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# A Review on Groundwater Quality Assessment

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**Abstract:** *Water is necessary for the continued existence of every living being. Water quality is typically defined by its physical, chemical, and biological properties. Therefore, it is essential to determine the suitability of water for drinking, irrigation, and industrial use. The quality of groundwater is of paramount importance, particularly due to increasing anthropogenic activities, which have led to contamination in many regions. The use of contaminated water leads to the spread of waterborne diseases among the human population. This review focuses on groundwater quality assessment, its key parameters, methods of monitoring, and emerging techniques. We discuss major contaminants such as heavy metals, nitrates, and microbial pathogens, and explore assessment tools like traditional chemical testing techniques.*

**Keywords:** Groundwater quality, contamination, heavy metals, nitrates, GIS

## I. INTRODUCTION

Groundwater accounts for nearly 30% of the Earth's freshwater resources and plays a critical role in meeting the water demands for drinking, agriculture, and industry (Jørgensen 2022).Groundwater is a critical resource that serves as a primary source of drinking water for a significant portion of the global population. According to the World Health Organization (WHO, 2019), approximately 2.2 billion people lack access to safely managed drinking water services, making groundwater quality assessment an essential aspect of ensuring public health and environmental sustainability. Groundwater is particularly vulnerable to contamination from various anthropogenic activities, including agricultural practices, industrial discharges, and urbanization (Foster et al., 2017). These activities can introduce a range of pollutants, such as heavy metals, pesticides, and pathogens, which may adversely affect water quality and pose health risks to consumers (WHO, 2017).

The quality of groundwater is influenced by both natural and human factors, which necessitates comprehensive assessment strategies to monitor and manage this vital resource effectively (Agarwal& Sharma, 2019). Various methods and technologies have been developed to evaluate groundwater quality, including chemical analysis, hydrogeological studies, and remote sensing techniques (Moges et al., 2020). Understanding the spatial and temporal variations in groundwater quality is crucial for the sustainable management of water resources, particularly in regions facing water scarcity or pollution challenges.

This review aims to provide a comprehensive overview of current methodologies employed in groundwater quality assessment, highlight the major contaminants of concern, and discuss the implications of groundwater quality on public health and environmental sustainability.

### Groundwater Quality Parameters

Groundwater quality is evaluated by analyzing its physical, chemical, and biological properties. Some of the key parameters include:

### Physical Parameters

- **Temperature**: Groundwater temperature influences various chemical reactions and biological processes within the aquifer. Higher temperatures can enhance the solubility of certain contaminants, potentially impacting water quality (Kumar et al., 2019).

- **pH**: pH is a crucial water parameter that influences its suitability for various uses, including drinking, bathing, cooking, washing, and agriculture. The desirable pH range for water is between 6.5 and 8.5 as prescribed by WHO (Table 1). It affects the solubility of minerals and metals, influencing the availability of nutrients and the toxicity of contaminants (Hach et al., 2017).
- **Electrical Conductivity (EC)**:Electrical conductivity refers to the ability of water to conduct an electrical current. It is directly linked to the concentration of ionized substances in the water and can also be associated with issues related to excessive hardness. High conductivity levels can indicate salinity or pollution, affecting both human health and agricultural practices (Urbano et al., 2020). The WHO standard limit for EC is 250 µs/cm (Table 1).Solutions of most inorganic acids, bases, and salts are generally effective conductors of electricity.
- **Turbidity**: Turbidity is a measure of the clarity of water and is influenced by the presence of suspended particles, such as silt, clay, and organic matter. An excessive amount of turbidity can house infections and lessen the efficacy of disinfection procedures. Turbidity can be measured either by its impact on light transmission, a method known as turbiditymetry, or by its effect on light scattering, referred to as nephelometry. The WHO prescribed limit of turbidity is 5 NTU.

