed 451 groundwater samples to assess uranium contamination and groundwater quality. The results revealed that groundwater in several districts contained uranium concentrations above the WHO permissible limit of 30 µg/L, with maximum levels reaching 300.8 µg/L. The study

also found positive correlations between uranium concentration and parameters such as electrical conductivity, fluoride, chloride, and nitrate, indicating a possible geogenic source of contamination. The findings highlighted serious concerns regarding the safety of shallow groundwater used for drinking and irrigation purposes in Haryana [7].A study conducted in Chandigarh and nearby areas such as Panchkula, Mohali, and Zirakpur examined the impact of urbanization and industrialization on groundwater quality. The study found that increasing population and human activities have led to groundwater contamination by harmful chemicals, fertilizers, and degradable wastes, negatively affecting both water quality and human health [8].A study conducted in the upper Ghaggar River Basin from Badisher-Koti in Panchkula to Ratanheri in Patiala evaluated the suitability of groundwater for drinking and irrigation purposes. Sixteen groundwater samples were analysed for physico-chemical parameters and heavy metal contamination. The study revealed that several water sources were unsuitable for drinking due to concentrations of certain parameters exceeding safe limits. Irrigation suitability was also poor because of elevated cadmium levels and medium to high salinity hazards. The deterioration in groundwater quality was mainly attributed to lithological composition and intensive agricultural activities in the region [9].A study in Chandigarh, Mohali, and Panchkula reported that leachate from open landfill sites has contaminated groundwater with heavy metals and organic pollutants. Elevated COD, ammonical nitrogen, and lead levels indicated groundwater quality deterioration due to improper municipal solid waste disposal and leachate seepage [10].A study conducted across Haryana assessed the spatiotemporal variations in groundwater quality and availability from 2021–2024, focusing on physicochemical parameters and heavy metal contamination. The study reported elevated levels of arsenic, lead, cadmium, and uranium in several districts, particularly Sonipat, Panipat, Fatehabad, and Sirsa, exceeding BIS and WHO permissible limits. Groundwater depletion was found to be severe in central, southern, and southwestern Haryana due to excessive groundwater extraction. Human health risk assessment indicated significant carcinogenic and non-carcinogenic risks associated with heavy metal ingestion through groundwater. The study highlighted the combined impact of anthropogenic activities and geogenic factors on groundwater deterioration and emphasized the urgent need for integrated groundwater management, pollution control, and artificial recharge strategies [11].

Study Area

Panchkula is situated in northeastern Haryana near Chandigarh and the Shivalik Hills. The district experiences semi-arid climatic

conditions with seasonal rainfall dominated by the southwest monsoon.Panchkula is located at approximately 30.7°N latitude and experiences a subtropical semi-arid climate. Groundwater in the region is mainly obtained through tube wells, hand pumps, and bore wells, which serve as the primary sources of water for domestic, agricultural, and industrial purposes. The district is characterized by diverse developmental activities including agriculture, expanding urban settlements, small-scale industries, and rapid construction and infrastructure development. These activities have significantly increased the demand for groundwater resources. The quality of groundwater in Panchkula is influenced by several natural and anthropogenic factors. Natural geological formations of the Shivalik Hills contribute to the mineral composition of groundwater, while human activities such as agricultural runoff containing fertilizers and pesticides, improper municipal waste disposal, industrial effluents, and excessive extraction of groundwater further affect its quality and lead to contamination risks.

Heavy Metals Contamination in Groundwater

Heavy metals are toxic metallic elements that contaminate groundwater through natural and human activities. Common heavy metals found in groundwater include arsenic, lead, cadmium, chromium, iron, and uranium. In Panchkula, contamination mainly occurs due to industrial effluents, agricultural runoff, and geological weathering. These metals are non-biodegradable and accumulate in water over time. Consumption of contaminated groundwater can cause serious health problems such as cancer, kidney damage, and neurological disorders.

- **Arsenic (As)**

Arsenic (As) contamination in groundwater has become a significant geo-environmental and toxicological issue worldwide, affecting over **100 million people** in nearly **21 countries**, and causing the disease known as **arsenicosis** [3]. In India, people living in the middle and lower Gangetic plains, as well as in certain parts of Central and South India with hard rock terrain, are more severely affected by arsenic contamination. These contaminants enter groundwater through various sources, including both natural processes and human activities [1]. Arsenic contamination is one of the most serious groundwater quality issues in India. It occurs due to both natural geological weathering of arsenic-bearing minerals and human activities such as industrial discharge, use of pesticides and fertilizers, and mining residues. Long-term consumption of arsenic-contaminated water can cause severe health problems including skin lesions, hyperkeratosis, lung and bladder cancer, cardiovascular diseases, and neurological disorders. Several studies conducted in the state of Haryana have reported arsenic concentrations in groundwater above the permissible limits in many districts [2].

