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Case Study IJWRE

Sustainable Groundwater Exploitation: A Case Study of Ado-Ekiti Community in Southwestern Nigeria

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Abstract

Sustainable groundwater management practices in Ado-Ekiti are vital to ensure the long-term availability of clean and reliable water resources for the community. Ado-Ekiti, like many other regions, relies heavily on groundwater for its water supply. This paper aims to examine the current groundwater exploitation practices in Ado-Ekiti and propose sustainable strategies for managing this vital resource. The study explores geological and geographical factors affecting groundwater availability, water quality, community involvement, governmental regulations, innovative technologies, economic considerations, and the challenges and solutions to ensure sustainable groundwater exploitation. Integrated investigations involving remote sensing and GIS were carried out with the primary aim of optimizing sustainable groundwater development in Ado-Ekiti, a region located in the southwestern part of Nigeria characterized by a challenging hard rock terrain for groundwater exploration. These studies have contributed to a better understanding of the region's hydrogeological conditions, water quality, and the dynamics of groundwater availability. However, the increasing population due to the three common academic institutions namely, ABUAD, EKSU and Federal Polytechnic and expanding urban area pose challenges to the sustainability of groundwater resources in the region. Efficient water resource utilization can be realized by strengthening existing water management institutions and enforcing regulations more rigorously. There is need to encourage the use of alternative water sources, such as rainwater harvesting, surface water reservoirs, and treated wastewater for non-potable purposes, reducing the reliance on groundwater.

Keywords: Groundwater, geological and geographical factors, water management, hydrogeological conditions, rainwater harvesting

INTRODUCTION

Water is the essence of life, and in a nation as diverse and populous as Nigeria, ensuring the sustainable exploitation of this vital resource is paramount. Nigeria, often referred to as the "Giant of Africa," is home to a vast and varied landscape, characterized by arid northern regions, lush forests, and a coastal belt. Water, particularly groundwater, plays a pivotal role in the country's economic development, environmental stability, and the well-being of its people. Groundwater, stored beneath the Earth's surface in porous rock formations called aquifers, is crucial for Nigeria. It is the primary source of drinking water for a significant portion of the population, particularly in rural areas where surface water sources may be limited. Groundwater is essential for agricultural irrigation, industrial activities, and the health of ecosystems. With Nigeria's population expanding and urbanizing, the need for reliable and clean groundwater is increasingly important [1–6].

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The hydrogeological characteristics, including subsoil structure, rock formations, lithology, and water location, play a pivotal role in determining the capacity of groundwater reservoirs. To evaluate

groundwater potential effectively, a precise and suitable methodology is necessary for a meaningful and unbiased analysis. A thorough examination has been conducted to explore the various approaches for estimating groundwater potential and identify the most appropriate technique for practical applications. Groundwater constitutes an integral component of the hydrological cycle (as depicted in Figure 1), which illustrates the perpetual movement of water among the ocean, atmosphere, and the Earth's surface.

Ado-Ekiti, a city in Ekiti State, Nigeria, has long depended on groundwater as its primary source of drinking water. The rising population and urban development in the area are exerting pressure on this valuable resource. Ensuring the sustainable exploitation of groundwater is crucial to maintaining a consistent water supply while protecting the environment. This paper presents a comprehensive analysis of sustainable groundwater exploitation practices for Ado-Ekiti [7–12].

LITERATURE REVIEW

Geological and geographical factors are fundamental in determining the feasibility and sustainability of groundwater exploitation in Ado-Ekiti, Nigeria. Understanding these factors is crucial for managing groundwater resources effectively and ensuring a long-term, reliable water supply. There are geological and geographical aspects that influence sustainable groundwater exploitation in the Ado-Ekiti region:

Geological Factors; Subsoil Structure

Figure 1 shows the geological map of Ado-Ekiti. The subsoil structure of Ado-Ekiti plays a significant role in groundwater exploitation. The presence of permeable geological formations, such as sand and gravel aquifers, allows water to infiltrate and be stored underground. Grasping the distribution and properties of these formations is crucial for effective water resource management.

