Assessment and restoration of water bodies at four sites maintained by the Archaeological Survey of India

Project led by
Bisleri International Pvt. Ltd.

Technical Report prepared by
IPCA Centre for Waste Management and Research
TERI School of Advanced Studies

Assessment and restoration of water bodies at four sites maintained by the Archaeological Survey of India

An Industry-Academia technical collaboration under the CSR activities of Bisleri International Pvt. Ltd. for rejuvenation of water bodies at ASI sites

Suggested format for citation

Kansal A, Chaudhuri RR, Vishwakarma CA, Vijhani A, Pandey S
Assessment and restoration of water bodies at four sites maintained by the Archaeological Survey of India, November 2025, BISLERI and ICWMR, TERI SAS

ISBN (Digital download and online): 978-81-685445-6-7

This report is a product of ICWMR, TERI SAS-Bisleri collaboration on water sustainability. Effort has been made to ensure accuracy of information, data, grammar, and language, with due acknowledgment of the sources.

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Executive Summary

Findings on Water Body Degradation

The assessment of four ASI water bodies revealed two distinct, critical issues driven by their hydrology. The stepwells, Neemrana Baori and Chand Baori (Category 1), face a severe water quantity crisis. Neemrana Baori is perennially dry, and Chand Baori shows a declining water level trend, primarily due to regional groundwater over-exploitation and its specific catchment characteristics. In stark contrast, the ponds—Rani Talab, Padmavati Talab, and Buddha-Buddhi Talab (Category 2)—are plagued by a water quality emergency. All are afflicted by dense, toxic blooms of the cyanobacterium Microcystis aeruginosa, which produces harmful microcystin toxins. This algal proliferation is fuelled by high nutrient loads from their catchments and stagnant water conditions, leading to dangerously high levels of organic matter, turbidity, and suspended solids. The water in the stepwell of Chand Baori exhibits similar water quality issues to those found in ponds.

Comprehensive Methodology for Site Assessment

The study employed a multi-faceted methodological approach to ensure a thorough assessment. This included extensive field surveys conducted jointly by the BIPL and TERI SAS teams from May to August 2025. The teams collected primary data through water and soil sampling, while secondary data were sourced from agencies such as the India Meteorological Department (IMD) and the Central Groundwater Board (CGWB). Advanced geospatial analysis was a cornerstone of the study, utilising Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (DEMs) to delineate micro-watersheds, analyse catchment areas, and map stream networks for each site. Furthermore, long-term rainfall trends from 1995 to 2024 were analysed using the non-parametric Mann-Kendall test and Sen's slope estimator to understand climatic influences. In the laboratory, detailed water quality analyses and treatability studies were conducted to identify pollutants and evaluate remediation strategies.

Solution for Toxic Algal Blooms

The project's most significant finding is the identification of an effective treatment for the harmful algal blooms. Laboratory treatability studies conclusively demonstrated that a synergistic solution of Iodine and Hydrogen Peroxide (HI) is highly effective in controlling Microcystis. The recommended protocol involves two doses of the HI solution, administered seven days apart. This treatment achieved a dramatic 94-97% reduction in algal biomass (Chlorophyll-a) and an 88-96% reduction in BOD across all pond samples, confirming its efficacy and making it the cornerstone of the quality restoration plan.

Implementation Plan for Water Quality Restoration

To operationalise the algal treatment, a detailed implementation strategy is recommended. For the large ponds (Rani, Padmavati, and Buddha-Buddhi Talab), the HI solution should be applied using a paddle boat fitted with aspirator bottles to ensure uniform surface distribution. For the smaller Chand Baori and Buddhi talab, handheld sprayers are sufficient. The treatment should be conducted once a year in March.

Strategy for Groundwater Recharge in Stepwells

For water-scarce stepwells, the primary recommendation is to construct dedicated groundwater recharge structures. Hydrological analysis revealed that while Chand Baori benefits from a larger catchment and its location on the windward side of the Aravalli hills, Neemrana Baori is situated on the rain-shadow leeward side, with a significantly smaller effective catchment, which explains its perennially dry state. The analysis suggests that surface runoff can be harnessed to slowly recharge the aquifers that supply these wells. The project proposes building five such structures: two in the Chand Baori catchment and three for Neemrana Baori. Each structure features a 1.2-meter-high brick wall spanning a monsoon stream, incorporating a filtration pit (containing sand, gravel, and boulders) and a 12-meter-deep perforated borehole that directly channels filtered water into the ground.

Cautious Investment in Water Quantity Augmentation

A critical recommendation regarding the recharge structures is to approach this investment with managed expectations. The report explicitly cautions that the impact on stepwell water levels will likely be minimal, possibly slowing the current rate of decline but not reversing it, due to extensive regional groundwater extraction. Therefore, this intervention is framed as a water stewardship effort rather than a guaranteed solution. Prerequisites include obtaining landowner permissions, as some sites are on private land.

Unified Path Forward and Required Collaboration

The path forward requires a clear, prioritised action plan. The immediate priority is restoring water quality in the ponds, which requires timely procurement of equipment and chemicals to initiate the HI treatment by March 2026. Concurrently, steps should be initiated to secure permissions and tender the civil works for the groundwater recharge structures at the stepwell sites. The successful execution of these recommendations hinges on a collaborative partnership among BIPL, which will fund and drive implementation, the ASI, which must provide site access, manpower and approvals, and TERI SAS, which can offer continued technical oversight. This combined strategy provides a scientifically grounded roadmap for preserving these historic sites.

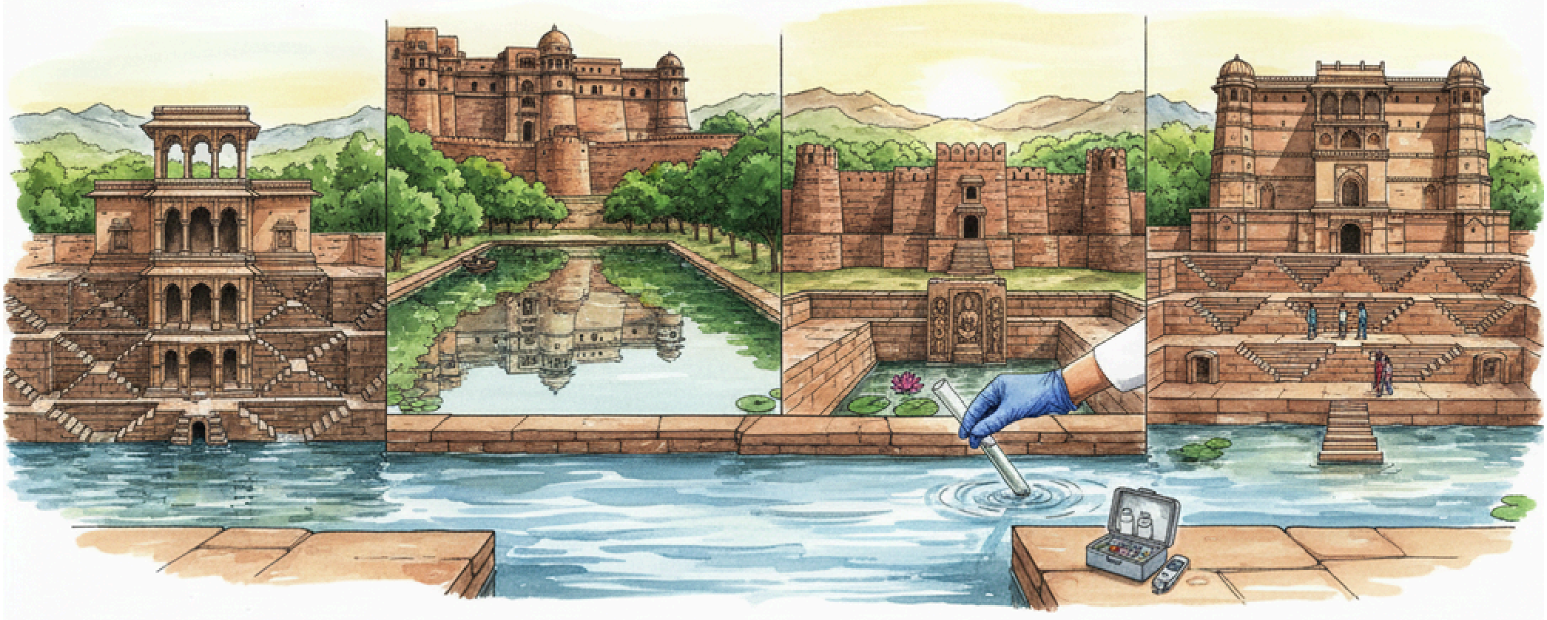
In conclusion, this study presents a clear, two-pronged strategy for rejuvenating the four ASI water bodies. For the ponds at Ranthambore and Kalinjar, as well as the stepwell at Chand Baori, the immediate and primary action is to implement the HI solution treatment plan to eradicate toxic algal blooms and restore water quality. For the stepwells at Neemrana Baori and Chand Baori, the recommended action is to construct targeted groundwater recharge structures, recognising this as a long-term stewardship effort with modest expected gains in water levels. The successful execution of these plans requires close collaboration between BIPL, ASI, and local stakeholders, ensuring that these historic water bodies are preserved as part of India's cultural and environmental heritage.

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction



1.1 Background

In the semi-arid and arid regions of India, such as Rajasthan and the Bundelkhand area (which spans Uttar Pradesh and Madhya Pradesh), small lakes and wells have historically served as vital water sources, particularly in areas without major perennial rivers. These regions are characterised by various water features, including lakes and ponds. Locally, lakes and ponds are referred to as taals or talabs, while those in ground-level depressions are called baoris or baolis. Some of these water sources are specially constructed wells that reach great depths, often tapping into deeper groundwater aquifers. These features are essential and reliable sources of water in otherwise dry areas. *In this report, pond, taal, and talab are used synonymously, and similarly, stepwell, baori, or baoli are similar terms.*

In these semi-arid regions, annual rainfall typically ranges from 500 mm to 800 mm. The landscape features the Aravalli Hills on one side and the Vindhya Mountains in Bundelkhand, with depressions and rugged plains extending from the foothills. Despite these challenging conditions, some agricultural activities occur in these areas, contributing to their diverse and uneven topography.

Over the years, tube wells have been drilled to provide water for both irrigation and drinking purposes. Unfortunately, the forest cover in the surrounding hills has diminished, traditional recharge zones have been disrupted, and new land use patterns have emerged. As a result, many water bodies are no longer meeting community needs effectively and are often ignored or abandoned.

While some ponds and baoris have potential for restoration, they require a scientific assessment of the overall water potential in their catchment areas, as this may have changed significantly due to altered water extraction practices. These changes may have compromised the ecological balance of nearby forests and the monsoon streams flowing down from the surrounding hills.

This study assesses the restoration potential of four water bodies, specifically in terms of water quantity and quality. These water bodies are currently maintained by the Archaeological Survey of India (ASI) and have been adopted by Bisleri International Pvt. Ltd. (BIPL) as part of their Corporate Social Responsibility (CSR) initiative. BIPL will implement potential restoration interventions work with the support of relevant stakeholders, including ASI.

The TERI School of Advanced Studies (TERI SAS) assists BIPL by providing technical expertise to identify the necessary and optimal interventions for these sites. Between May- September 2025, a joint team from BIPL and TERI SAS conducted site surveys at three ASI locations in Rajasthan, as well as one site at Kalinjer Fort in the Banda district of Uttar Pradesh, to assess the current conditions of the four selected sites.

The study covered the following sites:

- Chand Baori - Ambaneri in the Dausa district, Rajasthan
- Rani and Padmavati Talab at Ranthambore Fort in the Ranthambore forest, Rajasthan
- Buddha-Buddhi Talab in Kalinjer Fort, Uttar Pradesh

- Neemrana Baori in the Kotputli Behror district, Rajasthan

1.2 Basic description of water bodies

We categorise the sites into two groups based on some common features that they share.

Category 1 includes Neemrana Baori and Chand Baori, both of which are examples of artesian wells. These wells primarily replenish their water from groundwater flows, with a smaller contribution from surface runoff.

Category 2 consists of Rani, Padmavati, and Buddha-Buddhi talabs, which primarily rely on surface runoff for replenishment.

The primary issue affecting the water bodies in Category 1 is insufficient water replenishment, as these wells are nearly depleted. In contrast, the key concern for Category 2 is restoring water quality. Figures 1.1-1.4 depict the sites.

Figure 1.1 *Sample collection at Neemrana Baori*

Figure 1.2 *Sample collection at Chand Baori*

Figure 1.3 *Sample collection at Rani and Padmavati Talab of Ranthambore National Park*

Figure 1.4 *A view of Buddha Buddhi Talab and its water quality*

1.3 Methodological Tools

The key activities include collecting both primary and secondary data, conducting laboratory investigations, performing geospatial studies such as catchment delineation, and carrying out hydrogeological studies and borewell surveys. The overall methodology is illustrated in Figure 1.5.

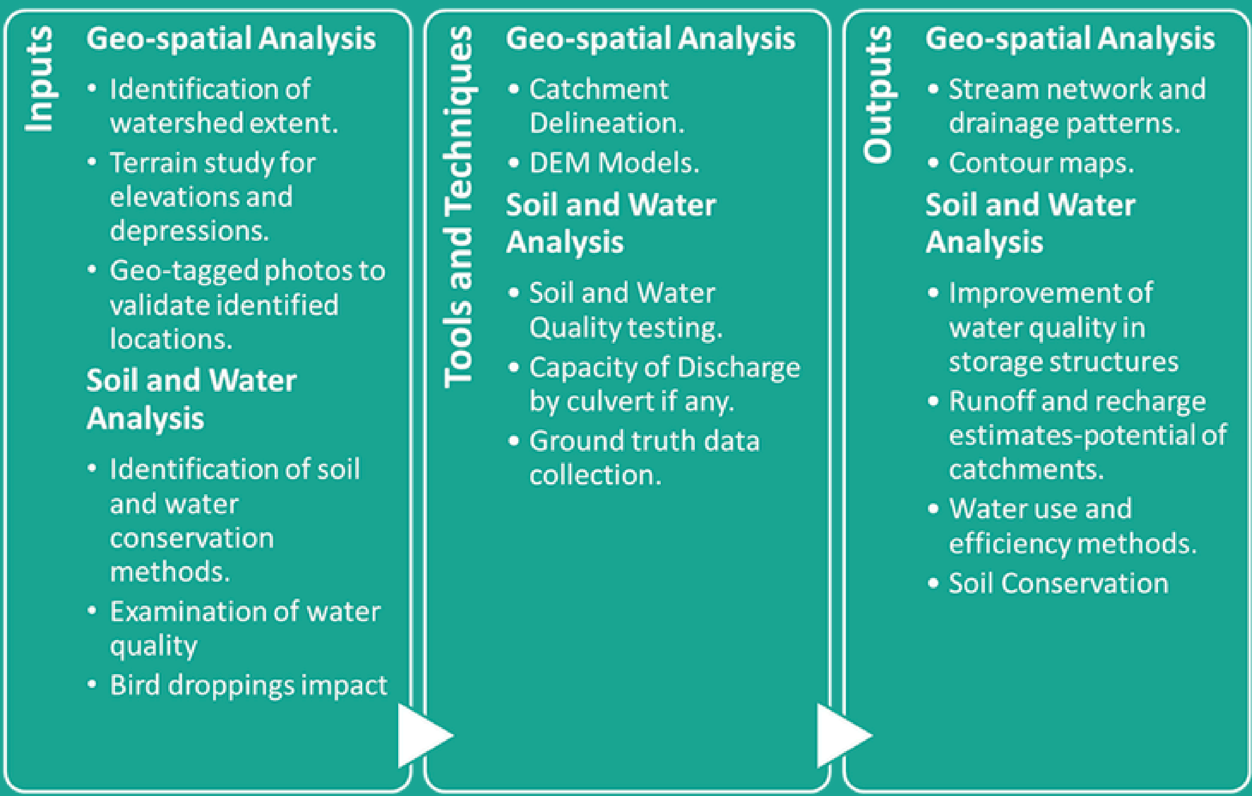


Figure 1.5 *Methodological framework of the study*

The necessary inputs for soil and water analysis, as well as for geospatial analysis prior to the monsoon, have been gathered through site visits and obtained from the India Meteorological Department (IMD), the Central Groundwater Board (CGWB), and the Shuttle Radar Topography Mission (SRTM).

