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Impact of Industrial Effluents on Groundwater Quality in Alwar District, Rajasthan: A Geographical and Environmental Analysis

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Abstract:
This study investigates the impact of industrial effluents on groundwater quality in Alwar district, located in northeastern Rajasthan, India. The district, known for its rapid industrial expansion, particularly through the RIICO industrial zones, faces growing challenges of water pollution due to both point and non-point sources. The study employs spatial and environmental data to assess groundwater contaminants such as fluoride, nitrates, chlorides and heavy metals, analyzing their concentration against BIS and WHO standards. It identifies pollution hotspots across different blocks and discusses the implications of water quality degradation on human health and ecological balance. Special emphasis is placed on how industrial activities, sewage discharges, agricultural runoffs and atmospheric pollutants cumulatively affect the hydrochemical parameters of groundwater. The study concludes with a call for policy revisions, stricter effluent monitoring and sustainable water resource management.

Keywords:: Alwar district, industrial effluents, groundwater contamination, water pollution, nitrate, fluoride, BIS/WHO standards, non-point source pollution, RIICO, health impacts.

Introduction:

The rapid pace of industrialization has significantly altered the natural environment, particularly in developing countries like India. One of the most concerning outcomes of this development is the degradation of water resources, especially groundwater, which serves as a vital source of drinking and agricultural water. Among various districts of Rajasthan, Alwar has emerged as a prominent industrial hub, housing several industrial clusters under the Rajasthan State Industrial Development and Investment Corporation (RIICO). While industrial growth has contributed to economic advancement, it has also led to serious environmental consequences, most notably the contamination of groundwater through the discharge of untreated or inadequately treated industrial effluents. Groundwater contamination in Alwar is influenced by a variety of factors, including direct discharge of pollutants, leaching of hazardous substances, urban runoff and agricultural practices involving excessive use of chemical fertilizers and pesticides. Toxic elements such as nitrates, fluoride, chloride, heavy metals and pathogens have been increasingly detected in groundwater samples across several blocks of the district. These contaminants not only exceed the permissible limits set by the Bureau of Indian Standards (BIS) and the World Health Organisation (WHO), but also pose severe health threats, including gastrointestinal diseases, fluorosis and waterborne infections. Given the region's dependence on groundwater for both domestic and agricultural use, understanding the extent and nature of its contamination is critical. This study, therefore, focuses on evaluating the block-wise quality of groundwater in Alwar district, determining the levels of various pollutants and assessing their potential impact on public health and the local environment. Through spatial analysis and interpretation of groundwater parameters, the study seeks to contribute valuable insights for sustainable water management and environmental planning in the region.

