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A Review on Groundwater Quality of Rewari Industrial Area, Haryana and Its Suitability for Domestic and Irrigation Purposes

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Abstract—Groundwater is an important source of water for domestic, agricultural and industrial purpose particularly in semi-arid and industrial areas of the world. In this study, the water samples were assessed comprehensively based on the physico-chemical parameters such as pH, TDS, EC, TH, major ions, SAR and RSC. The suitability of the groundwater for drinking purpose is determined by the comparison of the observed values with BIS, WHO and ICMR standards and the suitability for irrigation purposes is determined by salinity index, SAR and RSC index. This classification is also used to interpret groundwater evolution, to delineate primary groundwater types and to map the sources of pollution, using graphical techniques like Piper and Gibbs diagrams. The study brings to light the fact that both natural processes such as rock–water interaction and evaporation as well as anthropogenic activities such as industrial discharge, agricultural runoff, sewage leakage and groundwater extraction affect groundwater quality. The results show the presence of different degrees of contamination that influence both the usability of the water for drinking and for agricultural purposes. The study highlights, overall, the importance of ongoing monitoring, systematic evaluation and sustainable management to ensure safe, effective use of groundwater for current and future needs.

Keywords—Groundwater Quality, Rewari City, Haryana Groundwater, Industrial Area Pollution, Domestic Water Suitability, Irrigation Water Quality.

I. Introduction

It is a keystone of the hydrological cycle and is the major source of freshwater for drinking, domestic and irrigation purposes and also for industrial use in many parts of India particularly in semi-arid and rapidly urbanizing regions like Rewari Industrial Area (RIA) of Rewari city, Haryana. In the present scenario, the study "Quality of Ground Water of Rewari Industrial Area, Rewari city, Haryana (India) and its Suitability for Domestic and Irrigation Purpose" is of great significance because of ever-rising demand of water from the groundwater resources due to population increase, industrial development, agricultural intensification and climatic variability. Groundwater serves as the primary source of water in areas with low rainfall and scarce surface water, such as Rewari, where water quality is a key concern for sustainable water resources. Rewari has seen significant industrial growth over the last few decades, with small-scale manufacturing, engineering workshops, chemical related activities and allied industrial activities, which have led to changes in land use, and have exerted pressure on the local aquifer systems [1], [2], [3]. This has led to a degradation of the quality of the groundwater from natural geochemical processes and anthropogenic activities like discharge of untreated or partially treated industrial effluents, waste disposal, heavy application of fertilizers and pesticides in the surrounding agricultural area, and over-exploitation of groundwater beyond its natural recharge rate. All these factors affect the physico-chemical properties of the ground water and hence its suitability for different uses must be determined. The present study concentrates on the most important water quality parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium, magnesium, chloride, sulfate, nitrate, fluoride, alkalinity and other relevant parameters which play a significant role in assessing water potability and irrigation suitability. Groundwater quality is usually assessed by comparing the observed data with standard guidelines provided by various agencies like Bureau of Indian Standards (BIS 10500), World Health Organization (WHO) and Indian Council of Medical Research (ICMR) which sets permissible and desirable limits for safe drinking water. In many parts of Haryana, including Rewari district, moderate to high level of hardness, salinity and dissolved solids in groundwater were reported earlier which is due to the geological nature of aquifer materials being alluvial deposits rich in minerals and anthropogenic pollution inputs. Higher TDS and EC values generally indicate higher salinity which can impair the taste and quality of the water and can also be harmful for health if consumed for long periods. In a similar way, high nitrate levels in groundwater have been associated with agricultural runoff and contamination from sewage, resulting in potentially severe health consequences including methemoglobinemia or "blue baby syndrome" for infants. The monitoring of fluoride concentration is also important in the groundwater systems of Haryana because its deficiency and excess can cause dental and skeletal fluorosis and consequently create a public health problem[4], [5], [6]. In terms of irrigation, groundwater quality is a critical factor in assessing soil health, crop production and sustainability of agriculture. Irrigation suitability is measured by various parameters including sodium adsorption ratio (SAR), residual sodium carbonate (RSC), salinity hazard and permeability index.