1.3.1 Generation of contour lines

Contouring is the most widely used method for terrain mapping. A contour line connects points of equal elevation, while the contour interval represents the vertical distance between these lines. The base contour serves as the starting point for this process. Contour lines on a map provide a visual representation of elevation distribution, enabling analysis of slope gradients and landform features.

For this project, the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global Digital Elevation Model (SRTM DEM) dataset, which has a spatial resolution of

30 meters, was obtained from the U.S. Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/). The contour lines were created using the Contour tool located under the Spatial Analyst toolset in ArcGIS 10.8 software, with a contour interval set at 10 meters.

1.3.2 Pre-processing of DEM dataset for hydrological analysis

Before proceeding with watershed delineation, hydrological corrections were performed using the hydrological toolset of ArcGIS 10.8 software. This step is essential because Digital Elevation Models (DEMs) often contain depressions, referred to as sinks, which can trap and obstruct water flow. To analyse the drainage characteristics of the terrain, the sinks in the DEM dataset were identified, and the fill sink function was applied to create a depression-free DEM.

Once the DEM was hydrologically corrected (creating a filled DEM), the flow direction tool was used to determine the flow direction for each pixel. The numerical values for flow direction range from 1 to 128 (1 is E, 2 is SE, 4 is S, 64 is N and 128 is NE) distributed across eight directions: east, west, south, north, southeast, southwest, northwest, and northeast. Water flows toward the steepest neighbouring cell value (Ibrahim-Bathis & Ahmed, 2014).

Next, the flow accumulation tool was used to compute the cumulative upstream contributing area for each cell, simulating the hydrological behaviour across the terrain. Flow accumulation is a hydrological modelling process that establishes a drainage network based on the flow direction of each cell. The drainage network was then extracted using a conditional function, which considered pixels greater than or equal to a specified threshold determined through a trial-and-error method (Mark, 1983). Different studies employ varying threshold values based on the specific characteristics of the study area (Arnold, 2010; Qin & Zhan, 2012).

After generating the stream networks, the stream-link function was used to establish topological connectivity between the main channels and associated tributaries. Additionally, stream hierarchy was classified using the stream-order function according to Strahler's method. Finally, the pour point was determined at the outlet of the watershed, serving as the foundational input for the final delineation of the watershed.

1.3.3 Rainfall trend analysis

To evaluate the rainfall trend, we obtained a daily gridded precipitation dataset IMD for the period from 1995 to 2024, with a horizontal resolution of 0.25°. We applied the Mann-Kendall Test (MK test) to identify any monotonic upward or downward trends in the rainfall time series (Vijhani et al., 2021). he MK test is a non-parametric method suitable for testing independent and identically distributed data, assuming that the observations are not serially correlated over time.

To quantify the precipitation trend and its magnitude, we utilised Sen's slope estimator. Unlike ordinary least squares, Sen's slope (the Theil-Sen line) is calculated as the median of all pairwise slopes in the dataset (Sen, 1968). Positive values of Sen's slope indicate a consistently increasing trend, while negative values signify a consistently decreasing trend. This method allows us to assess whether the trend is linear or non-linear over time (Sen, 1968).

The Mann–Kendall statistic S is defined by equation 1.1:

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} \text{sign}(x_j - x_k) \qquad \text{...... (1.1);}$$

where, $\text{sign}(x_j - x_k) = 1$ if $x_j - x_k > 0$; $= 0$ if $x_j - x_k = 0$; $=-1$ if $x_j - x_k < 0$;

S is the variance, x is the time series of rainfall, n is the number of data points, and j and k are paired data points.

The variance S, denoted by (σ_s^2) is calculated by the following equation 1.2:

$$\sigma_s^2 = \frac{n(n-1)(2n+5) - \sum_{j-1}^{q} t_j(t_j-1)(2t_j+5)}{18} \qquad \text{.....(1.2);}$$

Where n is the number of data points, q is the number of tied groups in the dataset, and t_j is the number of data points in the jth tied group. Then S and σ_s^2 were used to compute the test statistic Z_s :

$$Z_s = \frac{s-1}{\sigma} \text{ if } S > 0; \quad Z_s = 0 \text{ if } S = 0; \quad Z_s = \frac{s+1}{\sigma} \text{ if } S > 0;$$

A positive and negative S value indicate an upward and downward trend, respectively.

1.3.4 Water quality analysis

A comprehensive study on testing, analysis, and treatability methods to enhance water quality is presented in Chapter 2.

Chapter 2

Restoration of Water Quality- Rani and Padmavati Talab, Buddha-Buddhi Talab and Chand Baori

Figure 2.1 illustrates the water condition as of May-June 2025. The water appears green due to algae. The physical appearance of the ponds indicates that Buddha Buddhi Talab is the worst affected, followed by Chand Baori, Rani Talab, and finally, Padmavati Talab. The water in these ponds remains stagnant for most of the year because there is no outlet, and they are primarily fed by rainwater runoff from the surrounding areas. These conditions are favourable for nutrient accumulation in the ponds, promoting algal growth.

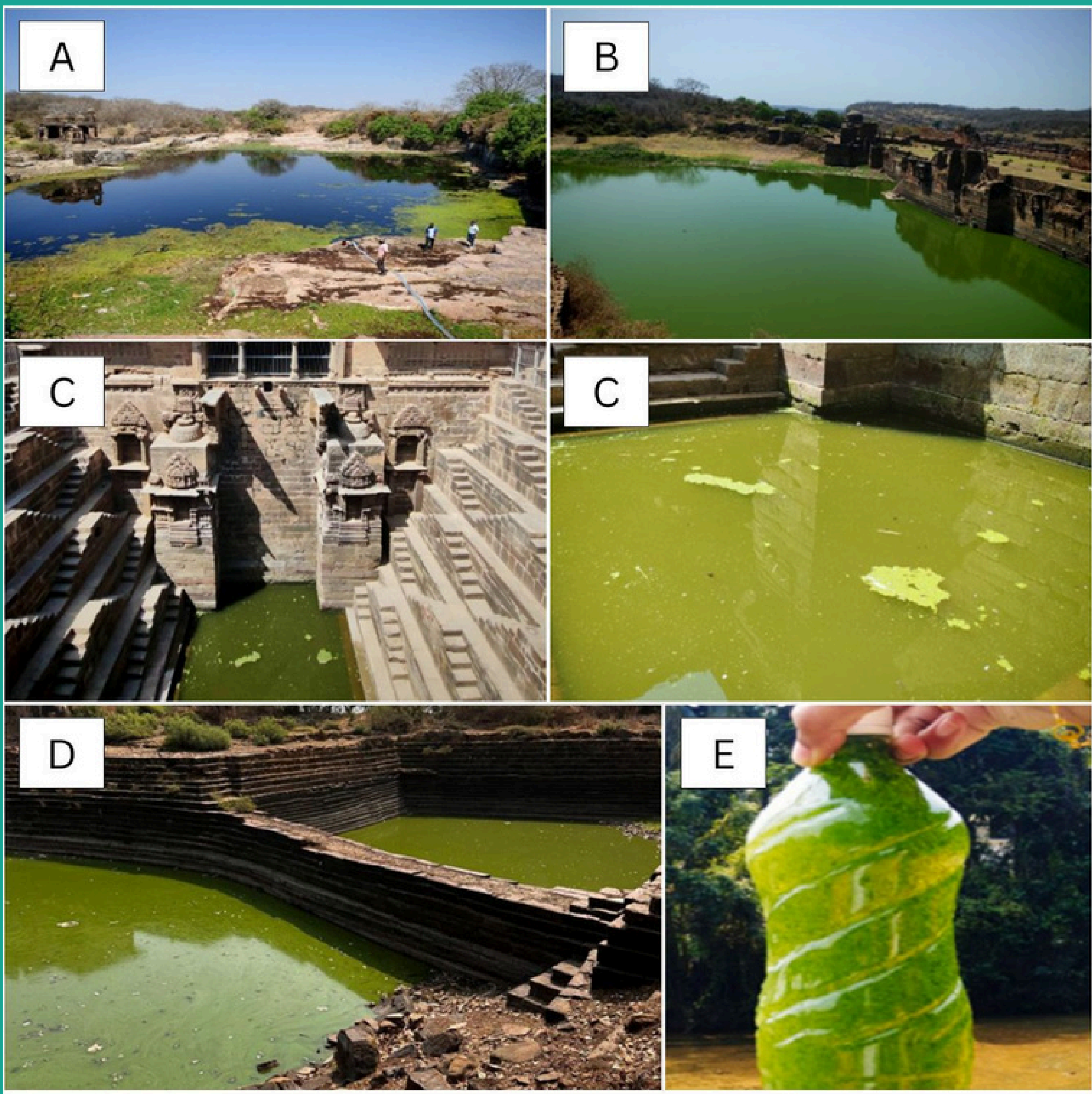


***Figure 2.1** Images of (A) Rani Talab (Ranthambore); (B) Padmavati Talab (Ranthambore); (C) Chand Baori; (D) Buddha Buddhi Talab; (E) Sample collection in the bottle.*

2.1 Scientific investigations

2.1.1 Collection of samples

Twenty litres of water from each pond were collected (grab sampling) and brought to the TERI SAS laboratory for further study. In the laboratory, the samples were stored at 25 ± 1 °C before the commencement of analytical tests.

2.1.2 Characterisation of samples

The physicochemical characteristics of water were determined according to the Standard Methods (APHA, 2005). Identification of the algae was performed using a binocular microscope following the taxonomic key. Chlorophyll-a (C_a) pigment was extracted by using the method of Mackinney (Mackinney, 1941). In brief, the samples were filtered by the membrane filtration unit, and the biomass was washed with distilled water, suspended in 4 mL of 80% methanol and homogenised well. The solution was then centrifuged for 5 minutes. The supernatant was saved, and the absorbance was measured at 663 nm using a UV-Visible spectrophotometer against methanol as a blank, as per equation (2.1).

$$\text{Chlorophyll-a (mg/L)} = A_{663} \times 12.63 \times \left(\frac{Vol_{sample}}{Vol_{methanol}}\right) \quad ......2.1$$

2.1.3 Water quality

As indicated in Table 2.1, the water sample exhibited a higher presence of the cyanophycean community, which may suppress the growth of other phytoplankton due to its ability to produce autotoxins. Increased oxidizable organic matter, CO_2, phosphate, calcium, and various metal ions significantly influence the growth of blue-green algal blooms. Microcystis is the most dominant species present in all water samples.

Table 2.1 *Physicochemical properties of water in Ponds*

Parameter	P1	P2	P3	P4
Predominant species	Microcystis aeruginosa	Microcystis aeruginosa	Microcystis aeruginosa	Microcystis aeruginosa
Cells/mL	425600	347600	42000	263000
Chlorophyll-a (mg/L)	3.26	2.65	0.69	1.89
Colour (Visual)	Dark Green	Dark Green	Light Green	Green
pH	8.2	8.7	7.4	6.8
Alkalinity (mg/L as $CaCO_3$)	74.5	69.8	78.4	84.6
Acidity (mg/L as $CaCO_3$)	12.6	13.2	12.1	14.8
TDS (mg/L)	152	164	162	175
Turbidity (NTU)	4.8	3.5	2.2	3.8
Dissolved Oxygen (mg/L)	2.3	1.2	3.1	2.8
BOD_5 (mg/L)	90	97	67	106
Nitrate (mg/L)	34.1	28.3	22.1	36.1
Phosphate (mg/L)	2.69	3.16	1.1	4.27
Sulphate (mg/L)	13.6	9.8	11.2	10.1
Total Iron (mg/L)	2.1	1.3	1.8	1.7
Chloride (mg/L)	43.6	15.1	12.1	25.4
Fluoride (mg/L)	0.9	0.7	0.6	1.1
Total Hardness (mg/L as $CaCO_3$)	92.4	98.6	48.2	43.1
TSS (mg/L)	137	123	68	89

P1- Buddha Buddhi Talab; P2- Chand Baori; P3- Padmavati Talab; P4 Rani Talab

Most of the chemical parameters mentioned in Table 2.1 are within the reference limits for Class B water bodies as defined by the CPCB, except for biochemical oxygen demand (BOD_5), turbidity, and TSS. A higher concentration of Microcystis bloom was confirmed by significantly higher turbidity and TSS values, whose growth can be attributed to the higher phosphate content. Compared with phosphate, nitrate salts were consumed significantly more during Microcystis growth.

2.2 Further discussions on Microcystis

Harmful algal blooms (HABs) occur when colonies of algae grow uncontrollably, producing toxic or detrimental effects on people, fish, shellfish, aquatic mammals, and birds. Under certain conditions, algae can proliferate, and some of these "blooms" produce toxins. The presence of algal blooms can discolour water bodies (NASA, 2025) and reduce carbon dioxide concentrations, which, in turn, raise pH levels (Merder et al., 2023). HABs are becoming an increasing concern in Indian ponds, often driven by factors such as nutrient pollution, water circulation patterns, and climate change (Huisman et al., 2018). These blooms, often dominated by cyanobacteria (commonly known as blue-green algae), can release toxins that are harmful to aquatic life and humans, disrupt ecosystems, and negatively impact water quality.

Among cyanobacteria, the most common species is Microcystis, which produces the toxin microcystin (Nakamura et al., 2003; Sigee et al., 1999). Under a microscope, these organisms appear as spherical cells grouped into colonies, sometimes coated with mucilage (Figure 2.2). This cosmopolitan freshwater cyanobacterium is characterised by its spherical cells that form colonies (Dvořák et al., 2023). Microcystin is associated with liver and kidney damage, leading the World Health Organisation (WHO) to establish a provisional guideline value for microcystin-LR (where L stands for leucine and R for arginine) of 1.0 µg/L in drinking water (USEPA, 2015a; WHO, 2002).