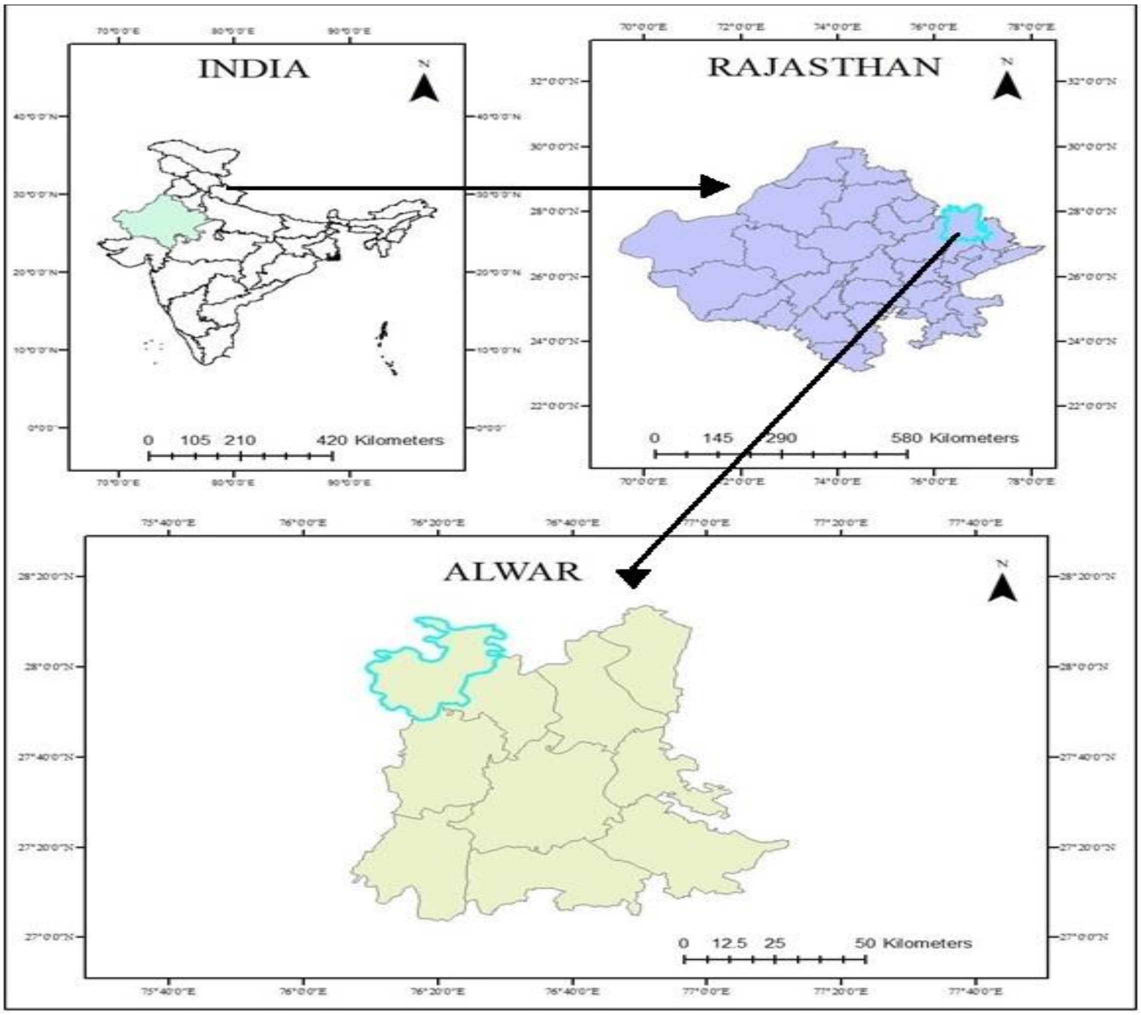
Objectives of the Study

- To examine the extent of groundwater contamination due to industrial effluents in Alwar district.

Study Area

Alwar district is situated in the northeastern part of Rajasthan, India. Geographically, it lies between latitudes 27º34'N and 28º4'N and longitudes 76º7'E to 77º13'E. The district occupies a strategic location and shares its northern and northeastern borders with the Rewari and Gurugram districts of Haryana.

Map 1: *Location of the Study Area*



Source: Prepared by research scholar with the help of Arc-GIS

Industrial Effluents and Water Pollution

The presence of human people has led to the creation of pollution, which has become irreversible in nature. Humans and their surroundings are inextricably linked in a mutually beneficial interaction. Regardless of the expense, it is imperative that the equilibrium between the two be preserved. On the other hand, the situation on the environmental front has experienced a significant transformation over the course of the past few years. An rising number of environmental risks have been brought about as a result of the draw towards urban aggregation in pursuit of work, which has led to the rapid rise of these environments. Additionally, the problem has been given additional dimensions as a result of the formation of numerous high-tech industries. It should come as no surprise that the growth of small units in such areas of economic activity has, to some extent, made the problem more severe.