Rock Formations

The type and distribution of rock formations impact the availability of groundwater. In Ado-Ekiti, geological formations like Precambrian and Basement Complex rocks have varying degrees of permeability. These geological formations can function as aquifers or aquitards, affecting the flow and storage of groundwater.

Lithology

The lithological composition of the subsurface materials affects the flow and storage of groundwater. Sedimentary rocks, for instance, can be porous and contain significant water-bearing zones. Conversely, igneous or metamorphic rocks are generally impermeable. In-depth lithological studies assist in locating potential groundwater sources. Geological faults and fractures can serve as conduits for groundwater flow [13, 14].

They can serve as conduits or barriers, impacting the distribution of groundwater. Understanding the location and orientation of faults and fractures is essential for sustainable exploitation.

Geographical Factors; Topography

Ado-Ekiti's topography influences the flow and recharge of groundwater. Areas with higher elevations may act as recharge zones, allowing rainwater to infiltrate and replenish aquifers. Lower-lying areas might serve as discharge zones where groundwater emerges as springs or feeds into streams.

Climate

Climate, specifically rainfall patterns, affects the availability of groundwater. Adequate precipitation ensures groundwater recharge. Variations in rainfall intensity and seasonality should be considered when assessing the sustainability of groundwater exploitation.

Surface Water Bodies

The presence of rivers, streams, and lakes in the geographical landscape can impact groundwater levels and quality. Interactions between surface water and groundwater play a crucial role in managing water resources effectively.

Vegetation and Land Use

The type of vegetation cover and land use practices in the area can influence groundwater recharge rates and water quality. Natural vegetation can enhance infiltration, while urban development may reduce recharge opportunities and introduce contaminants.

Distance to Coastal Areas

For coastal regions like Ado-Ekiti, seawater intrusion is a potential threat to groundwater quality. Geographical proximity to the coast should be considered when assessing sustainable groundwater exploitation.

