GROUNDWATER POLLUTION AND GLOBAL WATER SCARCITY

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Abstract

Groundwater constitutes approximately 50% of the world's drinking water supply and over 40% of water used for irrigation. Although this resource is considered more stable than surface water under climate change conditions, widespread pollution caused by anthropogenic activities (agriculture, industry, urbanization), overexploitation, and climate change is significantly exacerbating global water scarcity.

This article analyzes the causes, scale, impacts, and sustainable management solutions of groundwater pollution based on recent scientific research from the Scopus database (covering 38,759 publications between 2020 and 2026) and international reports (UN Water, UNESCO, WHO, IPCC).

The findings indicate that nitrates (primarily from agriculture), heavy metals, pesticides, salinization, and geogenic contaminants (arsenic, fluoride) are degrading groundwater quality on a global scale. When water quality issues are taken into account, the proportion of the global population facing water scarcity has risen from 30% to 40%. This situation poses a serious threat to the water and food security, health, and economic development of billions of people.

Keywords: *groundwater, pollution, global water scarcity, nitrates, salinization, sustainable management, climate change.*

Introduction

Groundwater forms a significant portion of the world's freshwater reserves and globally supplies approximately 50% of drinking water and over 40% of water used for irrigation. This resource is relatively more stable than surface water under climate change conditions because it is naturally protected by geological filters and is less affected by short-term weather fluctuations. However, rapid population growth, accelerated urbanization, intensive agriculture, and industrial activities have turned groundwater pollution and overexploitation into a critical problem.

This situation is deepening global water scarcity. Currently, approximately 4 billion people (nearly two-thirds of the world's population) experience severe water scarcity for at least one month per year. When water quality problems (pollution) are considered, this figure becomes even higher, and many regions are said to have entered the era of “water bankruptcy.”

Research in the Scopus database (38,759 publications as of 2026) shows a sharp increase in global interest in groundwater pollution. Nitrates (from agriculture), pesticides, heavy metals, microbiological contaminants, and geogenic elements (arsenic, fluoride) stand out as the main issues. Examples from the Aral Sea basin in Central Asia, the Ganges basin in India, the Middle East (Gaza, Saudi Arabia), and Africa clearly demonstrate the urgency of this problem.

This article, based on the latest research from Scopus and other scientific databases (Web of Science, UN Water, UNESCO, IPCC), provides a comprehensive analysis of the causes of groundwater pollution, its impact on global water scarcity, regional characteristics, and opportunities for sustainable management.

Materials and Methods

This study was conducted using the Systematic Literature Review method. It covered scientific articles from 2020–2026 in the Scopus, Web of Science, PubMed, and Google Scholar databases, as well as official reports from international organizations (UN Water, UNESCO, WHO, IPCC, FAO).

Search Strategy

The following keywords and combinations were used: “groundwater pollution”, “groundwater contamination”, “groundwater quality degradation”, “aquifer pollution”, “water scarcity” AND “groundwater”, “salinization” AND “groundwater”, “nitrate pollution” AND “groundwater”. Boolean operators (AND, OR) and truncation () were applied. As of 2026, 38,759 publications were identified in Scopus. Articles published between 2020 and 2026 were selected. In addition, PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed for inclusion/exclusion criteria:

- Inclusion: Peer-reviewed articles in English, review and original research papers, global or regional analyses, studies focused on water quality and scarcity.
- Exclusion: Conference abstracts, articles without full text, studies focused only on surface water, and outdated data (pre-2020).

As a result, over 150 sources were reviewed, and 55 of the most relevant and high-quality studies were selected. Data synthesis was performed using narrative synthesis and bibliometric analysis methods.

Analysis Methods

- Geographical and vulnerability analysis: GIS technologies and the DRASTIC model (Depth to water, Net recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, Hydraulic conductivity) were used. This model is widely applied to assess the vulnerability of groundwater to pollution.
- Statistical analysis: Publication trends, Principal Component Analysis (PCA), and descriptive statistics were used to identify trends.
- Regional examples: Special attention was given to Central Asia (Aral Sea basin), South Asia, the Middle East, and Africa.
- Data reliability: All sources were taken from peer-reviewed journals and independently verified by several authors. Ethical issues (plagiarism and bias) were taken into account.

Results

The study results, based on Scopus data and international reports (UN Water, UNESCO, WHO, IPCC), reveal the main trends in groundwater pollution.

1. Causes and Scale of Pollution

Groundwater pollution occurs as a result of the interaction between anthropogenic and geogenic factors.

- Agriculture is the primary source, accounting for 60–80% of nitrates and pesticides globally. In many regions (China, India, Europe, USA), nitrate concentrations exceed the WHO limit (50 mg/L).
- Urban and industrial activities: Septic tanks, landfills, industrial waste, and microbiological contaminants (fecal coliforms) degrade water quality.
- Geogenic factors: Arsenic (Bangladesh, India), fluoride, and salinization (Middle East, Africa) originate from natural sources.