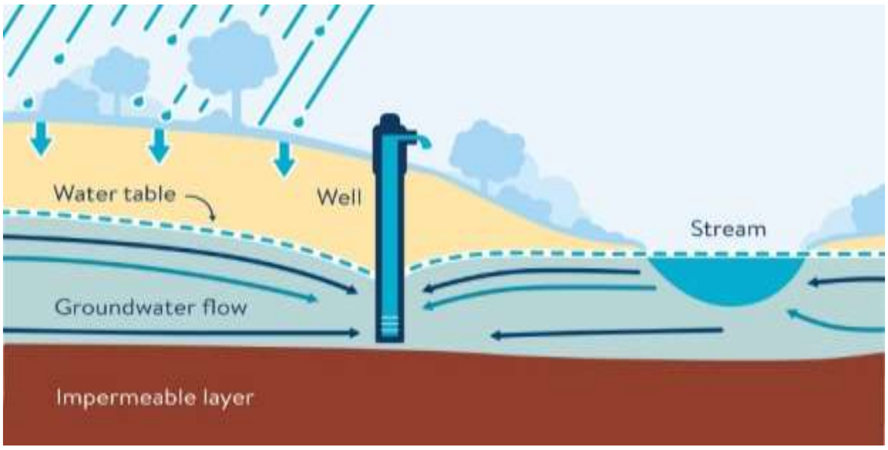

Fig. 1. Groundwater Quality

Soils high in sodium content will interfere with soil structure by displacing calcium and magnesium ions, which will result in a lower permeability, poor aeration and lower fertility levels. In a highly irrigated agriculture area around Rewari, water quality degradation has far-reaching implications for the productivity and soil quality of crops as a result of dependence on groundwater for irrigation[7], [8]. The situation is further complicated due to the impact of industries in Rewari as the industrial effluents can directly or indirectly be responsible for the entry of heavy metals, organic pollutants and other toxic substances into the subsurface environment due to seepage and infiltration. Water quality is slowly declining in some places due to the lack of efficient wastewater treatment facilities and poor enforcement of the regulatory mechanism associated with industrial pollution. Furthermore, groundwater extraction has led to falling water levels and low natural dilution, and high concentrations of dissolved ions, exacerbating water quality deterioration. The hydrogeological conditions of Rewari also play a significant role in the transport and storage of contaminants in the aquifer system and are mostly represented by alluvial plains with different degrees of permeability. The groundwater quality is also influenced by seasonal variations which occur from monsoon and post-monsoon based on the dilution effect and recharge. So, systematic monitoring and scientific assessment of groundwater quality takes a significant role in environmental management and planning in this context. The present study is an attempt to get a holistic picture of the situation of groundwater quality in Rewari Industrial Area by analysing representative samples of groundwater collected from various locations and then compared with the drinking and irrigation standards. This assessment can be used to identify areas of good and poor groundwater quality, the spatial variations and the main hydro chemical processes that control groundwater composition. The results of this study will be useful for policy makers, environmental planners and local governments in crafting efficient groundwater management plans, pollution control schemes and sustainable groundwater practices. Moreover, the study revealed that there is a need for continuous monitoring programmes, the use of modern water treatment technologies and strict enforcement of environmental laws to avoid any further degradation of groundwater resources. Enlightening the public about water conservation and prevention of water pollution is also very important in respect of the quality of groundwater in industrial area such as Rewari. In conclusion, the study highlights the significance of groundwater in Rewari Industrial Area and its growing strain, calling for immediate action to safeguard its future sustainability and reliability for future use in the context of both domestic and agricultural supplies. It is crucial to protect this vital resource for present and future generations by applying a scientific approach that includes hydro chemical analysis, environmental monitoring, and sustainable management practices, which will ensure balanced development without affecting environmental integrity.

II. Literature Review

Nancy 2026 et al. Groundwater is an important resource in the semi-arid zones such as Haryana, but due to heavy agriculture, urbanization and population growth, this resource has been depleted at a fast pace. In this study, spatial and temporal groundwater level changes are estimated by applying the GIS-based interpolation and trend analysis. The parameters of depth, fluctuation, rainfall, land use were combined using a weighted overlay method to create a groundwater sustainability index. The results indicate that there is a clear spatial variability, with generally good conditions in northeast and bad conditions in the central and southwestern regions. A temporal analysis shows that the groundwater level is decreasing over time, indicating areas of groundwater over-exploitation and critical conditions for groundwater management [9].

Mukherjee 2025 et al. Inefficient pumping systems in domestic, agricultural and industrial uses exacerbate groundwater depletion. The study points out that there is a need to increase the efficiency of the pumps, to manage the demand and to plan the water and energy policies together. The extraction of groundwater is a major factor in electricity usage and carbon emissions in urban areas such as Faridabad. Thus, sustainable urban planning and good governance are critical to ensure water balance, decrease energy consumption and car bon footprint in the long-term for sustainable environmen[10].

