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GIS Based Analysis Of Underground Water Using Ontology And Semantic Web

"Pankaj Vishwas Phadtare", Research Scholar, "Dr. Shailesh Kumar", PhD Guide.

ABSTRACT

Water is one of the most vital natural resources that sustains life and meets our fundamental needs. Every drop of water is valuable, making its preservation and judicious utilization essential. The accessibility of this resource is determined largely by surface and groundwater bodies. However, climate change—manifested through rising temperatures, shifting precipitation patterns, variability in rainfall, and sea level rise—has altered river flow and groundwater recharge. Consequently, groundwater resources are highly sensitive to these climatic changes. Rapid urbanization, industrial expansion, and intensive agricultural practices have significantly transformed land use patterns. This has led to excessive extraction of groundwater, causing not only depletion and over-mining of aquifers but also deterioration in water quality. Added to this, global warming, deforestation, and irregular rainfall have further aggravated water scarcity and reduced recharge potential. To address these challenges, geospatial technologies such as the Global Positioning System (GPS) and Geographic Information Systems (GIS) have emerged as powerful tools for analysing land resources and water availability. This study employs GIS-based analysis, integrated with ontology and semantic web techniques, to survey underground water resources and explore strategies to enhance their quality. Sustainable development in any region requires effective water resource management, and computer-aided analysis—particularly through the combined application of Remote Sensing (RS) and GIS—offers a highly valuable approach. The research focuses on applying RS and GIS to agricultural water management in India, aiming to improve efficiency and effectiveness in managing water resources. By assessing the current role of geospatial technology in Indian agriculture, the study introduces a proposed model where geospatial ontology and Query-based GIS (QGIS) are employed. The system is designed to identify areas, especially in hilly terrains, where rainwater can be effectively harvested and absorbed into the soil, thereby enhancing groundwater recharge and improving drinking water quality.

The QGIS framework allows for queries related to locating underground drinking water sources and mapping regions near the Western Ghats of Maharashtra, India. Additionally, semantic processes are incorporated for advanced query handling, enabling the system to identify areas suitable for rainwater stoppage and infiltration. The ontology-driven design ensures that query services are semantically linked, improving the search process and the overall utility of the model. This proposed model highlights the potential of integrating RS, GIS, ontology, and semantic web technologies to strengthen agricultural water management and support sustainability in India.

Keywords: GIS, ontology, semantic web.

INTRODUCTION

Water is a critical natural resource that supports life, agriculture, industry, and ecosystems. However, in many regions of the world, the lack of safe underground drinking water resources has become a pressing challenge, ultimately leading to water scarcity. Sustainable water management is therefore essential to meet current demands without compromising future availability. Recognizing this, the United Nations included *"Clean Water and Sanitation"* as one of its Sustainable Development Goals (SDG 6), with specific objectives focused on promoting global water recycling, safe reuse practices, and equitable access to clean water. Several countries have already demonstrated effective water reuse strategies. For example, the United States, Israel, and African nations such as Namibia (particularly in Windhoek) have implemented successful water reclamation and irrigation practices. Similarly, the European Union has supported multiple projects addressing drought and scarcity, and in 2012 formally acknowledged water reuse as a promising solution to mitigate these challenges.