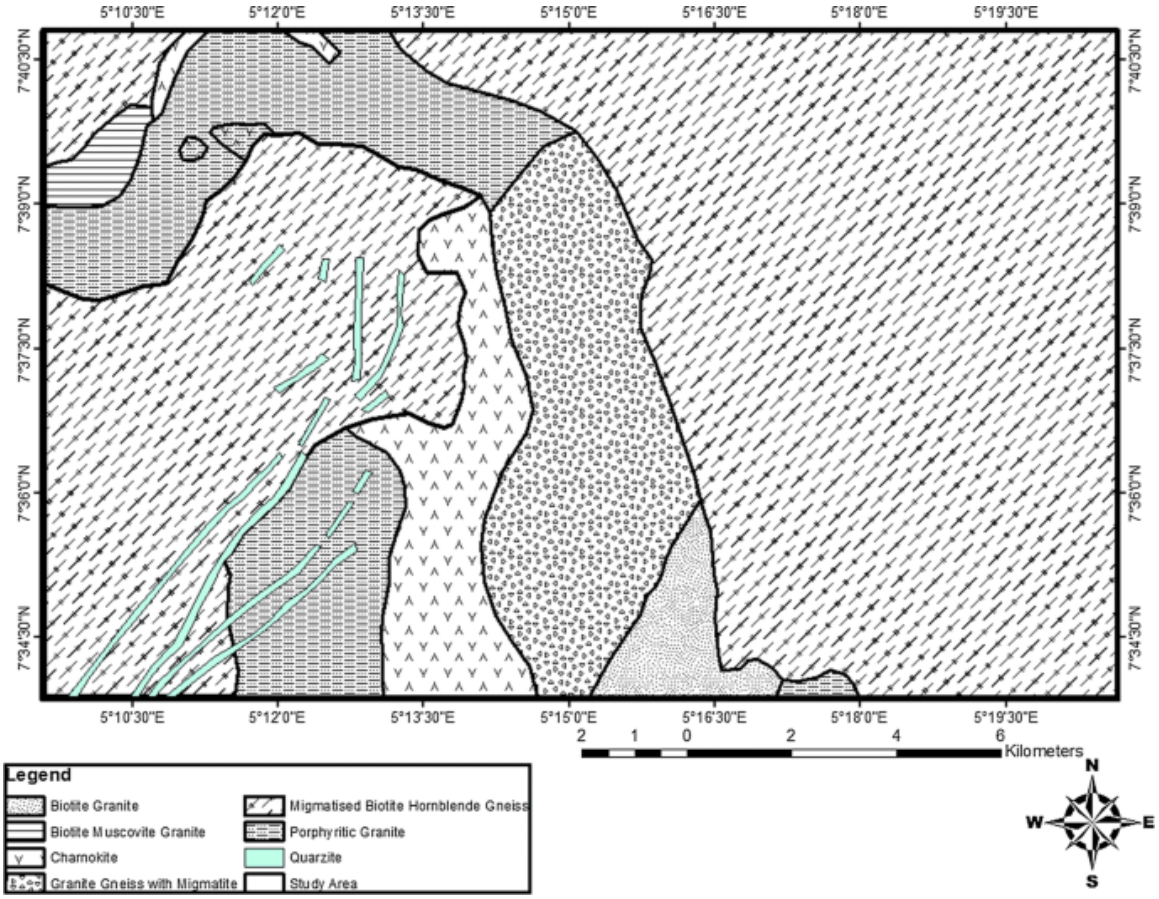

Figure 1. Geological map of Ado-Ekiti.

In Ado-Ekiti, the interplay of these geological and geographical factors determines the potential for sustainable groundwater exploitation. Conducting detailed geological surveys, hydrogeological studies, and ongoing monitoring of water levels and quality is vital for making well-informed decisions about groundwater management. Understanding the local geological and geographical characteristics is crucial for preserving this vital resource and ensuring its sustainability in the face of population growth and environmental challenges. Ekiti State University, located in Southwestern Nigeria, is situated on a geological foundation comprised of Precambrian Basement Rocks. The university relies heavily on various sources of water, including rainfall, surface water, and groundwater, to meet its water supply needs. In tropical and equatorial regions, natural weathering processes create superficial layers that exhibit different levels of porosity and permeability. These unconsolidated superficial materials can often serve as dependable aquifer units if they possess sufficient thickness and the right porosity and permeability characteristics. Concealed beneath these superficial materials, the basement rock may contain areas that are faulted, exhibiting incipient joints and fracture systems that have resulted from earlier tectonic events. Identifying and mapping these hydrogeologic structures can aid in pinpointing

potential groundwater prospect zones in a typical basement geological setting, as highlighted by Omosuyi et al., (2003) [14]. However, the crystalline basement rocks themselves generally do not possess inherent porosity and permeability. In such cases, secondary porosity features, including joints, lineaments, and weathered zones, become the primary sources for the occurrence, movement, and transmission of groundwater. Groundwater is usually located in unconfined conditions within shallow, moderately weathered zones and in semi-confined conditions within joints, fissures, and fractures that extend beyond these weathered areas. As the regional population rises and human activities expand, the demand for groundwater resources is increasing rapidly. Surface water, where it is available and accessible, often falls short of meeting the necessary water quality standards required for most domestic activities.

Previous studies and research on sustainable groundwater exploitation in Ado-Ekiti and its surrounding areas have provided valuable insights into the challenges and opportunities in managing this vital resource. These studies have contributed to a better understanding of the region's hydrogeological conditions, water quality, and the dynamics of groundwater availability. Here are some key findings and themes from previous research on this subject.

Hydrogeological Assessment

Several studies have focused on the hydrogeological characteristics of Ado-Ekiti. They have identified various aquifer types, their distribution, and their properties, helping to pinpoint potential areas for sustainable groundwater exploitation.