Jha 2024 et al. Due to the high population density and fast urbanization rate in the NCR region, the region has become highly dependent on groundwater resources for its domestic, agricultural and industrial requirements. The region receives adequate rainfall; however, the extraction of groundwater resources is greater than their natural replenishment, resulting in continuous depletion of the groundwater resources. Ground water is the sole available surface water source, with limited availability primarily in the monsoon season, accentuating the need for groundwater. As a result, rain water harvesting is identified as an effective solution to improve the groundwater recharge in the study area to the above-mentioned imbalance. Can be applied in urban and rural areas with appropriate traditional and modern methods. Also, additional surface water bodies must be rejuvenated and expanded in order to facilitate recharge. With reduced installation costs due to technological advancements, rainwater harvesting can be widely adopted. If the water deficient areas are given preference and rendered mandatory, groundwater sustainability can be greatly enhanced in the NCR region and levels of groundwater can be brought back from the plunge.Groundwater sustainability can be improved considerably in the NCR region and groundwater levels can be pulled out of their precipitous decline if the water deficient areas are given precedence and such systems are made mandatory [11].

Kaur 2024 et al. have state groundwater quality and distribution of aquifers in Mewat district, Haryana by using geophysical investigations. It is a tool that defines the horizontal and vertical freshwater and saline water zones based on the resistivity data. The higher the resistivity value, the more likely there is the presence of freshwater; the lower the resistivity value, the greater the likelihood of saline to brackish conditions. The results indicate that almost 55% of the area has saline ground water with limited ground water from shallow depths (up to 30 m) present mostly. Freshwater sources become increasingly scarce with depth and hard rock and saline formations are more prevalent. The study also emphasizes that infiltration rates can vary and that aquifer conditions are not uniform, which impacts the potential for groundwater recharge. A 3D hydrogeological modelling identifies problems including depletion, water-logging, high salinity and also high nitrate, sodium and chloride concentrations in some areas. In general, the results highlight the importance of water-saving groundwater use and sustainable planning to overcome the water scarcity and water quality problems in the region[12].

Sangwan 2023 et al. examines the alarming decline of groundwater levels in India, with a focus on southern Haryana. Based on secondary data from the Ministry of Water Resources, it analyses spatial patterns of groundwater depth using GIS techniques such as ArcGIS 9.3 and Kriging interpolation to map water table depth and fluctuations. The findings reveal that groundwater depletion is a serious issue in several states, including Punjab, Haryana, Uttar Pradesh, and parts of South India, mainly due to over-extraction for agricultural, industrial, and domestic needs. In southern Haryana, areas such as Mahendergarh district and Firozpur block of Mewat are identified as highly critical zones. The study emphasizes that rapid population growth and increasing water demand are the key drivers of depletion. It concludes by recommending sustainable and judicious use of groundwater resources along with effective management strategies to prevent further decline and ensure long-term water security[13].

Table 1: Literature Review

Authors/Year	Methodology	Research gap	Findings
Priyanka/2022[14]	Basin-based hydrochemical and spatial assessment of contamination sources in Turkey.	Lack of integrated nationwide studies linking pollution sources and health impacts.	Groundwater pollution arises from natural and human sources causing regional health risks.
Shrivastava/2022[15]	109 groundwater samples analyzed for drinking and irrigation purposes assessment.	Integrated trace metal and sewage contamination studies remain limited overall.	Groundwater shows Ca-Mg-HCO3 facies with trace metal and sewage contamination.
Mohanty/2021[16]	Developed Composite Water Sustainability Index (CWSI) using 17 indicators across Haryana districts.	Limited integrated district-level sustainability assessment of groundwater in North-West India.	Haryana shows moderate sustainability (0.534) with severe groundwater overexploitation and cropping pattern issues.
Vikas/2021[17]	APHA standard analysis of pond water quality parameters in Bareilly.	Limited seasonal correlation studies of pond water quality parameters.	Alkaline water with high hardness and strong parameter correlations observed.
Sunil/2021[18]	Batch adsorption study using wheat husk and brick powder for fluoride removal.	Limited low-cost adsorbent comparison studies for groundwater fluoride removal.	Both adsorbents effectively reduced fluoride; efficiency increased with dose and contact time.

III. Physico-Chemical Characteristics of Groundwater

The pH, TDS, EC, hardness, anions, SAR and RSC are all included in the groundwater assessment. These parameters establish water appropriateness for potable and/or irrigation purposes. Imbalances may lead to health hazards, soil erosion, and a decrease in crop yield. Effective monitoring can provide information about contamination from natural and anthropogenic sources to ensure safe groundwater use and sustainable use.[19].

A. ***pH Level***

A physico-chemical parameter of great significance in groundwater and determining the overall quality and useability is the pH which determines the acidity or alkalinity of the groundwater. It is rated from 0 to 14, with numbers below 7 being acidic, numbers above 7 being alkaline and a number of 7 being neutral water.