**Chemical Parameters**

- **Dissolved Oxygen (DO):** DO is a crucial parameter for evaluating water quality, as it is vital for maintaining both human health and aquatic life. High turbidity absorbs sunlight, causing the water to warm and subsequently lowering the DO levels. The highest permissible limit of DO is 5 mg/L as prescribed by WHO.
- **Hardness:** The elevated concentration of hardness may be attributed to the natural accumulation of salts, surface runoff, or direct contamination from human activities. The standard limit of hardness, proposed by WHO is a 500 mg /L. Total hardness (TH) levels exceeding 150–300 mg/L can lead to kidney stone formation and reduce the effectiveness of soap in producing lather.
- **Total Dissolved Solids (TDS)**: TDS represents the inorganic salts of magnesium (Mg), calcium (Ca), sodium (Na), potassium (K), and chloride ($Cl^-$) dissolved in groundwater. High TDS levels can affect water palatability and indicate contamination (Moges et al., 2020). Elevated TDS level can give drinking water a bitter, brackish, or salty taste, which can also negatively impact the aquatic species living in the water. According to WHO, the TDS level in groundwater samples ranged from 500-1000 mg/L (Table 1).
- **Nitrate:** Nitrate is commonly found in raw water and primarily exists as a nitrogen ($N_2$) compound in its oxidized state. Nitrate is generated from chemical and fertilizer factories, animal waste, decaying vegetation, and domestic and industrial discharges. As per WHO standard, the maximum limit of nitrate is 45 mg/L.
- **Sulfate:** Natural water contains sulfate ions, most of which are soluble in water. Many sulfate ions are produced through the oxidation of ores and are also present in industrial waste.A concentration of sulfate ($SO_4^{2-}$) exceeding 400 mg/L can have a laxative effect on human organs when combined with magnesium ($Mg^{2+}$) and sodium ($Na^+$).
- **Heavy Metals**: The presence of heavy metals like lead, arsenic, and mercury in groundwater is a significant health concern. These metals can enter groundwater from industrial activities, mining, and leaching from contaminated sites (Agarwal& Sharma, 2019). High levels of iron contamination in water can give it a brownish-red appearance and promote bacterial growth. Even at low concentrations, exposure to arsenic (As) can lead to carcinogenic effects, skin disorders, respiratory system damage, and hyperkeratosis. Excessive exposure to toxic zinc (Zn) can result in symptoms such as abdominal pain, electrolyte imbalance, vomiting, and dehydration.

**Table 1** Groundwater parameters with their WHO permissible limit

| Parameters | WHO standard limit (WHO 2017) |
|---|---|
| pH | 6.5-8.5 |

| | |
|---|---|
| Total Dissolved Solid (TDS) | 500-1000 mg/L |
| Electrical Conductivity (EC) | 250 µs/cm |
| Turbidity | 5 NTU |
| Hardness | 500 mg/L |
| Dissolved Oxygen (DO) | 4-6 mg/L |
| Calcium (Ca) | 200 mg/L |
| Magnesium (Mg) | 150 mg/L |
| Nitrate ($NO_3^-$) | 45 mg/L |
| Chloride ($Cl^-$) | 250 mg/L |
| Sulfate ($SO_4^{2-}$) | 250 mg/L |
| Iron (Fe) | 0.3 mg/L |
| Arsenic (As) | 10 ppb |
| Manganese (Mn) | 0.4 mg/L |
| Cupper (Cu) | 2 mg/L |
| Lead (Pb) | 0.01 mg/L |
| Cadmium (Cd) | 0.003 (mg/L) |

**Biological Parameters**

Groundwater quality is significantly influenced by biological parameters, which include the presence of microorganisms such as bacteria, viruses, protozoa, and fungi. These biological contaminants can have profound implications for public health and ecosystem integrity. Pathogenic microorganisms are of particular concern, as they can cause waterborne diseases when contaminated groundwater is used for drinking or irrigation (Guan et al., 2019).

The assessment of biological parameters in groundwater typically involves the enumeration and identification of indicator organisms, such as total coliforms and E. coli. These indicators serve as proxies for the presence of harmful pathogens, thereby providing an estimate of the microbial safety of the water (Pachepsky& Shelton, 2011). The presence of these microorganisms often indicates contamination from fecal sources, which can arise from inadequate sanitation practices, agricultural runoff, and industrial effluents (Guan et al., 2019).