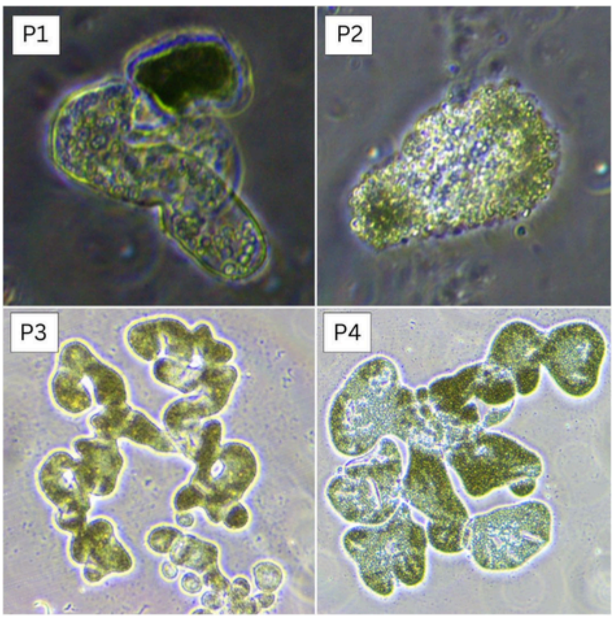


Figure 2.2 *Microscopic image of the Microcystis species as observed in the TERI SAS laboratory*

2.2.1 Factors for the growth of Microcystis sp.

Cyanobacteria require specific factors for optimal biomass growth and maintenance. These include:

1. Eutrophication- The presence of excessive nutrients, such as nitrogen and phosphorus, in water bodies promotes the growth of Microcystis species. Eutrophication and pollution tend to increase with rainfall due to the transport of contaminants and nutrient-rich runoff across freshwater environments (Chirico et al., 2020; Igwaran et al., 2024).

2. The hydrodynamic events of vertical and horizontal mixing relate to fluvial and alluvial processes (Igwaran et al., 2024). Changes in hydrological conditions, such as water levels, significantly influence algal growth, diffusion, migration, and the accumulation of blooms (Cheng et al., 2019).

3. Climate change leads to a higher proliferation rate of HABs. The impact of climate change may increase water acidification, raising dissolved CO_2 levels and enhancing photosynthesis by cyanobacteria. Under such conditions, light penetration into the water body is reduced, leading to the death of aquatic plants that require light for photosynthesis (Kasan et al., 2021).

4. Eco-physiological adaptation strategy- Certain cyanobacterial species, such as Microcystis, can move between nutrient-rich depths and the nutrient-rich upper layers of the water column due to thermal stratification. This adaptability enables them to thrive in diverse nutrient environments.

2.2.2 Characteristics of Microcystis sp.

Microcystin toxins are highly stable and are resistant to proteolytic and hydrolytic degradation, making their control a significant challenge. The life cycle and growth of Microcystis are closely linked to temperature, with peak blooms occurring during the warm summer months and declining as temperatures cool. During the colder winter months, Microcystis becomes dormant in sediments, forming thick-walled akinete that remain viable for extended periods.

Other factors influencing growth include pH, dissolved oxygen, and nutrients. During intense bloom events, the pH of surface water in aquatic systems typically increases, and the accumulation of blooms can release gases that compromise water quality and produce unpleasant odours. Most feeders, such as Mussels, Daphnia, and Tilapia, generally prefer to graze on other phytoplankton rather than Microcystis. This selective grazing results in a phenomenon known as allelopathy, making Microcystis one of the most toxic algae to both humans and aquatic zooplankton.

2.2.3 Management of Microcystis sp.

In the literature, various mitigation strategies for Microcystis sp. have been identified, including physical, biological, and chemical methods. Each method has its advantages and disadvantages. The physical methods consist of flocculation, filtration, and sedimentation. Flocculation involves adding chemicals to clump the algae together, making them easier to remove through filtration or sedimentation. Filtration uses physical barriers, such as screens or membranes, to separate the algae from the water. The effectiveness of each physical method can vary depending on specific conditions, the concentration of algae, and other ecological factors. Biological methods include the use of plant extracts (Jančula et al., 2007) or barley straw, as well as probiotic microorganisms and biotic interactions. Utilising natural predators of Microcystis sp., such as bivalves, can be somewhat successful; however, this approach may lead to hypoxia and acute toxicity that can kill the predators, ultimately providing more nutrients for Microcystis expansion through decay processes. The chemical methods typically involve the use of silver and copper-containing herbicides and algaecides (Gao & Keller, 2021), or surface-modified polystyrene nano-plastics (Zheng et al., 2023). However, the inorganic compounds in these algicides and herbicides can remain as secondary pollutants, posing additional ecotoxicological risks to aquatic ecosystems. Chemicals such as H_2O_2 exhibit selective toxicity towards cyanobacteria but usually promote the growth of chlorophytes under similar conditions (Yang et al., 2018). A study by Ajayan et al. (2011) highlighted the combined use of Iodine and H_2O_2 as an effective treatment for Microcystis sp. Iodine reacts with dissolved organic matter in the pond, producing iodinated disinfection by-products. Meanwhile, HI, formed upon interaction with H_2O_2, helps prevent the creation of these by-products (Shin et al., 2020). The synergistic addition of iodine and H_2O_2 had a significant impact by completely rupturing Microcystis cells and inhibiting their growth (Ajayan et al., 2023). The present study applied this method to control Microcystis growth in the pond.

Action of H_2O_2, I, and the combined I and H_2O_2 solution against the Microcystis bloom

According to the scientific literature,

1. Hydrogen peroxide (H_2O_2) disrupts and impairs the repair of the D1 protein found in the lumen of the thylakoid, which lacks the natural protection provided by chloroplasts present in other types of algae. This rapid turnover of the D1 protein is a critical component of the photosystem. Additionally, beneficial algal species increased following H_2O_2 treatment.

2. Notably, this method of killing cyanobacteria had no negative impact on fish or crustaceans. This is significant for aquaculture ponds that contain live animals.

3. Treatment with H_2O_2 may result in a drop in pH, thus may require the application of a buffer in ponds with low carbonate hardness.

4. Regrowth of Microcystis may occur after the first dose of H_2O_2 after 7 days. Thus, a second dose of H_2O_2 is needed on the 7th day to inhibit regrowth.

5. Iodine reacts with amino acids, nucleotides, fatty acids and hydrocarbons present in bacteria, algae, and fungi, thereby inhibiting DNA synthesis and preventing their growth.

6. Iodine reacts with dissolved organic matter in water to produce iodinated disinfection by-products. The production of byproducts is observed to be avoided by the addition of H_2O_2, owing to the formation of hypoiodous acid (HI).

2.3 Treatability study for Microcystis bloom in pond water

Based on the studies by Ng et al. (2023) and Ajayan et al. (2023), we hypothesise that an iodine-hydrogen peroxide (HI) solution containing equal proportions of 30 mM iodine and 1 M hydrogen peroxide will be effective in reducing Microcystis. We applied 1 mL of this HI stock solution per litre of pond water, administered twice, with an interval of 7 days between doses. Box 1 shows a sample calculation for preparing a 200 mL stock solution.

Four reaction tanks, each with a capacity of 30 litres, were used for the study. Mixing in each tank was achieved with diffused aerators (see Figure 2.3). The tanks were utilised to analyse water samples from four different locations: Buddha Buddhi Talab, Padmavati Talab, Chand Baori, and Rani Talab. On the first day, an initial dose of HI was added to each tank, and the tanks were kept under mixing conditions for one hour after dosing. The reaction tanks were maintained under natural light conditions. Water quality was then monitored on the seventh day by taking a 1-litre sample from each tank. Following this, a second dose of HI was administered to the same tanks and kept for another seven days. Water quality was monitored again on the fourteenth day.

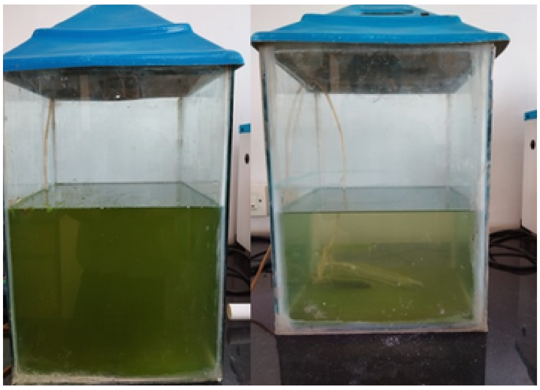


Figure 2.3 *Image of reaction tanks used for treatability studies. The image displays the water from Chand Baori before and after 7 days of treatment with HI in Padmavati Talab water*

Box 1. Preparation of stock solution

Preparation of approx. 100 mL of 1000mM H_2O_2

The H_2O_2 used for the experiment has a density of 1.11 g/mL and a concentration of 30 w/w%.

Molarity of H_2O_2= Density x concentration x 1000 / formula weight = 1.11 g/mL x 0.3 x 1000 / 34.01 = 9.791 M.

Using the formula $N_1V_1 = N_2V_2$; i.e. 9.971 x V_1 = 1 x (100 + V_1) gives V_1 = 10.3 mL. Therefore, approximately 10.3 mL of this product is required to make a 1 M H_2O_2 solution when mixed with 100 mL of water.

Preparation of approx. 100 mL of 30mM I

Molar mass of I_2: Approximately 253.8 g/mol; Moles of I_2 in 30 mM: 0.03 moles; Grams of I_2 needed: 0.03 moles * 253.8 g/mol = 7.614 grams. Thus, 76.1 mL of iodine solution having 10% strength is needed for a 100 mL solution.

2.3.1 Results

Tables 2.2 to 2.5 present the results of treatability studies, while Figure 2.4 displays the corresponding visual images. The water quality of the pond during the summer and monsoon periods shows only minor variations; specifically, the monsoon samples have approximately 10% lower concentrations. However, this difference does not affect the final water quality after HI treatment.

Table 2.2 *Changes in water quality with HI treatment in Buddha Buddhi talab*

Parameter	Raw water	7 days after the first dose		After 14 days, with the second dose administered on 7th day	
			% reduction		% reduction
Chlorophyll-a (mg/L)	3.26	0.85	74%	0.2	94%
pH	8.2	7.8	-	7.6	-
BOD5 (mg/L)	90	34	62%	11	88%

Table 2.3 *Changes in water quality with HI treatment in Chand Baori*

Parameter	Raw water	7 days after the first dose		After 14 days, with the second dose administered on 7th day	
			% reduction		% reduction
Chlorophyll-a (mg/L)	2.65	0.58	78%	0.11	96%
pH	8.7	8.1	-	7.9	-
BOD5 (mg/L)	97	31	68%	5	95%

Table 2.4 *Changes in water quality with HI treatment in Padmavati Talab*

Parameter	Raw water	7 days after the first dose		After 14 days, with the second dose administered on 7th day	
			% reduction		% reduction
Chlorophyll-a (mg/L)	0.69	0.13	81%	0.02	97%
pH	6.8	6.5	-	6.4	-
BOD5 (mg/L)	106	22	79%	5.5	95%

Table 2.5 *Changes in water quality with HI treatment in Rani Talab*

Parameter	Raw water	7 days after the first dose		After 14 days, with the second dose administered on 7th day	
			% reduction		% reduction
Chlorophyll-a (mg/L)	1.89	0.3	84%	0.04	97%
pH	7.4	7.1	-	6.9	-
BOD5 (mg/L)	67	15	78%	3	96%

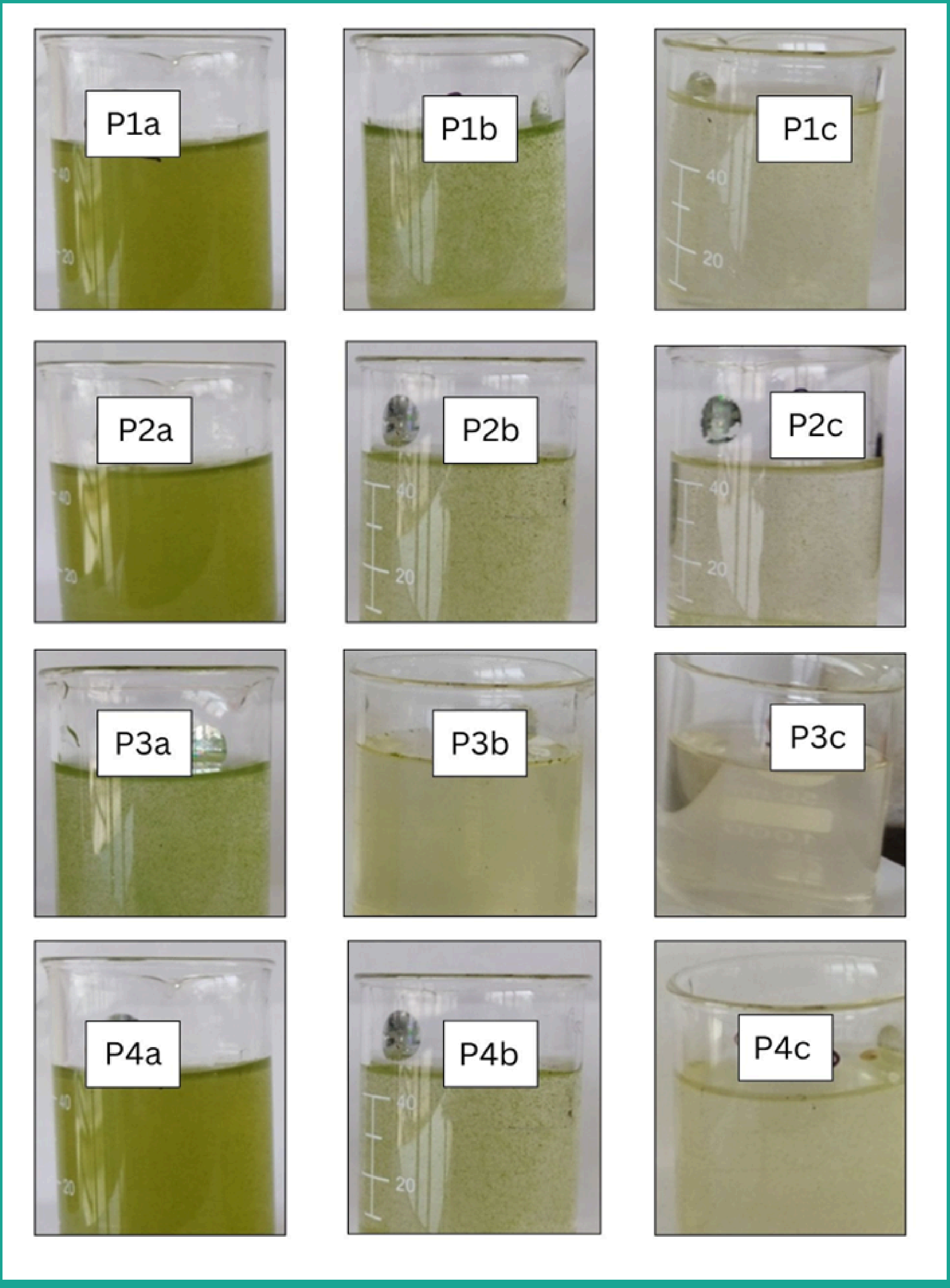


Figure 2.4 *shows visual images of the pond water. P1, P2, P3, and P4 represent Buddha Buddhi Talab, Chand Baori, Padmavati Talab, and Rani Talab, respectively. The labels a, b, and c indicate the condition of the water before treatment, after 7 days following the first*

The results align with existing literature on similar treatment methods. We did not observe any significant drop in pH, as the water has sufficient carbonate hardness, measured above 90 mg/L. We recommend dosing of HI be conducted once a year in March. In larger ponds, it may be necessary to use a boat or other application methods for dosing. Additionally, we recommend creating a buffer zone of 10 to 20 feet around the pond, with taller vegetation to filter excess nutrients. It is also essential to ensure that no bird is feeding within a 100-foot buffer zone around these ponds.