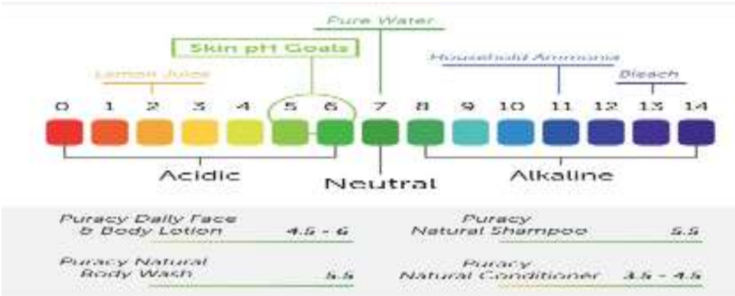

Fig. 2. pH Level

Groundwater pH can have a significant impact on the taste, chemical activity and reaction of the water and other solutes present. Excessively acidic water can corrode pipes and leach potentially harmful metals like iron, lead or copper from pipes, and extremely alkaline water can lead to an unpleasant taste or cause scaling on household appliances. Furthermore, pH can influence the solubility and toxicity of various chemical constituents influencing the stability and usability of water. The WHO guidelines and BIS (Bureau of Indian Standards) recommended the drinking water pH should be maintained in the range of 6.5 to 8.5; if the water lies outside this range, they are not suitable for human consumption or use [20].

B. ***Total Dissolved Solids (TDS) & Electrical Conductivity (EC)***

Total Dissolved Solids (TDS) are the sum of all inorganic and organic solids in solution within the ground water, consisting of salts, minerals and trace elements. It is a significant measure of water quality because it impacts upon the taste, palatability and usability of water for domestic purposes. Increased TDS results in salt or bitter taste in water and it might need treatment to be used for drinking. Electrical Conductivity (EC) is a measurement of the conductivity of electricity in water, which is determined by the presence and concentration of ions dissolved in water, like sodium, calcium, magnesium, chloride, and sulfate. EC and TDS are closely related with TDS increasing with the increase of EC. The higher the value of TDS and EC the higher the salinity, which can have a negative effect on the drinking and irrigation suitability. In irrigation, saline water will cause long term degradation of soil, lower crop yield and poor soil structure. So, there is a need to monitor TDS and EC to analyze the quality of the ground water resource and safe and sustainable utilization of the water resources[21].

C. ***Total Hardness (Calcium and Magnesium)***

The hardness in groundwater is due to naturally occurring dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions which are leached out of the rocks and soil formations it passes through, including limestone, dolomite and gypsum. Such minerals can be dissolved by the movement of water through the geological strata, giving water a higher hardness rating. Hard water does not usually present a health problem but it definitely has an impact on the use of water in the home and in industry. Scale buildup in household pipes, water heaters, boilers and appliances reduces the efficiency of these products and makes for expensive maintenance in the home. It also degrades the effectiveness of soaps and detergents so that more is used when cleaning. In the industrial industry, hard water can lead to scaling, fouling, and decreased productivity in cooling systems and production lines. Thus, the hardness of water plays an important role in the assessment of groundwater quality, which directly affects both the economic use and functional use of water. Hardness control and monitoring is important to maintain long-term sustainability of groundwater resources [22], [23].

D. ***Major Anions (Chloride, Sulfate, Nitrate, Fluoride)***

The major anions such as nitrate (NO_3^-), fluoride (F^-), chloride (Cl^-) and sulfate (SO_4^{2-}) have an important role in the overall quality and pollution of groundwater. Where nitrate is found in high levels, it is usually a result of infiltrated agricultural fertilizers, animal wastes or sewage system leakage, and is one of the most important indicators of anthropogenic contamination. Nitrate is known to be hazardous at levels found in drinking water, especially for infants, because it interferes with the ability of blood to carry oxygen (“blue baby syndrome”). However, fluoride can be a problem at higher concentrations, as it causes dental and skeletal fluorosis, a significant health issue in many regions of India, but can be beneficial at lower levels to prevent dental caries. High chloride content may arise from natural sources (rock-water interaction) and anthropogenic sources (domestic sewage, industrial effluents etc.) and thus gives water a salty taste and can be indicative of salinity intrusion. Likewise, sulfate ions are derived from the dissolution of minerals and industrial processes, and high concentration of sulfate can induce an undesirable taste and can have a laxative effect if consumed in excess. These anions collectively provide valuable data on groundwater pollution and have a significant impact on the potable and potable/agricultural uses of groundwater [24].

E. ***Irrigation Quality Indicators (SAR and RSC)***

The sodium adsorption ratio (SAR) and the residual sodium carbonate (RSC) are important indices for assessing the suitability of groundwater for irrigation. SAR reflects the relative amount of sodium ions to calcium and magnesium ions in water and is a good indicator of the potential effect of sodium on soil structure. At higher concentrations SAR, excess sodium ions replace calcium and magnesium ions on soil particle surfaces, resulting in soil dispersion, decreased permeability and poor aeration that ultimately impacts plant growth and agricultural production. RSC, on the contrary, is the measure of the amount of carbonate and bicarbonate in the water as related to the calcium and magnesium levels. High RSC values suggest that there are more carbonate and bicarbonate ions in soil solution than there are calcium and magnesium. High RSC values are characteristic of soil solutions with a higher ratio of sodium ions to calcium and magnesium ions because excess carbonate ions and bicarbonate ions may precipitate out calcium and magnesium. This process can lead to a progressive decrease in soil fertility and function for healthy crop growth over time. Therefore SAR and RSC are both important in irrigation water quality assessment and high values can result in long term degradation of the soil, lower crop production and loss of sustainability of the land use, especially in areas where groundwater is used for irrigation[25].

