The Role of Socio-Hydrogeology in Closing The Gaps Between Quantitative and Qualitative Approaches in Hydrogeological Mapping

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Abstract. Introduction: In numerous hydrogeological studies, the value of local knowledge concerning groundwater sources and contamination is often underestimated in favor of strictly scientific data. This oversight can result in an incomplete understanding of groundwater systems. Local communities possess valuable insights into seasonal variations, contamination origins, and historical water usage patterns that are not fully captured by scientific measurements alone. This perspective article shows the gaps between both quantitative and qualitative approach and how we can mixed those approaches to improve hydrogeological mapping in Indonesia. **Methods**: Scientific models are typically utilized to predict groundwater contamination risks based on parameters like land use and hydrological data. However, these models often fail to consider the community's perception of these risks. For example, a community might perceive the threat of contamination from nearby industrial activities to be higher than what scientific models indicate. This discrepancy can lead to distrust in scientific findings and resistance to proposed management strategies. **Discussions**: Hydrogeological mapping generally focuses on the physical availability of groundwater resources, often overlooking the specific needs and priorities of local communities. For instance, a hydrogeological study might determine that an area has adequate groundwater for agricultural purposes, yet may fail to recognize that the local community prioritizes drinking water access over agricultural use. This misalignment can lead to conflicts and inefficient resource allocation.

1. Background

In many studies about underground water (groundwater), scientists often focus solely on scientific data and overlook local knowledge from the community. This can lead to an incomplete understanding of the groundwater system. For example, local people have valuable insights about seasonal changes, sources of contamination, and historical water usage that scientific measurements might miss.

Scientific models usually predict groundwater contamination risks based on factors like land use and hydrological data. However, these models may not consider how the community views these risks. For instance, a community might believe that nearby industrial activities pose a higher contamination threat than what scientific models suggest. This difference in perception can lead to distrust in scientific findings and resistance to proposed water management strategies.

Hydrogeological mapping often focuses on the physical availability of groundwater without considering the specific needs and priorities of local communities. For example, a scientific study might conclude that there is enough groundwater for farming, but might fail to realize that the local community values drinking water access more than agricultural use. This mismatch can cause conflicts and inefficient use of resources.

This paper aims to showcase a new interdisciplinary subject and highlight its importance in understanding hydrogeological systems within society. Socio-hydrogeology, an emerging field, combines social sciences with groundwater studies by focusing on the interconnection between people and groundwater resources. This approach bridges the gap between science and society by incorporating local knowledge, risk perceptions, and community needs into groundwater management. By considering ethical, social, and cultural factors, socio-hydrogeology promotes more sustainable and effective groundwater management strategies. This integrated approach is particularly crucial for addressing complex groundwater issues in the face of global challenges such as population growth, climate change, and water scarcity.

2. Materials and Methods

2.1 Data Sources

To review the availability and development of the interdisciplinary field of "socio-hydrogeology," we utilized two comprehensive scientific databases: Dimensions and Lens. These databases were selected for their extensive coverage of academic publications, patents, and research data across various disciplines.

2.2 Search Strategy

We conducted systematic searches in both databases using a combination of keywords related to socio-hydrogeology. The primary keywords included:

- Socio-hydrogeology
- Social dimensions
- Hydrogeology
- Qualitative research
- Interdisciplinary research
- Water management
- Community engagement
- Sustainable development
- Environmental sociology
- Groundwater governance

2.3 Inclusion and Exclusion Criteria

To ensure the relevance and quality of the articles included in our review, we applied the following criteria:

Inclusion Criteria

1. Relevance to Socio-Hydrogeology: Articles must explicitly address the intersection of social and hydrogeological aspects.
2. Publication Date: Articles published within the last 20 years (2004-2024) to capture recent developments.
3. Language: Articles must be published in English.

4. Type of Research: Both qualitative and quantitative studies, as well as reviews and theoretical papers, were included.
5. Peer-Reviewed: Only peer-reviewed journal articles were considered.

Exclusion Criteria

1. Irrelevant Topics: Articles focusing solely on either social sciences or hydrogeology without integrating both fields.
2. Non-Peer-Reviewed Sources: Conference papers, editorials, and non-peer-reviewed articles were excluded.
3. Duplicate Records: Duplicate articles across the two databases were removed.

Data Extraction and Analysis

For each included article, we extracted the following information:

- Title and Abstract: To confirm relevance.
- Authors and Affiliations: To identify key contributors and institutions in the field.
- Publication Year: To analyze trends over time.
- Keywords: To understand the common themes and topics.
- Methodology: To categorize the types of research methods used.
- Findings and Conclusions: To summarize the main contributions to the field.

The extracted data were then analyzed to identify patterns, trends, and gaps in the current literature on socio-hydrogeology. This analysis aimed to provide a comprehensive overview of the field's development and highlight areas for future research. Below we presented a table summarizing the search strategy, inclusion and exclusion criteria, and data extraction and analysis for your review of socio-hydrogeology.

