

Recent Trends in Groundwater Quality Assessment and Contamination Mapping: A Review

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1. Abstract

Groundwater is a critical source for domestic and agricultural activities, yet it faces threats from human caused pollution and geogenic factors. This review paper produces recent advancements in groundwater quality assessment methodologies and spatial mapping techniques. By analysing 34 modern research studies, the paper evaluates the efficacy of various Water Quality Indices (WQI, HPI), advanced geochemical modelling (Piper, Gibbs plots), and numerical simulation tools like MODFLOW and MT3DMS. The integration of Geographic Information Systems (GIS) for contamination mapping is highlighted as a transformative trend. The findings suggest that a combined application of hydro chemical analysis and solute transport modelling offers a more effective framework for sustainable groundwater management.

2. Introduction

Groundwater serves as the backbone of water security in arid and semi-arid regions. However, environmental changes and rapid urban expansion have led to the leaching of pollutants into aquifers. Monitoring this degradation requires more than just laboratory analysis; it demands precise "Contamination Mapping" and "Trend Prediction" to maintain groundwater quality. Recent years have seen a shift from simple physicochemical reporting to complex mathematical indexing. The objective of this review is to provide a comprehensive roadmap of these recent trends, serving as a foundational guide for researchers focusing on groundwater preservation and assessment of groundwater quality.

3. Literature Review

- **Global and National Trends:** Talabi [1] and Sustainability Journal [9] identified diverse pollution sources globally. Ranjan [5] and Reddy [30] introduced Entropy-based WQI and AI models for precision.
- **Regional Studies (Gujarat):** Mishra [18] provided a foundational assessment of Bhavnagar. Shah [24, 19] focused on fluoride in Kalol/Gandhinagar, while Mangukiya [17] and Chaudhari [13] mapped urban pollution in Surat.
- **Specialized Analysis:** Nathalia [4] and Chaudhari [22] focused on the Heavy Metal Pollution Index (HPI). Saba [10] and Madhavan [14] specialized in transport modeling for Chlorides and Sulfates.
- **Modeling & Management:** Kanmani [7] and Rajaeian [12] applied Visual MODFLOW for prediction. For mitigation, Singh [23] and Mehta [34] proposed Managed Aquifer Recharge (MAR).

4. Comprehensive Methodology Framework

- **Indexing:** Weighted Arithmetic WQI [17, 21] and HPI [4, 22] are used to standardize quality scores.
- **Geochemical Modeling:** Piper Trilinear Diagrams [26, 27] classify facies, while Gibbs Plots [26, 27, 29] identify the origin of ions (Rock-water interaction vs. Evaporation).
- **GIS Mapping:** Inverse Distance Weighting (IDW) [6, 26, 33] in ArcGIS/QGIS is the standard for spatial visualization.
- **Simulation:** MODFLOW and MT3DMS [7, 10, 14] simulate flow and solute transport to predict future plume movement.

5. Conclusion

1. **Methodological Evolution:** A clear transition is observed from basic chemical analysis to standardized mathematical indexing. The widespread use of **WQI and HPI** [4, 17, 21, 22] provides a more reliable metric for assessing water suitability.
2. **Hydrochemical Insights:** Integration of **Piper and Gibbs plots** [26, 27] reveals that rock-water interaction is the primary driver of groundwater chemistry inland, whereas coastal aquifers are severely impacted by evaporation and salinity [13, 32].
3. **Advancements in Mapping: GIS and Remote Sensing** [6, 33] using spatial interpolation like **IDW and Kriging** [26, 28] have become essential for visualizing contamination "hotspots" and planning targeted interventions.
4. **Predictive Capability:** The adoption of numerical modeling through **MODFLOW and MT3DMS** [7, 10, 14] enables long-term planning by predicting the dynamic movement of contaminant plumes over time [12, 34].
5. **Mitigation Strategies:** The review identifies **Managed Aquifer Recharge (MAR)** [23] and **River Bank Filtration (RBF)** [8] as the most sustainable engineering solutions for restoring groundwater quality through natural dilution and filtration.

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