IV. Groundwater Quality Assessment for Domestic Use (BIS, WHO, ICMR)

Physicochemical parameters of Groundwater are compared with BIS, WHO and ICMR parameters and the assessment is done for domestic use. Various parameters such as pH, TDS, hardness, chloride, sulphate, nitrate, fluoride and heavy metals are measured to determine suitability. Toxicity and health risk assessment detects the elements that are harmful, like nitrate, fluoride, arsenic and lead, which can lead to serious disease on long-term exposure. Water is considered safe, permissible after treatment, or unsafe, depending on the compliance. This classification aids in determining the source of contamination and treatment options. Continuous monitoring is critical for public health protection, prevention of waterborne diseases and for safe and sustainable groundwater use[26].

A. Standard Guideline Comparison

The water quality assessment for domestic purpose is mainly done by comparing the standard guideline values given by BIS (Bureau Of Indian Standards), WHO (World Health Organization) and ICMR (Indian Council of Medical Research). These groups establish reasonable and acceptable limits on different physicochemical and biological parameters to ensure safe drinking water. BIS offers IS: 10500 with respect to India, WHO has health based standards and ICMR has long term health effects for the Indian populace. Groundwater parameters measured in groundwater studies, such as pH, total dissolved solids (TDS), hardness, chloride, sulphate, nitrate and fluoride are compared to these standards. Values outside of the desirables show possible health risk and require treatment, while values inside the desirables mean water is safe to drink. Through this comparative approach it is vital to determine the level of contamination and to ensure that groundwater is suitable for domestic and drinking water in both rural and industrial areas [27].

B. Physicochemical Parameter Evaluation

The evaluation of the physicochemical parameters is an important step in assessing the suitability of groundwater for domestic use. It includes the analysis of key water quality parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness, calcium, magnesium, chloride, sulphate, nitrate, and fluoride. All of these parameters are indicative of the chemical nature and mineral composition of the groundwater. For instance, pH is used for measuring acidity or alkalinity, and TDS measures the total amount of dissolved matter. The principal cause of hardness is the presence of calcium and magnesium ions, while high concentrations of chloride or sulphate could mean contamination from industrial or sewage effluents. Nitrate and fluoride are particularly important due to their direct health impacts. These parameters are compared with BIS, WHO and ICMR standards to check the water quality status. This evaluation is useful for determining contamination sources, understanding the hydrochemical processes and to know if groundwater needs treatment before use for domestic and potable water [28].

C. Toxicity and Health Risk Assessment

One of the essential processes in classifying groundwater is its suitability classification based on the quality of water, which is useful for categorizing the water for its domestic consumption. The classification is broadly made based on the comparison of observed physicochemical parameters with BIS, WHO and ICMR standards. Groundwater quality is classified according to how well it meets the standards, ranging from "safe for drinking" to "unsafe for direct consumption." Water is considered as fit for human consumption if it falls within the specified limit and can be used directly and if it exceeds the limit then it may experience simple treatment like filtration, boiling or chemical purification. If any of the parameters such as TDS, hardness, nitrate, heavy metals and other parameters are found to exceed the safety limit, the water is considered unfit and can have severe health consequences. The classification is used by policy makers, researchers, and local authorities to determine a safe water source, and to plan the necessary treatment. It also helps to promote sustainable groundwater management by identifying areas where water quality is declining, and identifying the anthropogenic and natural factors responsible for this.[29].

D. Suitability Classification of Water

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E. Public Health and Safety Perspective

From the public health and safety aspect of groundwater quality assessment, there is a direct link between water quality and human health. Improperly treated drinking water is a primary source of waterborne diseases, including long-term chronic diseases from exposure to toxic chemicals like dysentery, cholera and diarrhea. In industrial and urban areas, groundwater is frequently polluted by untreated effluents, chemicals used in agriculture and domestic sewage which can cause exposure to harmful substances. Groundwater monitoring is therefore necessary to ensure continued protection of public health and disease outbreaks are prevented. Guidelines are issued by various organisations such as BIS, WHO, ICMR etc. which help to keep the standards of drinking water safe. Public health interventions include frequent testing, public education about the risks of contaminated water, and treatment of contaminated water sources. Safe groundwater access not only enhances community health but also has socio-economic implications by alleviating health care costs and enhancing the quality of life for affected communities [30].