The only problem that arises is when their quantity exceeds the capacity of the ecosystem to absorb them. For example, the only time carbon dioxide becomes an issue is when its concentration rises. Point source pollution is a type of water pollution that is known to be the source of water pollution. Point source pollution is the term used to describe pollution. There are other sources of pollution that can be differentiated from it. In situations when the source of water pollution is unknown or if pollution does not originate from a single discrete source, the pollution that is referred to as non-point source pollution is the type of pollution that occurs. It can originate from a variety of sources, including pesticides, fertilizers, industrial wastes and other substances and it is extremely challenging to control. It is the non-point source pollution that is the primary and most significant contributor to water pollution on the planet.

Table 1: *Block-wise Analysis of Groundwater Contaminants in Alwar District, 2023*

	High EC (>4000 ÂµS/cm)	High Chloride (>1000 mg/l)	High Fluoride (>3.0 mg/l)	High Nitrate (>100 mg/l)
Bansur	0	0	8.7	44.9
Behror	11.8	6.2	12.1	2.2
Kathumar	115.4	107.8	133	53.4
Kishangarh Bas	3.7	0.2	0	109.8
Kotkasim	13.3	11.8	70.4	36.2
Lachhmangarh	115.2	111.5	60.7	53.5
Mandawar	30.6	13.6	0	39
Neemrana	60.5	32.4	0.2	52
Rajgarh	0.6	0.2	0	70.9
Ramgarh	52.6	51	59.3	127.8
Reni	0	0	0	0
Thanagazi	1.9	0	6.9	60.8
Tijara	0	0	0	195.3
Umren	0	0	0	17.7

Source: Report of Ministry of Micro, Small and Medium Enterprises, Rajasthan

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The block-wise analysis of groundwater contaminants in Alwar district for the year 2023 reveals significant spatial variations in water quality due to industrial and other anthropogenic activities. The highest levels of electrical conductivity (EC >4000 µS/cm)—an indicator of saline or mineral-heavy water—are recorded in Kathumar (115.4 µS/cm) and Lachhmangarh (115.2 µS/cm), suggesting high levels of dissolved salts likely linked to industrial discharge or agricultural runoff. Chloride contamination follows a similar pattern, peaking in Lachhmangarh (111.5 mg/l) and Kathumar (107.8 mg/l), further indicating salinity issues. In terms of fluoride concentration, which affects dental and skeletal health, Kathumar again shows the highest value at 133 mg/l, followed by Kotkasim (70.4 mg/l) and Ramgarh (59.3 mg/l). This suggests potential geogenic sources compounded by industrial influences. Nitrate levels, often associated with fertilizer leaching and sewage intrusion, are alarmingly high in Tijara (195.3 mg/l), Ramgarh (127.8 mg/l) and Kishangarh Bas (109.8 mg/l), posing serious health risks such as methemoglobinemia or "blue baby syndrome." Contrastingly, Reni and Umren report no significant contamination across all measured parameters, indicating relatively safer groundwater. However, the widespread presence of contaminants in blocks like Kathumar, Lachhmangarh and Ramgarh underscores the urgent need for groundwater quality monitoring, pollution control measures and sustainable water management practices across the district.

When contaminants that are present on the ground make their way into the water bodies that are located beneath the earth, they are the ones that create ground water contamination. If feces-contaminated water makes its way to the ground, it will be unsafe for human consumption since it contains diseases. Pathogens that have polluted ground water may contain bacteria, viruses and protozoa and in extremely rare instances, helminthic eggs may also be present. The consumption of this water can lead to the development of ailments such as cholera and diarrhoea. In a similar manner, nitrates are responsible for ground water pollution, which in turn affects children and creates a condition known as blue baby syndrome in rural populations of Bulgaria and Romania. It has been shown that the likelihood of blue baby syndrome increases when the content of nitrates in ground water is greater than 10 mg/L (10 ppm). It is also possible for excessive usage of nitrate fertilizers to produce water pollution. This is due to the fact that plants only use a relatively tiny amount of nitrates and the majority of it is deposited in the soil. This soil then eventually leaches into the ground water, which then contaminates the ground water. Having dental and skeletal issues is a result of drinking ground water that is contaminated with excessive levels of fluoride.