**Sources of Groundwater Contamination**

Groundwater contamination arises from a variety of anthropogenic and natural sources, leading to the degradation of this vital resource. Understanding these sources is essential for effective management and remediation strategies.Fig. 1 shows different sources of groundwater contamination.

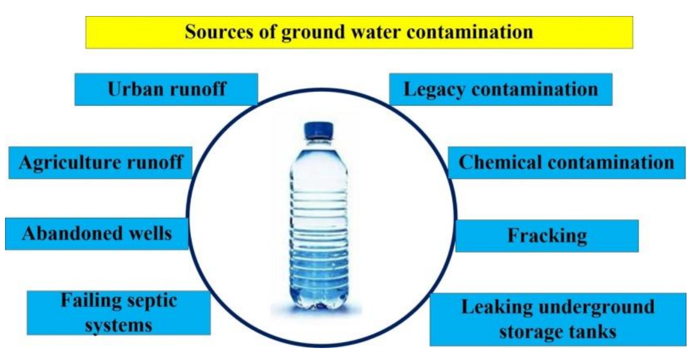


**Figure 1.**Various sources of groundwater contamination

- **Agricultural Activities**: The use of fertilizers, pesticides, and herbicides in agriculture is a major contributor to groundwater contamination. Nutrient runoff and leaching can introduce nitrates, phosphates, and toxic chemicals into the groundwater system, adversely affecting water quality (Nolan et al., 2002). Livestock operations can also contribute to contamination through the release of pathogens and excess nutrients from manure (McCray et al., 2005).

- **Urbanization and Land Use Changes**: Urban development often leads to increased impervious surfaces, which can enhance surface runoff and decrease groundwater recharge. Contaminants from storm water runoff, including oils, heavy metals, and chemicals from roadways, can seep into groundwater (Wang et al., 2018). Additionally, poorly managed septic systems and sewage leaks in urban areas can introduce pathogens and nutrients into the groundwater supply.
- **Industrial Discharges**: Industrial facilities often discharge various pollutants into the environment, which can infiltrate groundwater systems. Chemicals such as heavy metals, solvents, and hydrocarbons can leach from waste storage sites and contaminate nearby aquifers (Foster et al., 2017). Inadequate waste disposal and management practices further exacerbate the issue.
- **Natural Sources**: Groundwater can also be contaminated by natural processes. For instance, geological formations can contain naturally occurring heavy metals and arsenic, which can leach into groundwater under certain conditions (Ferguson &Gavis, 1972). Additionally, natural disasters, such as floods, can mobilize contaminants and introduce them into groundwater systems.

**Groundwater Quality Assessment Methods**

Groundwater quality assessment is critical for understanding the health of aquifers and ensuring safe drinking water. Common methods include:

**Traditional Sampling Methods**

Sampling sites should be strategically chosen to represent different aquifer conditions, including areas of potential contamination, recharge zones, and zones of high water use (APHA, 2017). Before collecting samples, wells must be purged to remove stagnant water. Groundwater samples should be collected using clean, pre-labeled containers. Containers must be suitable for the type of analysis to be performed (e.g., acid-washed bottles for trace metal analysis). Field parameters, including temperature, pH, turbidity, and electrical conductivity, are measured immediately upon sample collection. These measurements provide vital preliminary information about the groundwater's chemical characteristics.

**Chemical Analysis Methods**

Ion Chromatography method is widely used for quantifying anions (such as chloride, sulfate, and nitrate) and cations (such as Na, Ca, and Mg). This method provides high sensitivity and specificity, allowing for detailed chemical profiling of groundwater (Stumm& Morgan, 1996).Atomic Absorption Spectroscopy (AAS) is employed for the analysis of trace metals, such as Pb, Cd, As, and Hg. This technique measures the concentration of metals by detecting the absorption of specific wavelengths of light by metal ions in solution.