V. **Irrigation Water Quality Assessment (Salinity, SAR, RSC)**

The water quality of irrigation water is evaluated based on EC and SAR parameters, and RSC to know how it affects the soil and crop. Salinity stress is induced by high EC, which will affect plant growth and yield. SAR is an index of sodium hazard, which is the negative effect of excess sodium in soil on its permeability and structure. High SAR causes decreased aeration, reduced root growth and reduced productivity. RSC precipitates excess calcium and magnesium, thereby reducing the availability of calcium and magnesium, leading to an increase in soil alkalinity and sodium hazard. The use of poor-quality water leads to degradation of soils and low soil fertility. The different combinations of these parameters are used to determine whether irrigation water is safe, marginal or unsuitable. This classification will facilitate the selection of the appropriate crops, improved irrigation management, sustainable agriculture and prevent long-term soil degradation and loss of productivity [31].

A. ***Salinity Assessment (Electrical Conductivity – EC)***

The salinity of irrigation water is usually determined by the Electrical Conductivity (EC) of the water, which is based on the capacity of water to conduct electric current as a result of the presence of dissolved ions like sodium, calcium, magnesium, chloride or sulphate. The presence of EC is commonly used as a good indicator of total dissolved salt concentration in groundwater. High E.C. means high amounts of soluble salts in the water which will directly impact the soil properties and growth of plants. Osmotic stress occurs in plants under high salinity conditions and can impede the efficient uptake of water by the roots in the soil. This causes the plants to uptake less water, even when the soil is moist. This condition negatively affects seed germination, plant growth and general crop production. The constant application of high EC water to the soil over time may result in soil salinization, loss of agricultural land and fertility, and lower soil productivity, which will not support sustainable agriculture [32].

B. ***Sodium Adsorption Ratio (SAR)***

Sodium Adsorption Ratio (SAR) is an important parameter used to evaluate the suitability of irrigation water, as it measures the relative proportion of sodium ions compared to calcium and magnesium ions present in water. It is a key indicator of the potential sodium hazard in agricultural soils. When SAR values are high, it means that sodium dominates over calcium and magnesium in irrigation water. Excess sodium, when applied repeatedly through irrigation, tends to replace calcium and magnesium ions on soil exchange sites. This process leads to soil dispersion and breakdown of soil aggregates, resulting in deterioration of soil structure. As a consequence, the soil becomes compacted and less porous, which significantly reduces its permeability and infiltration capacity. Poor soil permeability restricts the movement of air and water within the soil, negatively affecting root development and plant growth. Ultimately, high SAR water usage leads to reduced agricultural productivity and long-term soil degradation[33].

C. ***Impact of High SAR on Soil***

Excess sodium in irrigation water replaces essential calcium and magnesium ions on soil exchange sites, which disrupts the natural balance of soil structure. This ion exchange process causes soil particles to disperse, breaking down stable soil aggregates into finer particles. As a result, the soil becomes compacted and loses its structural stability. Poor soil structure directly leads to reduced aeration, limiting the availability of oxygen required for healthy root respiration and microbial activity. In addition, the breakdown of soil aggregates decreases infiltration capacity, meaning that water movement through the soil becomes slow and uneven. This condition often results in surface waterlogging or, conversely, poor moisture distribution in the root zone. Over time, these adverse effects restrict root penetration and development, weakening plant growth and reducing nutrient uptake efficiency. Ultimately, continuous use of sodium-rich irrigation water leads to declining soil fertility, reduced crop productivity, and long-term degradation of agricultural land[34].

D. Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate (RSC) is an important parameter used to evaluate the suitability of irrigation water by determining the excess concentration of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) ions over calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. It is calculated to assess the potential of water to create sodium hazards in agricultural soils. When RSC values are high, carbonate and bicarbonate ions react with calcium and magnesium in the soil, leading to their precipitation as insoluble compounds. This reduces the availability of these essential nutrients in the soil solution. As calcium and magnesium decrease, sodium becomes the dominant cation, increasing the sodium hazard in the soil. This condition negatively affects soil structure by promoting clay dispersion and reducing soil permeability. Consequently, water infiltration and aeration are impaired, which adversely impacts root growth and nutrient uptake. Prolonged use of high RSC water ultimately leads to soil alkalinity, reduced fertility, and declining crop productivity, making it unsuitable for sustainable irrigation practices[35].

VI. Hydro chemical Classification of Groundwater

Hydrochemical classification groups groundwater based on ionic composition to understand its quality, origin, and evolution. It uses major ions and facies types, supported by graphical tools like Piper and Gibbs diagrams. These help identify controlling processes, pollution sources, and water suitability for drinking, domestic, and irrigation uses effectively[36].