Ontologies play a significant role in modelling domain-specific knowledge by defining structured classes, relationships, and instances. In the context of geospatial systems, ontologies provide semantic meaning to spatial data and help standardize the vocabulary used across the World Wide Web (WWW). For effective analysis of land and water resources, geospatial technologies such as the Global Positioning System (GPS) and Geographic Information Systems (GIS) are widely employed. GIS enables mapping, analysis, and representation of spatial datasets, while metadata and geospatial ontologies enhance the quality, interoperability, and usability of these datasets for practical applications. The integration of semantic web technologies with geospatial data further enhances analysis and knowledge discovery. This integration incorporates diverse data formats such as databases, maps, images, tables, and texts, transforming them into meaningful, query able information. By linking queries semantically to ontology-based services, geospatial semantic systems provide more accurate and efficient results. Service-oriented architectures further extend this capability by enabling scalable, distributed access to geospatial knowledge. The semantic web—often described as a "web of linked data"—facilitates publishing, sharing, and connecting structured information such as identifiers, dates, classifications, and scientific properties. Key technologies enabling this vision include the Resource Description Framework (RDF), Web Ontology Language (OWL), SPARQL (SPARQL Protocol and RDF Query Language), and Simple Knowledge Organization System (SKOS). RDF provides a metadata framework for describing resources, OWL supports expressive knowledge representation, SPARQL allows querying and manipulation of RDF datasets, while SKOS enables representation of concept schemes such as taxonomies and vocabularies. Together, these technologies enrich geospatial ontologies and improve semantic interoperability.

In this study, we present a GIS- and ontology-based framework for analysing underground water availability and improving its quality through the application of semantic web technologies. By combining GIS, GPS, Remote Sensing (RS), and ontology-driven approaches, the system enhances groundwater assessment and supports sustainable water management practices. The proposed model demonstrates how semantic integration of spatial datasets can optimize queries, identify potential rainwater harvesting zones, and improve decision-making in regions facing water scarcity.

OBJECTIVES

The primary aim of this research is to develop a GIS- and ontology-based framework for analysing the availability and quality of underground water resources using semantic web technologies. The specific objectives are outlined as follows:

1. **Assessment of Groundwater Availability and Quality**
   To identify and evaluate the availability, quantity, and quality of underground water by extracting and analysing data in structured formats (rows and columns) derived from satellite imagery and groundwater particle analysis.
2. **Examination of Groundwater Constituents**
   To investigate the key chemical and physical properties of underground water, including total dissolved solids, trace materials, metals, chlorides, sulphides, and other critical ingredients influencing water quality.
3. **Identification of Suitable Aquifers**
   To locate and characterize aquifers that serve as sustainable sources of groundwater, ensuring long-term water security, while also identifying regions with the highest potential for groundwater availability.
4. **Analysis of Groundwater Parameters and Influencing Factors**
   To analyse essential groundwater parameters such as pH, acidity, dissolved metals, sulphides, and chlorides, along with external environmental and geological factors such as climate, air density, humidity, geomorphology, rainfall, geology, slope, lineament, land use/land cover (LULC), drainage density, and topographic wetness index.
5. **Evaluation Using Remote Sensing and GIS**
   To utilize Remote Sensing (RS) and ArcGIS technologies for evaluating groundwater potential zones, integrating spatial datasets with semantic web and ontology-driven approaches to support efficient groundwater management.

NEED OF THE STUDY.

The demand for groundwater has risen significantly across the globe due to rapid population growth, urbanization, industrialization, and intensive agricultural practices. In India, where surface water resources are limited, a large portion of domestic, industrial, and agricultural needs, including drinking water, is met by groundwater. Since access to clean and safe drinking water is a fundamental human right and a prerequisite for human health and well-being, the availability and quality of groundwater play a decisive role in ensuring sustainable social and economic development. The hydro chemical composition of groundwater directly determines its suitability for household, irrigation, and industrial applications. Therefore, understanding groundwater chemistry is essential for evaluating water quality, especially in rural regions where communities rely heavily on groundwater as their primary source. Factors such as geology, hydrology, climatic conditions, and geochemical characteristics influence groundwater quality, and the severity of groundwater-related environmental issues varies across locations. Groundwater continues to remain the primary and most reliable source of irrigation, household supply, and potable water in India.

