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GIS-Based Aquifer Management through MGNREGA: An Empirical Study in Rajnandgaon District, Chhattisgarh

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Abstract: This study explores the integration of Geographic Information Systems (GIS) and the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) in addressing groundwater management challenges in Rajnandgaon district, Chhattisgarh. By identifying recharge zones and constructing 2,087 mini percolation tanks, the initiative achieved significant improvements in groundwater levels, agricultural productivity, and rural employment. GIS enhanced site selection precision, ensuring resource efficiency. Challenges such as non-functional assets and resource misallocation highlight the need for robust frameworks. Policy recommendations include scaling GIS-based interventions, fostering community participation, and adopting IoT-driven monitoring systems.

Keywords: GIS-Based Aquifer Management, Groundwater Recharge, MGNREGA Implementation, Water Conservation Strategies, Sustainable Rural Development.

Introduction

Groundwater is a critical resource for agriculture, drinking water, and industrial uses, particularly in rural India, where over 60% of the population relies on groundwater for irrigation. However, unsustainable extraction, erratic monsoon patterns, and climate-induced vulnerabilities have caused widespread groundwater depletion.

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Rajnandgaon district in Chhattisgarh epitomizes these challenges, with its semi-arid conditions, reliance on agriculture, and recurrent water scarcity. The declining groundwater levels in the district threaten agricultural productivity, food security, and rural livelihoods, underscoring the need for innovative and sustainable water management solutions.

Geographic Information Systems (GIS) have emerged as powerful tools for addressing resource management challenges by enabling precise mapping, spatial analysis, and informed decision-making. GIS applications in groundwater management facilitate the identification of high recharge potential zones, optimize resource allocation, and support data-driven planning. When combined with government initiatives such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), GIS offers a scalable framework for linking water conservation with rural employment generation.

MGNREGA, launched in 2005, aims to provide livelihood security through guaranteed wage employment and the creation of durable assets. The program has been instrumental in promoting water conservation through activities such as constructing check dams, desilting tanks, and building percolation structures. By integrating GIS with MGNREGA, Rajnandgaon district implemented a comprehensive approach to aquifer management, addressing both water scarcity and unemployment.

This paper evaluates the initiative's impact on groundwater recharge, agricultural productivity, and socio-economic resilience. The study also highlights operational challenges such as resource misallocation and maintenance gaps. Through a synthesis of GIS mapping, field data, and stakeholder inputs, this research provides insights into scalable and sustainable models for aquifer management in rural India.

Needs

Effective groundwater management requires a robust understanding of the region's hydrological, social, and economic needs. Rajnandgaon district faces acute water scarcity, with declining groundwater tables threatening agriculture and domestic water supplies. An analysis of local conditions revealed key challenges:

1. **Water Scarcity**: Groundwater accounts for 80% of irrigation and domestic needs. Seasonal droughts exacerbate resource depletion.
2. **Climate Vulnerability**: Erratic rainfall and increasing temperatures reduce natural recharge rates, intensifying the water crisis.

3. **Livelihood Challenges**: The region's dependence on agriculture leaves rural communities vulnerable to water scarcity. Unemployment during non-agricultural seasons further compounds socio-economic issues.

GIS-based interventions address these needs by integrating hydrological data to identify recharge zones, while MGNREGA provides the financial and institutional framework to implement large-scale conservation projects. This integration ensures that resources are allocated effectively, maximizing the socio-economic and ecological benefits of interventions.

Review of Literature

Groundwater conservation and socio-economic development are critical areas of research in rural development. The integration of Geographic Information Systems (GIS) with water resource management and government initiatives like the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) has proven effective in addressing water scarcity while promoting livelihoods. This section synthesizes insights from diverse research studies examining the roles of GIS, MGNREGA, and related strategies in sustainable water resource management.

GIS has transformed groundwater management by enabling precise mapping and targeted interventions. Gupta et al. (2017) demonstrated the use of GIS for delineating recharge zones, enhancing aquifer management efficiency. Mogaji et al. (2018) utilized GIS-based models to develop groundwater favorability maps in semi-arid regions, highlighting its scalability. Shirazi et al. (2012) applied the DRASTIC model using GIS for aquifer vulnerability assessments, offering actionable insights to mitigate contamination risks. Lee et al. (2020) combined machine learning and GIS to create predictive maps of groundwater availability, showcasing the technology's adaptability in water resource planning.