A. Concept of Hydrochemical Classification

It refers to the systematic process of grouping groundwater according to its chemical composition in order to understand its overall quality, origin, and evolution. This classification is mainly based on the relative concentration of major dissolved ions such as calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate, and nitrate present in the water. By analyzing these chemical constituents, researchers can identify the hydrochemical nature of groundwater and determine the processes that control its composition. It also helps in distinguishing between fresh recharge water, mineralized water, saline water, and contaminated water. This approach is essential for interpreting how groundwater interacts with surrounding geological formations and how natural and human-induced activities influence its quality. In addition, hydrochemical grouping provides valuable insights into the suitability of water for drinking, domestic, and irrigation purposes. Overall, it serves as an important scientific tool for assessing groundwater conditions and supporting effective water resource management and environmental protection strategies[37].

B. ***Major Ionic Composition***

Classification of groundwater is primarily based on the dominance and relative proportions of major dissolved ions present in water, which include cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}), and anions such as bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), and nitrate (NO_3^-). These ions are responsible for defining the chemical character and hydrochemical facies of groundwater. The dominance of specific ions helps in identifying whether the water is fresh, hard, saline, or polluted in nature. For example, calcium and bicarbonate-rich water generally indicates recent recharge and good quality groundwater, whereas sodium and chloride dominance may suggest salinity or anthropogenic contamination. Similarly, elevated sulphate or nitrate levels often point toward industrial, agricultural, or sewage influences. By analyzing these ionic patterns, hydrochemical classification provides a clear understanding of groundwater quality, geochemical processes, and its suitability for various uses such as drinking, domestic consumption, and irrigation purposes[38].

C. ***Hydrochemical Facies Identification***

Groundwater is categorized into different hydrochemical types, commonly known as hydrochemical facies, based on the dominance of major ions present in the water. One of the most common types is the $Ca–HCO_3$ (calcium–bicarbonate) facies, which generally represents fresh groundwater formed through recent recharge and interaction with carbonate rocks, indicating relatively good water quality. Another important type is the Na–Cl (sodium–chloride) facies, which is often associated with saline water conditions, evaporation effects, or contamination from industrial, agricultural, or sewage sources, making it less suitable for drinking and irrigation purposes. In addition to these, mixed water types also occur when no single ion pair dominates, indicating transitional stages of groundwater evolution or mixing of different water sources. These classifications help in understanding the geochemical processes controlling groundwater composition, identifying pollution impacts, and assessing the suitability of water for domestic, agricultural, and industrial uses in a systematic and scientific manner[39].

D. ***Graphical Representation Methods***

Tools such as the Piper diagram, Durov diagram, and Gibbs diagram are widely used graphical methods for interpreting groundwater chemistry and understanding hydrochemical processes. The Piper diagram is one of the most commonly used tools, which helps in classifying water types by plotting the relative percentages of major cations and anions, thereby identifying hydrochemical facies and overall water characteristics. The Durov diagram extends this analysis by providing a clearer view of geochemical evolution and possible mixing processes, helping to identify relationships between different water samples. The Gibbs diagram, on the other hand, is used to determine the dominant mechanisms controlling water chemistry, such as rock-water interaction, evaporation, or precipitation dominance. Together, these diagrams provide a comprehensive understanding of groundwater behavior, origin, and evolution. They are highly useful in hydrogeological studies for assessing water quality, identifying contamination sources, and evaluating the suitability of groundwater for drinking, domestic, and irrigation purposes[40].

VII. Sources of Groundwater Contamination in Industrial Area

Groundwater contamination in industrial areas is caused by effluents, solid waste leachate, agricultural runoff, sewage leakage, over-extraction, and chemical storage spills. These pollutants introduce toxic substances, nutrients, pathogens, and salts into aquifers, degrading water quality. As a result, groundwater becomes unsafe for drinking, domestic use, and irrigation purposes[41].

A. Industrial Effluent Discharge

Industries release large quantities of wastewater that often contain untreated or partially treated chemical substances, heavy metals, and various toxic compounds. These industrial effluents may include contaminants such as lead, cadmium, chromium, mercury, oils, dyes, solvents, and other hazardous organic and inorganic materials. When such wastewater is discharged without proper treatment, it seeps into the surrounding environment and gradually infiltrates through soil layers. Due to the porous nature of soil, these pollutants can percolate downward and reach the groundwater aquifers over time. In industrial clusters, where multiple manufacturing units operate in close proximity, the cumulative discharge of effluents significantly increases the risk of groundwater contamination. Once these harmful substances enter the aquifer system, they persist for long periods and are difficult to remove naturally. This contamination not only deteriorates the chemical quality of groundwater but also poses serious health risks to local populations, making the water unsafe for drinking, domestic, and agricultural purposes[42].

