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Spatial Planning for Resilient Water Infrastructure in Rural India – An Approach from Village Panchayats Level

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Abstract Rural communities in India frequently face water stress, exacerbated by climate change and the degradation of natural resources, with vulnerable groups, including women and children, being most affected. Addressing water security at the grassroots level requires participatory, bottom-up approaches, with Village Panchayats, the lowest level of local governance, serving as critical agents of change. This study focuses on spatial planning strategies for resilient water infrastructure at the Village Panchayat scale, using Barkoha Village Panchayat in Chhatarpur district, Madhya Pradesh, as a case study. The research integrates indigenous knowledge, lived experiences, and technological advancements to tackle water security challenges. A detailed watershed and morphometric analysis were conducted to understand the hydrology and natural drainage of micro watersheds, revealing the loss of natural drainage and ponds, thus emphasizing the need for restoration. Discussions with residents and experts further informed strategies for creating resilient water infrastructure. By emphasizing capacity building, data generation, participatory engagement, and strategic planning, the study presents a practical, scalable framework tailored to local capacities. The spatial representation of challenges and solutions provides critical insights for replicating these efforts in other Village Panchayats, contributing to sustainable and resilient water management at the grassroots level.

Keywords: resilient water infrastructure, spatial planning strategies, morphometric analysis, bottom-up approaches

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1. INTRODUCTION

Water scarcity is a pressing concern discussed in global forums. The World Meteorological Organization reports a steady decline in terrestrial water storage, decreasing by 1 cm^3 per year over the last two decades (World Meteorological Organization (WMO), 2021). The World Health Organization predicts that by 2030, around 700 million people will face forced displacement due to drought, risking their livelihoods and causing significant stress (World Health Organization, n.d.).

The water situation in India is particularly concerning, as the country currently has only 4% of the global water resources for its substantial 18% share of the world's population (The World Bank, 2023). As a developing nation, India faces significant social and economic disparities, with agriculture contributing a substantial 18.3% to its GVA (Gross Value Added) (The National Statistical Office (NSO), Ministry of Statistics and Programme Implementation (MoSPI), 2023), relying heavily on irrigation which consumes 78% of available water resources. Projections indicate a decline in per capita water availability from 1545 m^3 to 1140 m^3 between 2011 and 2050 (Press Information Bureau, 2017).

Rural India paints a stark picture, with only 18% having access to piped water supply as of 2016, as highlighted by the National Family Health Survey (International Institute for Population Sciences (IIPS), 2017). The rural water supply systems in India have long grappled with issues such as institutional accountability, labor-intensive water retrieval methods, poor water quality, seasonal shortages, and unequal distribution. The Comptroller and Auditor General (CAG) reported in 2018 that despite an expenditure of Rs 81,168 crores between 2012 and 2017 for rural piped water supply, only 18% coverage was achieved, with supply ranging from 40 to 55 liters per capita per day (lpcd) (Suhag, 2018). Traditional and local water resources in rural India, once carefully managed, are now faltering due to changing climatic conditions and evolving agricultural practices. Unfortunately, compared to investments in piped water supply, little has been allocated to maintaining these traditional water sources, critical for rural agricultural needs. Climate change has further exacerbated challenges in rural areas, with reduced rainfall impacting arid regions. Consequently, there is an urgent need to adapt agricultural practices and ensure the resilience of rural water ecosystems in the face of climate change's impending impacts. Recognizing that the capacity for adaptation, learning, and transformation is critical to building resilient communities, this research aims to strengthen these capacities by developing and synthesizing existing knowledge on achieving water security in rural areas.

1.1 Resilient Water Infrastructure

The Inter-Governmental Panel on Climate Change (Intergovernmental Panel on Climate Change, 2014) defines resilience as ‘The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation'. Building resilience is indeed a crucial focus area in the sustainable development of systems.

The changing climate is greatly impacting existing water infrastructure. Enhancing the resilience of these systems involves prioritizing four key areas: effective utility management, implementing full-cost pricing for services, promoting water efficiency, and protecting natural resources (Santora & Wilson, 2008). Climate change is significantly impacting two key aspects among the four mentioned: effective utility management and protection of resources. As temperatures rise and rainfall patterns shift, the hydrological ecosystems of various regions are disrupted. Therefore, prioritizing effective utility management and safeguarding water resources becomes imperative in the face of climate change. The key focus for effective utility management is implementation of active and effective protective programs, environmental management system, asset management, capacity development, and selection of innovative cost-effective technologies (United States Environmental Protection Agency, 2006).

1.2 Watershed Approach and Spatial Planning

The watershed approach is a critical tool for addressing water resource challenges, focusing on the integrated management of soil, water, and vegetation to improve community well-being (Goswami, 2018). Advancing watershed-based tools is essential for reducing future water infrastructure costs and providing alternatives to traditional approaches. Key components of watershed planning include source water protection, water quality trading, decentralized onsite infrastructure management, sustainable watershed financing, and strategies to restore impaired waters (United States Environmental Protection Agency, 2006). Community participation is fundamental, as the success of watershed management relies on the active involvement of local residents, particularly in water efficiency efforts at the grassroots level. Leaders and organizations promoting water efficiency in buildings and landscapes also play a crucial role (United States Environmental Protection Agency, 2006).

Effective management of watershed requires integrating spatial data with socio-economic, political, and environmental factors. GIS is a powerful tool for developing hydrologic and hydraulic models, aiding in decision-making (Rao & Kumar, 2004).

1.3 Watershed Management in Rural Areas of India

Watershed management tools are particularly vital in rural areas, where technological capabilities for decision-making are often limited. Traditional methods of water resource management in rural communities have become insufficient due to climate change and unsustainable agricultural practices. The Government of India prioritizes watershed programs for the holistic development of rain-fed and drought-prone regions (Shiferaw & Reddy, 2008). Effective watershed management in rural areas depends on collaboration among stakeholders and collective action within watersheds. This involves enabling institutions to establish rules for managing common assets like grazing lands, check-dams, agroforestry, and soil and water conservation practices, along with designing local user groups and watershed committees for implementation (Shiferaw & Reddy, 2008).

In semi-arid rural regions, where financial and institutional capacities are limited, simple yet efficient techniques are crucial to combat shifting rainfall patterns and disrupted hydrological systems. Integrating GIS tools with readily available environmental datasets, local knowledge, and socio-economic data can improve watershed management outcomes.

2. RESEARCH METHOD

This research seeks to integrate the lived experiences of local communities, and technological advancements to effectively address water security challenges. A central aim is to create an easily replicable model, tailored to the existing capacities of diverse stakeholders involved in water security, that can enhance the ability of other villages in the study region to achieve water security through a case study approach. The research design includes problem identification, the development of data and information systems, and the use of advanced assessment methods and techniques, culminating in the formulation of strategies and identification of projects that support sustainable water security.

The research objectives are driven by the imperative to comprehend and address water scarcity in rural areas at a grassroots level. Firstly, the study seeks to understand the socio-economic and environmental conditions in the village to assess the impact of water scarcity. Secondly, it aims to analyze the hydrological system to ascertain the extent and causes of depleting natural water resources within the village. Thirdly, the research endeavors to develop strategic directions for mitigating the identified issues and promoting resilient water infrastructure. Emphasizing the importance of grassroots research, the study acknowledges existing literature on water scarcity in rural areas while highlighting the necessity for case studies to capture local nuances.

The study's methodology (as shown in Figure 1) involved a comprehensive approach to data collection and analysis. Over two days, the Village Panchayat was visited, engaging with the community through community involvement and citizen science principles. Primary data was gathered on the historical and current state of local water resources, water scarcity, educational and health facilities, infrastructure, and environmental challenges faced by the Village Panchayat. The techniques used for data collection, includes group discussions, public interviews, citizen science mapping, interviews with the Village Panchayat officials, and observational surveys. Data was gathered and categorized by hamlet (Cluster of houses) wise in the selected Village Panchayat, focusing on different sectors of study. This primary survey data provided insights into both general development issues and specific challenges related to water scarcity, as informed by the local population. 55 respondents including 40 adults (25 male and 15 female), and 15 children were surveyed.

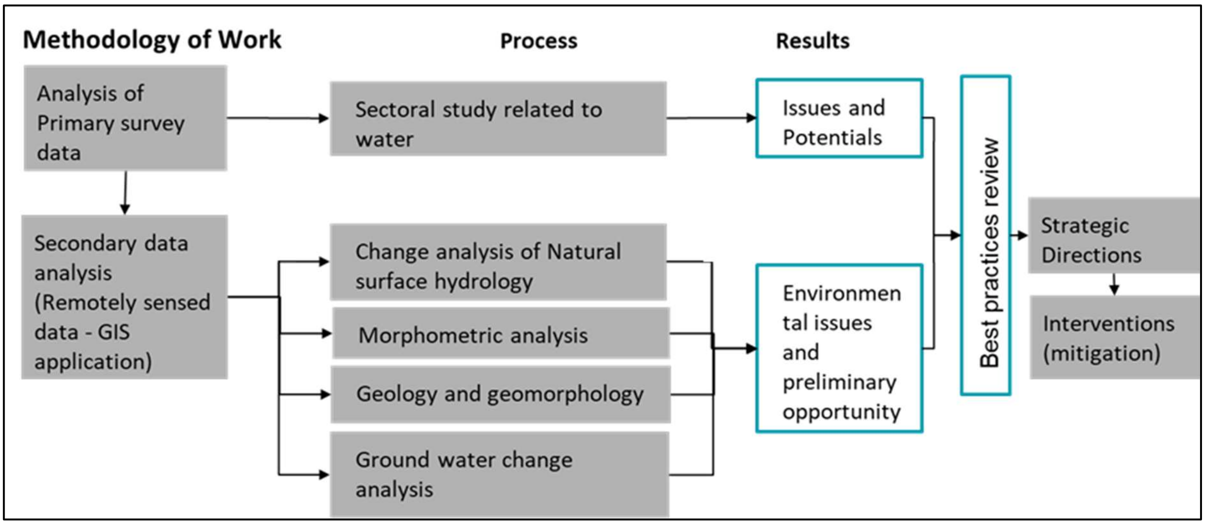

Figure 1. Methodology

Building upon this dataset, a focused secondary data analysis was conducted. This analysis included studies on changes in natural surface hydrology, morphometric analysis, geology and geomorphological analysis, and groundwater change analysis. Integrating secondary data analysis with primary survey findings strengthened the understanding of ground realities and identified potential strategies and interventions. The culmination of this effort was the development of a spatial plan for implementing practical water management and harvesting infrastructure in the selected village. This plan aims to address identified challenges and leverage opportunities uncovered through a combination of community engagement and scientific analysis.

2.1 Study Area - Climate Condition

The study area is located in the Bundelkhand region, one of the most semi-arid landscapes in central India, known for its frequent drought conditions. According to a study by Singh et al. (2022), Chhatarpur district was identified as a priority area due to its high rainfall variability, as indicated by the Relative Departure Index, second only to Sagar district. Within Chhatarpur, Barkoha Village Panchayat was selected for detailed investigation.

NASA Power data for 2022 recorded maximum and minimum temperatures of 46.84°C and 2.49°C, respectively, with an annual rainfall of 1116.1 mm. Over a 71-year period (1951–2022), the average annual rainfall was 1015.88 mm, with peak rainfall during June to September.

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The Standardized Precipitation Index (SPI) analysis (McKee et al., 1995) method was used to assess drought conditions and understand the extent of severity in the Village Panchayat. This analysis helped in understanding the severity of climate conditions in the Village Panchayat (refer to Figure 2). The annual rainfall data, sourced from the Climate Research Unit, was used for the period from 1951 to 2022 to gain insights into the trends and patterns.