The role of MGNREGA in water conservation and rural development is well-documented. Ranaware et al. (2015) found that MGNREGA projects in Maharashtra improved aquifer recharge and agricultural productivity through the construction of percolation tanks and check dams. Bhaskar et al. (2016) emphasized MGNREGA's integration with watershed management, which amplified ecological and socio-economic benefits. Esteves et al. (2013) documented the program's success in creating climate-resilient assets, mitigating the impacts of erratic rainfall, and securing water supplies.

Climate change has intensified the need for adaptive resource management strategies. Shirazi et al. (2012) highlighted the utility of GIS-based models in identifying aquifers at risk of depletion under changing climatic conditions. Russo et al. (2015) explored managed aquifer recharge (MAR) techniques and emphasized the importance of GIS-based site selection for sustainable outcomes. Kaushik et al. (2015) underscored GIS's role in tackling groundwater depletion in climate-stressed regions, while Anantha et al. (2021) demonstrated MGNREGA's capacity to mitigate drought impacts and enhance community resilience.

Beyond water conservation, MGNREGA has contributed to socio-economic development. Gupta et al. (2023) noted the program's alignment with Sustainable Development Goals (SDGs), including poverty reduction and gender equity. Narayanan et al. (2014) emphasized MGNREGA's participatory approach, where local stakeholders drive resource management decisions. These studies underscore the convergence of GIS and MGNREGA as a transformative model for rural development, fostering inclusivity, efficiency, and sustainability.

However, challenges persist. Kouli et al. (2009) highlighted inadequate monitoring, resource misallocation, and limited community awareness. Verma and Shah (2018) advocated for policy convergence between MGNREGA and other watershed initiatives, emphasizing the need for capacity building in GIS applications and fostering community ownership to enhance sustainability.

Research Methods

The methodology employed in this study integrates Geographic Information System (GIS) technology, satellite imagery, and field-based data collection to achieve sustainable aquifer management and groundwater recharge under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) program in Rajnandgaon District, Chhattisgarh. By combining geospatial analysis with community-driven planning, this systematic approach ensures scientifically informed, resource-efficient, and socially impactful interventions.

Data Collection

The study utilized diverse datasets to identify groundwater recharge zones and plan effective interventions. Sentinel-2B imagery from the European Space Agency's Copernicus program provided high-resolution multispectral data for post-monsoon analysis. ALOS PALSAR Digital Elevation Model (DEM) data, with a spatial resolution of 12.5m, was acquired from the Alaska Satellite Facility to analyze topographical features. Cadastral maps and land ownership records were sourced from Chhattisgarh Bhuiyan to identify government land suitable for interventions. Field data was collected through site visits and consultations with gram panchayats, technical assistants, and district officials.

GIS-Based Analysis

GIS tools were employed to delineate groundwater potential zones by integrating topographical features, soil characteristics, and drainage patterns. Sentinel-2B imagery and ALOS PALSAR DEM data facilitated contour mapping to identify low-lying areas suitable for recharge structures. Drainage networks were delineated using DEM data, and flow accumulation models were applied to refine stream networks. These analyses pinpointed ideal locations for constructing mini percolation tanks.

Implementation and Monitoring

Site selection was guided by GIS findings and community input, ensuring alignment with local needs. Mini percolation tanks were constructed across 813-gram panchayats, adhering to standardized designs and technical guidelines. Geo-tagging was employed to track construction progress, ensuring transparency and accountability. Post-construction groundwater levels were monitored using borewell data from the Central Ground Water Board (CGWB), and community feedback was gathered to assess socio-economic benefits.

Addressing Challenges

Challenges such as data inconsistencies and limited technical expertise were mitigated through capacity-building initiatives and the use of open-access GIS datasets. The methodology emphasizes sustainability by promoting community ownership of assets and scalability through replicable GIS-based planning frameworks. This approach ensures that interventions are durable, scientifically informed, and aligned with the goals of groundwater conservation and rural development.