Groundwater Quality

Researchers have assessed the quality of groundwater in the region, examining parameters, such as pH, electrical conductivity, and the presence of contaminants. Understanding water quality is essential for ensuring the safety of groundwater for consumption and various uses.

Groundwater Recharge

Studies have investigated the mechanisms of groundwater recharge in Ado-Ekiti, considering factors, such as rainfall patterns, land use, and soil properties. This information is critical for maintaining groundwater levels.

Over-Extraction and Declining Water Tables

Research has highlighted the issue of over-extraction in certain areas, leading to declining water tables. This can have adverse effects on water availability and ecosystem sustainability.

Hydrogeological Mapping

Various studies have produced hydrogeological maps of the region, which serve as important references for groundwater management and sustainable exploitation.

Community Involvement

Some research has explored community participation and awareness in groundwater management. Engaging local communities is a vital aspect of ensuring sustainable water use.

Impact of Urbanization

As Ado-Ekiti experiences urban growth, researchers have examined how urbanization affects groundwater resources, including changes in land use and pollution risks.

Climate Change Impacts

A few studies have addressed the potential impacts of climate change on groundwater availability and recharge rates, considering factors, such as altered precipitation patterns and increased temperatures.

Innovative Techniques

Research has explored innovative technologies and techniques for enhancing sustainable groundwater exploitation, such as managed aquifer recharge, rainwater harvesting, and groundwater modeling.

Case Studies

Research often includes case studies from specific locations within Ado-Ekiti, providing insights into the unique challenges and solutions relevant to those areas. These previous studies and research efforts have laid the foundation for understanding the groundwater dynamics in Ado-Ekiti. They offer a wealth of knowledge that can inform policies, management practices, and sustainability initiatives in the region, contributing to the responsible and long-term exploitation of groundwater resources.

Sustainable groundwater management practices in Ado-Ekiti are vital to ensure the long-term availability of clean and reliable water resources for the community. Ado-Ekiti, like many other regions, faces challenges related to groundwater over-exploitation, water quality degradation, and environmental impacts. Implementing sustainable management practices is essential to address these challenges. Here are some key practices for sustainable groundwater management in Ado-Ekiti:

Groundwater Monitoring

Establish a robust groundwater monitoring system to track water levels, quality, and trends over time. Regular monitoring helps with early detection of problems and informed decision-making.

Rainwater Harvesting

Promote rainwater harvesting techniques for both residential and institutional use. Capturing rainwater for non-potable purposes like irrigation, flushing toilets, and industrial processes reduces the demand on groundwater. Promote the use of efficient irrigation techniques in agriculture to reduce water waste and lessen dependence on groundwater for irrigation.

Pollution Control

Implement measures to prevent contamination of groundwater sources. This includes proper disposal of hazardous materials, regulation of industrial practices, and monitoring of agricultural runoff.

Community Engagement

Engage local communities in groundwater resource management. Educate them on the importance of responsible water use and empower them to participate in conservation efforts.

Government Regulations

Collaborate with local and national government bodies to ensure clear and enforceable regulations and policies for groundwater management. Advocating for the enforcement of these regulations is essential.

Innovative Technologies

Explore and implement innovative technologies for groundwater management, such as real-time monitoring systems, advanced filtration techniques, and modeling tools for better decision-making.

Economic Considerations

Integrate economic aspects into groundwater management, assessing the cost-effectiveness of various practices and considering the economic benefits of sustainable management.

Educational Programs

Establish educational programs and workshops to enhance the understanding of groundwater issues among students, professionals, and the public. Knowledge-sharing is vital for responsible management.

Protection of Recharge Areas

Identify and protect groundwater recharge areas, which are crucial for maintaining groundwater levels. Preventing land-use changes that could harm recharge zones is essential.

Legislation and Enforcement

Advocate for strong groundwater protection legislation and enforce existing laws that relate to groundwater resources. Holding violators accountable is vital.

Research and Data Collection

Support ongoing research and data collection related to groundwater resources. Conducting regular hydrogeological surveys and studies is essential for effectively understanding and managing these resources.