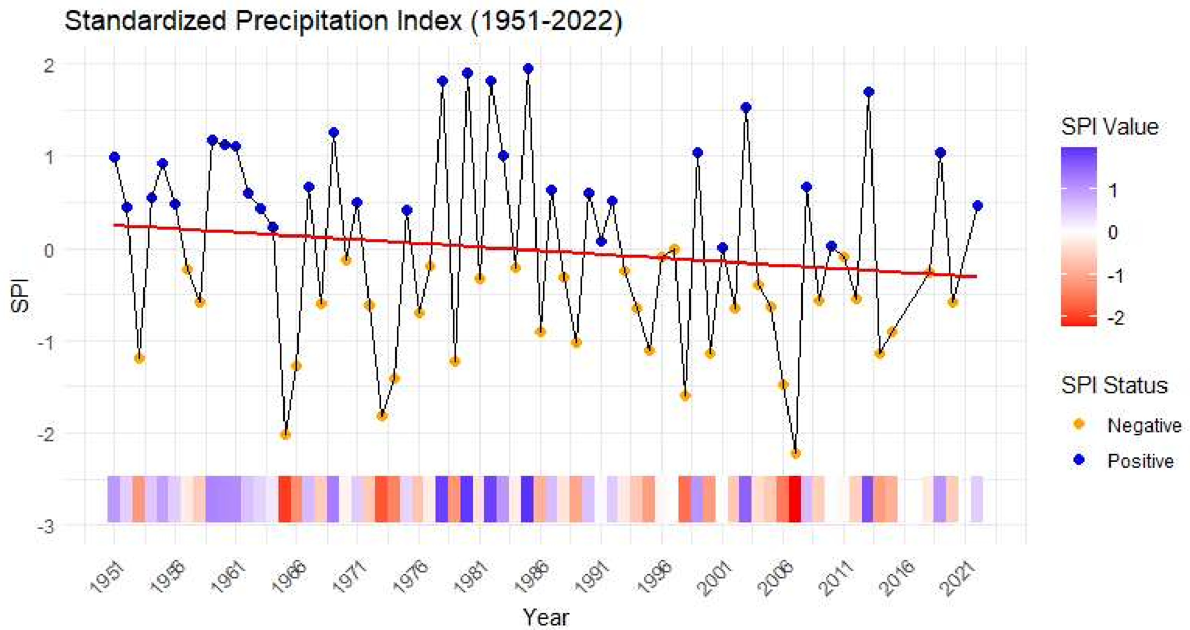

Figure 2. Standardized precipitation index - Calculated for Barkoha Village Panchayat (self-created)

The SPI analysis clearly indicates a declining trend in SPI values, with more negative values occurring in recent years, reflecting increasingly dry conditions. According to McKee et al. (1995), more negative SPI values represent more severe drought conditions. Based on the suggested categories, three levels of drought were identified across the dataset: Moderate Drought, Severe Drought, and Extreme Drought. While the calculated SPI values show a declining trend and an increasing occurrence of dry conditions — with 4 incidents in the first period (1951–1973), 4 in the second period (1974–1996), and 5 in the last period (1997–2022) (refer Table 1) — the significance test conducted using a t-test did not produce a p-value low enough to confirm that this change is statistically significant.

Table 1. Drought condition occurrence based on SPI (self-created)

Periods	Moderate Drought	Severe Drought	Extreme Drought
1951-1973	2	1	1
1974-1996	4	0	0
1997-2022	3	1	1

However, considering the severity of the region's drought conditions, its semi-arid nature, and the declining trend of SPI values (indicating reduced rainfall), it is evident that this

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Village Panchayat requires necessary precautionary measures to combat the worsening impacts of climate change in the coming years.

2.2 Study Area - Location and Environment

Barkoha Village Panchayat, located in the Chhatarpur district of Madhya Pradesh (Figure 3), spans 23.1 km^2 (24°55'23.7" N, 79°38'46.1" E). Positioned along major district roads (Figure 4). Falling within the Ken River Basin, Barkoha is linked to the Kutni lake and River, which form part of the upstream hydrological system draining into the Yamuna. The area is surrounded by small forest patches, ponds, and lakes, with access to government schools, colleges, and administrative offices. Future livelihood opportunities are anticipated from the proposed Chandrapura Industrial Area, situated less than 1.5 km away from the Village Panchayat.

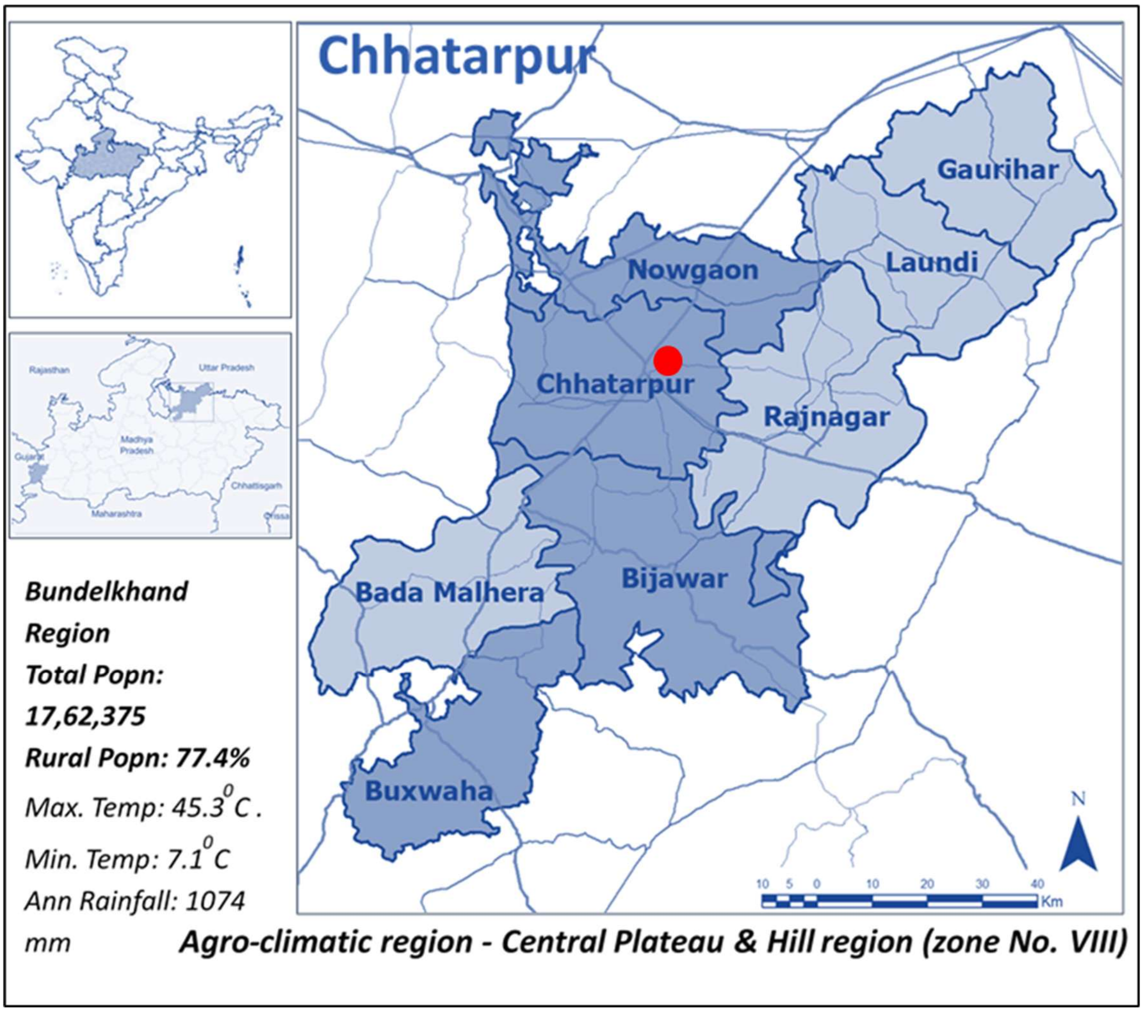

Figure 3. Chhatarpur district (Self-created)

As per Village Panchayat records, Barkoha has a population of 4,850 (2011 census), comprising 699 households and a child population of 396. The sex ratio is balanced at 955 females per 1,000 males, and Scheduled Castes and Scheduled Tribes make up 561 and 337 individuals, respectively. However, the literacy rate stands at only 39%, significantly lower than Chhatarpur district's average of 63.74%. Agriculture is the primary livelihood, with many residents engaged in cultivation, cultivation labor or migrant labor. A major 44% of land is cultivated, while the remaining 40% is under forest cover in the Village Panchayat. The Village Panchayat consists five hamlets—Barkoha (8.85 km^2), Radhepur (8.03 km^2), Taripurwa (5.86 km^2), Chaprapurwa (3.7 km^2), and Dhamrapurwa (0.89 km^2). The Village Panchayat being in the boundary of the Chhatarpur town (Figure 4) also has a planned layout area. Temporally between 2013–2023 there is minimal changes in built-up areas in the planned layout area, reflecting slow growth.

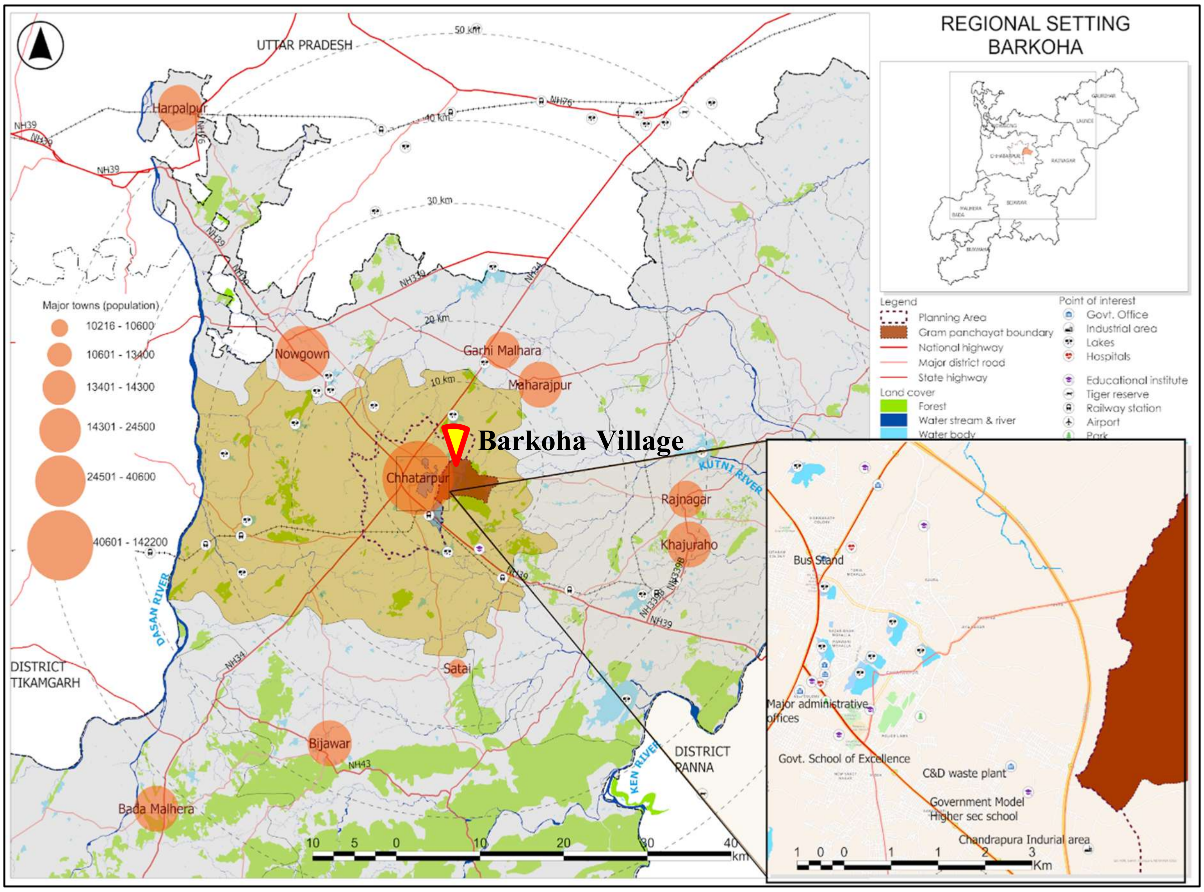

Figure 4. Regional setting of the Village Panchayat (Self-created)

Refer to Figures 5 and 6 for an overview of land cover, as well as the natural physiography, including elevation, natural streams, and water bodies in the Village Panchayat. Agriculture area and practice dominates, with 60–70% of the farm land cultivated during Rabi and Kharif seasons. Key crops include groundnut, urad, and soybean (Kharif), and wheat, jowar, and mustard (Rabi). Irrigation depends on groundwater borewells, wells, and rainfed methods.