Results and Discussion

GIS Mapping and Site Selection

GIS mapping was central to the project's success, enabling precise identification of groundwater recharge zones. By analyzing data from Sentinel-2B and ALOS

PALSAR DEM, the initiative generated detailed maps of the region's hydrology, including slope analysis, soil permeability, and drainage patterns. **Figure 1** displays the Groundwater Potential Zone Map, categorizing the district into high, moderate, and low recharge potential zones. This zoning facilitated targeted interventions, ensuring that resources were directed to areas with maximum impact.

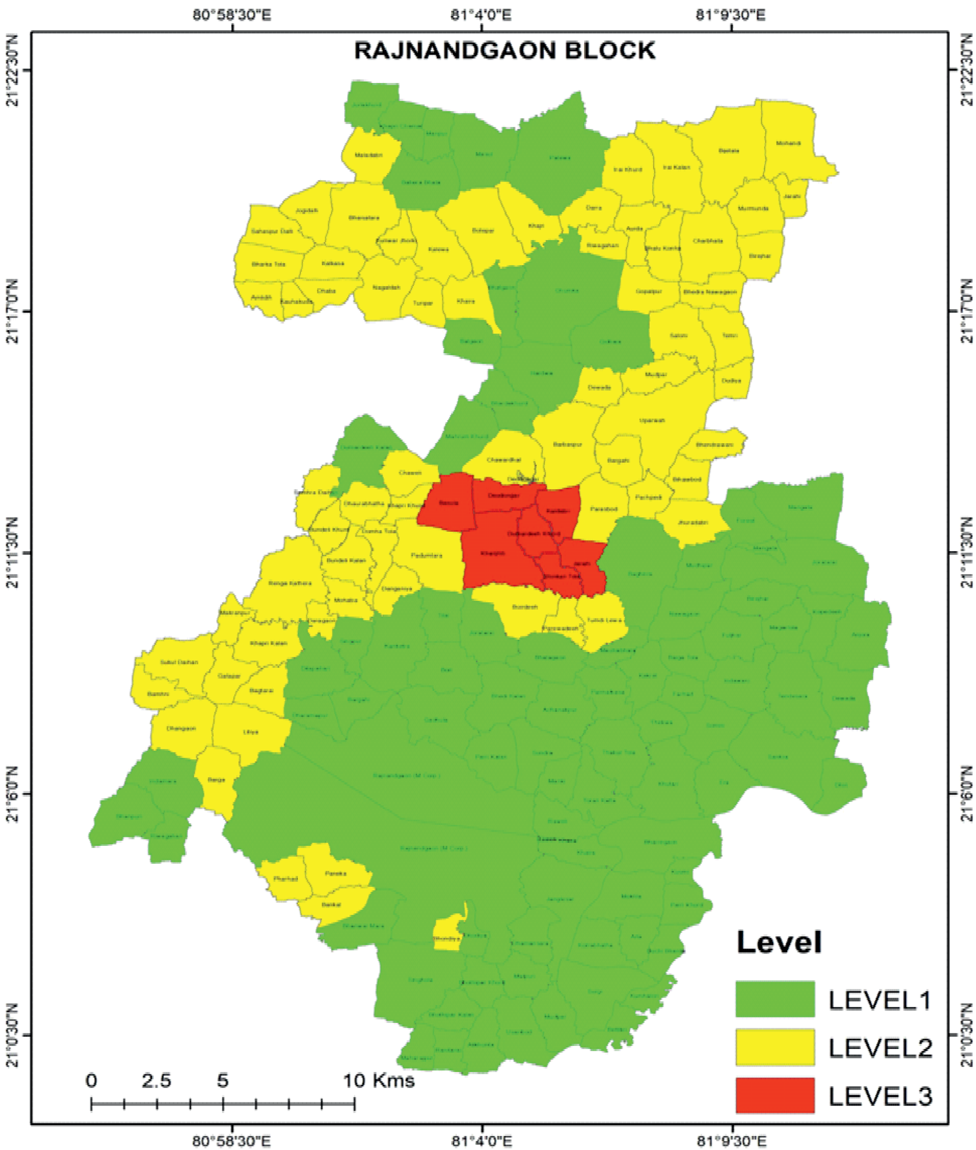

Figure 1: Ground water potential zone map of Rajnandgaon block (CGWB, 2019-21)

Drainage mapping, depicted in **Figure 2**, revealed natural water flow paths and accumulation points. These insights guided the construction of percolation tanks in low-lying areas, ensuring optimal water capture. Contour analysis, as shown in **Figure 3**, identified terrain slopes and elevations, which were critical for designing tanks that aligned with natural gradients.