2.4 Recommendations

In large ponds like Rani, Padmavati, and Buddha Buddhi Talab, it is advisable to use a paddle boat to skim off floating solids and apply the HI solution. The movement of the paddle and boat will create adequate mixing conditions at the surface of the ponds. This method is effective since Macrocystis, a type of floating algae, predominantly resides in the top 30 cm of pond water, where over 90% of this species can be found.

We recommend using a paddle boat that can accommodate two people for propulsion. Additionally, the back of the boat should hold two 25-litre aspirator bottles containing the HI solution. An example of this paddle boat and the aspirator bottle is shown in Figure 2.5. Additionally, a 2000-litre capacity Syntax tank will be located near the pond to prepare the stock solution of HI. For small water bodies, such as Chand Baori and Buddhi Talab, we recommend using handheld sprayers, as shown in Figure 2.6. Images of commercially available hydrogen peroxide and iodine solution are given in Figure 2.7.

https://www.tarsons.com/product/narrow-mouth-round-carboy-with-stopcock-pp/

Figure 2.5 *An example of the paddle boat and aspirator bottle*

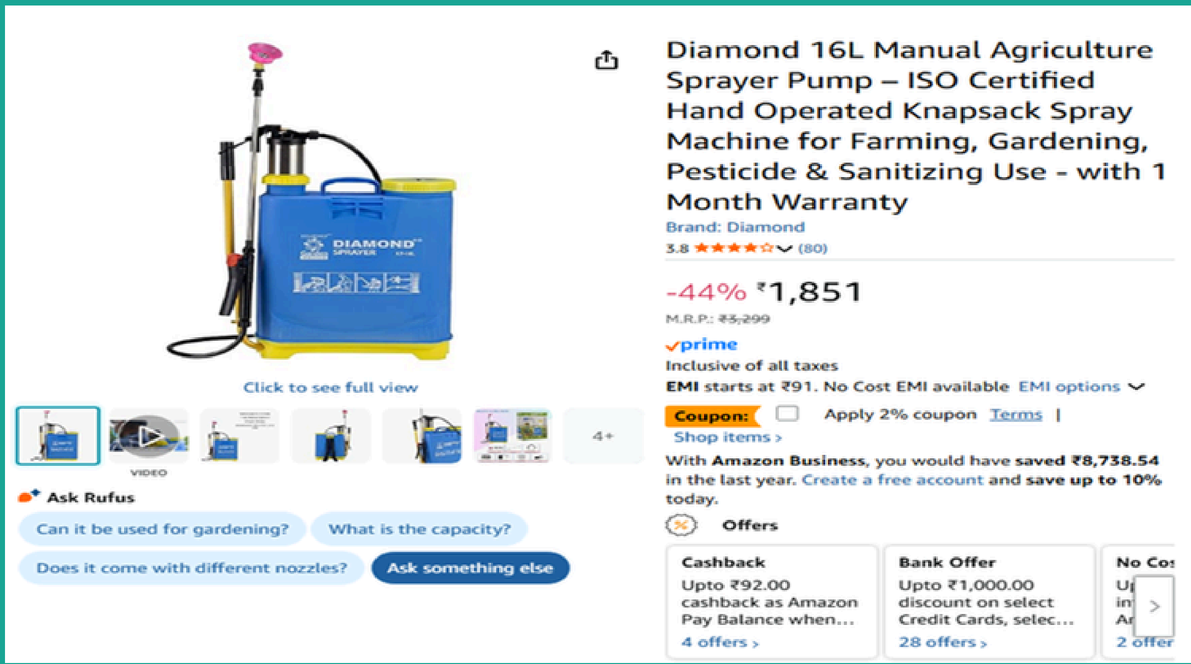


Figure 2.6 *Hand-operated sprayer to administer the HI solution*

Figure 2.7 *Images of commercially available hydrogen peroxide and iodine solution*

We recommend the following procedure for treating water.

From November 2025 to February 2026

1.Construct a 2 m x 2 m x 0.6 m brick masonry platform to place stock solution tanks (plastic drum/syntax tanks) one each near Rani, Padmavati and Buddha Buddhi Talab. These tanks should be provided with a tap at the bottom to draw stock HI solution in the aspirator bottles.

2. Buy paddle boat, chemicals, tanks, sprayers, aspirator bottle etc. as explained in Tables 2.6 and 2.7.

In March in 2026 and 2027

Day 1. Skim out floating solids and moss.

Skimmed material to be disposed of with the solid waste disposal system at the site. Besides, prepare a stock HI solution in tanks. **It is suggested that floating matter be skimmed from the ponds once every quarter.**

Days 2 and 3. Administer the first dose of the HI solution. Carefully calibrate the discharge rate from the aspirator bottles by using a measuring cylinder.

Days 8 and 9. Administer the second dose of the HI solution.

Day 10. Collect water samples for analysis.

2.5 Procurement plan for water quality restoration

The procurement plan for water quality restoration and quantity requirement of H_2O_2 and I_2 are provided in Tables 2.6 and 2.7 respectively. For restoring the water quality, procurement of equipment such as paddle boat, skimming net, aspirator bottle etc. can be carried out through centralised purchase while construction of platform for stock solution tank can be done locally at the intervention sites.

The procurement plan for the purchase of H_2O_2 and I_2 can also be made in advance since quantity of chemicals required annually are already estimated.

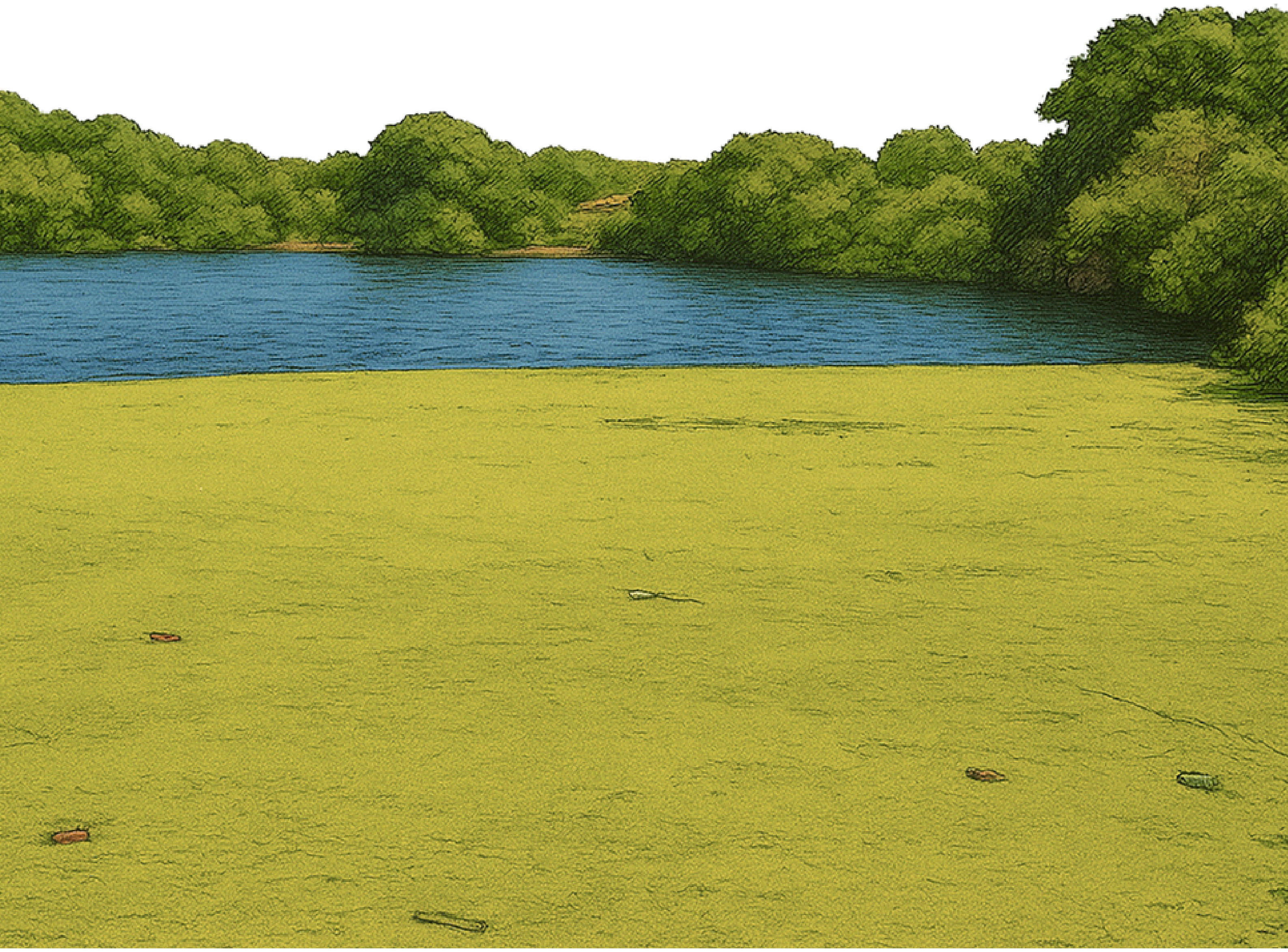
Table 2.6. *Procurement plan for water quality restoration*

Water body	Requirements	Procurement Plan
Rani Talab	Paddle Boat-1 Skimming net -1 Aspirator Bottle (25L)-2 Plastic drum/tank 2000 L with a tap at the bottom - 1	Centralised Purchase
	Platform for stock soln tank	Local work
Padmavati Talab	Paddle Boat-1 Skimming net -1 Aspirator Bottle (25L)-2 Plastic drum/tank 2000 L with a tap at the bottom - 1	Centralised Purchase
	Platform for stock soln tank	Local work
Chand Baori	Skimming net -1 Sprayer Pump -2	Centralised Purchase
Buddha Buddhi Talab	Paddle Boat-1 Skimming net -1 Aspirator Bottle (25L)-2 Plastic drum/tank 1500 Lwith a tap at the bottom - 1 Sprayer Pump - 2	Centralised Purchase
	Platform for stock soln tank	Local work

Table 2.7 *Annual quantity requirement of H_2O_2 and I_2 for water treatment in the first two years*

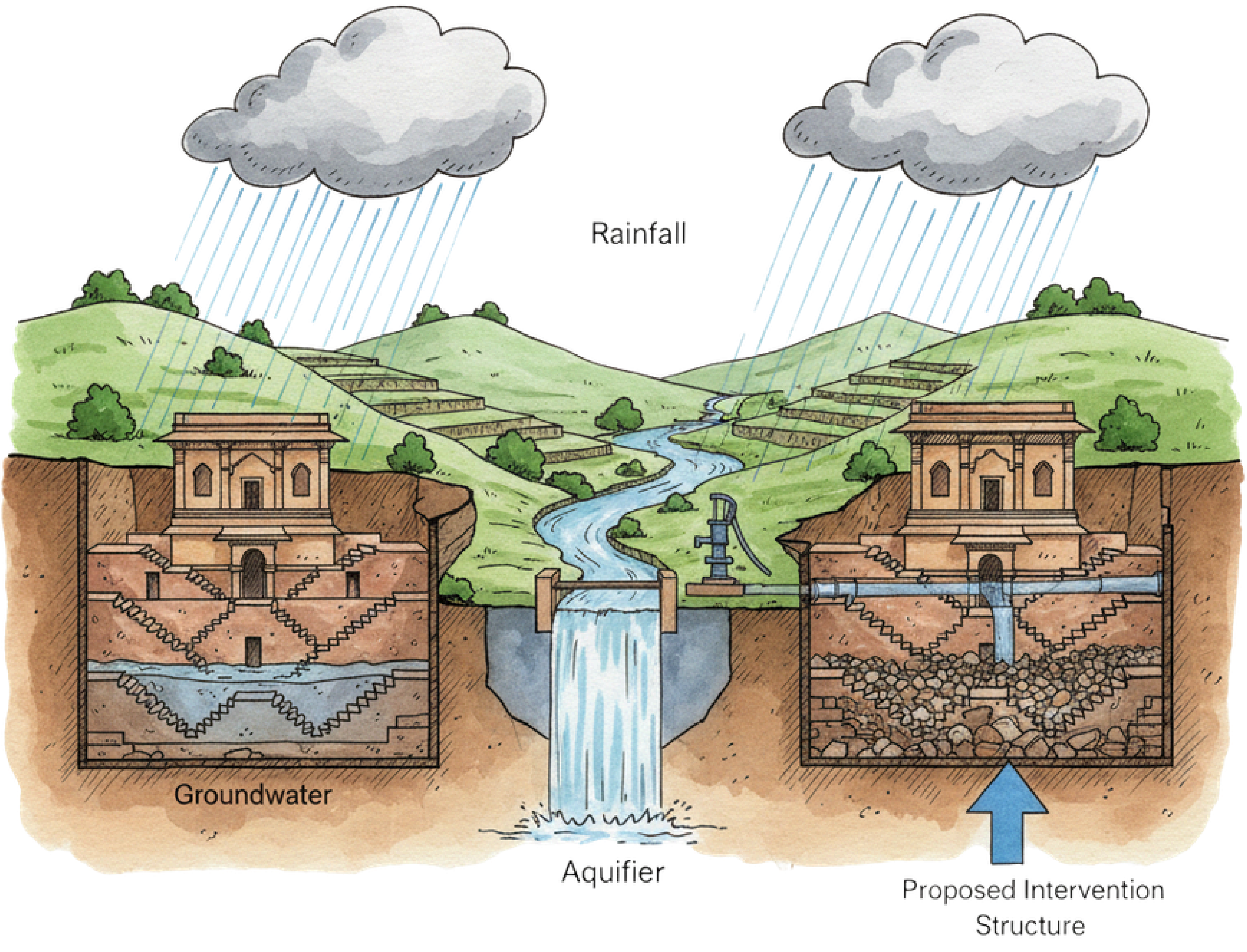
Water body	HI Soln per dose	Quantity (Ltrs) per dose* (adding 10% handling loss)		Annual quantity requirement* (Ltrs)	
		H_2O_2 (7.6%)	I_2(10%)	H_2O_2 (7.6%)	I_2(10%)
Rani Talab	1667	440	74	880.0	148.0
Padmavati Talab	1743	465	77	930.0	154.0
Chand Baori	20	5.5	1.1	11.0	2.200
Buddha-Buddhi Talab	1210	320	55	640.0	110.0

**Quantity may vary according to the purity of the chemical, as explained in Box 1*



Chapter 3

Micro watershed analysis and activities for water quantity augmentation



Stepwells, such as Chand Baori and Neemrana Baori, are situated in arid regions where they primarily rely on groundwater recharge. However, groundwater levels in these areas have declined over the years due to overexploitation of the aquifer. As a result, Chand Baori is experiencing a decreasing trend in water levels, while Neemrana Baori's stepwell has dried up, with water available only for a few days during the monsoon season.

In contrast, the ponds at Buddha Buddhi and Ranthambore forests are located in semi-arid regions and receive adequate recharge from surface runoff, which allows them to function as perennial ponds. Annexure 1 of the report provides a watershed analysis of these sites.