However, increasing water scarcity has made groundwater conservation and management an urgent necessity. This study addresses these challenges by utilizing ontology- and GIS-based systems to enhance the process of identifying, mapping, and managing underground water resources. Geospatial technologies, particularly the Global Positioning System (GPS) and Geographic Information Systems (GIS), provide advanced tools for analysing and measuring land and water resources. When integrated with Remote Sensing (RS) data, GIS offers a powerful computer-aided approach for sustainable resource management. The key objective of this research is to identify groundwater resources through satellite imagery and multi-year geospatial datasets, enabling the detection of rainwater flow from mountainous regions and potential sites for water retention. By locating these stoppage zones, it becomes possible to enhance groundwater recharge as water infiltrates into the soil rather than flowing directly into rivers and eventually to the sea. This process contributes to improving both the quality and quantity of groundwater.

Furthermore, this research focuses on assessing water quality by analysing its chemical, physical, and biological characteristics against established standards of use. Parameters such as ecosystem health, pollution levels, suitability for human consumption, and overall water safety serve as key indicators of water quality. Since water quality directly impacts water supply reliability and determines the available options for sustainable usage, GIS-based analysis becomes indispensable for monitoring and improving groundwater resources. Thus, the need for this study arises from the growing dependence on groundwater, the pressing issues of water scarcity and quality deterioration, and the requirement for advanced geospatial and semantic web technologies to manage underground water resources more effectively.

Research Methodology and Design

Research Philosophy

Research philosophy deals with the origin, nature, and development of knowledge, as well as the methods through which data about a phenomenon is collected, analyzed, and utilized. In this study, the primary data sources include satellite imagery of underground water resources and water sample datasets collected from the study area. Real-time monitoring of key groundwater quality parameters such as pH, turbidity, dissolved oxygen, total dissolved solids (TDS), and temperature is carried out. These datasets form the basis of further analysis using a combination of Remote Sensing (RS), ArcGIS, and QGIS techniques. Thus, the research philosophy is grounded in geospatial and geo-informative system analysis to identify and locate underground freshwater resources for sustainable future use. Quantitative methods, such as laboratory experiments, are employed to establish relationships between selected water quality variables. While such experiments allow generalizations, they are often limited by oversimplification and lack of real-world context. Field experiments and surveys complement this by incorporating real-world settings, thereby improving realism. Case study approaches are also adopted to explore phenomena in their natural setting, enabling the researcher to ask "how" and "why" questions regarding the complexity of processes influencing groundwater quality and availability. Simulation and forecasting techniques, such as regression and time-series analysis, are also integrated to model possible future scenarios of groundwater availability. Furthermore, applied research principles are employed, combining practical solutions for water resource management with theoretical insights, ensuring that the research holds both academic and societal relevance.

Data Collection and Analysis

Groundwater samples are collected from multiple locations within the study area, particularly during the post-monsoon season to account for natural recharge conditions. Sampling procedures ensure integrity by: Collecting water in one-litre acid-washed polyethylene bottles sealed tightly to prevent contamination. Measuring field parameters such as pH, electrical conductivity (EC), and TDS on-site. Transporting samples under controlled conditions to avoid alteration. Using laboratory techniques such as flame photometry, volumetric analysis, and spectrophotometry to determine concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, and hardness as $CaCO_3$. Performing ionic balance error (IBE) analysis within the acceptable tolerance of ±5%. Spatial datasets are supported by Survey of India topographic sheets (57F/10 and 57F/11). Coordinates of sampling sites are recorded using Garmin GPS devices and integrated into ArcGIS for spatial analysis. Inverse Distance Weighted (IDW) interpolation is applied to generate thematic maps showing the spatial distribution of groundwater quality parameters such as pH, TDS, calcium, magnesium, sodium, chloride, sulphates, phosphates, nitrates, and fluoride. These maps are further integrated to create a comprehensive groundwater quality index (WQI) map. Comparison with World Health Organization (WHO) standards allows classification of groundwater samples into categories ranging from potable to unfit for drinking.