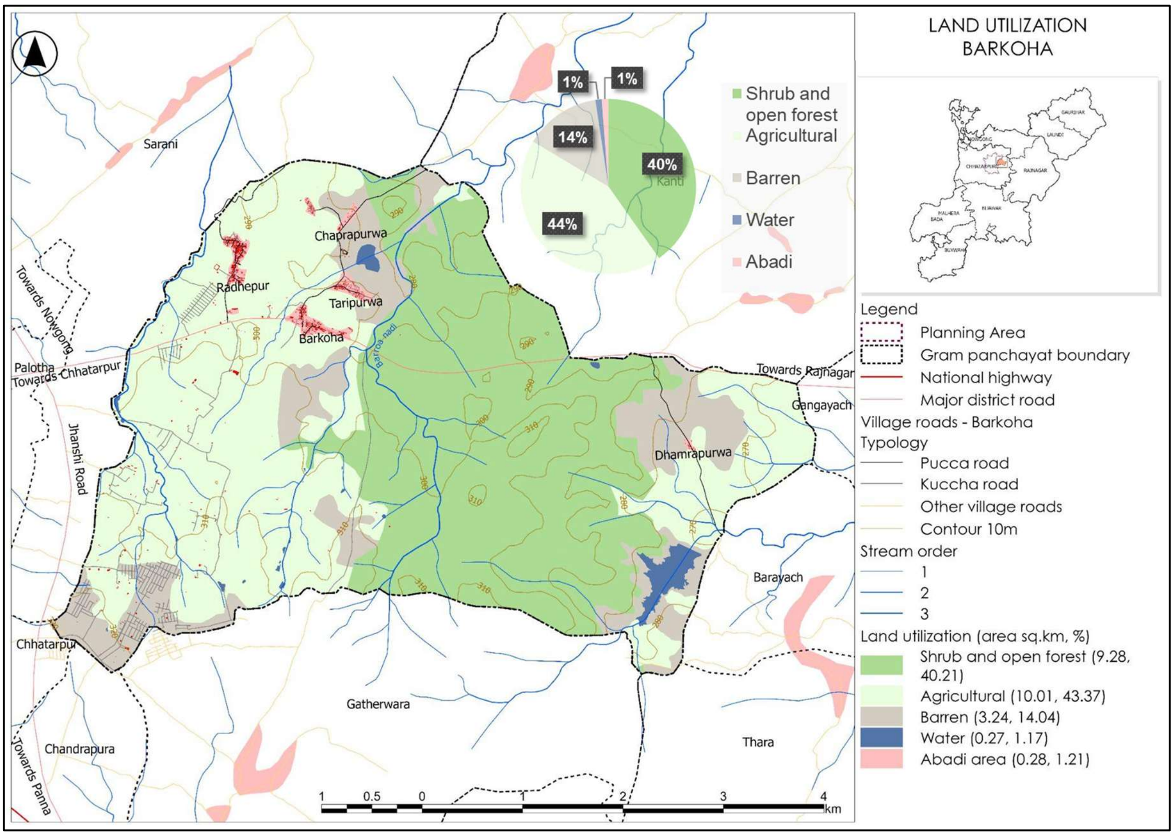

Figure 5. Land cover & land utilization of the Village Panchayat (Self-created)

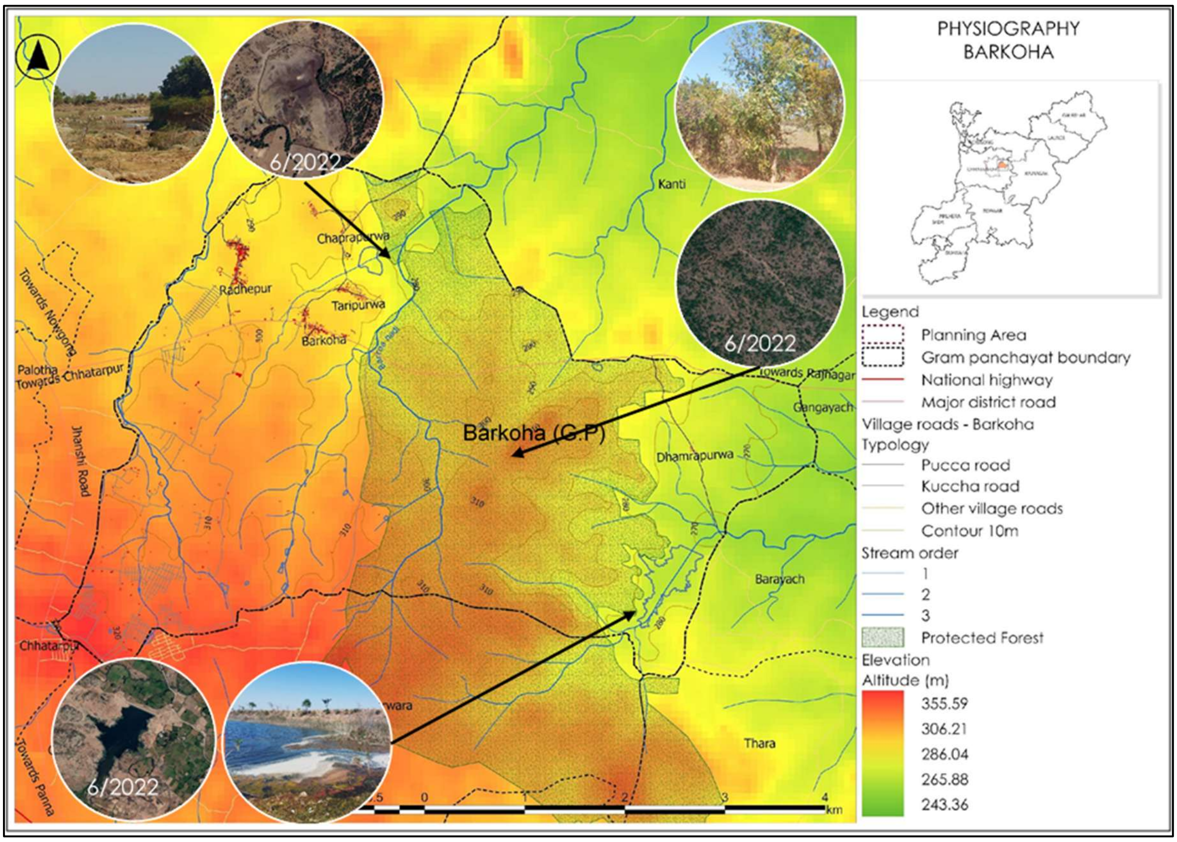

Figure 6. Environmental profile of the Village Panchayat (Self-created)

3. ANALYSIS AND FINDINGS – PRIMARY SURVEY DATA

Understanding livelihood and quality of life in the Village Panchayat is done based on the availability and accessibility of essential facilities. Data collection (as highlighted in Table 2) focused on sectors such as water security, waste management, drainage, transportation, infrastructure, economy, education, health, hygiene, and environmental degradation. Surveys were conducted across residential areas in the four hamlets, categorized by sector, and recurring issues were identified as a potential problem.

Table 2. Assimilated primary survey sectoral data (self-created)

Evaluation criteria		**Hamlets in the Barkoha Village Panchayat**			
		Barkoha	**Taripurwa**	**Radhepur**	**Dhamarapurwa**
Population		769	382	1177	38
Health Facility (available)		Private clinic	Not available	Not available	Not available
Education Facility (available)		Middle school	Primary school	Primary school	Non-functional school
Using Education Facility (Rank - 1 being better and 4 being worse)		1	3	2	4
Social Infrastructure	**Anganwadi**	Not available	Available	Available	Not available
	Community hall	Not available	Non functional	Non functional	Not available
Other infrastructure		Farmers society (serving all the hamlets, located in Barkoha hamlet)			
Physical Infrastructure	**Water supply**	Not available	Not available	Not available	Not available
	Strom Water Drain	Clogged and dysfunctional	Clogged and dysfunctional	Clogged and dysfunctional	Not available
	Electricity	Available	Available	Available	Unreliable
	Solid waste management	Not available	Not available	Not available	Not available
Occupation		Cultivators, Agri labours, daily labours, Animal husbandry	Cultivators, Agri labours, daily labours, Hand works (pottery)	Cultivators, Agri labours, daily labours, Animal husbandry	Cultivators, Agri labours, daily labours, Hand works (pottery)
Agriculture		Wheat, Sorghum, Mustard, Chana, Peanut			
Economic Wealth (Rank - 1 being better and 4 being worse)		2	3	1	4
Environmental Issue		Open waste disposal	Soil mining	Open waste disposal	Soil mining

Water security

Water scarcity is a significant issue, with most wells, the primary domestic water source, drying up in summer. Borewells also face seasonal depletion. During the survey, many wells were dry despite functioning well in previous years. Piped water connections are unavailable, forcing residents to rely on tank water. Women often travel over a kilometer to access water, particularly during summers. The water scarcity situation is leading to conflicts often in the Village Panchayat. This scarcity disproportionately affects women and children. For instance, a school in the Taripurwa hamlet (Figure 7) though equipped with toilets, faces water shortages year-round, resulting in no use for the children in the school Non-functional handpumps further exacerbate the issue of sanitation and health. Local people report declining groundwater levels in the village – noted through the declining water level in the wells around.

Economy

The economy is primarily agriculture-based, but water scarcity has led to reduced yields, impacting socio-economically marginalized groups who depend on agricultural labor. Consequently, many have turned to migrant labor, particularly in Taripurwa and Dhamrapurwa Abadi areas (hamlets). Radhepur and Barkoha residents are more engaged in animal husbandry, with 1,800–1,900 buffaloes and cattle producing 1,000–1,500 liters of milk daily, mostly sold in Chhatarpur town. Based on the primary survey, high transportation costs in the milk selling business highlight the need for a better supply chain system.

Education

Each hamlet has a primary school, though some, like in Dhamrapurwa, remain unused post-COVID-19, depriving children of education. Barkoha has a functional middle school, but for higher education children rely on institutions Chhatarpur town. Awareness and accessibility improvements are critical for education-deficient areas in the Village Panchayat

Physical and Social Infrastructure

Electricity connections exist across all hamlets, with 24-hour domestic supply and 12-hour irrigation supply, except in Dhamrapurwa, which faces irrigation electricity issues. The Village Panchayat lacks a dedicated sewage system. Stormwater drainage is inadequate, with clogs and damage leading to greywater disposal in low-lying areas, worsening hygiene conditions. Solid waste collection mechanisms are absent, and waste, including cow dung, is openly dumped and burned along the roadsides, contributing to health hazards. Social infrastructure like *Anganwadis* (a center providing care for mothers and young children in a rural area), community halls, and farmer societies exists but is underutilized or dysfunctional.

Environment

Natural resources such as lakes and small ponds were assessed for their functionality. Two large lakes were studied: the Thara Reservoir (19.58 ha), located in the southeast, is in good condition but is mostly used by other adjoining panchayat (Barayach Panchayat). The smaller lake near Taripurwa faces reduced water levels despite being used for water chestnut harvesting once. Illegal soil mining, particularly near Taripurwa hamlet's streams, poses significant hazards of soil erosion and damaged hydrological systems.