Case Studies

Examine successful instances of sustainable groundwater management in similar regions to gain valuable insights and best practices.

Community-Based Organizations

Encourage the formation of community-based organizations focused on water resource management. These organizations can play a key role in monitoring, conservation, and awareness-raising. By implementing these sustainable groundwater management practices, Ado-Ekiti can secure its water supply for the future, protect the environment, and promote responsible water use. Sustainable groundwater management is crucial not only for Ado-Ekiti but for the broader global effort to ensure the availability of this essential resource.

RESEARCH METHODOLOGY

Integrated investigations involving remote sensing and GIS were carried out with the primary aim of optimizing sustainable groundwater development in Ado-Ekiti, a region located in the southwestern part of Nigeria characterized by a challenging hard rock terrain for groundwater exploration. In this study, Landsat satellite images were employed for mapping land use and land cover, as well as analyzing lineaments to identify potential groundwater sources. Furthermore, the Shuttle Radar Topographic Mission Digital Elevation Model was utilized to obtain data on drainage networks, slopes, and geomorphological characteristics. The data obtained from these sources were used to create thematic maps, which were subsequently analyzed for their hydrogeological significance. These thematic maps were reclassified and integrated using suitable software tools. To ensure the accuracy of the results, the generated groundwater potential maps were validated against existing data on groundwater yield. The analysis revealed that the study area encompassed approximately 110.9 square kilometers of light vegetation and bare soil, while rock outcrops covered a total area of 14.9 square kilometers. Various hydrogeomorphic units, such as hills, pediments, pediplains, alluvium, and valley fills, were identified in the region. The lineament analysis indicated predominant orientations in the NNW–SSE, ENE–WSW, and NNE–SSW directions, with subsidiary trends in NW–SE and W–E directions. The application of geospatial techniques has been acknowledged as instrumental in improving our understanding of the hydrogeological characteristics of this basement terrain. These findings will be crucial for the efficient planning and management of groundwater resources in the crystalline basement terrain. The Ado-Ekiti metropolis is situated above the hydrogeologically complex crystalline basement rocks. These rocks exhibit hydraulic properties characterized by significant variations over short distances, often hindering the development of high-yield groundwater wells. The region has experienced a notably high rate of borehole failures.

These boreholes were unable to sustain a continuous flow of water for more than 5 minutes. The prevalent borehole failures in the area to a lack of comprehensive knowledge about the hydrogeological characteristics of the challenging hard rock terrain. These studies and others have underscored the

urgency for improvements in the conventional methodology to enhance the outcomes of groundwater development. Geological factors significantly influence the occurrence and movement of groundwater. The crystalline basement rocks in this area possess only secondary porosity, primarily originating from joints, fissures/fractures, and intergranular porosity. Satellite-based remote sensing data have the capacity to unveil structural features, such as faults, fractures, and various landforms. The integrated approach, particularly noteworthy for its applicability in hard-to-reach areas, holds the potential to substantially contribute to the water resources of Ado-Ekiti and its surrounding regions. The primary objective of this study is to employ geospatial techniques to gain insights into the hydrogeological conditions typical of hard rock terrains. This knowledge aims to support the optimal and sustainable development of groundwater resources in Ado-Ekiti.

The lineament extraction process involved the utilization of Landsat Enhanced Thematic Mapper (ETM +) sensor data from path 190 and row 055, acquired in the year 2005. Automatic lineament extraction was carried out using PCI Geomatica 2013, while ArcGIS 10.2.2 was employed for this purpose. Subsequently, lineament statistics were generated using Rockware 15.

The Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) was used to extract drainage networks, slope, and geomorphological features. The ArcHydro module was employed to extract drainage networks, and comprehensive geomorphological and slope maps were prepared. Several topographic analyses were performed on the DEM, which included sink filling, flow direction determination, flow accumulation calculation, stream order assessment, and stream-to-feature identification. To address sinks and remove peaks within the data, the spatial analyst tool in ArcMap was.