In this chapter, we will provide relevant information about the Neemrana Baori and Chand Baori sites, drawing on a detailed watershed analysis. The focus of this chapter will be on potential activities aimed at enhancing water quantity in these stepwells.

3.1 Rainfall and groundwater situation

Table 3.1 explains the water availability in the Chand Baori and Neemrana Baori watershed. The groundwater depth in the table is reported based on the outcome of the survey conducted in this study, and the stepwell depth is estimated using a GPS instrument.

Even though Neemrana Baori receives an annual average rainfall of 720 mm, it has been observed that the stepwell is located on the rain shadow or leeward side of the Aravalli, thus receiving far less rainfall than the district average of 720 mm. Mann-Kendall rainfall trend analysis (Figures 3.1 and 3.2) indicates that Chand Baori exhibits an increasing rainfall trend, whereas Neemrana Baori displays a declining trend.

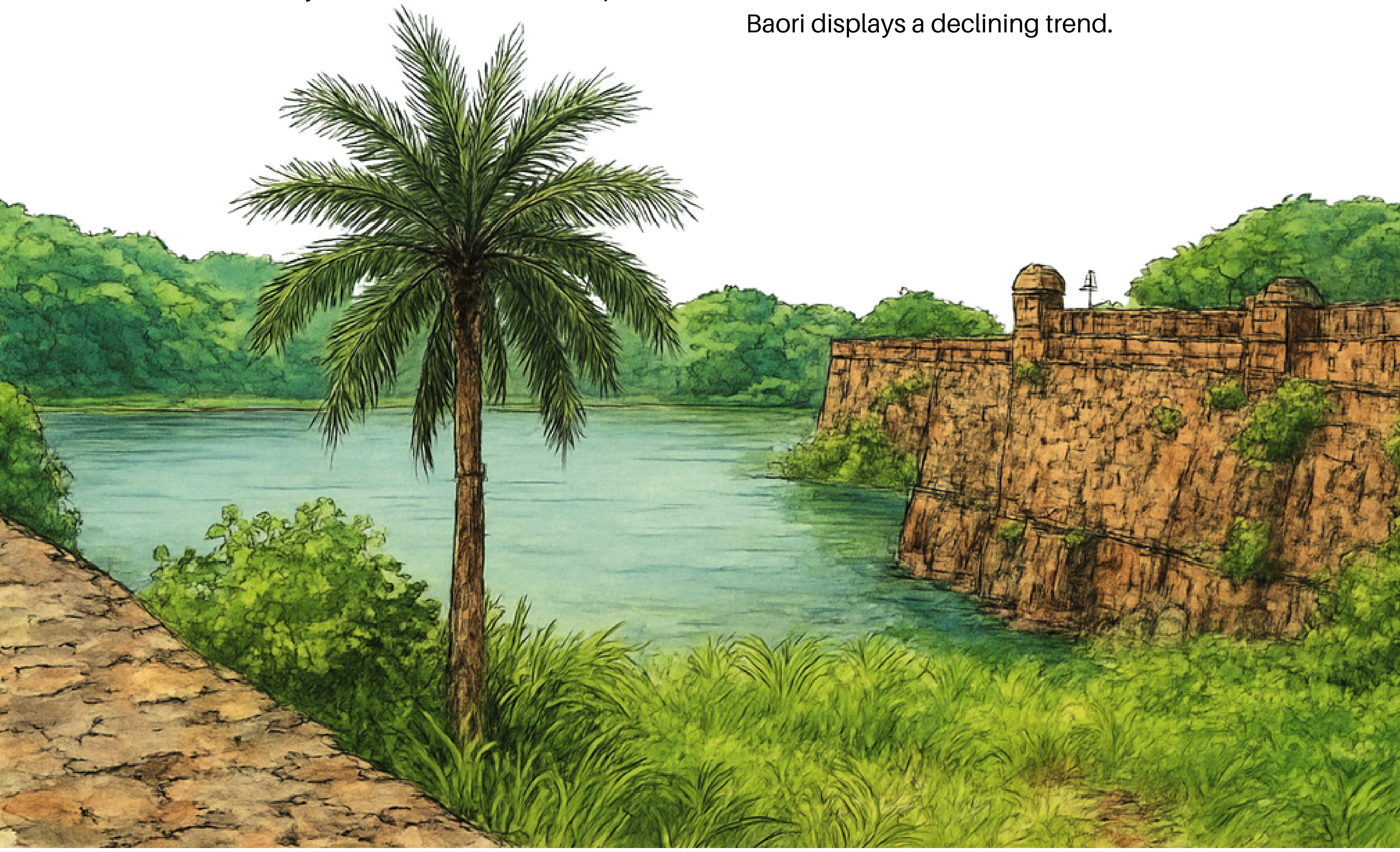


Table 3.1 *A brief profile of the water situation*

Location	Major land-use	Annual rainfall (mm)	GW depth (m)	Depth of stepwell from GL (m)	Other water sources
Chand Baori	Domestic and agriculture	600- 680	45-200	25	Banganga and Sanwan rivers are mostly dry.
Neemrana Baori	Domestic, Industrial and Agriculture	720-780	70-200, near the stepwell, the depth is about 150 m	50	No river, minor streams that flow during rainfall period

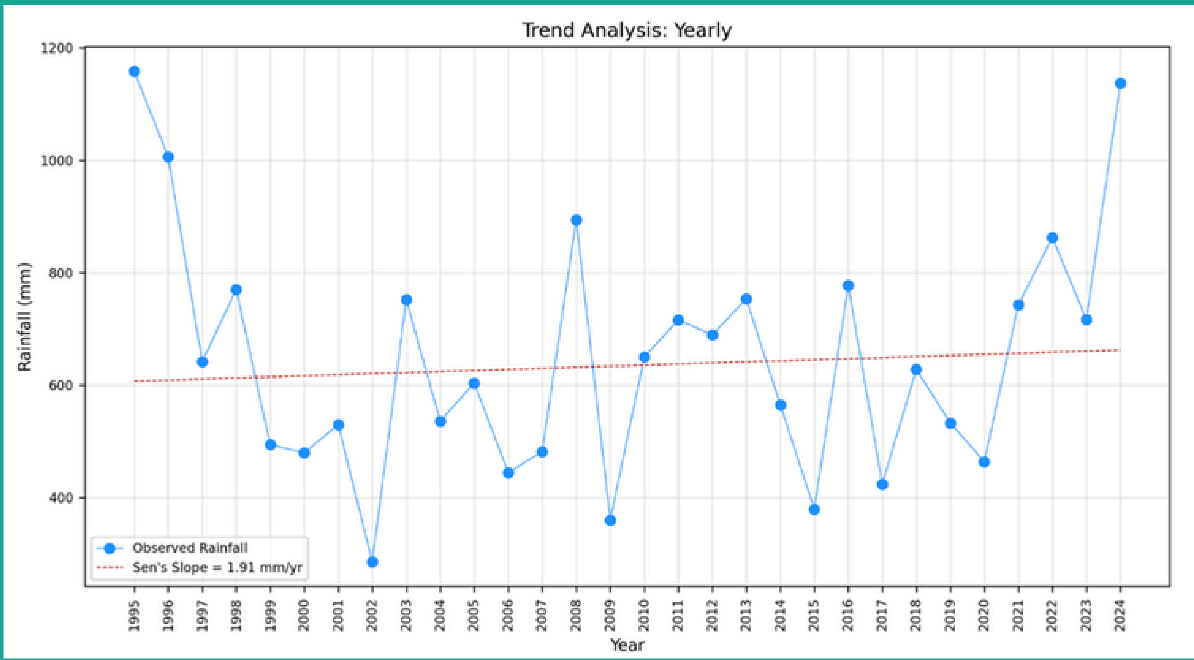


Figure 3.1 *Rainfall trend analysis at Chand Baori*

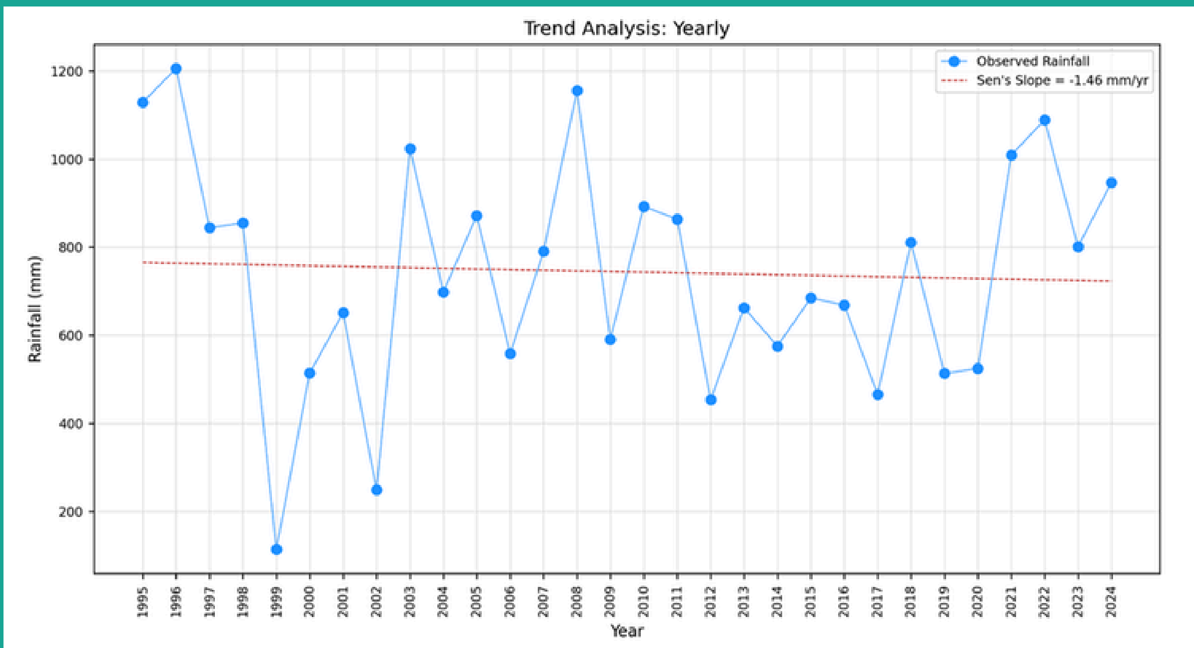


Figure 3.2 *Rainfall trend analysis at Neemrana Baori (Sen's slope is -1.46 mm/year)*

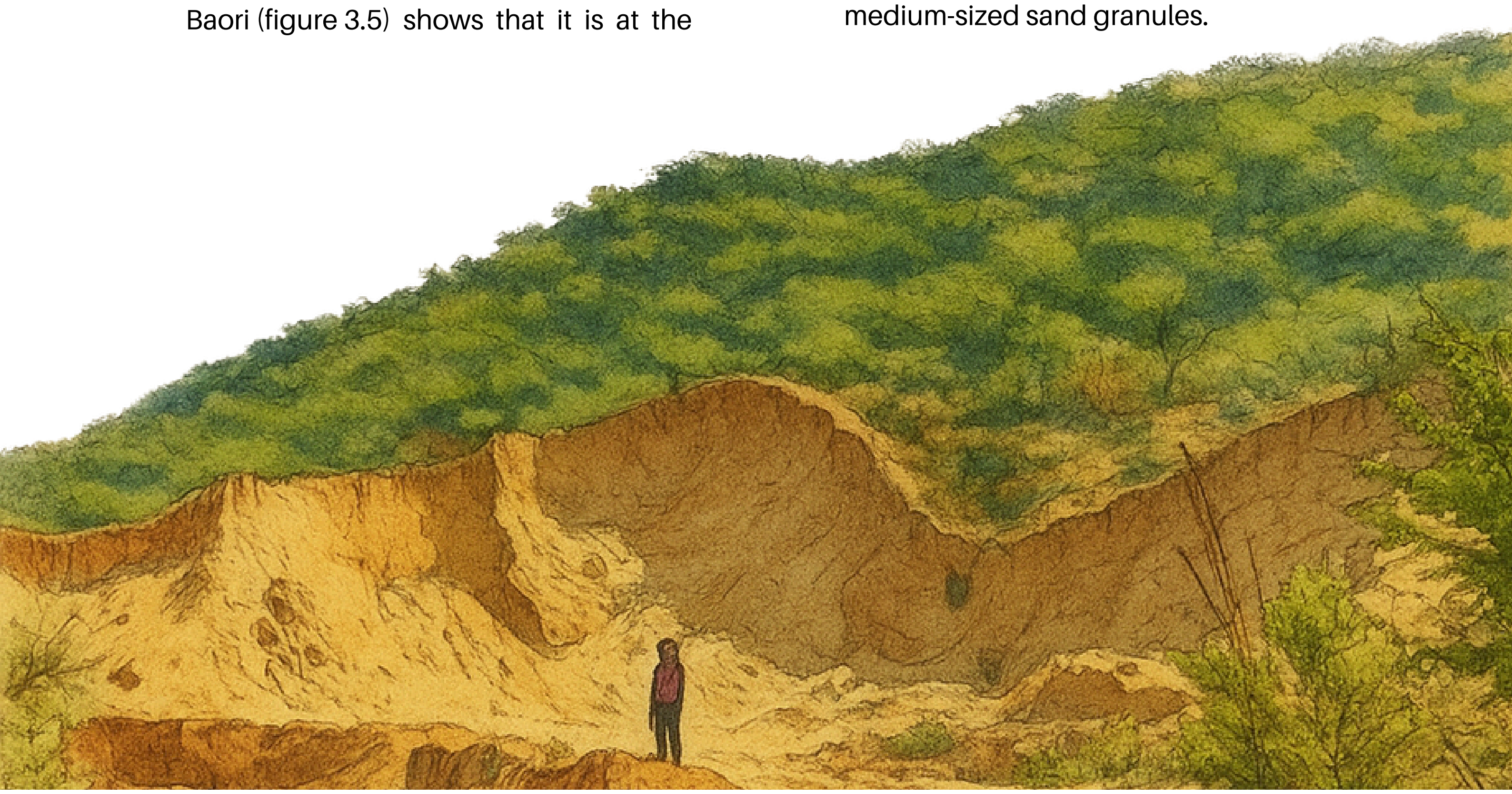
Both regions face water stress and rely on groundwater. However, while Chand Baori has a consistent water supply throughout the year, Neemrana Baori is practically dry for most of the year. The reasons for this difference are as follows:

- Chand Baori is located on the windward side of the Aravalli, which allows it to receive a substantial amount of water from monsoon streams during the season (see Figure 3.3). Additionally, it is near the Banganga and Sanwan Rivers, both of which flow within 300 to 450 meters of the Baori. Even though both rivers are dry, the water that flows during the monsoon fills the soil pores, helping to recharge the aquifer. In contrast, Neemrana Baori is situated on the leeward side of the Aravalli, resulting in significantly less water flow in monsoon streams (see figure 3.4). While the Sahibi River flows nearby, it is dry.

- Digital elevation contour map Chand Baori (figure 3.5) shows that it is at the downstream fringe of the watershed area; thus, the aquifer receives water from a large portion of the watershed. On the other hand, Neemrana is situated on the edge of two micro-watershed boundaries (Figure 3.6), located at the upper edge of the watershed; thus, the aquifer receives water from a relatively small watershed area.