- **Lead (Pb)**

Lead contamination in groundwater mainly occurs due to industrialization and improper urban waste disposal. Major sources of lead include battery industries, paints and pigments, plumbing materials, vehicular emissions, and sewage contamination. Lead is highly toxic even at trace concentrations and can accumulate in the human body over time. Consumption of lead-contaminated water may cause serious health problems such as brain damage, reduced IQ in children, kidney dysfunction, anaemia, and hypertension. Due to its long-term toxic effects, lead contamination poses a significant risk to human health and groundwater quality.

- **Chromium (Cr)**

Chromium contamination in groundwater mainly occurs due to various industrial activities. Major sources include electroplating industries, leather tanning units, textile industries, and metal processing units. Among its different forms, hexavalent chromium (Cr VI) is highly toxic and carcinogenic. Exposure to chromium-contaminated water can lead to several health problems such as skin irritation, respiratory disorders, kidney damage, and cancer-related effects. Therefore, chromium pollution poses a serious threat to both groundwater quality and public health.

- **Cadmium (Cd)**

Cadmium contamination in groundwater is commonly associated with industrial and agricultural activities. Major sources of cadmium include phosphate fertilizers, industrial sludge, batteries, and plastic industries. Continuous exposure to cadmium-contaminated water can cause serious health problems such as bone deformities, kidney damage, hypertension, and an increased risk of cancer. Due to its toxic nature and ability to accumulate in the body, cadmium poses a significant threat to environmental and human health.

- **Iron (Fe)**

Iron is a naturally occurring element in groundwater and mainly enters water through the dissolution of rocks and minerals. Other sources of iron contamination include corrosion of pipes and industrial wastes. Although iron is an essential nutrient, excessive iron in drinking water can cause problems such as gastrointestinal disorders and a metallic taste in water. High iron content also leads to staining of utensils, clothes, and plumbing systems, affecting the overall quality and usability of water.

- **Uranium and Selenium**

Recent studies conducted in northwestern India, including the states of Haryana and Punjab, have reported increasing contamination of groundwater by uranium and selenium [4]. The presence of these elements in drinking water poses serious health risks to humans. Long-term exposure may lead to kidney toxicity, bone disorders, radiological hazards, and adverse

reproductive effects. Therefore, rising uranium and selenium levels in groundwater have become an important environmental and public health concern.

Sources of Heavy Metal Contamination in Panchkula

Heavy metal contamination in groundwater of Panchkula occurs due to both natural and human-induced sources. Natural sources include weathering of rocks, soil erosion, geogenic dissolution, and the influence of the Shivalik geological formations, which release metals into groundwater over time. Anthropogenic activities also contribute significantly to contamination. Agricultural practices such as excessive use of fertilizers, pesticides, insecticides, and irrigation return flow introduce toxic metals into the soil and groundwater. Industrial activities including metal processing, electroplating, and chemical discharge further increase pollution levels. Rapid urbanization contributes through landfill leachates, sewage leakage, and construction debris. In addition, overexploitation of groundwater continuously alters groundwater chemistry, leading to the mobilization and accumulation of toxic heavy metals in aquifers.

Methods for Detection and Analysis

The detection and analysis of heavy metals in groundwater involve systematic sampling and advanced analytical techniques. Groundwater samples are commonly collected from borewells, tube wells, and hand pumps to assess the quality of drinking water in different areas. Various analytical methods are used for accurate detection of heavy metals, including Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), UV-Visible Spectrophotometry, and X-Ray Fluorescence techniques. In addition to heavy metal estimation, important water quality parameters such as pH, electrical conductivity, total dissolved solids (TDS), hardness, and heavy metal concentration are also measured to evaluate the overall groundwater quality.

Remediation and Control Measures

Various remediation and control measures are used to reduce heavy metal contamination in groundwater. Adsorption techniques using activated carbon, biochar, and magnetite nanoparticles are considered effective for the removal of toxic metals from water. Reverse Osmosis (RO) systems are also widely used because they can efficiently remove contaminants such as arsenic, lead, chromium, and uranium from drinking water. Rainwater harvesting plays an important role in groundwater recharge, helping to dilute contaminants and improve overall groundwater quality. Phytoremediation, which involves the use of plants capable of absorbing heavy metals, is another eco-friendly method for cleaning contaminated soils and water bodies. In addition, regular groundwater monitoring and strict implementation of environmental regulations by organizations such as the Central Ground Water Board and the Haryana State Pollution Control

Board are essential for effective contamination management and protection of public health.

Conclusion

Heavy metal contamination in groundwater has become a significant environmental and public health issue in Panchkula and other regions of Haryana. Both natural geological conditions and anthropogenic activities contribute to the accumulation of toxic metals in groundwater resources. Arsenic, lead, chromium, cadmium, uranium, and selenium are among the major contaminants of concern. Continuous exposure to contaminated groundwater can lead to severe chronic health effects including cancer, kidney dysfunction, and neurological disorders.Proper groundwater management, periodic monitoring, public awareness, and advanced remediation technologies are urgently required to ensure safe drinking water and sustainable groundwater resources in Panchkula.

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