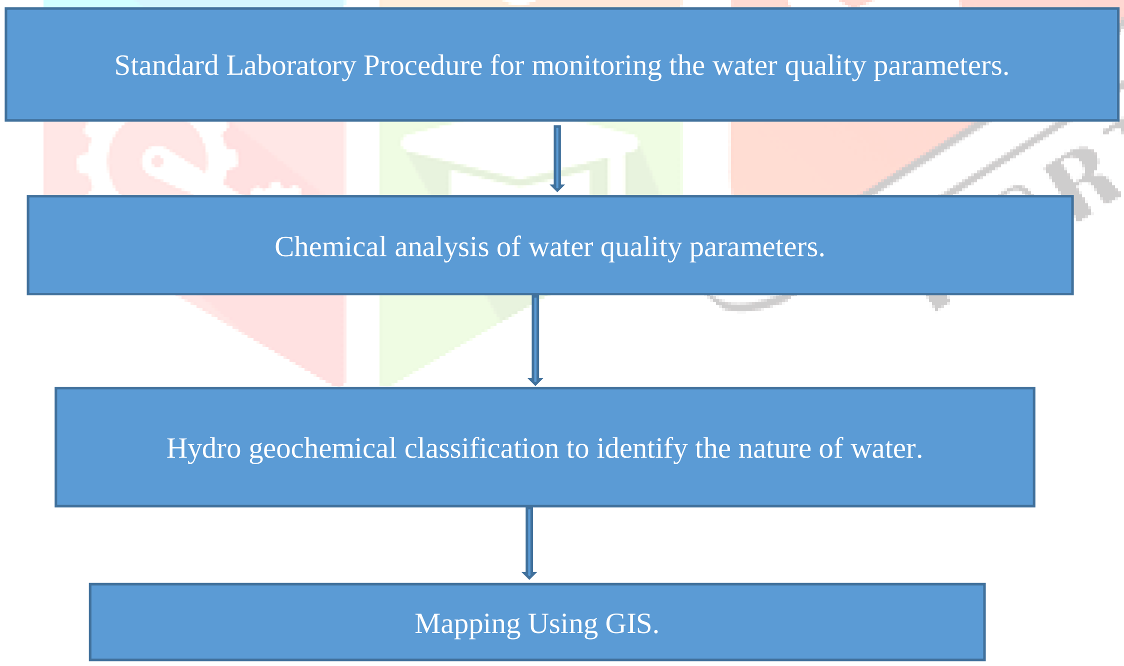
Research Design

The proposed system integrates ontology and semantic web principles with geospatial technologies. Ontology ensures semantic structuring of groundwater-related queries, while GIS and RS provide the analytical framework for mapping and identifying groundwater resources. The methodology emphasizes locating rainwater flow paths from mountainous terrains and identifying suitable stoppage zones for natural recharge, which directly contributes to improving both the quality and quantity of underground water.