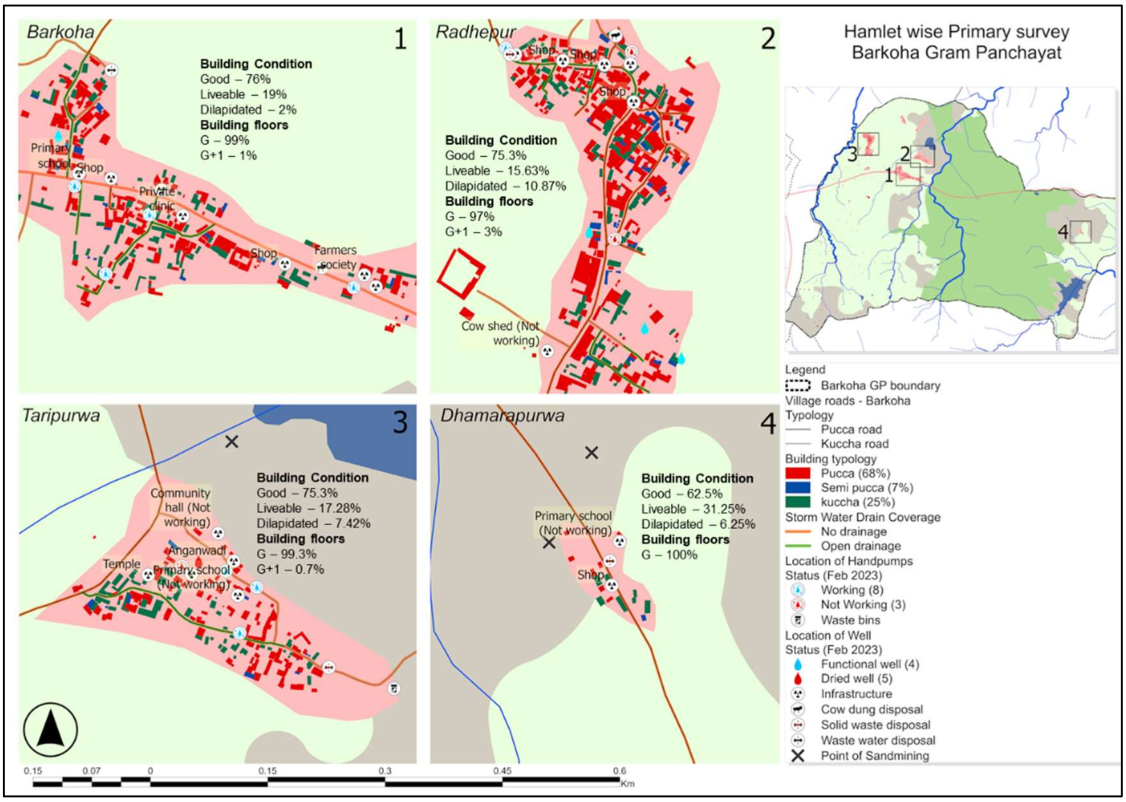

Figure 7. Hamlet wise assimilated primary survey data (Self-created)

4. WATERSHED ANALYSIS

A watershed is an area of land that drains or "sheds" water into a specific water body (National Geographic Education, n.d.). Watershed management is a dynamic approach focused on the coordinated management of land, water, vegetation, and other resources within a specific area to achieve ecological sustainability, social well-being, and economic development (Wang et al., 2016). Watershed analysis in drought prone regions is essential for devising strategies to harness rainwater and preserve soil integrity. Key factors such as soil composition, precipitation patterns, and vegetation cover shape hydrological processes and determine a watershed's functionality. Refer to Figure 8 for few of the pictures from the field visit where the local conditions of the village and its hydrology is understood.

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Figure 8. Survey pictures from the Village Panchayat

Barkoha Village Panchayat is located upstream of the Kutni River system. For the analysis the three watersheds (covering the Village Panchayat) were taken as the analysis unit. Using GIS technology and data from the Cartosat-1 Digital Elevation Model (DEM), micro watersheds were delineated to analyze the hydrological system of the Village Panchayat. Additionally, morphometric analysis—a quantitative study of landforms—was conducted to assess watershed stability, maturity, and flow patterns, providing essential insights into the Village Panchayat's hydrological problem This analysis, as highlighted in Manjare (2015), Kottagoda and Abeysingha (2017) and Asfaw (2019), is instrumental in devising soil and water conservation strategies. The detailed aspect of the watershed analysis has been studied in two parts, i.e., the surface system and subsurface system of the watershed. The details are discussed in the following sections.

4.1 Lost Natural Drainage and Pond (Surface System)

One of the lakes near Taripurwa fails to reach its full capacity. The Village Panchayat comprises three main watersheds (Figure 9). An initial surface assessment with the help of Google Earth imagery near Taripurwa Lake identified damaged surface, confirmed as "Broken grounds" through consultations with landscape experts. Broken Ground is the weathered part of the land caused due to erosion during heavy rain at the time of flooding (Figure 9). These features result from disrupted drainage, causing runoff water to deviate from natural flow paths and damage surfaces. Proper channelization into natural drainage systems is essential to prevent this issue. A localized examination of this feature and the drainage flow path to Taripurwa Lake revealed a small pond lost to agricultural land

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conversion. Survey of India Toposheets (2010) verified, shows that there was an adjacent pond and is not existing now which shows that this have got converted to agricultural land (Figure 10), leading to reduced inflow into the lake. Additionally, a comprehensive analysis of natural drainages (orders 1 to 3) was conducted to assess their health.

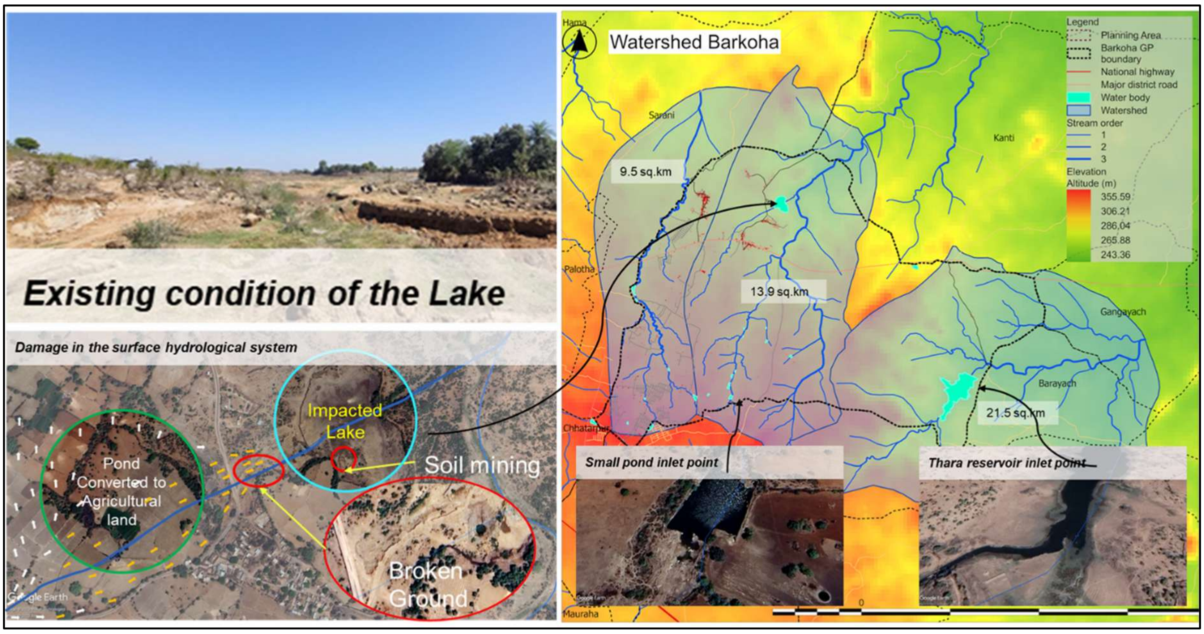

Figure 9. Main watersheds and the affected lake (Broken grounds) in the Village Panchayat (Self-created)

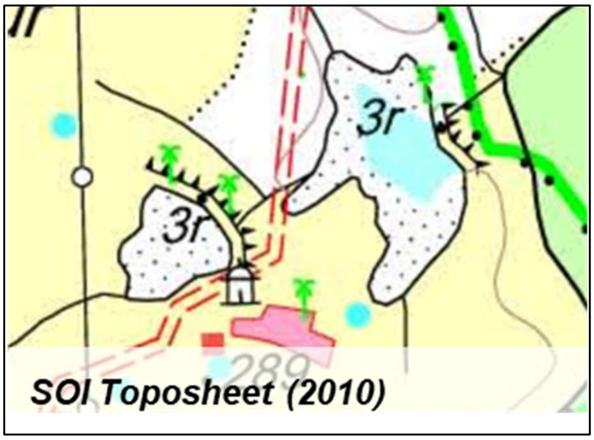

Figure 10. Topo sheet, Survey of India 2010

Surface regularity (with Google Earth imagery) near lakes and ponds was also examined. While the Thara reservoir's inlet and outlet land surfaces are gradual and smooth, the areas near smaller ponds are irregular, showing broken ground features, highlighting the need for stabilization. Stabilizing natural drainage systems requires implementing soil conservation mechanisms and designing proper inlet-outlet structures to regulate water flow and preserve water bodies' functionality. Intervention section provide an overview of natural drainage conditions, emphasizing the necessity of protecting and restoring these critical hydrological systems to ensure water flow stability and lake capacity restoration.

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4.2 Morphometric Analysis for Watershed Prioritization (Surface System)

Morphometric analysis evaluates watershed characteristics and maturity levels based on morphometric values, guiding the selection of suitable soil and water harvesting methods to mitigate soil erosion. By offering a detailed, quantitative profile of a catchment area, morphometric analysis plays a key role in applications like watershed prioritization, and the conservation of natural resources. This approach is particularly useful for studying watersheds, as it reveals relationships among various catchment features such as stream order, stream length, and drainage patterns (Shekar & Mathew, 2022).

Using DEM data and hydrological analysis tools in GIS applications (Arc Map), micro watersheds (Figure 11) were delineated (within the main three watersheds), and morphometric values calculated and watersheds were prioritized for conservation.

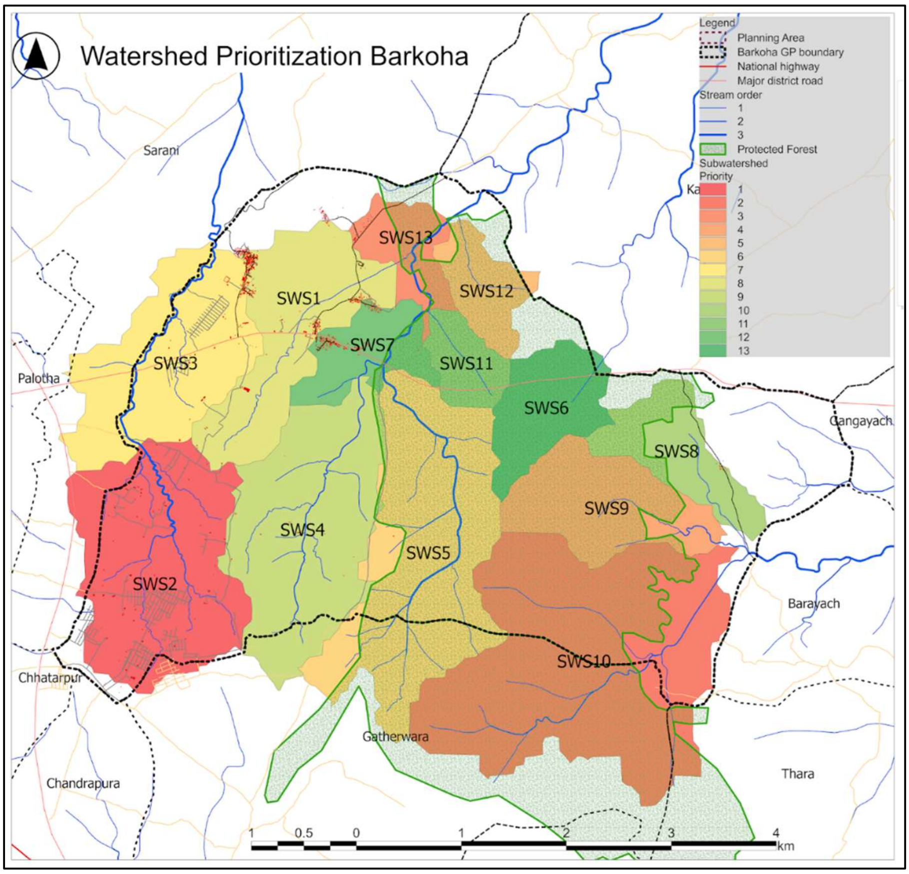

Figure 11. Priorities of watershed for conservation (Self-created)

Table 3 presents the selected morphometric factors along with their respective meanings for the watershed. These factors were chosen based on the specific characteristics of the watershed they represent, with a primary focus on their relevance to water flow dynamics and peak flow conditions, which are closely linked to soil erosion potential (as in the case of Bifurcation ratio). Additionally, the Hypsometric Integral provides a comprehensive understanding of the watershed's geomorphic maturity, which is also linked to soil erosion processes. Refer (Shekar & Mathew, 2024) for detailed understanding of each factors.