Table 1 Summary of methods

Section	Details
Search Strategy	Databases: Dimensions, Lens. Keywords: Socio-hydrogeology, Social dimensions, Hydrogeology, Qualitative research, Interdisciplinary research, Water management, Community engagement, Sustainable development, Environmental sociology, Groundwater governance
Inclusion Criteria	1. Relevance to Socio-Hydrogeology; 2. Publication Date: 2004-20243. Language: English; 4. Type of Research: Qualitative, Quantitative, Reviews, Theoretical papers; 5. Peer-Reviewed Articles
Exclusion Criteria	1. Irrelevant Topics; 2. Non-Peer-Reviewed Sources; 3. Duplicate Records
Data Extraction	Information Extracted:- Title and Abstract; - Authors and Affiliations; - Publication Year; - Keywords; - Methods; - Findings and Conclusions

Data Analysis	Analysis Focus:- Patterns and Trends; - Key Contributors and Institutions; - Common Themes and Topics; - Types of Research Methods; - Main Contributions and Gaps in Literature

3. Analyses and Discussions

3.1 Hydrogeological Challenges in SE Asia

Hydrogeological challenges in Indonesia and Southeast Asia encompass both social and technical domains. Urban areas face increasing water scarcity due to rapid development, population growth, and climate change[1–5]. Groundwater overexploitation in cities like Jakarta has led to quality degradation and supply shortages[6]. To address these issues, a hybrid socio-technical approach has been proposed, integrating public education, community participation, and indigenous technologies[7].

Ecohydrological approaches and integrated water resource management strategies have been implemented to ensure sustainable development and protect societal livelihoods. These efforts involve partnerships between universities, local governments, and NGOs[8].

However, challenges persist in providing adequate safe water for human consumption, which is considered both a basic need and a human right. Continued research and integrated management strategies are necessary to address these complex hydrogeological problems.

3.2 Qualitative Approach in the Field of Hydrogeology

Hydrogeological research increasingly recognizes the need for qualitative approaches alongside quantitative methods. While hydrogeology strives to be quantitative, its models and predictions are often hypothetical and difficult to prove definitively[9]. The field faces challenges in addressing complex societal issues related to water resources, requiring advancements in fundamental understanding, interdisciplinary approaches, and educational reforms[10].

Qualitative social science research can contribute significantly by providing insights into the lived experiences of individuals within hydrological systems and highlighting nuances in social-hydrological interactions[11]. This approach can enhance understanding of groundwater governance, adaptation to water scarcity, and sustainability planning.

Integrating qualitative methods with traditional hydrogeological research can lead to more comprehensive and effective water management strategies, addressing the complex interplay between water and society[10,11].

3.3 Social Dimensions in Hydrogeology

The social dimensions in hydrogeology encompass a multifaceted interplay between human communities and groundwater resources, emphasizing the necessity for integrating social factors into hydrogeological research and management practices. This integration is crucial for addressing local water-related issues effectively, as traditional hydrogeological approaches often overlook the socio-economic and cultural contexts that shape water governance and usage[12,13]. The concept of socio-hydrogeology has emerged as a vital framework for understanding these interactions, advocating for the inclusion of local knowledge and community engagement in groundwater management[12,14].

The socio-economic dimensions of hydrogeology are critical in evaluating the sustainability of groundwater resources. Studies have shown that socio-economic factors, such as

local governance structures, economic incentives, and cultural practices, significantly influence groundwater use and management[15–17]. For example, the integration of economic valuation methods in groundwater protection strategies has highlighted the importance of considering local community perspectives and willingness to pay for sustainable practices[18]. This approach aligns with the broader goals of integrated water resources management (IWRM), which seeks to balance environmental, social, and economic objectives in water governance[15,19].

3.4 Socio-Hydrogeology as a New Discipline?

The socio-hydrogeological perspective underscores the need for interdisciplinary collaboration between natural and social scientists to address the complex challenges associated with groundwater management[20,21]. By fostering partnerships that bridge scientific knowledge with local insights, researchers and practitioners can develop more effective and equitable management strategies that reflect the diverse needs and values of communities[16,17].

This collaborative approach is essential for navigating the socio-political dynamics that often hinder sustainable groundwater governance, particularly in regions facing rapid environmental changes and socio-economic pressures[22,23].

3.5 Part of Human-Environment System

The concept of human-environment systems (HES) encompasses the complex interactions between humans and their surroundings. HES research principles include modeling complementary human and environmental systems, considering hierarchies, and analyzing feedback loops[17].

Adaptation within HES aims to reduce negative environmental impacts and improve sustainability, though a unified theoretical framework is lacking[12]. The human-activity-geographical-environment relationship can be viewed through classical and non-classical models, with different temporal scales of analysis[21]. Human ecology, a related concept, is described as a multidimensional system comprising individuals and their reciprocal interactions with global environments, impacting health outcomes[24].