- Chand Baori has a large area to catch and store direct rainwater compared to Neemrana Baori.

- Soil type analysis conducted in this study reveals that Chand Baori has fine sand interspersed with medium sand and silt, resulting in an infiltration rate of 40 mm/hr. In comparison, Neemrana Baori predominantly consists of fine sand and has a nearly identical infiltration rate. However, under saturated conditions during the monsoon season, the soil in Chand Baori may exhibit a slightly better infiltration rate due to the presence of medium-sized sand granules.



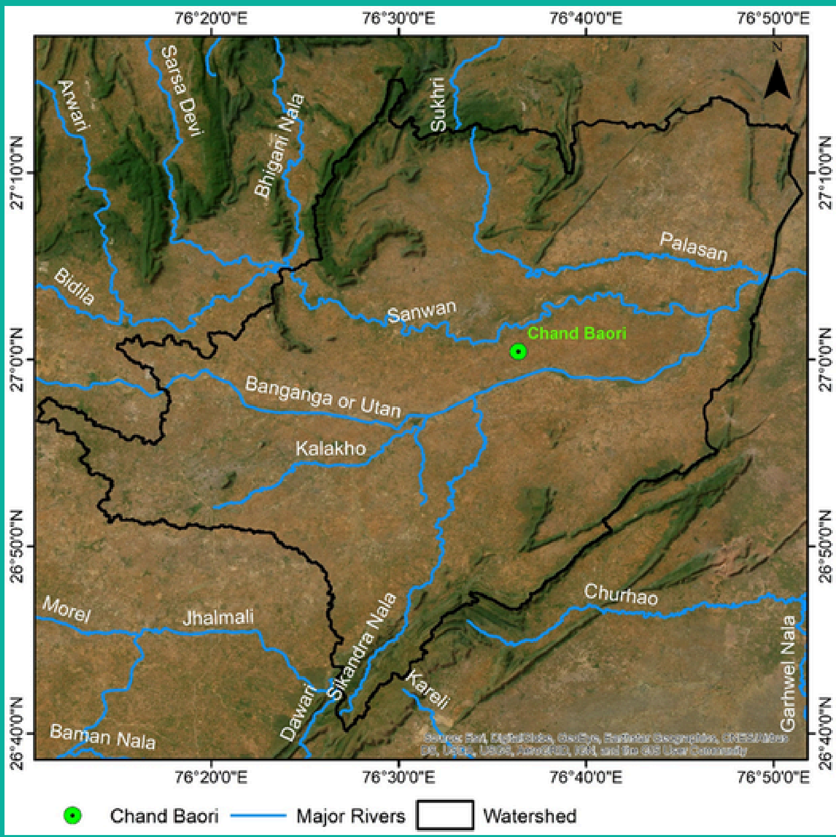


Figure 3.3 Major streams in the catchment area of Chand Baori

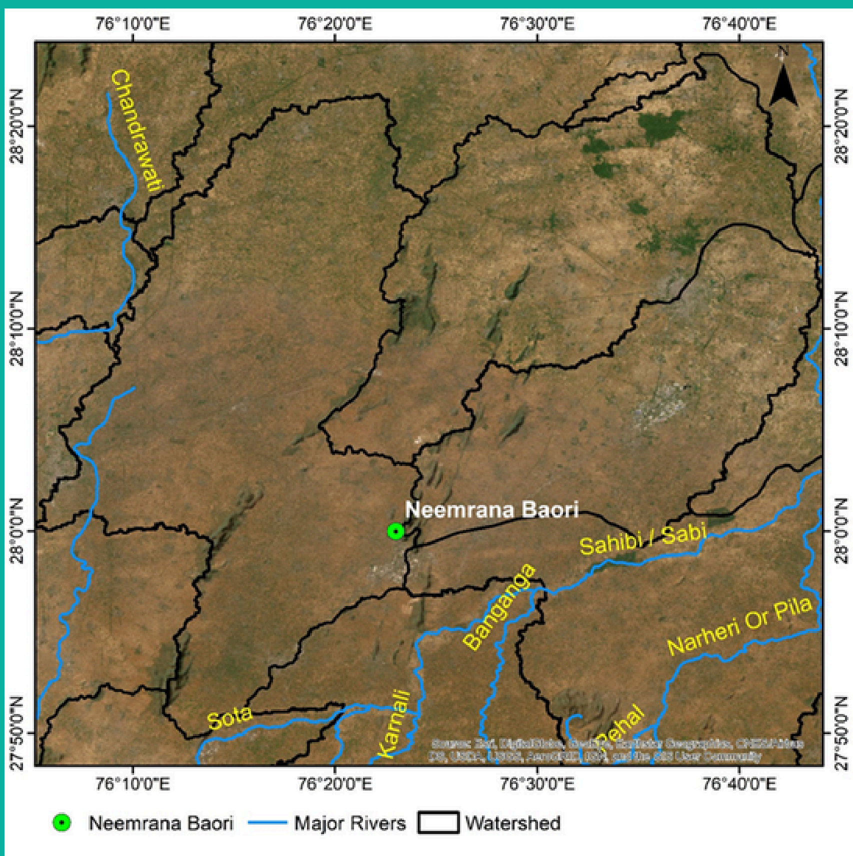


Figure 3.4 Major streams in the Neemrana Baori stepwell catchment

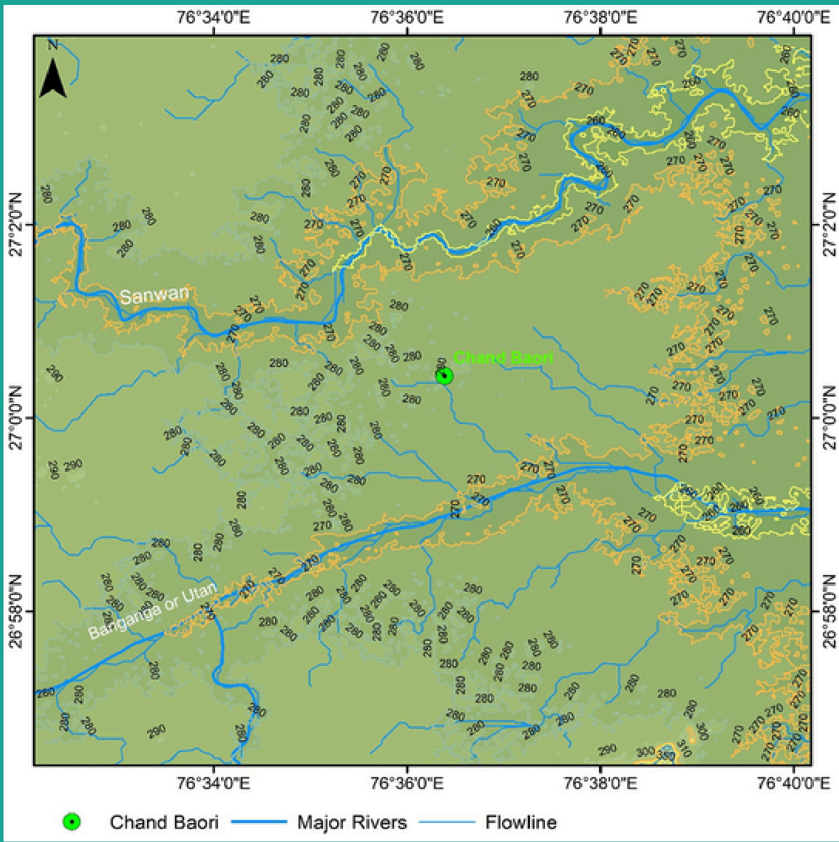


Figure 3.5 *DEM-based terrain analysis and stream network mapping (Enlarged View)*

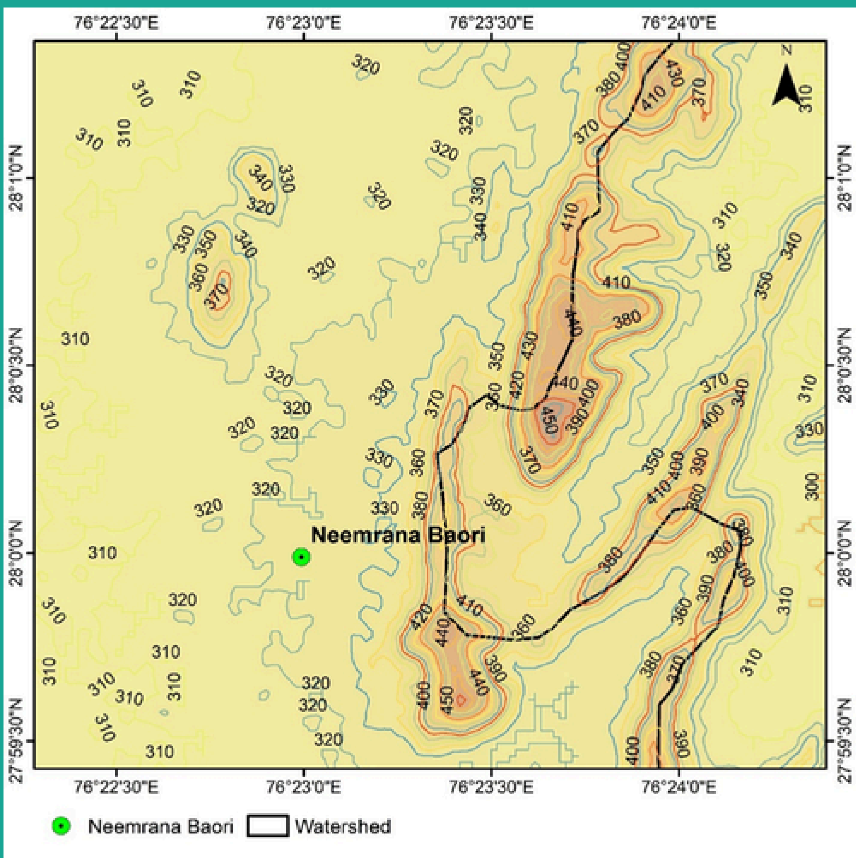


Figure 3.6 *Detailed contour mapping of Neemrana Baori*

Highest Elevation: 450m
Lowest Elevation: 310m

3.2 Recommendations

The only source of water available for stepwell augmentation in these regions is rainwater. While we expect that recharging groundwater through structures in monsoon streams may not lead to noticeable improvements in water levels, these efforts could help slow the rate of groundwater decline. This limited effectiveness is due to the over-exploitation of groundwater for agricultural, domestic, and industrial activities. Additionally, any measures for controlling and utilising groundwater by other sectors are beyond the agency responsible for implementing this project's jurisdiction.

Based on the hydrological analysis, we estimate that the peak flow volume (H-peak hourly rainfall) resulting from a 50 mm/hour rainfall in Neemrana Baori will be approximately 4.97 m^3/s, while in Chand Baori it will be approximately 38 m^3/s. A run-off coefficient of 0.4 has been applied in both cases. As shown in Table 3.2, the incremental amount of water that can be collected annually from the proposed structures is approximately 43,000 litres in Neemrana Baori and approximately 51,000 litres in Chand Baori.

We propose two groundwater recharge structures at Chand Baori and three at Neemrana Baori. Figures 3.7 and 3.8 show the locations of the recharge structures, and Table 3.3 provides the precise locations of these structures. Figure 3.9 gives the civil work details of the recharge structure.

Table 3.2 *Groundwater recharge potential.*

Site	Watershed area (m2)	Rainfall (mm)	Expected runoff (mm)	Incremental recharge from proposed structures (Ltrs)
Neemrana Baori	877144	740.4	518	43,512
Chand Baori	6856470	649.1	450	51,854

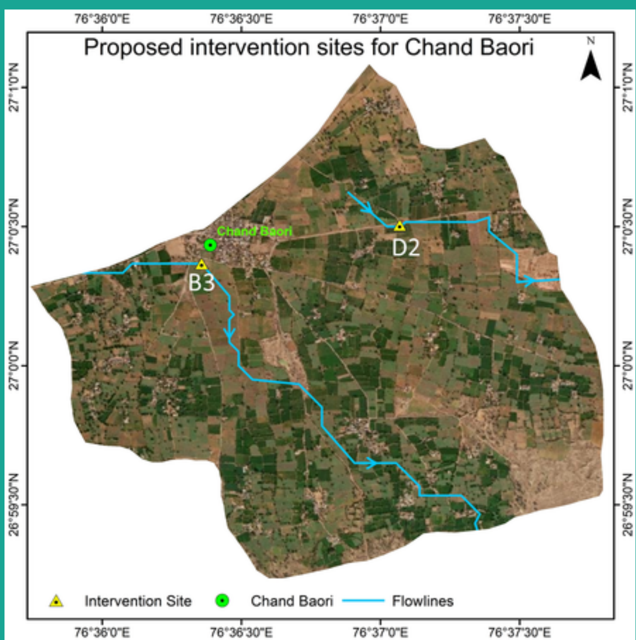


Figure 3.7 *Location of the recharge structure (B3 and D2) at Chand Baori*

__Table 3.3__ Location coordinates of recharge structures

Site	Location ID	Latitude	Longitude	Length (m)
Chand Baori	B3	27.0061	76.6059	4310.81
	D2	27.0084	76.6178	4940.69
Neemrana Baori	1	28.0005	76.3834	465.98
	2 (currently an informal waste dumping site)	28.0003	76.3861	223.60
	3	27.9997	76.3849	509.49

__Figure 3.8__ Location of the recharge structures (1, 2, and 3) at Neemrana Baori

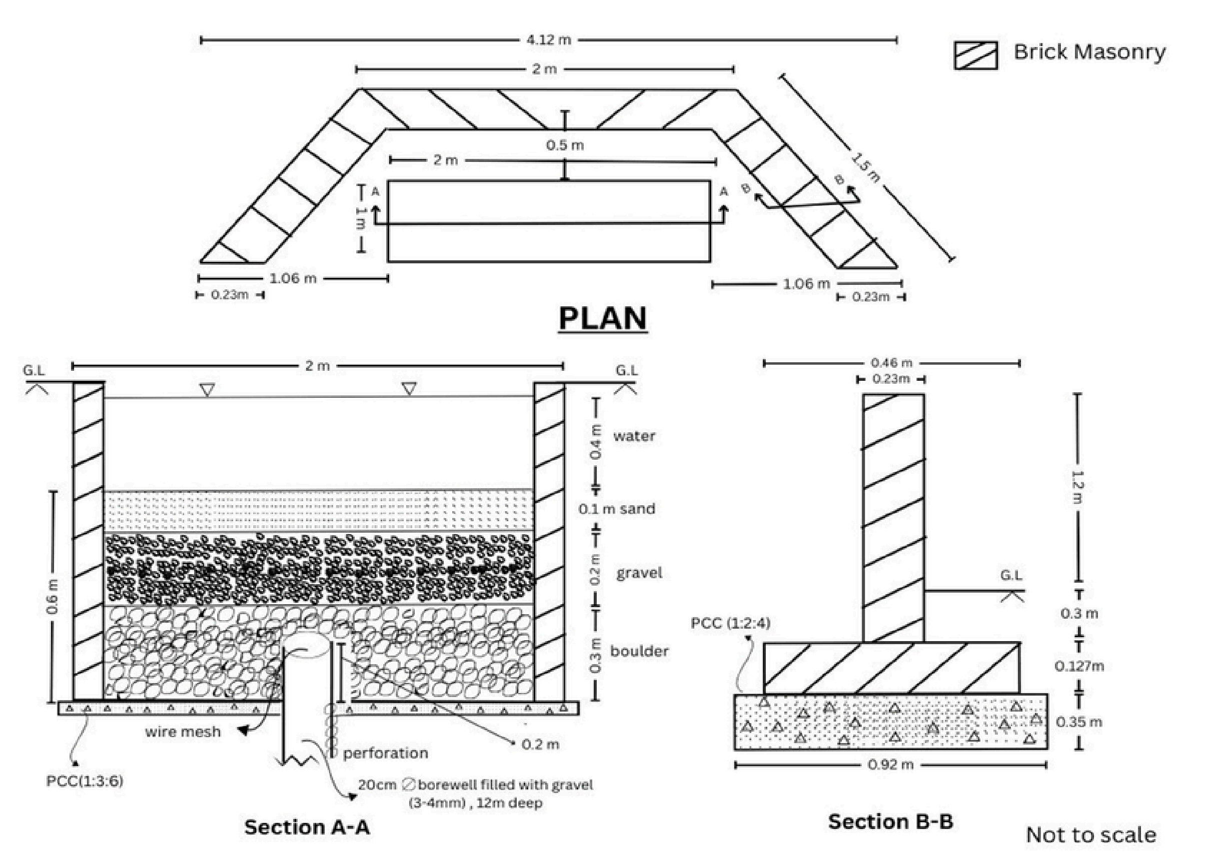


***Figure 3.9** Proposed Intervention Structure for groundwater recharge*

A brick wall is proposed to be constructed at a height of 1.2 meters above ground, with a width of 4 meters, spanning the streams. The design includes a water pit, as shown in section A-A of Figure 3.9, featuring layers of gravel, boulders, and sand with the specified dimensions. Additionally, a borehole with a diameter of 20 cm will be installed, equipped with a wire mesh and perforations. The depth of the borewell is proposed to be 12 meters. The wall section, including the footing, is illustrated in section B-B. The recharge pit should be cleaned of settled sand and silt before the onset of the monsoon and every 15 days during the monsoon period. **Additionally, we propose reviving the pit at the temple near the Chand Baori site, as shown in section A-A of Figure 3.9.**

The material estimate for civil work on one structure is provided in Table 3.4.