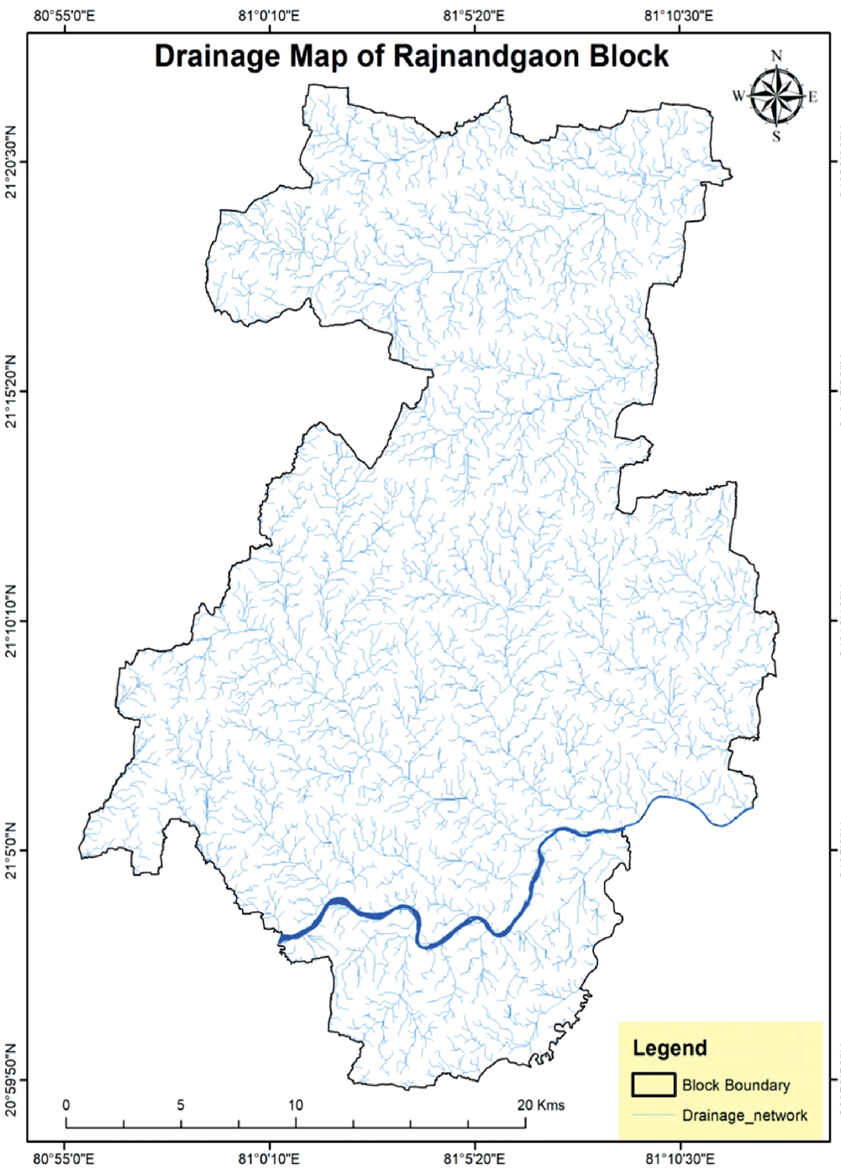

Figure 2: Drainage map of Rajnandgaon block (ALOS Palsar DEM, 2022)