The creation of a land use and land cover (LULC) map for the study area was based on Landsat 8 imagery from path 190 and row 055, obtained in 2015.

The Ecognition Developer software was utilized for image classification. Additional data inputs included a geological map at a 1:250,000 scale (3300/6/66/3289/OS) created by the British Government Ministry of Overseas Development, and a topographical sheet 1000/404/6.68 compiled.

The study's methodology involved several stages: data preparation (mainly digitization), data pre-processing (georeferencing and resampling), data processing (including edge detection and principal components analysis or PCA), and data analysis and integration (such as lineament extraction and statistics, geostatistical analysis, and Inverse Distance Weighting or IDW interpolation).

Thematic layers, including lithology, geomorphology, drainage density, slope, lineaments, and land use/land cover, were extracted and reclassified based on their hydrogeological significance. Different themes and their respective categories were assigned weightage factors based on their relevance to groundwater prospects. The reclassified layers were then combined within a GIS environment to create a composite groundwater potential map for the study area. The validity of the generated groundwater potential zones was confirmed through field checks and by comparing them with existing groundwater yield data.

RESULTS AND DISCUSSION

In Nigeria, the ownership and management of land and its associated mineral resources are governed by the Land Use Act of 1978, which places these assets in trust for the benefit of the people. This legal framework aims to ensure that the wealth generated from natural resources is shared for the benefit of all. However, when it comes to water resources, particularly groundwater, the legal landscape is less defined. The Act seems to fall silent on the governance and management of this critical resource.

Under the Land Use Act, individuals are granted the right to own land and construct buildings for a period of 99 years upon obtaining a Certificate of Occupancy. This right can be renewed upon

expiration. However, should valuably resources, such as crude oil or gold be discovered on the same land, the State reserves the right to claim ownership of these resources and, if necessary, revoke the Certificate of Occupancy to safeguard the public interest in these valuable assets.

Groundwater, however, remains an area of uncertainty. This ambiguity arises perhaps because the government acknowledges its limitations in providing an adequate supply of potable water for the population. As a result, the riparian system, where individuals exploit groundwater at their discretion, has become a common practice. This is done without the need for permits, regulatory oversight, or penalties for overuse or misuse.

To address this situation, it is recommended that groundwater resources within each state be brought under the protective umbrella of the 1978 Land Use Act. Groundwater should be granted the same protected status as precious resources like gold and crude oil. As such, special permits should be required for well ownership. However, recognizing the prevailing high poverty rate in the country and the pressing need to achieve the Millennium Development Goal (MDG) related to clean drinking water, it is proposed that licensing for water prospecting should not incur additional charges. Instead, the licensing process should impose additional responsibilities on prospective well owners to ensure the sustainable and responsible use of this common resource.

These responsibilities could encompass the following key points:

1. *Professional qualifications:* Only individuals with recognized qualifications and certifications in well drilling should be allowed to drill wells. This will ensure that drilling is carried out competently and safely.
2. *Data sharing:* Private drilling operators should be obligated to submit data to a centralized database. This practice can help reduce the costs associated with exploratory drilling and provide decision-makers with crucial information for sub-regional reconnaissance.
3. *Remote sensing and monitoring:* Private drilling operations should be equipped with remote sensing meters to track the withdrawal rates. This helps not only in managing the resource effectively but also enables operators to plan for the eventual closure and remediation of the wells.

Furthermore, to assert control over its water resources, Nigeria must significantly upgrade its entire water resources data management system. This endeavor should involve close collaboration between the Federal Ministry of Water Resources (FMWR), its subsidiaries, and State Water Agencies (SWAs). Such cooperation can facilitate the collection, sharing, and analysis of critical information. Additionally, hydrogeological mapping of the entire country should be completed to thoroughly understand and inventory all water-bearing formations.