These perspectives highlight the interconnected nature of human-environment systems and emphasize the need for integrated approaches to understand and address the challenges arising from these complex relationships (Figure 1).

3.6 Consequences of Overlooking Socio-Economic Aspects in Groundwater Research

Failing to conduct socio-economic observations when studying groundwater systems can have significant impacts, particularly in both urban and rural areas:

- Water Scarcity and Inequity: Without understanding socio-economic contexts, urban groundwater management strategies may fail to meet the needs of marginalized communities, leading to unequal water distribution and scarcity in low-income neighborhoods.
- Increased Contamination Risks: Ignoring local knowledge about historical industrial activities can result in underestimating contamination risks. This oversight can lead to public health crises as communities continue using contaminated water sources.
- Public Distrust: When local communities are not involved in groundwater management decisions, there can be a lack of trust in scientific recommendations. This distrust can hinder the implementation of effective water management policies.
- Misaligned Water Priorities: Rural communities often have different water usage priorities, such as agricultural vs. drinking water needs. Without socio-economic

observations, management strategies might focus on one at the expense of the other, leading to conflicts and resource misallocation.

- Loss of Traditional Knowledge: Many rural communities have generations of knowledge about local water sources, seasonal changes, and contamination signs. Ignoring this knowledge can result in less effective groundwater management.
- Economic Hardships: Poorly designed groundwater management policies that do not consider the economic realities of rural populations can exacerbate poverty, as communities may rely heavily on groundwater for their livelihoods, especially in agriculture.

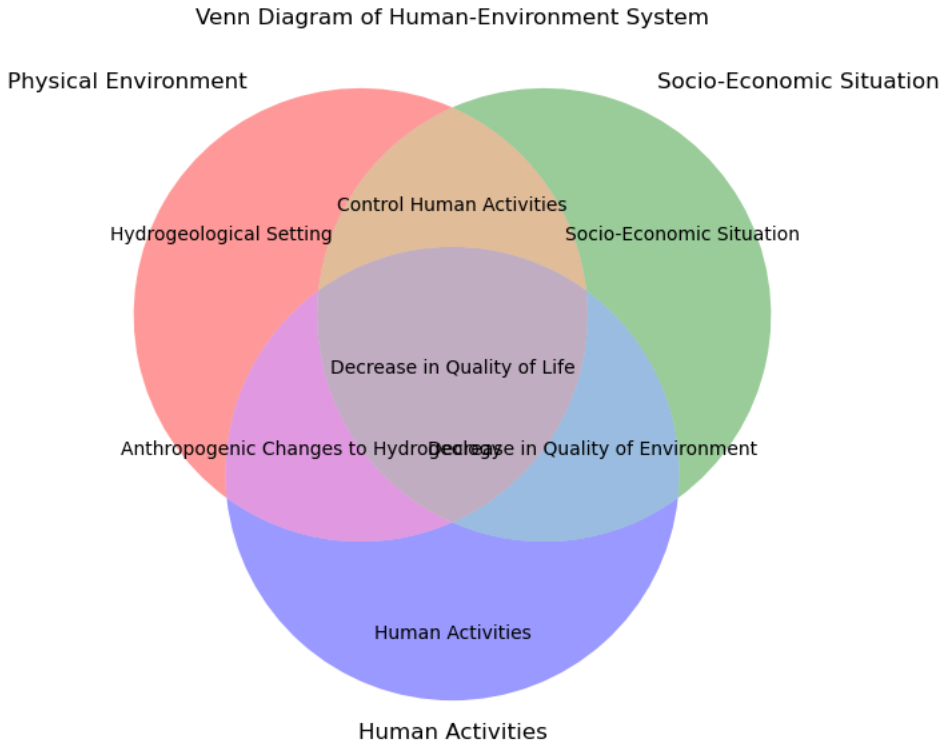

Figure 1 Venn Diagram of Hydrogeology and Socio-Economic System in Human-Environment System.

4. Conclusions

The social dimensions of hydrogeology are integral to understanding and managing groundwater resources sustainably. By adopting a socio-hydrogeological framework that prioritizes community engagement, interdisciplinary collaboration, and socio-economic considerations, stakeholders can enhance the resilience and sustainability of groundwater systems in the face of growing challenges.

Overlooking socio-economic aspects in groundwater research can lead to significant consequences that undermine effective water management and community well-being. These impacts include water scarcity and inequity in urban areas, increased contamination risks, public distrust in scientific recommendations, misaligned water priorities between different stakeholders, loss of valuable traditional knowledge, and economic hardships for rural populations.

To address these challenges, it is crucial to adopt a socio-hydrogeological approach that integrates community engagement, local knowledge, and socio-economic considerations into groundwater management strategies. This holistic approach can lead to more equitable, sustainable, and effective water resource management practices that benefit both urban and rural communities while safeguarding precious groundwater resources for future generations.

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