Sewage from urban storms - It can be attributed to the densely crowded cities. It originates from workplaces and private residences. This is because pavement and buildings cover a significant portion of the land surface in suburban and urban regions, which means that the water does not seep into the ground when it rains or snow melts. These storm water systems transport a wide variety of pollutants, including dirt, oil, lawn fertilizers and pesticides, directly to rivers and streams, where they contribute to the contamination of water supplies. In the case of natural landscapes, these pollutants are entrapped inside the pores of the soil and water is filtered. However, in urban areas, where water is unable to seep into the ground, it washes away all of these pollutants into water bodies, so polluting them. Furthermore, the high velocity at which this storm water flows reduces the amount of silt that is removed from the embankments of water bodies, which ultimately results in the pollution of water.

Pollutants in the atmosphere are caused by dust particles that are suspended in the air and that eventually make their way into bodies of water through precipitation. Among its components is carbon dioxide, which is generated by the combustion of fossil fuels; the quantity of this gas is growing and when it mixes with water molecules, it results in the formation of sulphuric acid. There is also the formation of sulphuric acid by the combination of water molecules and sulphur dioxide, which is created by volcanoes and factories. The burning of coal and products derived from petroleum also results in the production of sulphur dioxide. Additionally, nitric acid is produced when nitrogen dioxide is combined with water in a similar manner. In addition, particles play a significant role in the process of water contamination. Rain is the primary means by which particulates come into contact with bodies of water.

Water Quality Parameters with their Guideline Values and their Potential Health Effects

Water quality parameters include physical, chemical and biological characteristics that determine the safety of drinking water. Key parameters include pH (6.5-8.5), turbidity (<1 NTU), total dissolved solids (TDS <500 mg/L), nitrates (<50 mg/L), fluoride (0.5-1.5 mg/L) and heavy metals like lead (<0.01 mg/L). Deviations from these guideline values can lead to health issues such as gastrointestinal diseases, neurological disorders, fluorosis, kidney damage and cardiovascular problems, highlighting the importance of regular water quality monitoring.

Table 3.2: *Water Quality Parameters Potential Health Effects in Alwar District*

S. No.	Operational Parameters	BIS (Permissible Limit)	WHO (Permissible Limit)	Potential Impact on Health
1.	pH	6.5–8.5	6.5–8.5	Affects mucous membrane, bitter taste and corrosion
2.	Turbidity (NTU)	1–5	–	High level is associated with disease-causing bacteria
3.	TDS (mg/l)	500–2,000	500–1,000	Undesirable taste, gastrointestinal irritation, corrosion, or incrustation
4.	Total hardness (mg/l)	200–600	200–500	Poor lathering with soaps, deterioration of the quality of clothes and scale forming
5.	Dissolved oxygen (mg/l)	6	–	Corrode water lines, boiler and heat exchangers
6.	chloride (mg/l)	250–1,000	200–300	Eye/nose irritation, stomach discomfort, increase corrosive character of water

7.	Calcium (mg/l)	75/200	100–300	Vascular calcification included blood pressure, lipids and lipoprotein level
8.	Magnesium (mg/l)	30–100	–	Eczema in children
9.	MPN/100 ml	–	10	Nausea, vomiting and diarrhoea

Source: Water quality parameters and standards as per ICMR/WHO/BIS.