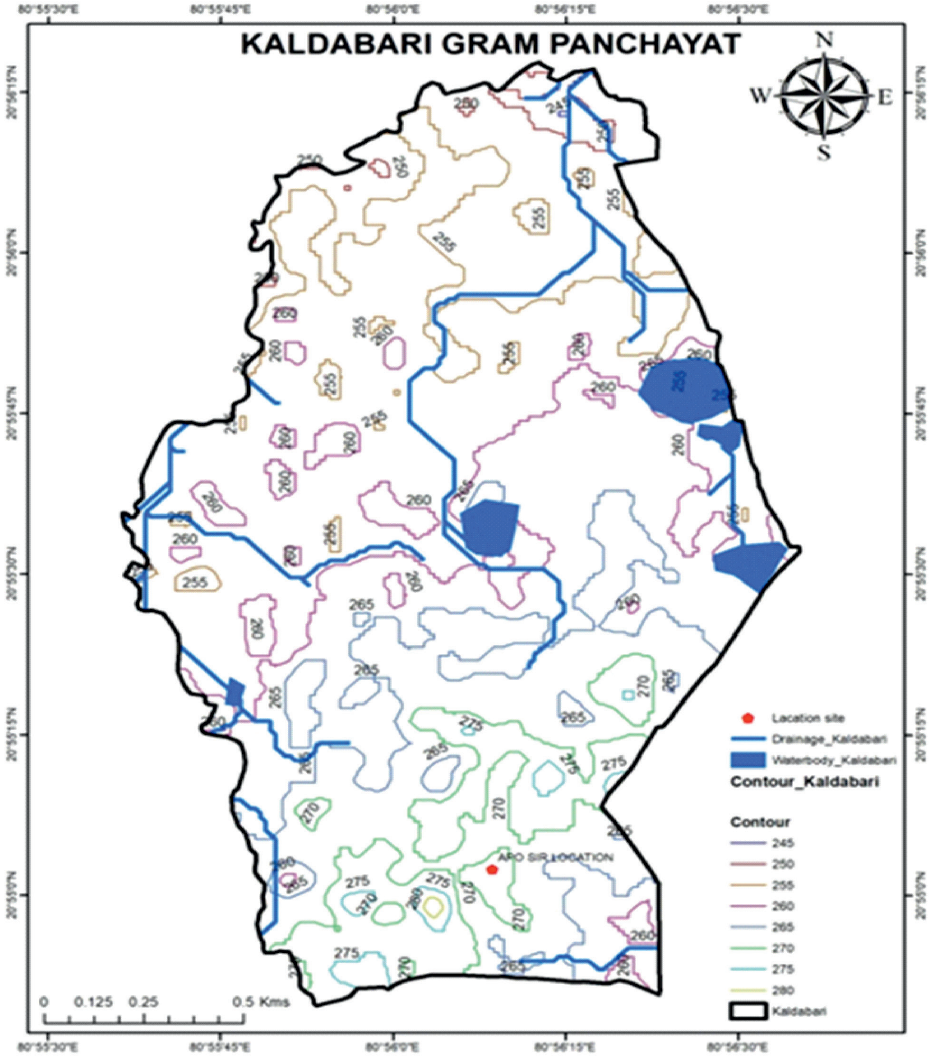

Figure 3: Contour map of Churiya block, (ALOS Palsar DEM)

The precision achieved through GIS aligns with findings by Mogaji et al. (2018) and Shirazi et al. (2012), who highlighted GIS's ability to optimize water resource planning. This methodology underscores the importance of integrating modern tools with traditional conservation techniques.

Planning

The planning phase involved integrating GIS data with community-driven processes to ensure relevance and sustainability. **Figure 4** illustrates the planning workflow, highlighting the collaboration between district authorities, gram panchayats, and technical teams. Key steps included:

- **Data Integration**: Satellite data, field surveys, and historical groundwater records were combined to create comprehensive recharge zone maps.
- **Community Participation**: Gram panchayats were engaged in identifying local priorities, ensuring that interventions addressed specific needs.
- **Iterative Design**: Feedback from field teams was incorporated to refine site selection and project designs.