The decision to invest in groundwater recharge should be approached with caution.

1. **Obtain Consent:** It is essential to obtain consent from the property owner where the recharge structure will be installed. Although the structure is small—only 1.2 meters tall and covering an area of approximately 6 m^2—permission is still required. For example, in the case of Chand Baori, the location is on private agricultural land, while one of the Neemrana Baori sites has an illegal waste dump.

2. Expected Impact: The impact of groundwater recharge on the water availability in the stepwells is expected to be minimal and may not be easily noticeable. It may only slow the declining trend in water levels at most.

Despite these concerns, we still recommend exploring the possibility of installing the recharge structure as part of water stewardship efforts.

***Table 3.4** Material estimate of recharge structure*

Description of the civil work	Estimated volume (m)
PCC (1:2:4) below the wall	1.61
PCC (1:3:6) as the floor of the pit	0.4
Brick masonry (1:5, cement: sand)	1.4
Excavation work	5.8
PVC pipe (perforated, 20 cm dia)	12 (in meters)
Sand	0.4
Gravel	1.2
Boulder	1.2
Wire mesh (m)	0.04

2

Annexure

Rani and Padmavati Talab- Micro Watershed Analysis

Site description

The Rani Talab and Padmavati Talab are two water bodies situated within the Ranthambore Fort, part of the Ranthambore National Park, approximately 13 km from Sawai Madhopur, Rajasthan. Rani Talab is at an altitude of 451 meters (26° 1' 21.46" N, 76° 27' 14.47" E), while Padma Talab is at 449 meters (26° 1' 8.73" N, 76° 27' 11.51" E) as illustrated in Figure a. Both water bodies are situated near the ridge line, allowing for rapid runoff accumulation during rainfall. The surrounding forest area is sparse due to limited soil and large rocks, resulting in rapid runoff into the water bodies and a consistent water supply throughout the year, despite poor infiltration caused by the rocky terrain.

Findings from Pre-Monsoon investigations

Both Rani Talab and Padmavati Talab have sufficient water during the peak summer months, which is accessed through wells for local use. The vegetation near Ranthambore Fort is sparse because it is located at the highest elevation with minimal soil cover. Much of the soil has already eroded, leading to limited infiltration and groundwater recharge. Consequently, greater emphasis has traditionally been placed on the surface water stored in Rani Talab and Padmavati Talab. Both water bodies appear to be nutrient-rich and contain a significant population of microalgae. For further details, refer to Chapter 2.

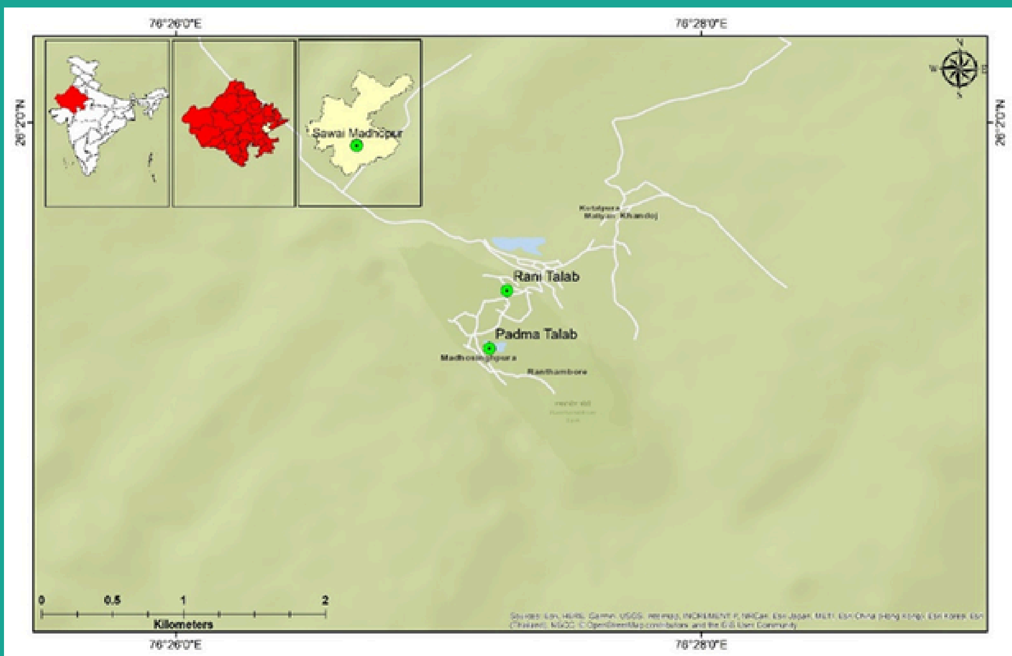


Figure a *Location map of Rani Talab and Padmavati Talab*

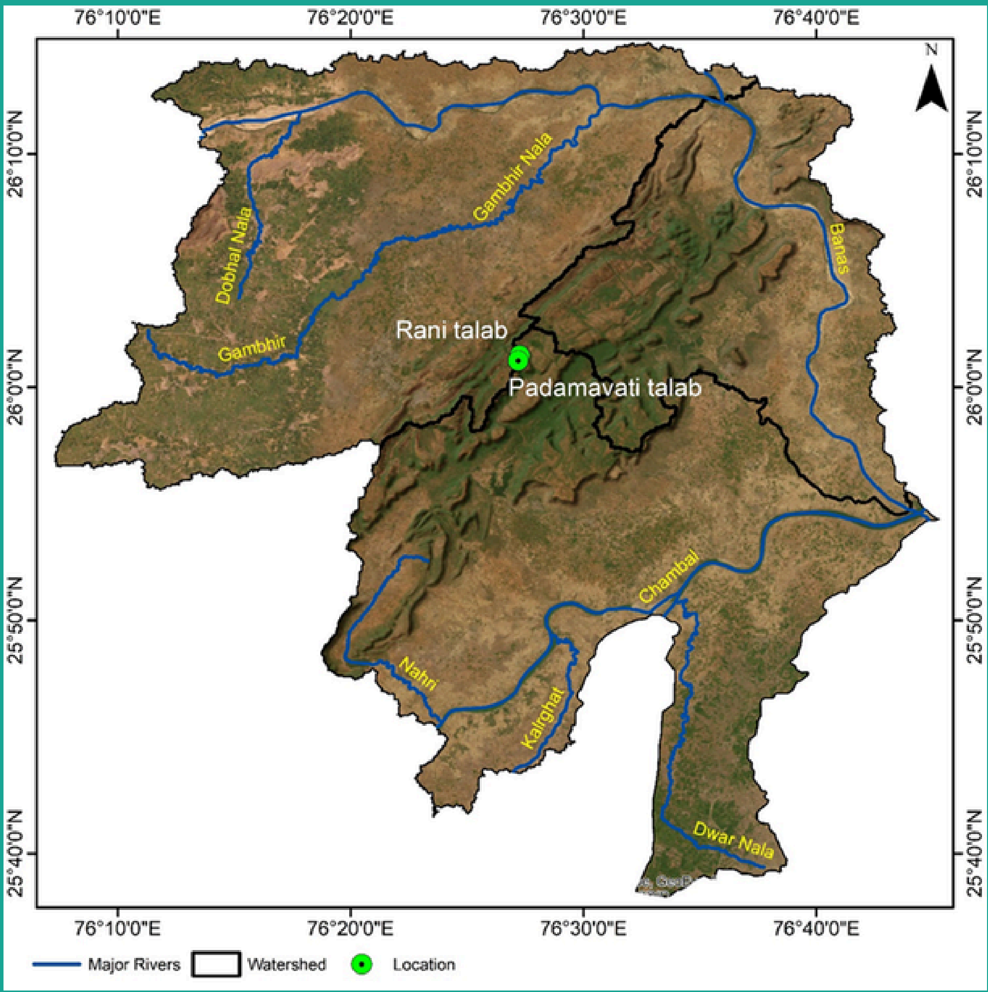


Figure b *Major River in the catchment area*

The watershed analysis utilised SRTM DEM datasets to evaluate the study site's elevation and streamflow into two nearby water bodies, both situated at roughly 449 meters elevation (see Figure b). The DEM revealed limited flowlines leading to these bodies (refer to Figure c).

In terms of rainfall, the Sawai Madhopur district, which receives high annual precipitation averaging 771 mm (predominantly between 700 and 800 mm), ensures adequate runoff to keep the water bodies perennial, with rare drought years (see Figure d). Additionally, the hard rock geology below prevents water seepage.