Typically, the process undertaken was delineating the micro watershed and the identifying streams and its orders using the well-known Strahler's method (ESRI, n.d.). These processes are very well incorporated in most of the GIS platform and the most widely used Arc Map as well. After delineation and identification of the micro watersheds and the streams it requires to calculate the morphometric values, which is essentially the size and shape of the micro watershed. The GIS application provided options to calculate different size factors like length, perimeter, and putting the formula would result in getting the morphometric values assessed for. Table 4 shows the resultant values of morphometric factors calculated for the micro watersheds delineated in the village panchayat including the cumulative value of the factors based on which they have got prioritized for conservation.

Table 3. Selected morphometric factors and the watershed characteristics

Morphometric Factors	Watershed Characteristics	Source
Bifurcation ratio (Br)	High Br → early hydrograph peak with a potential for flash flooding during the storm events.	(Howard, 1990)
	High Br → Highly disturbed watershed with more distortion in the drainage pattern	(Nag, 1998)
Drainage density (Dd)	High Dd → More impermeable subsurface, less vegetation and less infiltration.	(Luo, 2000)
	Low Dd → Good sites for groundwater recharge	(Harlin & Wijeyawickrema, 1985)
Stream frequency (Sf)	High Sf → More impermeable subsurface, less infiltration	(Altaf et al., 2013)
	Low Sf → Early peak discharge of watershed	(Altaf et al., 2013)
Drainage texture (Dt)	High Dt → Fast peak flow and more erosion	(Altaf et al., 2013)
Form factor (Ff)	High Ff → Round watershed resulting in high peak flow for short duration	(Youssef et al., 2010)
Circularity ratio (Rc)	High Rc → Elongated watershed, permeable surfaces, resulting in greater basin lag time helping in delayed time to peak flow	(Altaf et al., 2013)
Hypsometric integral (HI)	High HI (>0.6) → Young stage (high erosion)	(Fuladi & Deshmukh, 2023)
	Medium HI (0.6–0.35) → Naturally dissected, mature landform (medium erosion)	(Fuladi & Deshmukh, 2023)
	Low HI (<0.35) → Stabilized stage (no erosion)	(Fuladi & Deshmukh, 2023)

The analysis results (Table 4) indicate that the following sub-watersheds hold the highest priority for conservation measures:

SWS2: Located in an area with new development planned along the western part of the Village Panchayat, showing significant disturbance due to ongoing development activities, which are negatively impacting the hydrological system.

SWS10: The largest sub-watershed, draining to the Thara reservoir, with a significant portion within a forest area. This provides a substantial opportunity for implementing water and soil conservation measures.

SWS13: Previously discussed in relation to the lake near Taripurwa, which is not filling to full capacity due to damages in the system, highlighting a need for intervention to restore its function.

Table 4. Resultant morphometric values (Self-created)

Sub watershed	Mean Bifurcation Ratio	Drainage Density	Stream Frequency	Drainage Texture	Form Factor	Circularity Ratio	Hypsom-etric Integral	Total Sum	Priority
SWS1	1.35	4.536	27.835	6.577	0.278	0.361	0.504	41.442	9
SWS2	**3.386**	**4.61**	**47.078**	**17.085**	**0.548**	**0.539**	**0.496**	**74.539**	**1**
SWS3	0.751	5.148	29.536	8.816	0.426	0.525	0.472	45.605	8
SWS4	1.635	4.452	23.973	8.083	0.312	0.489	0.496	49.439	4
SWS5	1.392	4.561	30.028	9.447	0.282	0.352	0.492	46.563	7
SWS6	0.278	3.922	18.627	2.885	0.379	0.536	0.492	28.121	13
SWS7	1.667	4.333	23.457	3.558	0.329	0.357	0.501	34.202	12
SWS8	0.833	3.981	28.246	5.109	0.34	0.474	0.516	38.341	10
SWS9	1.405	4.158	32.026	5.803	0.34	0.552	0.504	47.237	5
SWS10	**1.38**	**4.572**	**30.739**	**12.908**	**0.481**	**0.437**	**0.484**	**55.001**	**2**
SWS11	1	3.269	25	4.276	0.366	0.434	0.491	35.183	11
SWS12	0.808	4.242	34.848	5.727	0.312	0.53	0.503	46.944	6
SWS13	**2.194**	**4.657**	**37.313**	**5.051**	**0.727**	**0.343**	**0.498**	**50.784**	**3**

The priority watersheds (shown in Figure 11) are experience the highest number of damaged drainages, with minimal to no vegetation cover, as indicated by drainage assessment from the primary survey and Google Earth imagery discussed in the later part. Protecting and stabilizing the natural drainages in these regions is critical to prevent further degradation from construction activities and land conversions.

4.3 Watershed Subsurface Analysis

The subsurface analysis examines geomorphology, geology, and groundwater conditions. Data sourced from India- Water Resource Information System (WRIS) highlights the Bundelkhand region's critical geology, including Pedi plains and Pediment-Inselberg Complex landforms predominantly composed of granite, which has poor groundwater recharge characteristics. This poses a major challenge for groundwater replenishment. Fracture areas within these formations, however, offer potential for recharge. Additionally, Quartz reef material, present along the Village Panchayat's hillocks, acts as a barrier to groundwater movement. Detailed geomorphologic information is presented in Table 5, with spatial distribution illustrated in Figure 12.

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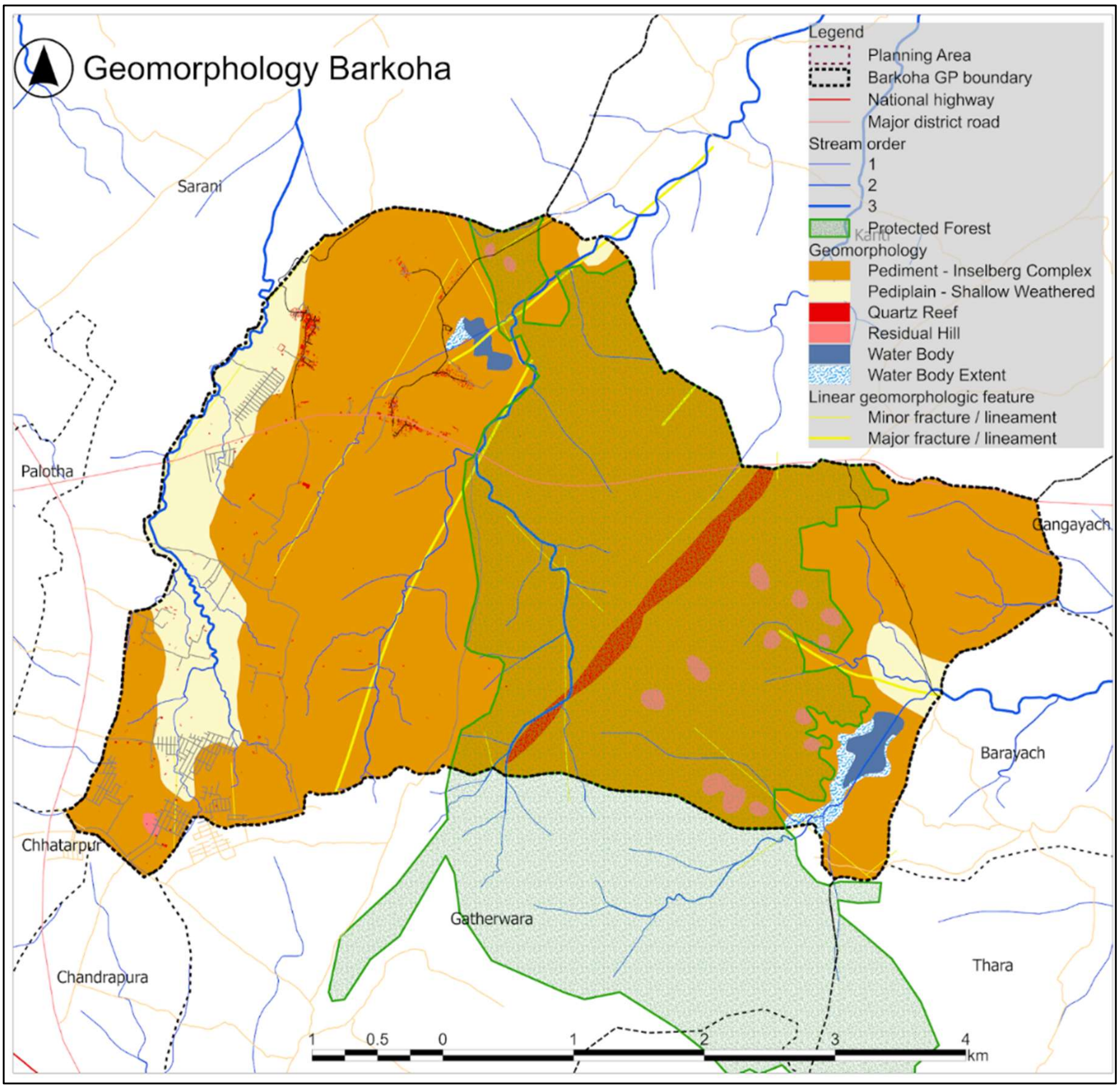

Figure 12. Geomorphology of the Village Panchayat (Self-created)

Table 5. Geomorphologic characteristics (Self-created, sourced from India WRIS)

Property	*Pediplain – shallow weathered*	*Pediment – Inselberg Complex*
Material	***Granite***	***Granite***
Aquifer form	***Weathered rock & Fissured rock***	***Fissured rock***
Depth to water table	***7 -10 m***	***10 – 15 m***
Water quality	***Potable***	***Potable***
Required depth of well	***40 – 60 m***	***80 – 90 m***
Yield range	***50 – 100 cu. m/day***	***10 – 50 cu.m/day***
Recharge conditions	***Moderate***	***Limited***
Zone of recharge	***Micro fracture zones***	***Micro fracture zones***

Groundwater level shows a declining trend, as reported in the primary survey. This was further analysed using data from the Rajiv Gandhi National Drinking Water Mission (sourced through the panchayat officials). These are data from observatory wells, although no

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observatory wells exist in the Village Panchayat, data from nearby wells were interpolated using GIS-based Kriging (Figure 13).