Gas Chromatography-Mass Spectrometry (GC-MS) method is particularly effective for detecting and quantifying VOCs and other organic compounds in groundwater. GC-MS combines gas chromatography for separation with mass spectrometry for identification, allowing for precise and sensitive detection of contaminants (Miller et al., 2002).

**Remote Sensing and Geographic Information System (GIS)**

Remote Sensing (RS) and Geographic Information System (GIS) technologies have revolutionized groundwater quality assessments by providing innovative tools for data collection, analysis, and visualization. Remote sensing involves the acquisition of information about the Earth's surface using satellite or aerial imagery.

GIS is a powerful tool for managing, analyzing, and visualizing spatial data related to groundwater quality. GIS allows for the integration of diverse datasets, including geological, hydrological, and water quality data. By overlaying these datasets, researchers can visualize spatial relationships and identify areas at risk of contamination (Miller et al., 2017).

GIS can be used to map potential contamination sources, such as landfills, industrial sites, and agricultural fields. By analyzing the proximity of these sources to groundwater recharge areas, stakeholders can prioritize areas for monitoring and intervention (Nisbet et al., 2019). GIS tools enable the assessment of groundwater vulnerability by integrating hydrogeological data and land use information. Vulnerability mapping helps identify areas that are more susceptible to contamination, aiding in the development of management strategies (Francesconi et al., 2020).

**Statistical Approaches**

Statistical approaches play a crucial role in groundwater quality assessments by enabling researchers to analyze complex datasets, identify trends, and draw meaningful conclusions regarding groundwater conditions. These methods assist in the interpretation of water quality data, helping to understand spatial and temporal variations in groundwater quality, assess contamination risks, and evaluate compliance with regulatory standards.

In descriptive statistics, mean, median, and mode help identify the average values of water quality parameters. Standard deviation, variance, and range provide insights into the variability and distribution of groundwater quality data. Multivariate statistical methods are essential for analyzing complex datasets with multiple variables. Correlation coefficient (r) determines the strong or weak relationship between each environmental parameter and its value may be positive or negative and may be ranged from − 1 to + 1. **Principal Component Analysis (PCA)** reduces the dimensionality of large datasets while retaining most of the variability and this method is useful for identifying underlying factors influencing groundwater quality (Jolliffe, 2002). Cluster analysis groups sampling sites based on similarities in water quality parameters. This technique helps identify zones of similar groundwater quality and can reveal spatial patterns of contamination (Hirsch et al., 1991).

**Case Studies on Groundwater Quality**

Several regional studies have highlighted the critical state of groundwater quality across the globe:

Arsenic contamination in groundwater, particularly in Bangladesh and parts of India, has reached alarming levels. Chronic exposure to arsenic through drinking water has resulted in widespread health issues, including skin lesions, cancer, and developmental disorders (Chakraborty 2021).

A study collected groundwater samples from various locations around Kanpur which contained high concentrations of chromium, lead, and other toxic substances. They reported chromium levels exceeding the permissible limits set by the Bureau of Indian Standards (BIS). They also revealed the primary source of pollution being contaminated effluents from tanneries, improper waste disposal, and inadequate wastewater treatment (IITR 2017).

Rapid industrialization in China has led to the contamination of groundwater with heavy metals such as cadmium, chromium, and mercury, particularly in the industrial regions. Monitoring and remediation efforts are ongoing, but significant challenges remain (Li 2022).

## II. CONCLUSION

Groundwater quality assessment is crucial for ensuring the sustainability of this vital resource. Traditional chemical testing methods, combined with advanced remote sensing, and GIS offer comprehensive solutions for monitoring and managing groundwater contamination. Addressing both established pollutants like heavy metals and nitrates, as well as emerging contaminants, will be essential for safeguarding groundwater resources for future generations.An integrated approach to groundwater management will be vital in securing this valuable resource for future generations.Continued research and collaboration among stakeholders will be essential to protect groundwater resources for future generations.

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