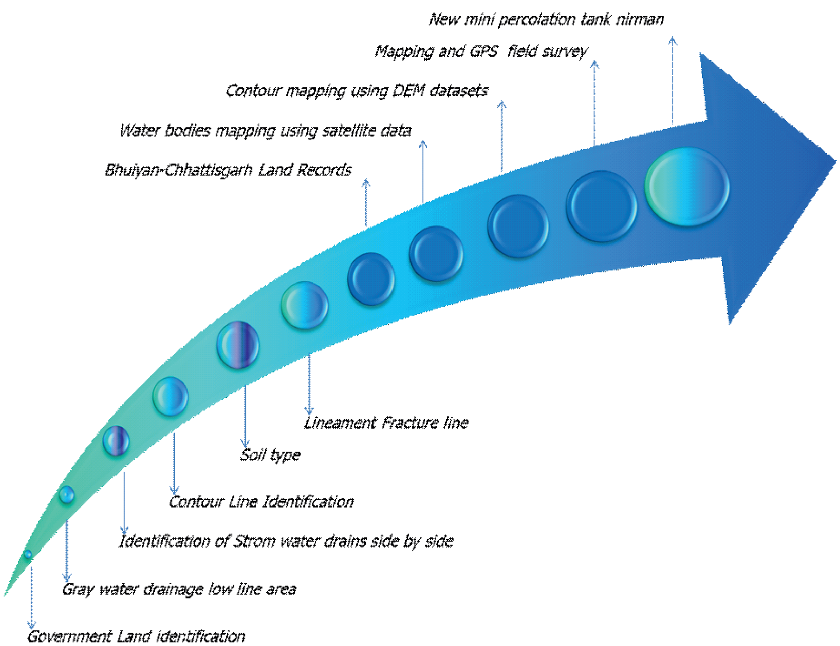

Figure 4: Flow chart for planning, method and execution

This participatory approach enhanced the project's alignment with local conditions, reflecting best practices in integrated resource planning. Planning efficiencies also minimized resource wastage, as validated by studies on GIS-driven development frameworks (Gupta et al., 2017).

Employment Generation

The initiative created over 1.25 million workdays under MGNREGA, benefiting 813-gram panchayats. Employment opportunities spanned unskilled labor for tank construction and skilled roles in supervision and technical assistance. Wage transparency was ensured through direct bank transfers, reducing delays and promoting trust.

Figures 5 highlight the diverse roles undertaken by workers, including excavation, bunding, and site preparation. Women constituted 46% of the workforce, reflecting the program's emphasis on inclusivity and gender equity. Field training sessions, equipped workers with practical skills, enhancing their employability beyond the project.

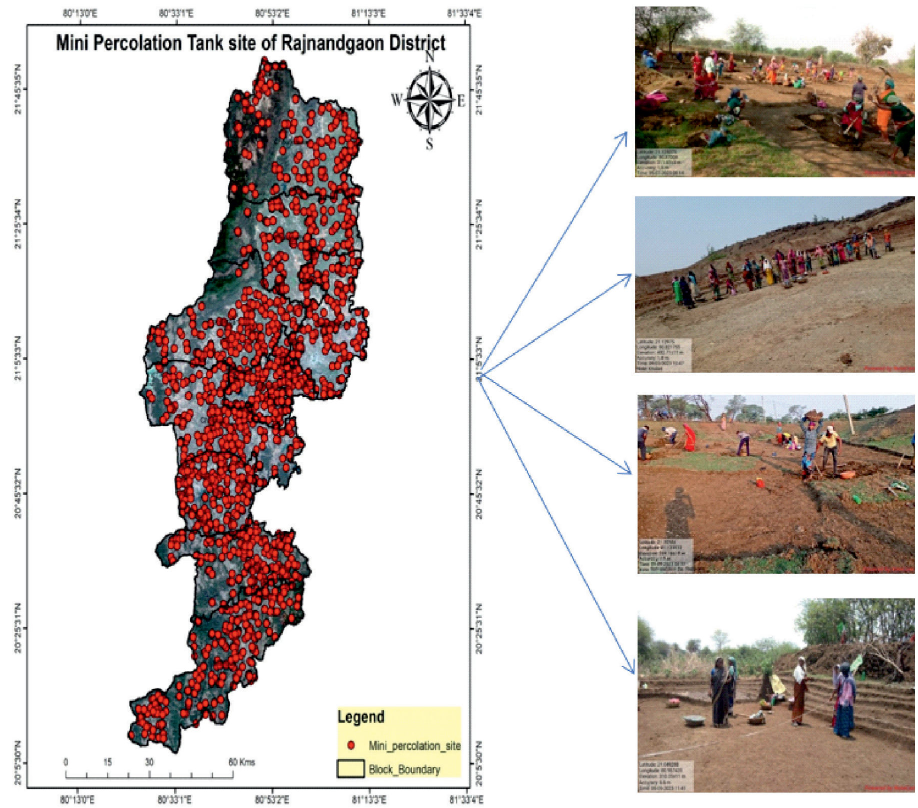

Figure 5: Location map of Mini percolation tank nirman sites

The socio-economic benefits align with Sinha et al. (2017), who documented MGNREGA's capacity to alleviate rural unemployment while creating durable assets. This dual impact underscores the transformative potential of linking livelihood generation with conservation goals.