Methodology Workflow

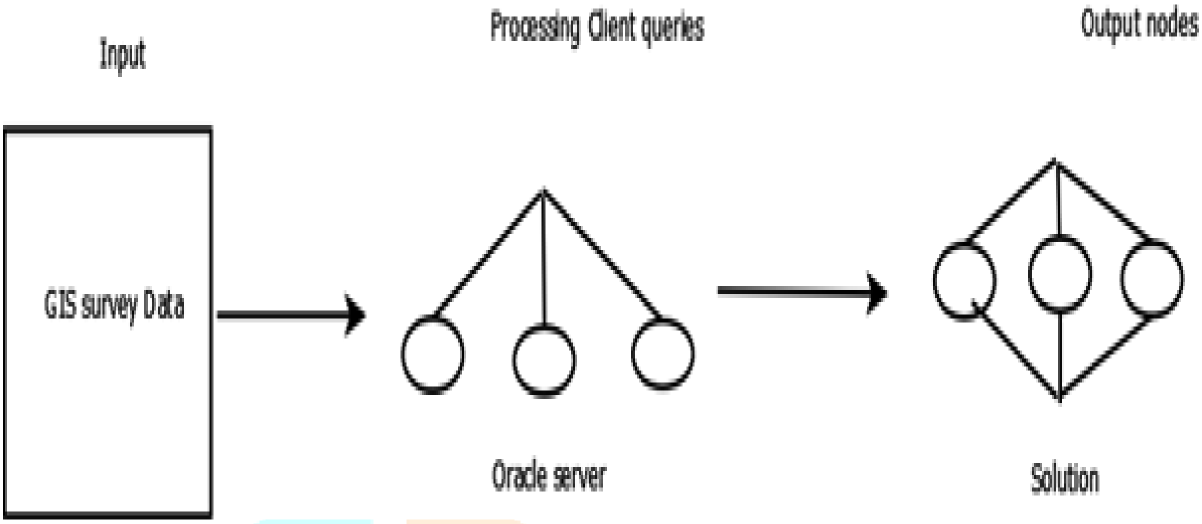
- Data collection through field sampling and satellite imagery.
- Real-time monitoring of groundwater parameters.
- Laboratory analysis of hydro geochemical properties.
- Spatial data integration and mapping using ArcGIS and QGIS.
- Ontology-based query processing to semantically relate groundwater data.
- Generation of groundwater quality and potential maps.
- Comparative evaluation with WHO water quality standards.

Methodology Chart



Graphical User Interface Structure

(Query based Solution Model)



Graphical User Interface (GUI) Structure

The research employs a query-based solution model with the following algorithm:

1. Survey the entire study area.
2. Use ArcGIS to locate regions experiencing groundwater scarcity.
3. Apply mapping and location techniques to delineate high-potential recharge zones.
4. Analyse historical and current data (rainfall, seasonal variations, land use) in tabular formats for detailed comparison.
5. Integrate census and hydrological survey data for temporal analysis (monthly, quarterly, seasonal).
6. Apply simulation techniques and GIS-based interpolation (IDW) to generate maps identifying groundwater potential zones.

Conclusion and Future Scope

This research demonstrates the potential of integrating GIS, Remote Sensing (RS), and ontology-driven semantic web technologies for analyzing and managing underground water resources. The study highlights how groundwater quality mapping can serve as a valuable tool for future planning of groundwater availability, sustainable utilization, and quantity development programs. The spatial distribution maps generated through GIS provide a clear representation of groundwater quality and quantity across the study area, enabling effective monitoring, assessment, and prediction of future conditions. The findings of this study have practical applications in land use planning, rainwater harvesting, and the formulation of groundwater development strategies. By identifying rainwater flow paths and potential stoppage zones, the methodology supports natural groundwater recharge and improves both the quality and quantity of available resources. Furthermore, the study recommends adopting comprehensive groundwater management measures, including the implementation of storage technologies, soil moisture conservation, awareness programs, and the establishment of groundwater quality monitoring frameworks. From a broader perspective, the outcomes of this research can be directly applied to groundwater recharge (GWR) potential mapping, sustainable water resource management, and policy formulation. The combined use of GIS and RS proves particularly effective in identifying high-potential recharge areas, especially during heavy rainfall periods, where water can be retained and absorbed into the soil rather than lost through rapid runoff.

Future Scope

The present work opens multiple avenues for further exploration:

- Expansion of the study to larger geographical areas with diverse hydrogeological settings to test the scalability of the proposed framework.
- Integration of machine learning and artificial intelligence techniques with GIS and RS for improved prediction and classification of groundwater potential zones.
- Development of dynamic groundwater recharge models using real-time monitoring data.
- Implementation of ontology-based decision support systems to aid policymakers, planners, and local authorities in sustainable groundwater management.
- Long-term monitoring and evaluation of the effectiveness of rainwater harvesting and recharge strategies identified through this study.

In conclusion, this research provides a systematic framework that not only enriches groundwater management practices but also ensures sustainable utilization of resources to meet the future needs of communities and ecosystems.

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