B. Improper Solid Waste Disposal

Open dumping of industrial and municipal solid waste is a major source of groundwater contamination, particularly in rapidly urbanizing and industrial areas. When waste is left exposed on open land without proper lining or treatment facilities, it undergoes physical, chemical, and biological decomposition due to rainfall and environmental conditions. During this process, a highly contaminated liquid known as leachate is formed. This leachate contains a complex mixture of dissolved organic matter, inorganic salts, heavy metals, nutrients, and toxic substances. As it percolates through the soil, it gradually infiltrates deeper layers and eventually reaches the subsurface aquifer system. Once groundwater is contaminated by leachate, its quality deteriorates significantly, showing increased levels of TDS, chloride, nitrate, and harmful metals. In industrial and urban regions, continuous dumping intensifies the pollution load, making groundwater unsafe for drinking, domestic, and irrigation purposes. The long-term impact includes persistent aquifer degradation and serious environmental and public health risks[43].

C. Agricultural Chemical Runoff

Excessive use of fertilizers, pesticides, and herbicides in agricultural practices significantly contributes to groundwater contamination, especially in areas surrounding industrial and urban regions. Chemical fertilizers applied to enhance crop productivity often contain high amounts of nitrogen and phosphorus compounds. When applied in excess or during improper irrigation practices, these chemicals are not fully absorbed by plants and remain in the soil. During rainfall or irrigation, these residual chemicals dissolve in water and gradually infiltrate through soil layers, eventually reaching the groundwater system. Nitrate (NO_3^-) is one of the most common contaminants found in such cases and poses serious health risks, particularly methemoglobinemia in infants. Similarly, phosphates and pesticide residues can persist in the subsurface environment, affecting both water quality and ecological balance. Over time, continuous agricultural runoff leads to gradual degradation of groundwater quality, making it unsafe for drinking and domestic use while also impacting long-term soil and water sustainability[44].

D. Domestic Sewage Leakage

Leakage from septic tanks, drainage systems, and sewage pipelines is a significant source of groundwater contamination, particularly in densely populated and semi-urban areas. When these sanitation systems are poorly designed, improperly maintained, or structurally damaged, untreated or partially treated wastewater can seep directly into the surrounding soil. This wastewater contains high levels of organic matter, harmful microorganisms, and nutrients such as nitrogen and phosphorus compounds. As it percolates through the soil profile, these contaminants gradually reach the groundwater aquifers. The presence of pathogens such as bacteria, viruses, and protozoa poses a serious health risk, leading to waterborne diseases like diarrhea, cholera, and dysentery. Additionally, the excessive organic load increases biochemical oxygen demand (BOD), further degrading water quality. Nutrient enrichment may also promote undesirable chemical changes in groundwater. Continuous leakage from such sources significantly deteriorates groundwater quality, making it unsafe for drinking and domestic purposes and posing long-term public health challenges in affected regions.

E. Over-Extraction of Groundwater

Excessive pumping of groundwater for domestic, agricultural, and industrial purposes leads to a continuous decline in the water table, creating significant environmental and hydrogeological impacts. As groundwater levels drop, the natural pressure within aquifers decreases, which can disturb the balance between fresh and contaminated water zones. This condition increases the risk of contaminated surface water, such as agricultural runoff, sewage, or industrial effluents, seeping more easily into the groundwater system. In coastal and semi-arid regions, over-extraction can also lead to the intrusion of saline water into freshwater aquifers, resulting in increased salinity levels. High salinity affects the potability of groundwater and reduces its suitability for irrigation by degrading soil quality and crop productivity. Additionally, the lowering of the water table reduces the natural dilution capacity of aquifers, allowing pollutants to become more concentrated. Overall, excessive groundwater pumping accelerates contamination risks and threatens the long-term sustainability of groundwater resources[45].

VIII. Conclusion

Groundwater quality assessment indicates that its suitability for drinking and irrigation depends on key physico-chemical parameters such as pH, TDS, EC, hardness, major ions, SAR, and RSC. These parameters reflect both natural geological processes and human-induced contamination. Elevated levels of dissolved salts, nutrients, and toxic ions often result from industrial effluents, agricultural runoff, sewage leakage, over-extraction, and chemical storage spills, leading to deterioration of groundwater quality. Irrigation indicators like SAR and RSC further show adverse impacts on soil structure, permeability, and agricultural productivity due to sodium and carbonate hazards. Hydrochemical classification helps in identifying water types and understanding groundwater evolution and pollution pathways using tools such as Piper and Gibbs diagrams. Comparison with BIS, WHO, and ICMR standards is essential for determining whether water is safe, permissible after treatment, or unsafe for use. Overall, continuous monitoring, proper assessment, and sustainable management practices are essential to protect groundwater resources, ensure safe water supply, and maintain environmental and agricultural sustainability.

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