Groundwater Recharge Impact

The constructed percolation tanks stored a cumulative 16.3 lakh cubic meters of water, significantly improving groundwater availability across 50,000 hectares. **Figure 6** depicts a completed tank, illustrating its integration with the surrounding landscape. Post-implementation assessments showed a rise in groundwater levels by 1.5–2 meters, benefiting agriculture and domestic water supplies.

Figure 6: Mini percolation tank nirman at Godalwahi Gram Panchayat

Farmers reported a 25–30% increase in crop yields, with many adopting double-cropping cycles. This shift reduced dependency on rainfall, enhancing food security and household incomes. The intervention also restored dry wells and boreholes, improving access to drinking water.

These outcomes align with studies by Russo et al. (2015) and Kaushik et al. (2015), who emphasized the importance of targeted recharge interventions in mitigating water stress. The tanks also strengthened climate resilience by stabilizing water resources during droughts.

Challenges in Asset Utilization

Despite its successes, the project faced challenges in sustaining its impact. Non-functional assets accounted for 8% of the total due to inadequate maintenance and silt accumulation. Misallocation of resources led to tanks being constructed in low-recharge zones, reducing their effectiveness. **Table 1** summarizes these issues, highlighting the need for improved planning and monitoring mechanisms.

Table 1: Sanctions of Mini percolation tank nirman (till march, 2023)

Sr No	*Block Name*	*Gram Panchayat*	*Sanctioned*
1	A. Chowki	69	183
2	Chhuikhadan	107	213
3	Chhuria	118	260
4	Dongargaon	76	229
5	Dongargarh	101	220
6	Khairagarh	114	208
7	Manpur	59	245
8	Mohla	57	256
9	Rajnandgaon	112	273
	Total	813	2087

Coordination gaps among stakeholders further delayed implementation and hindered asset sustainability. Addressing these challenges requires adopting IoT-based sensors for real-time monitoring and fostering stronger community ownership of interventions.

Conclusion and Recommendations

Conclusion

The Rajnandgaon initiative stands as a significant model of integrating advanced geospatial technology with rural development programs to address the dual challenges of groundwater depletion and rural unemployment. By combining the precision of Geographic Information Systems (GIS) with the socio-economic focus of the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), the project showcased the potential for innovative, data-driven solutions in water resource management and socio-economic upliftment.

One of the most notable achievements of the initiative was the construction of 2,087 mini percolation tanks, which were strategically located in high groundwater recharge zones. Using GIS and field-based data, the initiative ensured optimal site selection, leading to an increase of 1.5–2 meters in groundwater levels across targeted areas. These tanks collectively stored 16.3 lakh cubic meters of water, benefiting over 50,000 hectares of farmland. This resulted in reduced dependency on erratic monsoon rainfall and allowed farmers to adopt double-cropping cycles, enhancing food security and agricultural productivity.

The initiative also demonstrated significant socio-economic impacts. It generated over 1.25 million workdays under MGNREGA, with a focus on inclusivity and transparency. The employment of 46% women in the workforce highlighted the gender-responsive approach of the program, empowering rural women through wage security and skill development. Direct wage transfers further ensured financial transparency and timely disbursement of funds. Beyond immediate employment, the initiative fostered long-term benefits by equipping workers with skills in sustainable construction and maintenance practices.

Despite these commendable achievements, the project faced challenges, including the non-functionality of approximately 8% of constructed assets due to poor maintenance and resource misallocation. Certain tanks were constructed in low-recharge zones, highlighting the need for enhanced validation processes during planning. Additionally, the absence of robust monitoring systems and gaps in inter-departmental coordination hindered the overall efficiency of implementation. These challenges underscore the need for a more comprehensive and systematic approach to ensure sustainability and scalability.

In conclusion, the Rajnandgaon initiative underscores the transformative potential of integrating technology, policy, and community-driven approaches in addressing water scarcity and socio-economic challenges. By leveraging GIS and combining it with the participatory ethos of MGNREGA, the project has laid the foundation for scalable and replicable models in sustainable resource management.