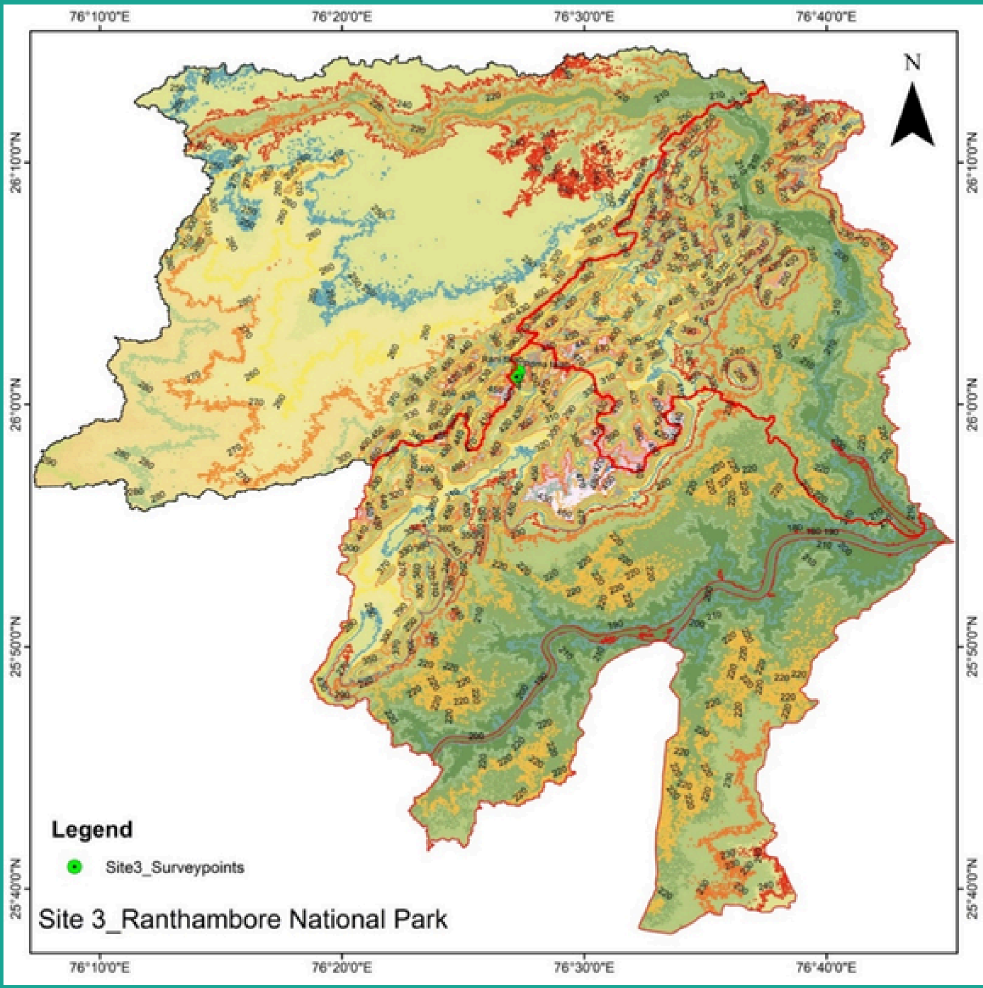


Figure c DEM-based contour mapping

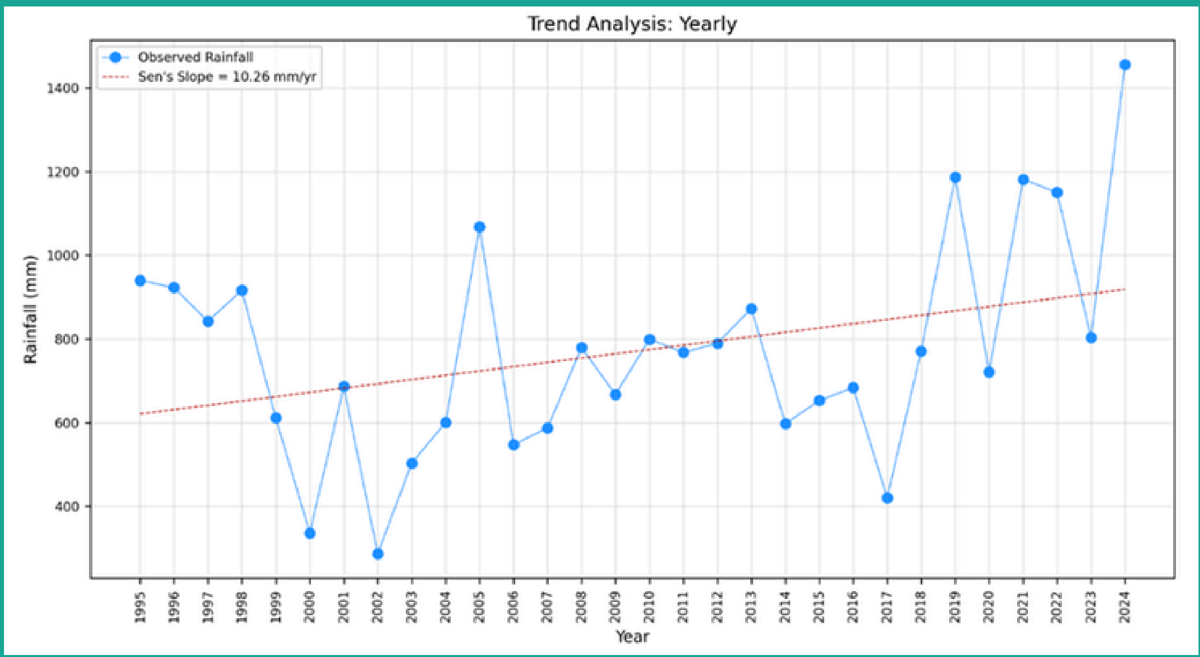


Figure d *Trend analysis for yearly rainfall at Ranthambore*

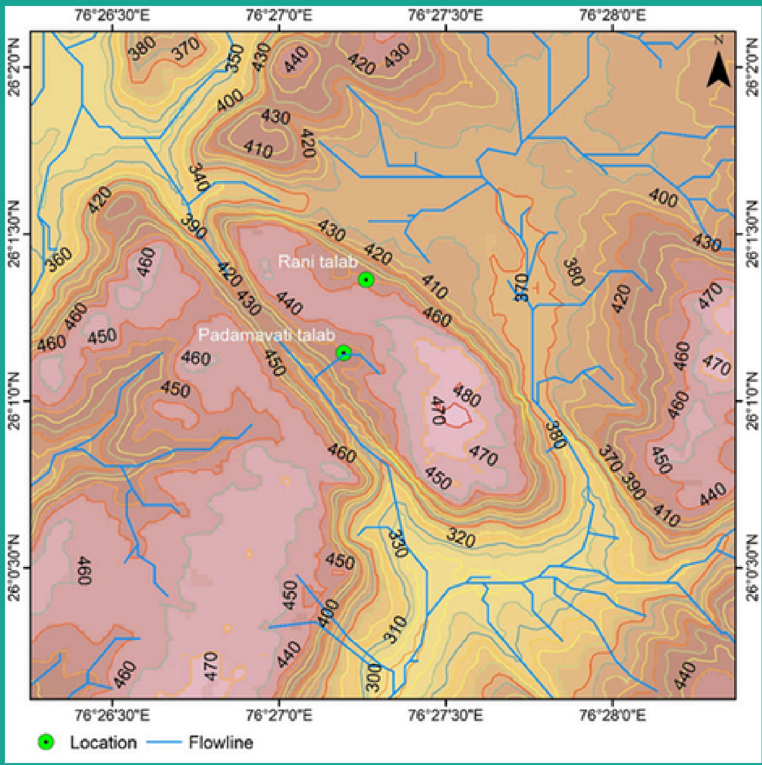


Figure e *DEM-based terrain analysis and stream network mapping (enlarged view)*

The Ranthambore forest contains various water bodies fed by stream flowlines from the Ranthambore fort (see Figure e). These flowlines enhance the forest's water supply during rainfall but also lead to runoff from the two waterbodies within the fort area.

During our site visit, we noted that both waterbodies had sufficient water but faced challenges related to water quality. Samples were collected for assessment and recommendations. Water availability isn't a concern due to adequate rainfall; however, a water treatment plan is necessary for rejuvenating the waterbodies, as detailed in Chapter 2.

Buddha Buddhi Talab Micro Watershed Analysis

Site description

Buddha Buddhi Talab is situated within Kalinjar Fort in the Banda district of Uttar Pradesh on a flat-topped hill of the Vindhya range, at an elevation of 283 meters as illustrated in Figure f. The Talab itself is 373 meters high (24°59'54.77"N, 80°29'26.51"E) and is the highest point of the Table Mountain range. The area features several water bodies but has less fertile soil and sparse vegetation. The fort is situated 93 kilometers from the Khajuraho Group of Temples and is accessible by road.

The site features two talabs, separated by a wall, which are primarily replenished by rainwater from their catchment area. The average annual rainfall is approximately 1,000 mm, ranging from 800 mm to 1,200 mm (Figure g), which is considered sufficient. The convergence of streamlines ensures a steady water supply in the talab. Most water flows from the ridge to the streams below the fort, with a 50-meter elevation difference and a distance of around 100 meters, facilitating water accumulation during rainfall (Figures h and i).

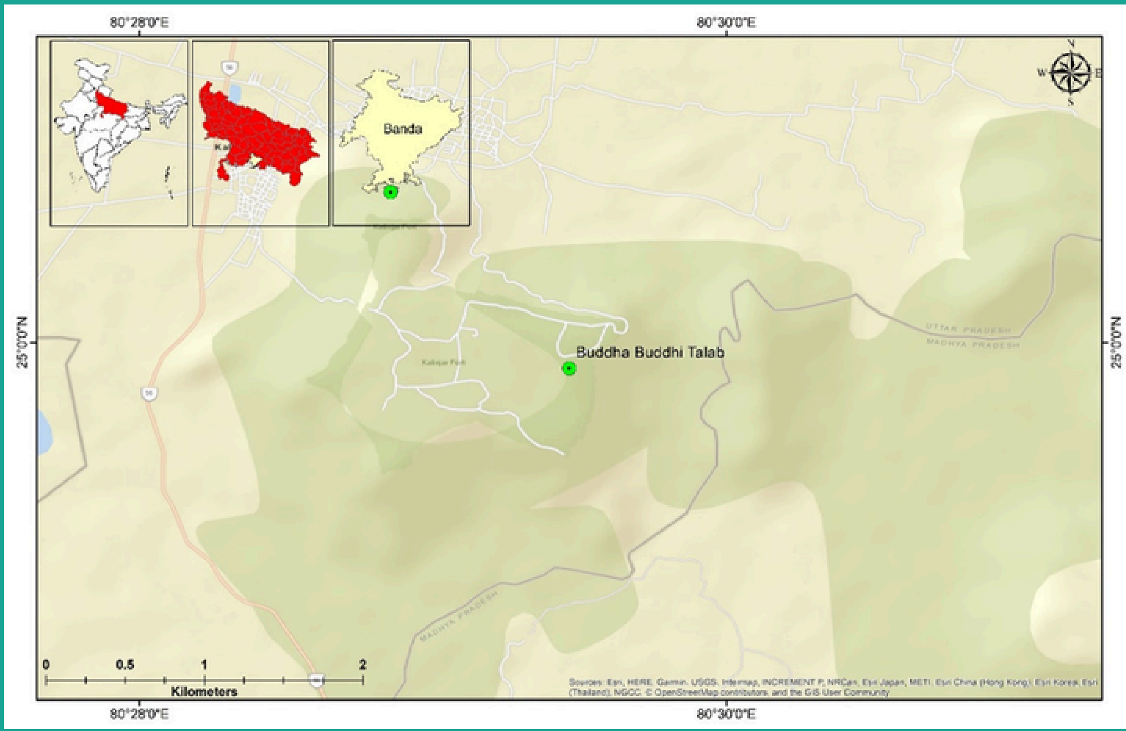


Figure f *Location map of Buddha Buddhi Talab*

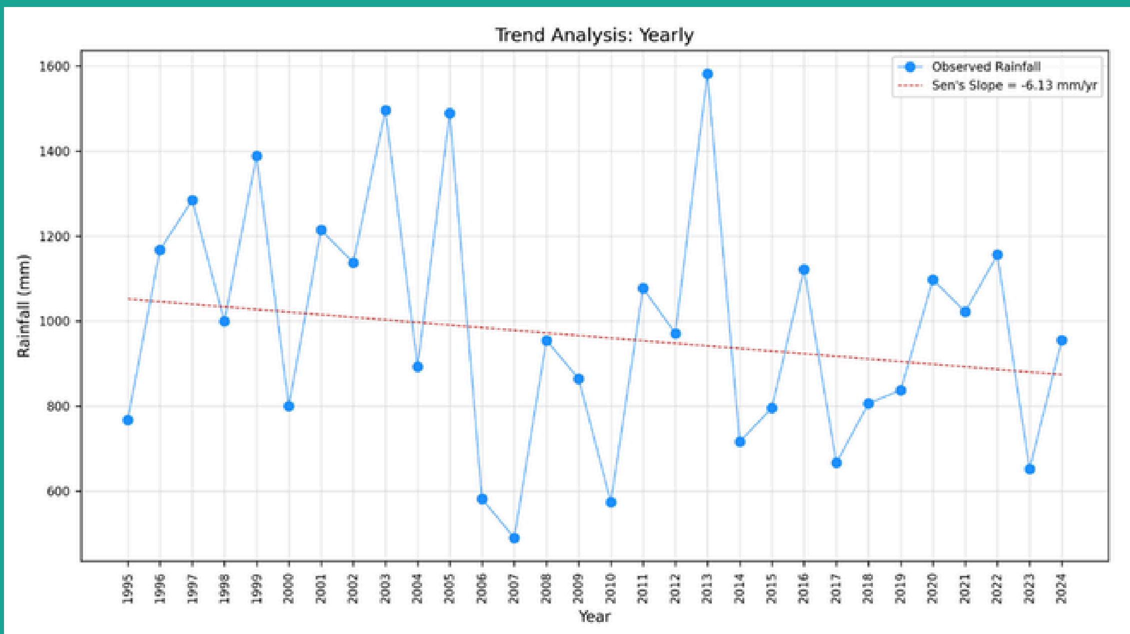


Figure g *Trend analysis for yearly rainfall at the Banda district*

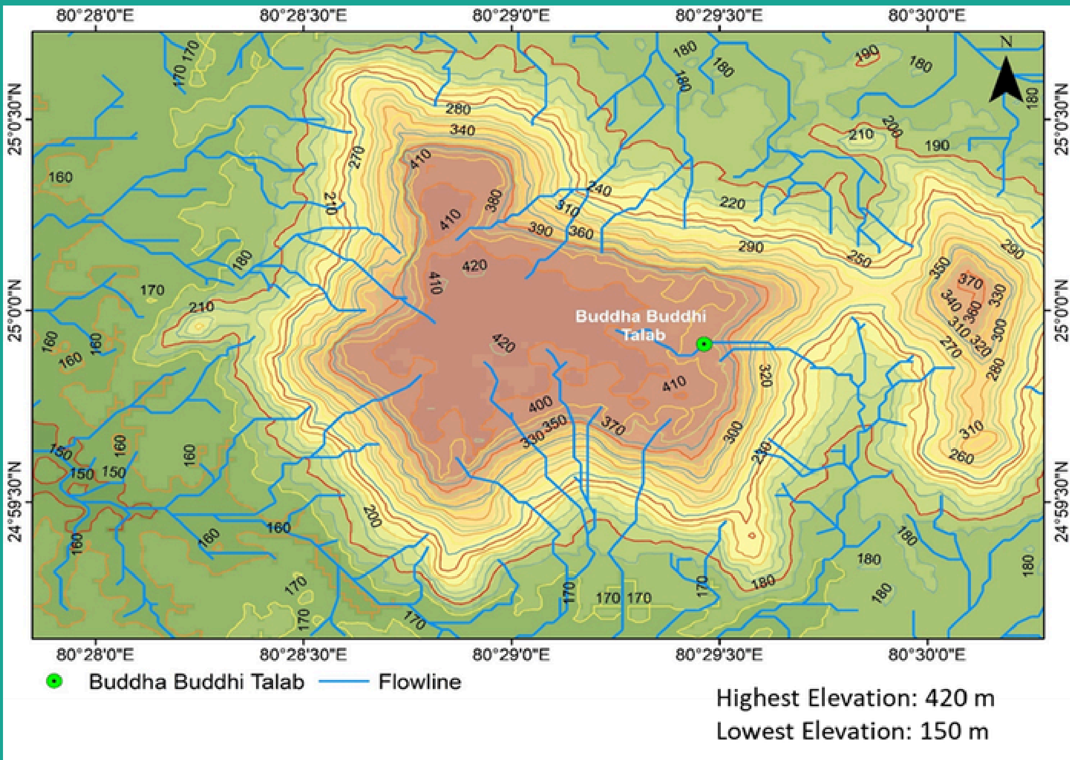


***Figure h** DEM-based contour mapping*

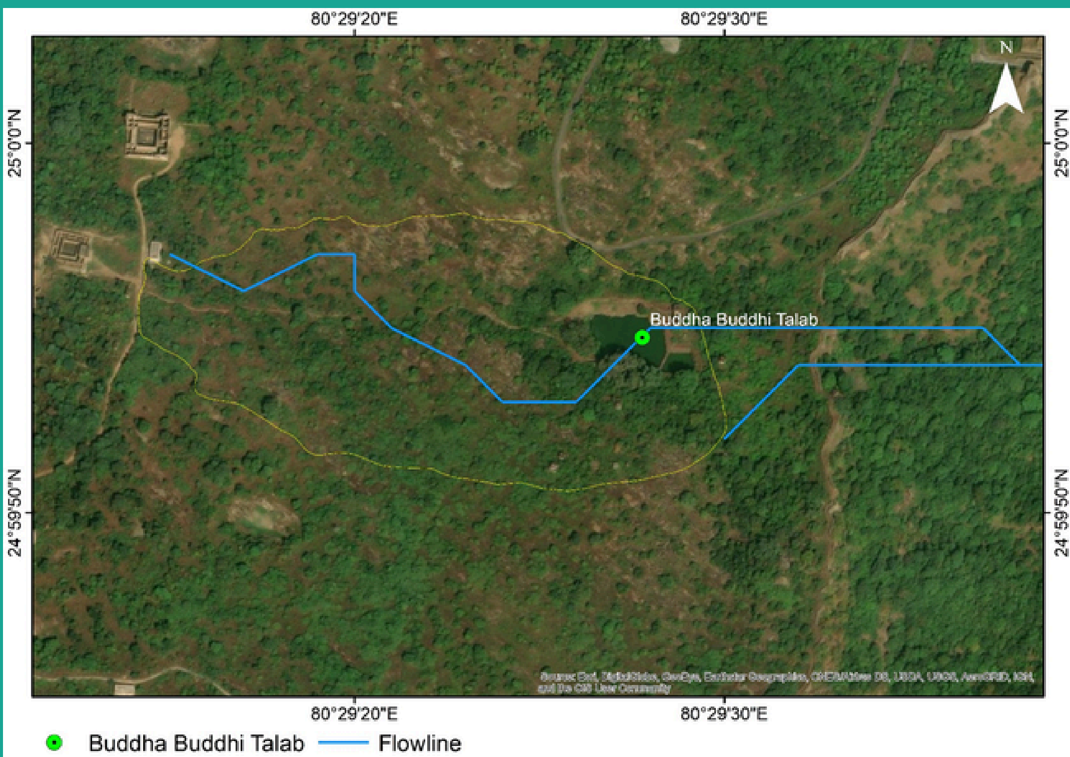


***Figure i** Major flowline converging into the Buddha Buddhi Talab*

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