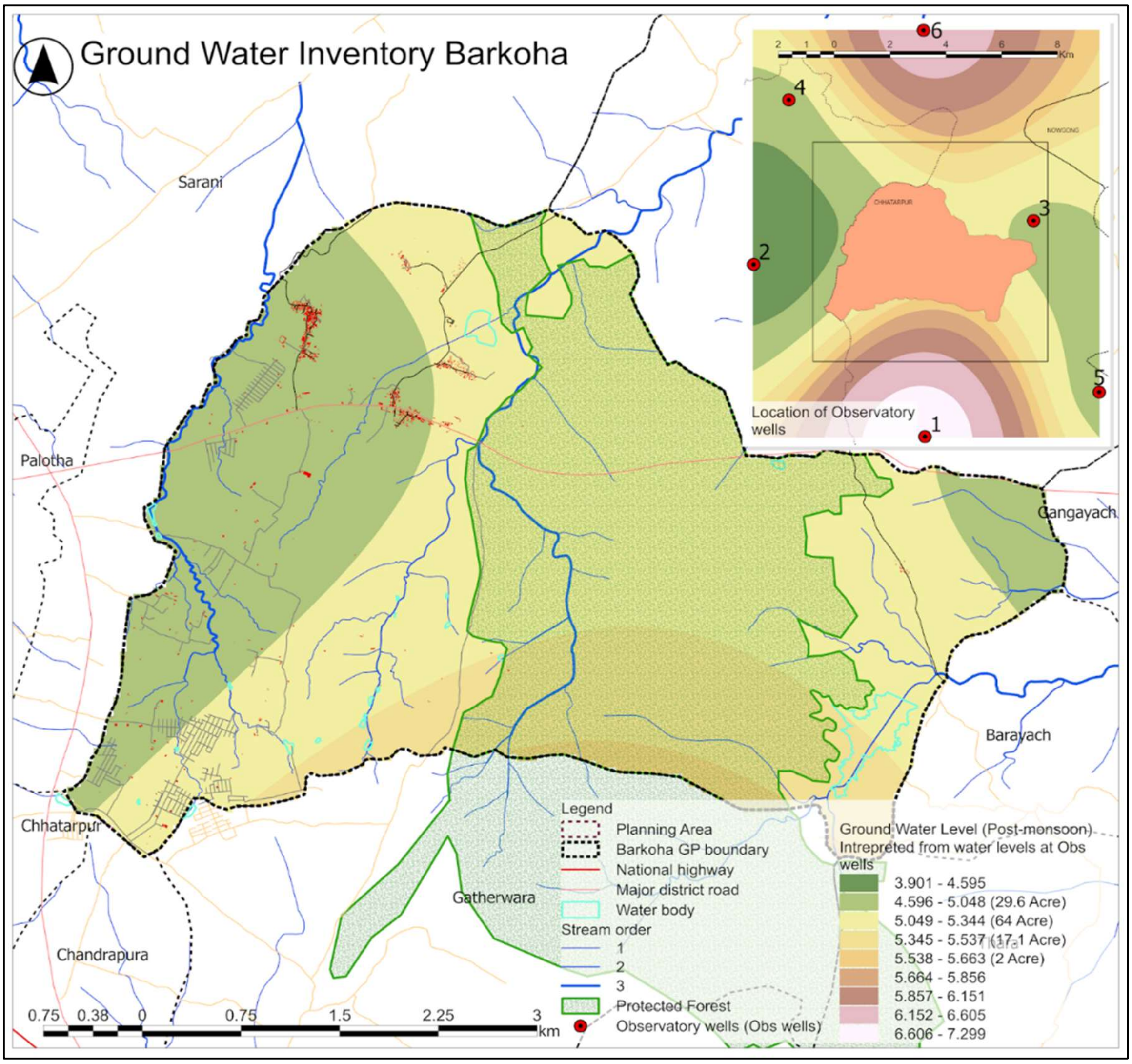

Figure 13. Groundwater status in the Village Panchayat (Self-created)

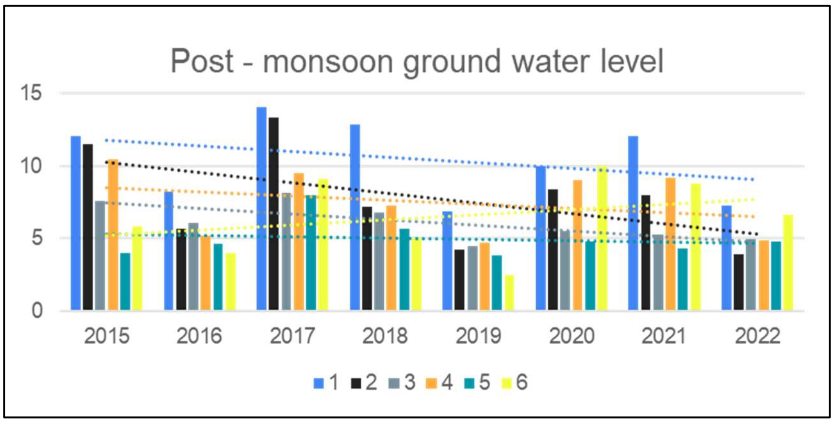

Figure 14. Groundwater level in the observatory wells (Self-created, data source: Rajiv Gandhi National Drinking Water Mission)

Temporal analysis reveals significant groundwater depletion, with many wells drying up during pre-monsoon periods, likely due to agricultural overexploitation and the changes in the rainfall pattern (Figure 14).

5. STRATEGIC DIRECTIONS

The analysis identified several critical issues requiring urgent attention to advance water security in the Village Panchayat. These issues were prioritized by severity and urgency, forming the basis for strategic interventions and recommendations.

The DPSIR (driver, pressure, state, impact and response) Framework was used to guide strategic responses, integrating elements such as identified potentials and climate change pillars (Hazard, Exposure, and Vulnerability). The framework emphasized leveraging identified potentials as a primary determinant for response strategies. Figures 15 and 16 detail the approach, including interventions designed to address critical groundwater issues, enhance recharge potential, and mitigate the impacts of overexploitation. Based on the preceding analysis, several priority issues requiring immediate attention were identified to make the Village Panchayat progress towards water security. These issues were prioritized based on their severity and urgency, serving as the foundation for developing strategies, interventions, and recommendations. Potential solutions were also considered to enhance intervention feasibility.

A comprehensive literature review of key reports and research publications informed the formulation of targeted interventions for water management and sustainability in the Village Panchayat. (Gray & Srinidhi, 2013) discuss the economic valuation of watershed development, highlighting the importance of sustainable practices that enhance both ecological and socio-economic outcomes. (NITI Aayog, 2021) provides best practices in water management, particularly in semi-arid regions. The proposed methods below, such as check dams and swales, align with these practices to conserve water, control erosion, and improve soil health, crucial for sustainable agricultural and water resource management. (Rajendran, 2004) highlights the role of dairy cooperatives in rural development, specifically in improving milk production, marketing and empowering women. (Kale et al., 2022) explore the importance of community-led water management initiatives, emphasizing local ownership in managing water resources. This informs the proposal for establishing a Village Water Management Committee to oversee and maintain water systems, ensuring long-term sustainability. Finally, Nasery (2011) discusses the potential of biogas systems in rural communities, focusing on waste management and energy production. The integration of these community driven approaches resulted in the identification of the intervention and the CRSDP plan (Figure 20).

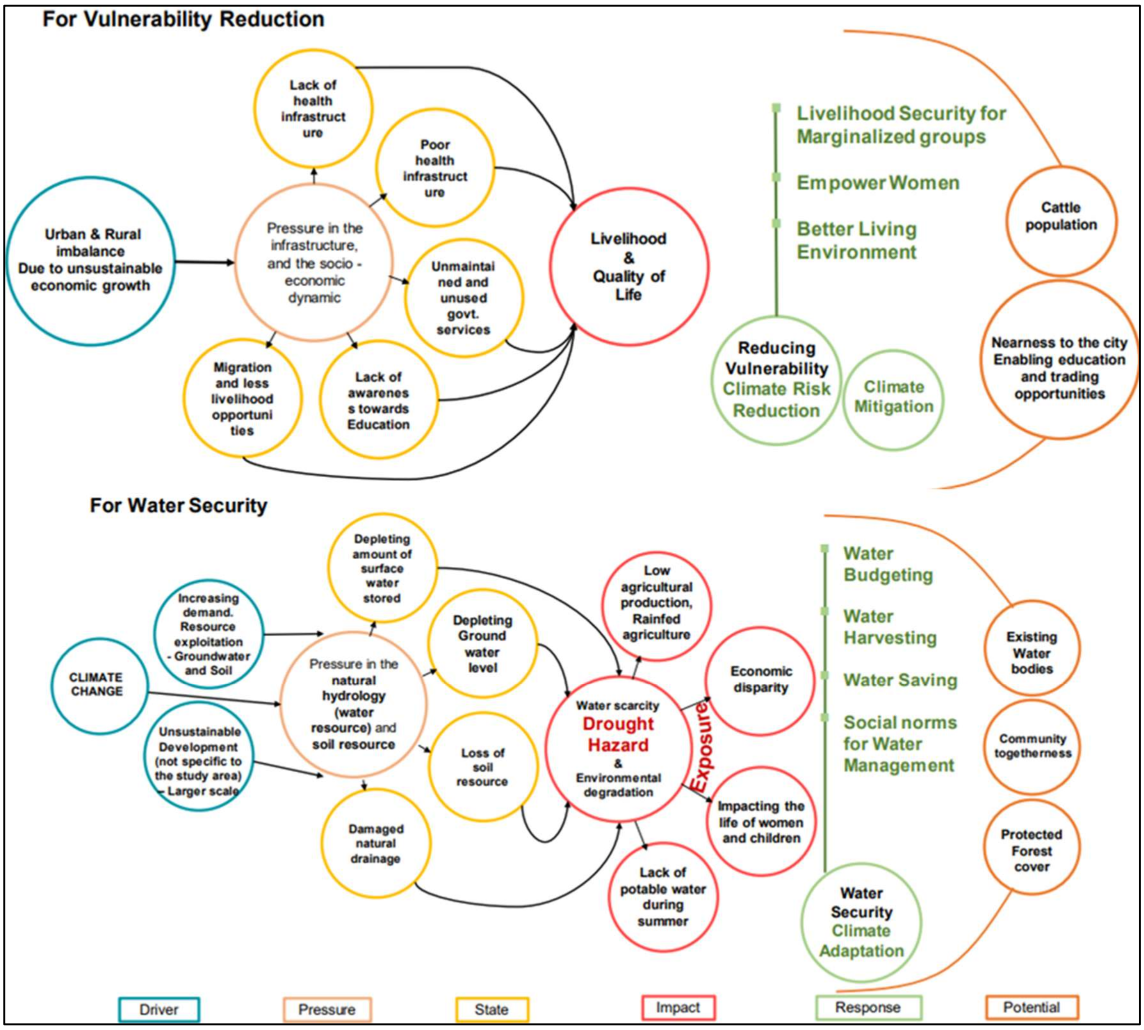

Figure 15. Strategic directions for achieving water security & climate resilience (Self-created)

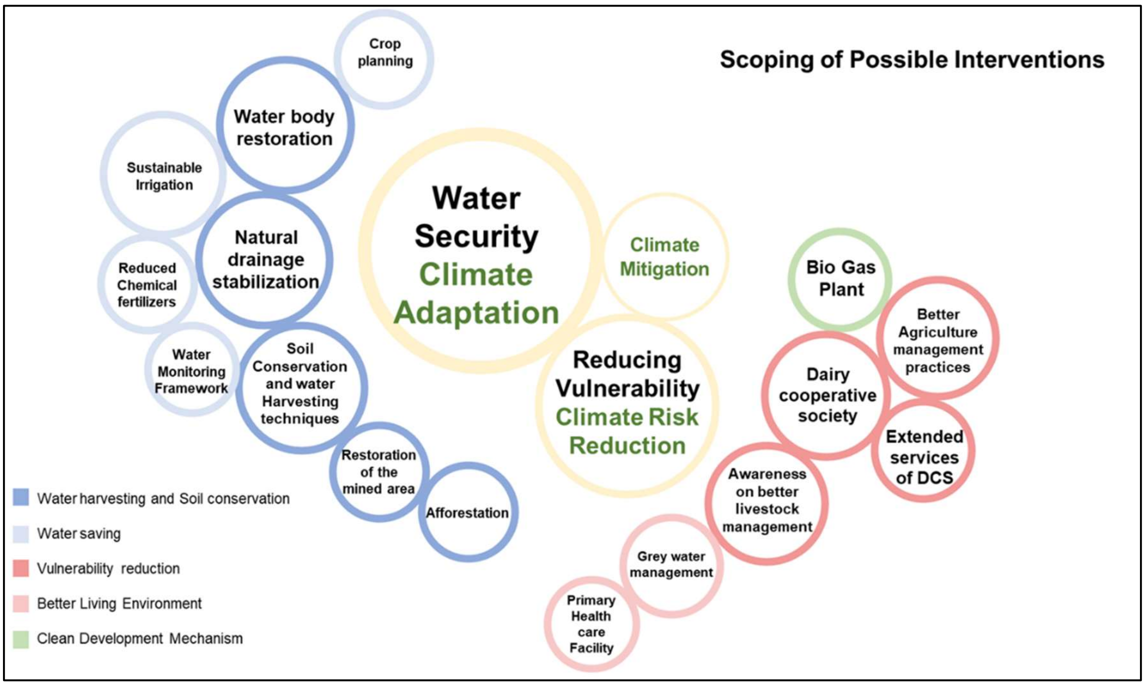

Figure 16. Scoping for possible interventions (Self-created)

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6. DISCUSSION

This section delves into the proposed interventions and their rationale, addressing the identified problems in the Village Panchayat. A comprehensive approach is essential, with community involvement at the center. Interventions are categorized into four main areas: Surface hydrology stabilization, Law enforcement for protecting natural drainage, Runoff speed control, and Water harvesting.