Water quality is a crucial factor in guaranteeing the safety of water for consumption and other uses. It is assessed by measuring different factors based on criteria established by organisations such as the Bureau of Indian Standards (BIS) and the World Health Organisation (WHO). When these indicators are within acceptable limits, they guarantee the safety of water for human health. For example, the pH of water, which ideally falls within the range of 6.5 and 8.5, serves as an indicator of its level of acidity or alkalinity. Excessively acidic water can cause the release of toxic metals such as lead from pipes, while extremely alkaline water can cause a bitter taste and the formation of deposits in plumbing systems. According to BIS rules, the recommended range for turbidity, measured in NTU, is between 1 and 5. Elevated turbidity levels can support the growth of pathogenic bacteria, resulting in gastrointestinal diseases. Total Dissolved Solids (TDS) are an important characteristic that must be carefully monitored. The acceptable limits for TDS range from 500 to 2,000 mg/l according to the Bureau of Indian Standards (BIS) and from 500 to 1,000 mg/l according to the World Health Organisation (WHO). Elevated total dissolved solids (TDS) can result in an unpleasant flavour, gastrointestinal distress and contribute to the erosion or buildup of deposits in water systems.

According to BIS, it is recommended to maintain the total hardness of water, which is determined by the concentration of calcium and magnesium salts, within the range of 200 to 600 mg/l. This is important because excessive hardness can result in inadequate lathering of soaps, damage to clothing and the formation of scale in water heaters. Aquatic life relies on a minimum required level of 6 mg/l of dissolved oxygen, which is crucial for their survival. Insufficient amounts of dissolved oxygen can also cause water distribution systems to corrode. The BIS recommends maintaining chloride levels between 250 to 1,000 mg/l, but the WHO suggests a narrower range of 200 to 300 mg/l. An excessive amount of chloride in water can cause it to taste salty and become more corrosive, which can potentially irritate the eyes, nose and stomach. According to BIS guidelines, water should contain calcium within a range of 75 to 200 mg/l for optimal bone health. However, the World Health Organisation (WHO) proposes a somewhat wider range of 100 to 300 mg/l. Excessive calcium intake can result in vascular calcification, which can have an impact on blood pressure and cholesterol levels.

It is advisable to monitor magnesium levels in water, as the BIS recommends a range of 30 to 100 mg/l. Excessive magnesium in water has been associated with illnesses such as eczema in children. Finally, it is important to minimise the presence of coliform bacteria, which is quantified using the Most Probable Number (MPN). The World Health Organisation (WHO) advises a maximum threshold of 10 Most Probable Number (MPN) per 100 millilitres of water. Elevated levels beyond this threshold indicate the presence of faecal pollution, which can result in waterborne illnesses such as diarrhoea, nausea and vomiting. The water quality metrics are essential when considering water pollution, as surpassing the allowable thresholds can lead to substantial health hazards. Contaminants such as chemicals, garbage and pathogens deteriorate the quality of water, rendering it unsuitable for human consumption and detrimental to ecosystems. Consistent surveillance and strict compliance with these criteria are crucial in order to avert the detrimental impacts of water pollution on both public health and the ecosystem.

Conclusion

The present study highlights the alarming impact of industrial effluents on the groundwater quality in Alwar district, Rajasthan. The findings reveal that several blocks, particularly Kathumar, Lachhmangarh, Neemrana and Ramgarh, exhibit significantly high concentrations of contaminants such as fluoride, nitrate, chloride and electrical conductivity, exceeding the permissible limits set by BIS and WHO standards. These pollutants, primarily resulting from unchecked industrial discharges, urban runoff and agricultural practices, pose a serious threat to public health, leading to diseases like fluorosis, gastrointestinal disorders and blue baby syndrome. The degradation of groundwater quality not only endangers human health but also disrupts the ecological balance and reduces the availability of safe drinking water in rural and urban areas alike. The study emphasizes the urgent need for stricter enforcement of environmental regulations, adoption of cleaner production technologies and regular monitoring of industrial effluents. Furthermore, community awareness and the promotion of sustainable water management practices are essential to mitigate the long-term consequences of groundwater pollution. The study underscores the importance of an integrated approach involving policy makers, industries and local communities to ensure the protection and sustainable use of groundwater resources in industrial regions like Alwar. Without timely intervention, the contamination of groundwater may escalate, causing irreversible damage to human health and the environment.

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