Recommendations

The findings of this initiative provide critical insights into policy and operational improvements that can enhance the effectiveness of similar projects in other regions. The following recommendations aim to address the identified challenges while building on the successes of the initiative:

1. **Scaling GIS-Based Interventions**: The integration of GIS technology in planning and implementation has proven to be highly effective in optimizing resource allocation. Expanding this approach to other water-stressed regions is imperative. Governments and local bodies should invest in advanced geospatial tools, including IoT-enabled monitoring systems, to enhance data collection and performance tracking. These tools can provide real-time insights into groundwater levels, asset performance, and recharge efficiency, enabling timely interventions and data-driven decision-making.
2. **Strengthening Community Ownership**: Ensuring the long-term sustainability of assets requires active community participation. Local communities should be involved not just in the planning stages but also in the maintenance and monitoring of constructed assets. Organizing training sessions and workshops for residents on basic maintenance practices will foster a sense of ownership. For example, forming local maintenance committees or engaging self-help groups (SHGs) can ensure regular upkeep of percolation tanks, reducing dependency on external support.
3. **Enhanced Policy Convergence**: Aligning MGNREGA projects with other state and national-level water resource programs, such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) and watershed management initiatives, can significantly amplify the impact of such interventions. Policy convergence ensures optimal resource utilization, prevents duplication of efforts, and fosters synergy between different schemes. Collaborative frameworks between departments can enhance efficiency and deliver holistic solutions to water and livelihood challenges.
4. **Real-Time Monitoring and Transparency**: One of the major challenges faced during the project was the lack of robust monitoring mechanisms. Implementing real-time monitoring systems using IoT sensors and geo-tagging can greatly improve the tracking of asset performance. These systems can be integrated with GIS-based dashboards to provide stakeholders with actionable insights into the functionality and impact of constructed assets. Transparency can be further enhanced by making this data accessible to local communities and ensuring regular public audits.
5. **Capacity Building for Technical Teams**: Building the technical capacity of gram panchayats, field staff, and technical assistants is crucial for the effective

execution of GIS-based projects. Training programs should focus on developing expertise in GIS applications, sustainable construction techniques, and resource management. Additionally, capacity-building initiatives should emphasize the use of open-access datasets and standardized tools to improve data accuracy and ensure uniformity in implementation.

6. **Focus on Climate Resilience**: Given the increasing impact of climate change on water resources, future projects should prioritize the design and construction of climate-resilient infrastructure. Integrating agroforestry, watershed management, and soil conservation techniques with percolation tank construction can enhance the overall ecological benefits of interventions. For instance, promoting vegetation along tank peripheries can reduce evaporation losses and improve groundwater recharge.
7. **Strengthening Inter-Departmental Collaboration**: Effective implementation of large-scale projects requires seamless coordination among various departments, including water resources, rural development, and local governance. Establishing inter-departmental task forces and joint planning committees can streamline decision-making processes and improve project oversight. Regular meetings and shared digital platforms for data exchange can further enhance collaboration.
8. **Adopting a Participatory Approach in Planning**: The participatory ethos of MGNREGA was instrumental in the project's success. Expanding this approach by involving local stakeholders, including gram panchayats and community leaders, in planning and decision-making processes can enhance the relevance and sustainability of interventions. Participatory planning ensures that projects are tailored to local needs and priorities, fostering greater acceptance and ownership among beneficiaries.
9. **Replicability and Scalability**: The methodology adopted in Rajnandgaon offers a scalable model that can be replicated across other regions facing similar challenges. By documenting best practices, lessons learned, and operational frameworks, the initiative can serve as a reference for policymakers and practitioners. Future projects should adopt a flexible approach, allowing for adjustments based on regional variations in hydrology, socio-economic conditions, and community dynamics.

10. **Continuous Impact Evaluation**: Establishing mechanisms for regular impact evaluation is essential to assess the long-term effectiveness of interventions. Periodic evaluations should focus on changes in groundwater levels, agricultural productivity, and socio-economic outcomes. These evaluations can inform future planning and help refine strategies to address emerging challenges.

By implementing these recommendations, similar initiatives can maximize their impact while addressing the challenges of water scarcity, rural livelihoods, and climate resilience. The Rajnandgaon initiative provides a blueprint for sustainable resource management, demonstrating the power of technology-driven, community-centered approaches in transforming rural landscapes.

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