6.1 Surface Hydrology Stabilization

Addressing surface hydrology is crucial for achieving water security. State of natural drainage systems was categorized as healthy functional, lack of vegetation, broken ground with minimal vegetation, broken ground with no vegetation, and lost drainage, (Figure 17). Areas lacking vegetation require grasses, shrubs, and trees to strengthen drainage and reduce runoff speed, aiding soil conservation. Broken grounds require earthwork to withstand heavy runoff and prevent erosion. Enhancements like dried mulches can improve water permeability within fractured zones.

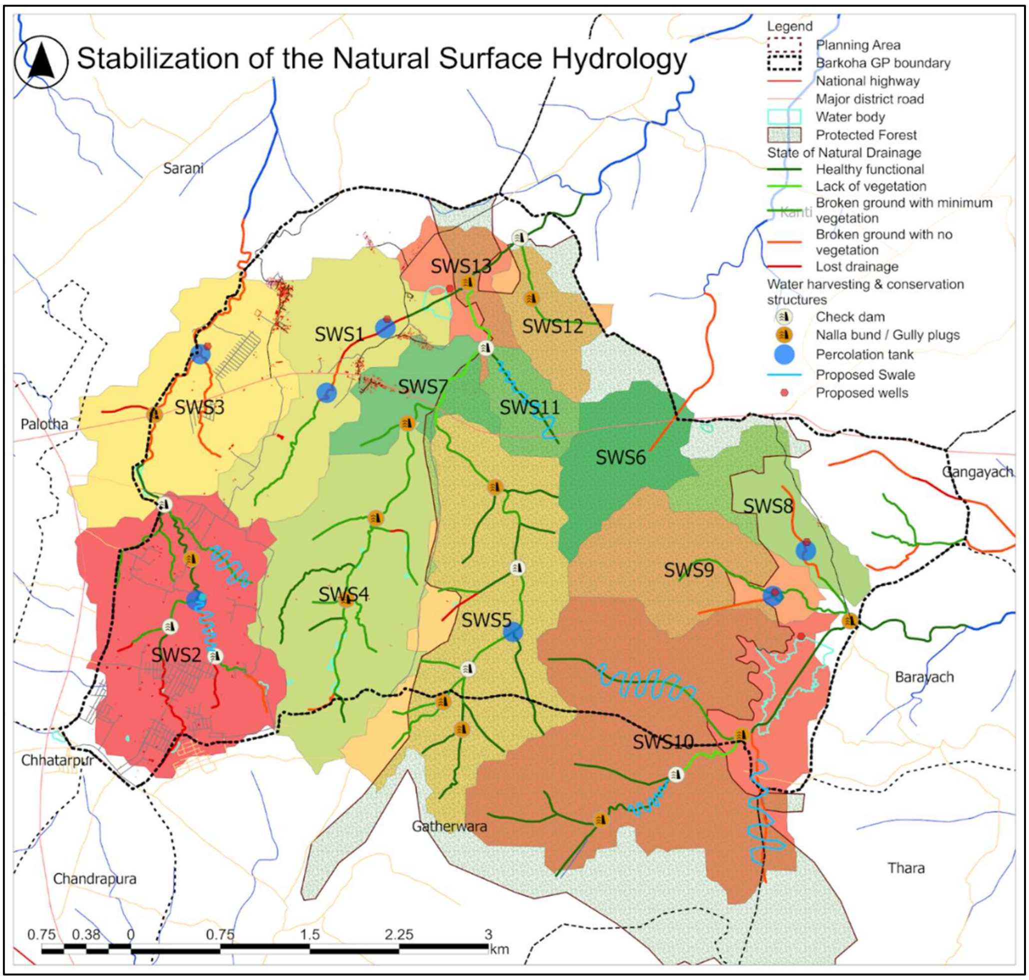

Figure 17. Interventions for natural hydrology stabilization (Self-created)

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6.2 Law Enforcement and Monitoring for Natural Drainage

Protecting natural drainages from encroachments is critical, especially in areas with urbanization potential. While laws mandate a 30-meter no-development buffer along water bodies, smaller drainages often lack such safeguards. A state-level framework is a necessary recommendation to protect lower-order drainages. At the Panchayat level, forming a Village Water Management Committee can ensure monitoring and maintenance, as shown in the community proposals section.

6.3 Runoff Speed Control and Water Harvesting

Managing rainwater runoff speed is critical for soil and water conservation. Methods such as Nala bunds, check dams, gully plugs, percolation tanks, and swales from the Integrated Watershed Management Programme were prioritized based on the resultant watershed priority. Check dams are essential in areas with high runoff velocity, while percolation tanks, paired with wells, ensure groundwater access during dry periods. The calculated morphometric values provide valuable insights into the characteristics of each watershed, helping to identify appropriate soil and water conservation strategies, as well as potential water harvesting interventions. These values, when combined with an understanding of local geology and groundwater conditions, form the basis for suggesting suitable measures for each sub-watershed.

For instance, in the northern part of the village—where groundwater levels are low but the presence of pediplain with shallow weathered geology offers moderate recharge potential—percolation tanks have been recommended to enhance groundwater recharge. Similarly, in the highest priority sub-watersheds, interventions such as check dams and swales have been proposed to control the velocity of surface runoff and reduce erosion.

Additional methods like Boomerangs and Infiltration Basins were proposed inthe protected forest area. Boomerangs trap sediment and impede sheet flow, while Infiltration Basins capture rainwater, runoff, and greywater. Afforestation initiatives in protected forest are also proposed to enhance groundwater recharge and biodiversity.

The proposed intervention locations are indicative, based on basic hydrological flow principles. However, detailed engineering studies are necessary to ensure their effective design and implementation. These preliminary recommendations were informed by literature review findings and are illustrated in Figure 17.

6.4 Lake Rejuvenation

Reduced water inflow in lakes, caused by drainage loss or land-use conversion, requires urgent intervention. Lake rejuvenation begins with protecting natural drainage (Figure 18).

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Key measures include fortifying pond and lake boundaries, desilting, and grading to maximize capacity. Stabilizing lake beds with traditional rock methods and establishing vegetation zones along boundaries enhance stability and biodiversity. Vegetation placement should align with runoff flow lines, requiring additional coverage in areas with significant stream flow.

Topographical remodeling through mounds and deep-water areas accommodates diverse species and improves ecosystem services. Lakes can also support vulnerable groups through activities like water chestnut harvesting and fishing initiatives (Figure 19). Diversion swales, positioned slightly off contour, increase water absorption while redirecting surplus runoff downhill, enhancing water levels. For example, Taripurwa Lake's lower-order drainage channels can be converted into major streams using diversion swales, with check dams diverting water for irrigation.

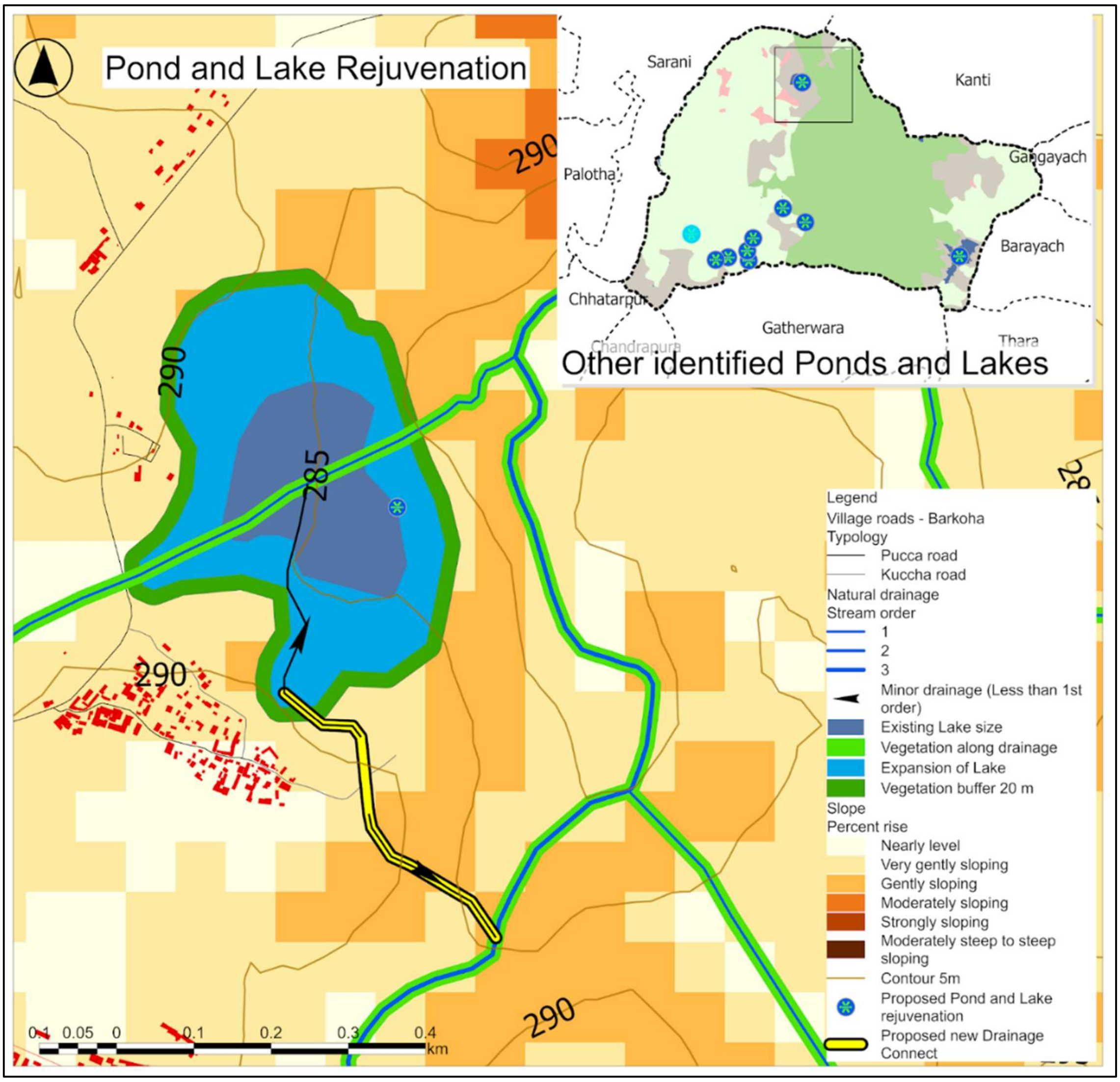

Figure 18. Pond and lake rejuvenation (Self-created)

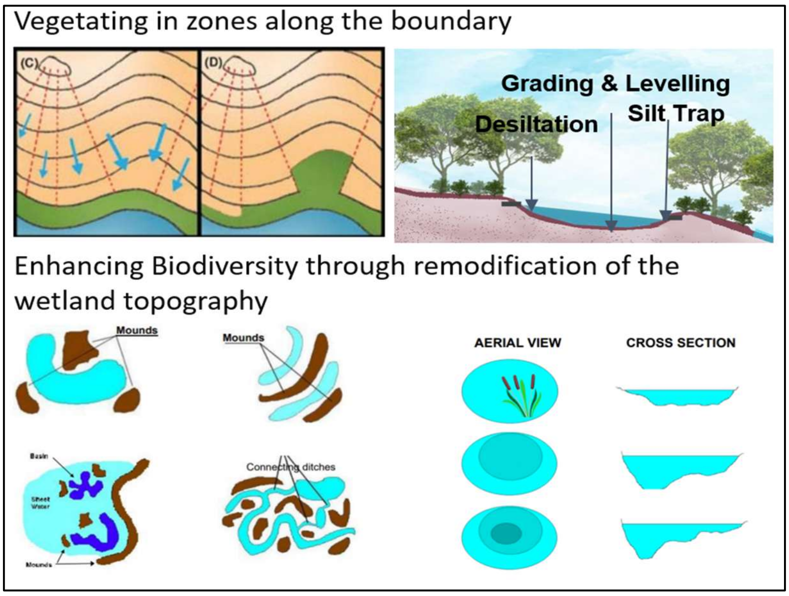

Figure 19. Lake boundary and topography modification

6.5 Community Togetherness Intervention (Holistic Approach)

Community engagement is key to successful implementation. Highlighted by many watershed development case studies, this approach envisions a plan integrating water management with diverse livelihood opportunities. A Dairy Cooperative Society (DCS) is recommended to leverage the Panchayat's cattle and buffalo population. The DCS would focus on milk collection, animal care, and village development, improving livelihoods for marginalized groups. Allocating exclusive membership for women can empower them economically and socially, positively influencing education outcomes. Additionally, a community biogas plant is recommended to manage solid waste, produce clean fuel, and generate manure for sustainable agriculture, ultimately reducing irrigation water demand. The plant, can be owned by the Village Panchayat, aligns with clean development mechanisms. A Village Water Management Committee is also recommended to enhance water management, promote sustainable practices, and facilitate water budgeting. This committee would foster community resilience and cohesion.