In the interest of efficiency, FMWR and SWAs should serve as comprehensive information hubs, providing detailed insights into national water resources and prospecting licenses. While FMWR focuses on hydrogeological mapping, SWAs can conduct sub-regional reconnaissance using satellite imagery, aeromagnetic surveys, and ground observations to obtain in-depth information on groundwater conditions in their respective areas.

To maximize the impact of available resources, budgetary allocations, funding, and their implementation should emphasize transparency and accountability. The issue of fiscal accountability has been raised by aid agencies, underscoring the need for efficient resource utilization. Aid organizations, despite recognizing Nigeria's strategic position in Africa and the world, may be hesitant to commit substantial financial resources due to concerns regarding accountability.

Alongside efficient use of current water resources, there is an increasing global focus on the 'soft path' approach to water resource management. This approach focuses on optimizing the use of existing resources rather than simply building more infrastructure for water supply. In this context, the fact that

83% of water provided by SWAs cannot be accounted for underscores the need to enhance the operational efficiency of these agencies. Proper management of surface water can relieve pressure on groundwater resources, thus preserving them for future generations.

Efficient water resource utilization can be realized by strengthening existing water management institutions and enforcing regulations more rigorously. Polluters should be held accountable for their actions, and the public should be made aware that groundwater is a common resource that should be protected for the benefit of all.

Nigeria stands at a critical juncture in its water resource management. By integrating and upgrading data systems, enhancing transparency, and promoting sustainable groundwater use, the country can secure its water resources for the future while ensuring equitable access to this vital resource.

CONCLUSION

Ado-Ekiti's reliance on groundwater as its primary water source necessitates a shift toward sustainable groundwater exploitation. Implementing rainwater harvesting, managed aquifer recharge, improved well construction, and advanced monitoring, in conjunction with a focus on water quality, community involvement, regulatory compliance, innovative technologies, and economic considerations, will ensure the long-term availability of clean and safe groundwater in Ado-Ekiti. Addressing challenges and learning from successful case studies will be essential in this endeavor.

Recommendations

1. *Comprehensive hydrogeological studies:* Conduct detailed hydrogeological studies to understand the aquifers, groundwater flow patterns, and recharge sources in the Ado-Ekiti area. These studies will help identify sustainable yield and suitable well locations.
2. *Regular monitoring and data collection:* Establish a groundwater monitoring network to collect data on water levels, quality, and aquifer behavior. Regular data collection is essential for informed decision-making.
3. *Well spacing and location:* Implement guidelines for well placement, ensuring that wells are spaced appropriately to avoid interference and the creation of cones of depression. Avoid drilling wells in low-lying areas to prevent contamination.
4. *Water quality protection:* Implement strict regulations and monitoring to protect groundwater quality. Prevent the discharge of pollutants, chemicals, and waste into areas near wells or recharge zones.
5. *Community awareness and education:* Educate the community about the importance of sustainable groundwater management and the need for conservation. Encourage responsible water use practices.
6. *Water conservation measures:* Implement water conservation programs that promote efficient use of groundwater, especially in agriculture and domestic settings.
7. *Legislation and regulation:* Develop and enforce local groundwater management regulations and standards to control drilling, well construction, and abstraction. Include penalties for violations.
8. *Licensing and permitting:* Introduce a permitting system for well construction and groundwater abstraction, ensuring that only licensed drillers can operate in the area.
9. *Diversify water sources:* Encourage the use of alternative water sources, such as rainwater harvesting, surface water reservoirs, and treated wastewater for non-potable purposes, reducing the reliance on groundwater.
10. *Emergency response plan:* Develop a contingency plan to address groundwater emergencies, such as well failures, contamination incidents, or droughts.
11. *Collaboration and stakeholder engagement:* Collaborate with local communities, government agencies, NGOs, and academic institutions to promote sustainable groundwater management and share expertise.
12. *Research and innovation:* Support research initiatives focused on groundwater management, aquifer recharge, and innovative technologies for water treatment and conservation.

13. *Regular maintenance and rehabilitation:* Ensure that existing wells are properly maintained and rehabilitated as needed to prevent losses in well efficiency and quality.

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