saketh shetty paper

Article *in* Sustainable Water Resources Management · September 2023

DOI: 10.1007/s40899-023-00938-8

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Sustainable Water Resources Management (2023) 9:165
https://doi.org/10.1007/s40899-023-00938-8

ORIGINAL ARTICLE

Community input to quantification of lake restoration benefits: a pilot study of coastal Karnataka Lake, India

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Received: 2 June 2022 / Accepted: 28 August 2023

Abstract
Lake restoration is one of the regional initiatives aimed at increasing natural resource-based livelihoods. Typically, data on lake inflows/outflows or benefits are not available. Under the circumstances, the best way to collect data is through a questionnaire survey and interviews with residents of the area. The study aims to determine the present condition of the lake and quantify the advantages of the lake on crop productivity after and before the construction of the bund. A reconnaissance investigation of the area found that the lake might have an impact within a 5 km radius. As a result, a survey was carried out within a 5 km radius. The total amount of lake water used for agriculture is 33264 mm^3. The incorrect management of the lake's water has resulted in a water deficit in the study region. Consequently, residents who benefit from the lake are increasingly dependent on alternative water sources, such as wells and small ponds. As a result, the yield decreased by 20.45%. After the bund construction was built across the outflow of lake water, the profit increased by 37.88%, making more water available throughout the year. According to the study, appropriate conservation efforts require community input. Instead of focusing on high-cost technology in coastal Karnataka, this study suggests that water resource managers should restore surface water bodies, providing more water benefits for the public.

Keywords Lake restoration · Agricultural productivity · Community participation · Questionnaire survey · Bund

Introduction

Lake restoration aims to restore deteriorated or polluted lakes. Water pollution severely threatens human health and the environment; lake restoration is essential to resolving this issue. Protecting coastal lake water is critical since the unlimited consumption of freshwater aquifers directly causes groundwater quality issues. Because of the possibility of seawater intrusion, coastal groundwater systems are vulnerable to reduced recharge, contamination from natural and anthropogenic sources, and overexploitation (Barik et al. 2021). The lake collects rainfall runoff and improves water seepage to aquifers. Furthermore, such storage structures work as sponges, reducing local flooding possibilities. Water is more frequently available in coastal places, and water in open wells is saline; considerable pumping extraction results in massive groundwater depletion.

According to Lathashri and Mahesha (2015)'s research in coastal Karnataka, heavy pumping diminishes the seaward freshwater gradient, which can even be reversed in some situations. This produces severe saltwater intrusion from the sea, seriously damaging internal freshwater aquifers, and restoration could take years. Because of the terrain and porous lateritic soil composition, large dams are not preferred in coastal Karnataka. Residents of the study area depend on surface water in this scenario, such as open wells or small ponds. However, the main challenge in coastal Karnataka is seawater intrusion, which is especially vulnerable during the monsoon season (January to June) (Sylus and Ramesh 2015). The water in open wells dried up after the

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Published online: 18 September 2023

non-monsoon season (March to April), increasing groundwater demand for agriculture. It has resulted in widespread over-abstraction of groundwater resources, which is unsustainable in the long run (Rodell et al. 2009). Historically, the loss of groundwater availability has reduced agricultural production and created poverty. This is also one reason farmers switch to more valuable crops, such as areca nut and coconut. As a result, the study suggests that restoring dying lakes can provide consistent water for crop productivity throughout the season.

A multidisciplinary approach is required to examine the coastal Karnataka agricultural system and the efficiency of lake restoration projects designed to meet these problems. The Indian government has considered the restoration of lakes as one solution to the country's water scarcity. In this context, undertaking scientific investigations for lake restoration measures should be prioritized (Goyal et al. 2021). To our knowledge, further local scientific research on quantifying lake water benefits is needed.

A community survey is carried out to collect information from beneficiaries of the lake, since no historical data are available on the storage/inflows of lakes. The current lake has been used for many years. The lake's water dries by the end of the summer, resulting in a water shortage for crop production every year. As a result, the lake's beneficiaries rely on other water sources, such as open wells and ponds. The study drew on community input to determine the benefits of the existing lake, as well as the current condition and additional actions needed to improve the current lake. On the other hand, the lake basin requires more water for agriculture all year. This research has been done to study the impact of post-and pre-construction of a bund to the lake's outlet water to improve the area's socio-economic development.

Locational details of the study site

The current study focuses on Kavoor Lake, where the Netravati River and its tributary, the Gurupuraa River, meet the Arabian Sea. The Kavoor Lake can be situated northeast of Mangaluru (Fig. 1). Mangaluru is situated on India's west coast, surrounded to the west by the Arabian Sea and to the east by the Western Ghats. Mangaluru City has a total area of 184.45 km^2.