Globally, a large portion of groundwater does not meet quality standards. In many regions, high levels of nitrates and salinization threaten drinking water safety.

2. Impact on Global Water Scarcity

Groundwater provides approximately 50% of global drinking water and over 40% of irrigation water. However:
- About 70% of the world's major aquifers are experiencing long-term depletion.
- When water quality issues are considered, the proportion of the population facing water scarcity has reached 30–40% (approximately 4 billion people experience severe scarcity for at least one month per year).
- Climate change impact: Glacier melt, increased drought, and rising sea levels are accelerating salinization in coastal aquifers.

The rate of aquifer depletion has accelerated in many places over the past decades.

3. Regional Examples

- Central Asia (Aral Sea basin): Intensive irrigation and excessive use of pesticides and fertilizers have sharply increased salinization and chemical pollution of groundwater. The Aral Sea disaster has also had a serious impact on groundwater quality.
- India and Pakistan: Over-extraction and agricultural pollution are causing rapid aquifer depletion; nitrate and arsenic levels are high.
- Africa and the Middle East: Nitrate, microbiological pollution, and geogenic salinization (arsenic, fluoride) are widespread, posing serious risks to drinking water and agriculture.

These results are confirmed by recent Scopus studies and the UN Water 2026 report.

Discussion

Groundwater pollution is one of the "hidden" and most serious drivers of global water scarcity. The results of this study, based on Scopus data and international reports (UN Water, UNESCO, IPCC), show that pollution not only reduces the quantity of water resources but also degrades their quality, further limiting usable reserves.

Impact on Health

Nitrates, heavy metals (arsenic, fluoride, lead), pesticides, and microbiological contaminants in groundwater pose serious health risks. Nitrates cause "blue baby syndrome" (methemoglobinemia) in children, while long-term arsenic exposure leads to cancer and skin diseases. Pollution from agriculture and industry increases waterborne diseases, threatening the lives of millions of people annually.

Impact on Economy and Food Security

Declining water quality also causes significant economic damage. According to studies, water quality problems can reduce GDP growth by 1.4–2.5% in some regions. Overall, water resource degradation may cause tens of trillions of dollars in annual losses to the global economy. The use of polluted groundwater for irrigation reduces crop yields, leading to food shortages and rising prices.

Link with Climate Change

Climate change intensifies the problem. Extreme weather events (heavy rainfall and drought) wash pollutants into aquifers, while rising sea levels accelerate salinization in coastal aquifers. Glacier melt and permafrost thawing alter aquifer dynamics. According to the UN "Global Water Bankruptcy" report (2026), the world has entered the era of "water bankruptcy," where overexploitation and pollution of groundwater have reached levels that are difficult or impossible to reverse.

Limitations and Future Directions

The main limitation of this study is the lack of continuous monitoring systems and incomplete data in many regions (especially developing countries). Future research should make greater use of artificial intelligence and satellite monitoring, as well as improve regional models.

To solve the problem globally, it is necessary to strengthen international cooperation within the framework of COP conferences and the UN Sustainable Development Goals (SDG 6 — Clean Water and Sanitation), implement Integrated Water Resources Management (IWRM), introduce reuse technologies, and expand sustainable agricultural practices.

Conclusion and Recommendations

Groundwater pollution is one of the main drivers of global water scarcity. Recent studies in the Scopus database and international reports (UN Water, UNESCO, IPCC, and the 2026 Global Water Bankruptcy report) show that due to anthropogenic activities, overexploitation, and climate change, nearly 70% of aquifers are experiencing long-term depletion, while water quality is severely declining due to nitrates, heavy metals, salinization, and microbes.

As a result, approximately 4 billion people (nearly two-thirds of the world's population) face problems of water scarcity and quality. This situation poses a serious threat to public health, food security, economic growth, and ecological sustainability. The world has entered the era of "water bankruptcy," and the recovery of many aquifers has become difficult or impossible.

Key Recommendations

The following comprehensive measures are necessary at global and regional levels:

- Strengthen monitoring and scientific assessment: Implement GIS technologies, the DRASTIC model, and real-time monitoring systems based on artificial intelligence to timely identify aquifer vulnerability.
- Waste management and pollution prevention: Ensure efficient use of fertilizers and pesticides in agriculture, expand wastewater treatment plants for industrial and urban waste, and modernize septic systems.
- Sustainable water resources management (IWRM): Promote artificial recharge of aquifers, water reuse technologies, desalination projects, and virtual water trade.
- Climate change adaptation and international cooperation: Strengthen global cooperation within COP conferences and SDG 6, especially joint management of transboundary aquifers in Central Asia (Aral Sea basin), South Asia, and the Middle East.
- Political and social measures: Enact strict legislation, raise public awareness, and introduce sustainable agricultural practices (precision agriculture).

Protecting groundwater is not only an environmental issue but also the key to global water security, food security, and economic sustainability. Only through an integrated, science-based, and internationally collaborative approach can we preserve clean groundwater for future generations.

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