The study's methodology provides an adaptable framework suited to various rural contexts, aligning with initiatives like the Atal Bhujal Yojana (A community led sustainable groundwater management scheme) by prioritizing sustainable groundwater use and community engagement. Involving local stakeholders ensures solutions are tailored to their needs while emphasizing capacity building and the use of technological tools like GIS for effective groundwater monitoring and decision-making.

Beyond water management, the study's holistic perspective integrates socio-economic and environmental sustainability, addressing immediate challenges and contributing to broader rural development goals. By enhancing community resilience and empowerment, this

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approach supports the long-term success of development initiatives. Refer to Figure 20, which present the outcome plan of this study and serve as a critical piece of the work for replicating similar efforts in other villages within the region.

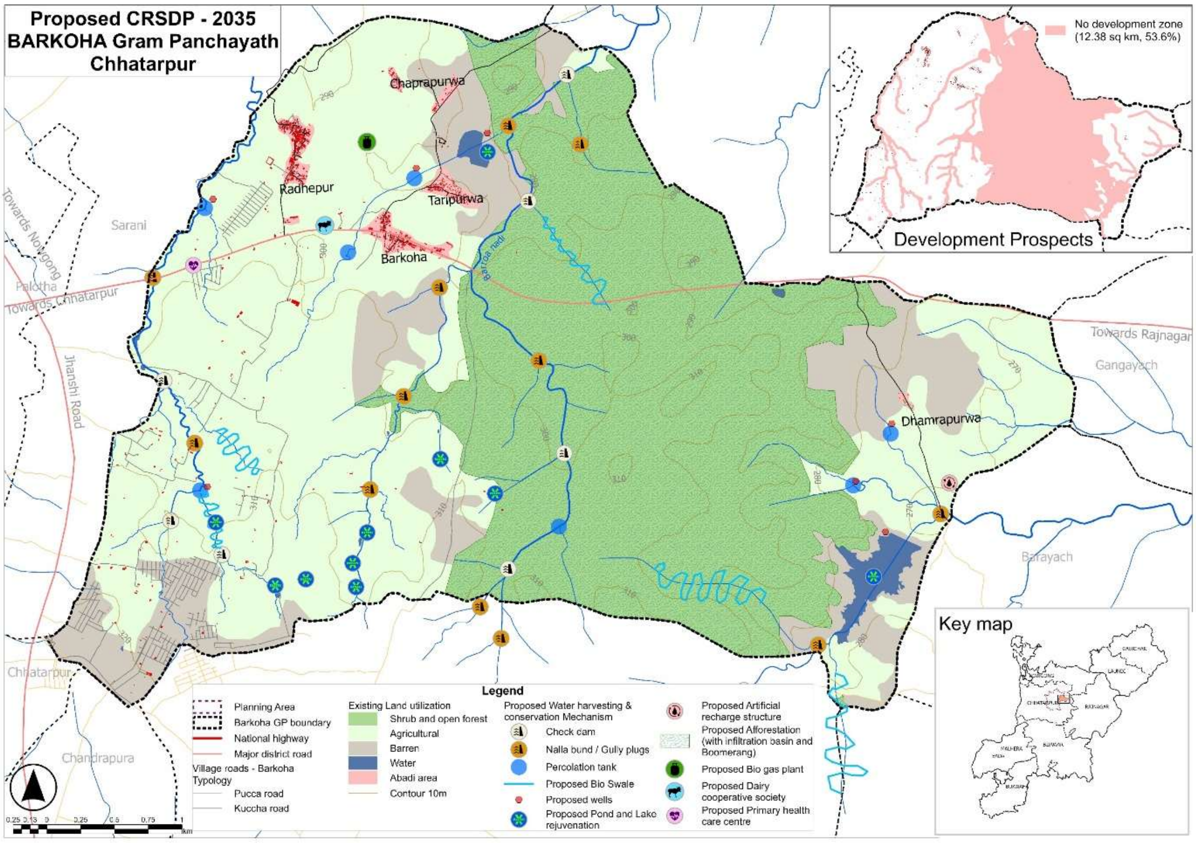

Figure 20. The proposed Climate Resilient Spatial Development Plan (CRSDP) (Self-created)

7. CONCLUSION

In conclusion, the integration of policy mechanisms into mainstream water management projects in rural areas is not only crucial but also imperative for maximizing effectiveness and ensuring long-term sustainability in addressing water-related challenges. The study delves into the intricate implementation mechanisms, highlighting the indispensable role of enabling policies and organizational setups. Government departments, including those under the Ministry of Rural Development and the Water Resource Department, provide the foundational framework for action, complemented by schemes such as PMGSY, MGNREGA, and the National Rural Health Mission. Moreover, the active involvement of NGOs, such as SHUDDHI, PRADHAN, Grow-Trees, and WOTR Climate Resilience for Rural India, plays a pivotal role in enhancing the success and impact of projects on the ground.

Placing a strong emphasis on community engagement and harnessing local knowledge and resources, the study aimed to foster resilient water infrastructure while simultaneously enhancing overall community development and well-being. Through targeted education and outreach efforts, the study seek to empower communities with the knowledge and tools needed to adapt to climate change-induced disasters and mitigate their impacts effectively. Furthermore, the study highlights the strategic utilization of simple, yet powerful, technological tools such as GIS and remote-sensed images.

In summary, through the concerted efforts outlined in the study it is aimed to pave the way for resilient water management practices and thriving, resilient communities in rural areas. By integrating policy mechanisms, fostering community engagement, raising awareness about climate change, and harnessing the power of technology, it is possible to create a more sustainable and equitable future for all.

REFERENCES

Altaf, F., Meraj, G., & Romshoo, S. A. (2013). Morphometric Analysis to Infer Hydrological Behaviour of Lidder Watershed, Western Himalaya, India. *Geography Journal*.

Asfaw, D. (2019). Quantitative analysis of morphometry on Ribb and Gumara watersheds: Implications for soil and water conservation. *International Soil and Water Conservation Research*.

Howard, A. D. (1990). Role of hypsometry and planform in basin hydrologic response. *Hydrological Processes*.

ESRI. (n.d.). *how stream order works*. Retrieved from pro.arcgis.com: https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-stream-order-works.htm

Fuladi, A., & Deshmukh, M. S. (2023). Hypsometric Analysis of WRC-1 Watershed, Chargarh River Basin, Central India: A Remote Sensing and GIS Approach. *Journal of Scientific Research*.

Goswami, N. K. (2018). *Watershed management and development*. Retrieved from Teriin.org.

Gray, E., & Srinidhi, A. (2013). *Watershed Development in India: Economic Valuation and Adaptation Considerations.* World Resources Institute.

Harlin, J. M., & Wijeyawickrema, C. (1985). Irrigation and groundwater depletion in Caddo county, Oklahoma. *Journal of the American Water Resources Association*.

Intergovernmental Panel on Climate Change. (2014). *Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Intergovernmental Panel on Climate Change.

International Institute for Population Sciences (IIPS). (2017). *National Family Health Survey (NFHS-4).* International Institute for Population Sciences.

Kale, E., Pinjan, H., & D'Souza, M. (2022). *Water Stewardship in Rural India: A How-to Manual.* Watershed Organisation Trust (WOTR), Pune.

Kottagoda, S., & Abeysingha, N. (2017). Morphometric analysis of watersheds in Kelani river basin for soil and water conservation. *Journal of the National Science Foundation of Sri Lanka*.

Luo, W. (2000). Quantifying Groundwater-Sapping Landforms With a Hypsometric Technique. *Journal of Geophysical Research Atmospheres*.

Manjare, B. S. (2015). Prioritization of sub watersheds for sustainable development and management of natural resources: An integrated approach using remote sensing and, GIS techniques. *16th Esri India User Conference 2015*. ESRI.

McKee, T. B., Doesken, N. J., & Kleist, J. (1995). Drought Monitoring with Multiple Time Scales (English). *American Meteorological Society*.

Nag, S. (1998). Morphometric analysis using remote sensing techniques in the chaka sub-basin, purulia district, West Bengal. *Journal of the Indian Society of Remote Sensing*.

Nasery, V. (2011). *Biogas for rural communities.* Center for Technology Alternatives for Rural Areas, IITB.

National Geographic Education. (n.d.). *Encyclopedia Entry - Watershed*. Retrieved from education.nationalgeographic.org: https://education.nationalgeographic.org/resource/watershed/

NITI Aayog. (2021). *Compendium of Best Practices in Water Management 2.0.* National Institution For Transforming India (NITI) Aayog.

Press Information Bureau. (2017). *Shortage of Water.* Press Information Bureau, GOI.

Rajendran, K. (2004). Dairy co-operatives and milk marketing in India: Constraints and opportunities. *Journal of Food Distribution Research*.

Rao, K. D., & Kumar, D. S. (2004). Spatial Decision Support System for Watershed Management. *Water Resources Management*.

Santora, M., & Wilson, R. (2008). Resilient and Sustainable Water Infrastructure. *American Water Works Association Journal*.

Shekar, P. R., & Mathew, A. (2022). *Morphometric analysis for prioritizing sub-watersheds of Murredu River basin, Telangana State, India, using a geographical information system.* Journal of Engineering and Applied Science.

Shekar, P. R., & Mathew, A. (2024). Morphometric analysis of watersheds: A comprehensive review of data sources, quality, and geospatial techniques. *Watershed Ecology and the Environment*.

Shiferaw, B., & Reddy, V. R. (2008). Community watershed management in semi-arid India: The State of Collective Action and its Effects on Natural Resources and Rural Livelihoods. *Collective Action and Property Rights for Sustainable Development*.

Singh, V., Bhadauria, P. K., Kashyap, P. S., & Verma, R. (2022). Assessment from Drought Perspective for Bundelkhand Region, India. *International Journal of Environment and Climate Change*.

Suhag, R. (2018). *CAG Audit Report Summary - National Rural Drinking Water Programme.* PRS Legislative Research.

The National Statistical Office (NSO), Ministry of Statistics and Programme Implementation (MoSPI). (2023). *Second Advance Estimates of National Income, 2022 - 2023.* The National Statistical Office (NSO), Ministry of Statistics and Programme Implementation (MoSPI).

The World Bank. (2023). *How is India addressing its water needs?* Retrieved from https://www.worldbank.org/en/country/india/brief/world-water-day-2022-how-india-is-

DOI10.5595/001c.142692

addressing-its-water-needs#:~:text=Communities%20lead%20India's%20groundwater%20conservation%20efforts&text=The%20country%20has%2018%20percent,water%2Dstressed%20in%20the%2

United States Environmental Protection Agency. (2006). *Sustaining Our Nation's Water Infrastructure.* United States Environmental Protection Agency.

Wang, G., Mang, S., Cai, H., & Liu, S. (2016). Integrated watershed management: evolution, development and emerging trends. *Journal of Forestry Research*.

World Health Organization. (n.d.). *Drought*. Retrieved from https://www.who.int/health-topics/drought#tab=tab_1

World Meteorological Organization. (WMO). (2021). *2021 State of Climate Services: Water.* World Meteorological Organization.

Youssef, A. M., Pradhan, B., & Hassan, A. M. (2010). Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery. *Environmental Earth Sciences*.