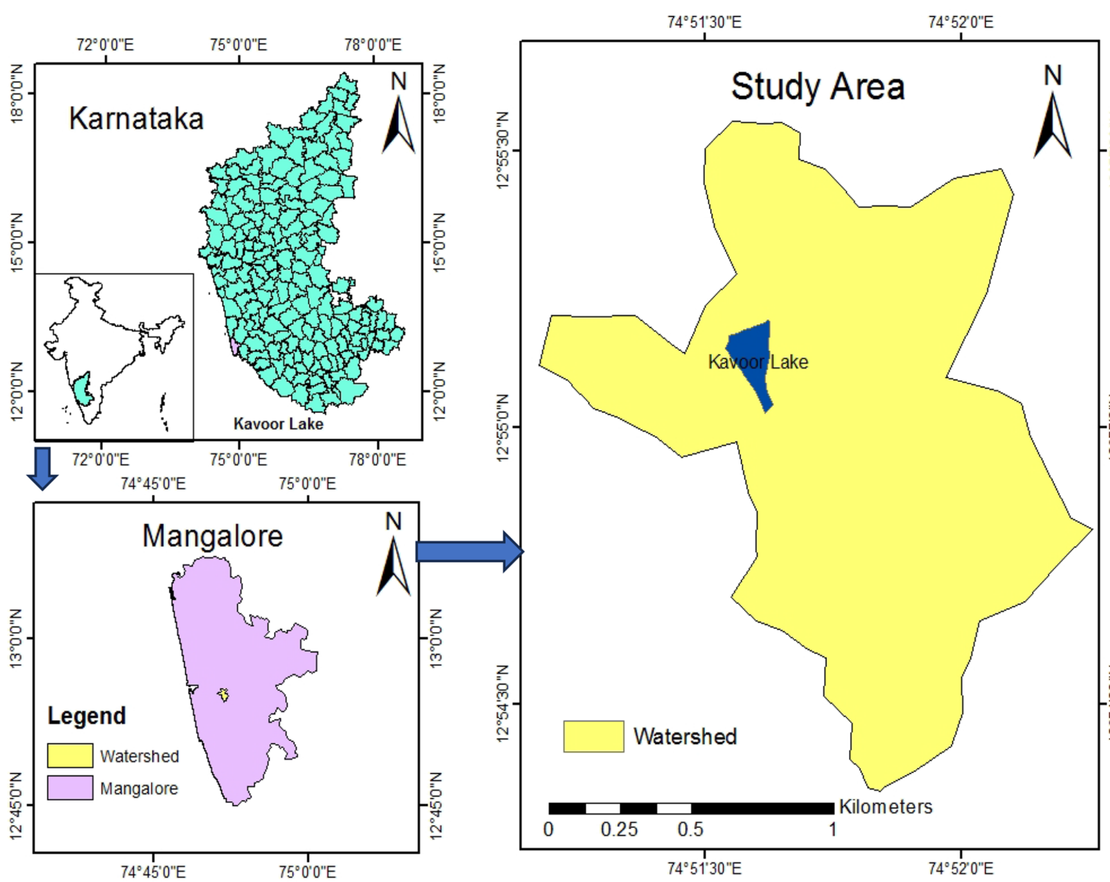


Fig. 1 Map of Coastal Karnataka showing Kavoor Lake

The lake is located in the Mangalore Taluk of the Dakshina Kannada district, at 12°55′48" N, 74°51′34" E (Fig. 1). As it is situated in Kavoor, it is known as Kavoor Lake. The district's climate is tropical monsoon, with temperatures ranging from 35 to 40 degrees Celsius and humidity levels ranging from 58% to 75%. The average annual rainfall in the region is 3900 mm, and the lake is situated about 10 km from Mangalore city, at 22 m above sea level. This lake has a basin of 3.39 hectares and a length of 300 m. The eastern side is covered in plantation crops of coconut and areca nut, while the western side is covered in an asphalt road. The lake's gradient is northwestward (Sushmitha et al. 2015). Many nutrients from agricultural areas enter the lake as runoff. Hence, the lake's current condition is eutrophic (Fig. 2). The northern and southern banks covered with forest.

An inlet points toward the lake's southeast corner. A discharge point to a northwest stream allows adjacent fields to be irrigated. The check dam controls the discharge (Fig. 3).

Materials and methods

The projected lake was semi-urban, and restoring it will benefit the most significant number of people. The concern was that the lake should meet the beneficiaries' daily water demands while increasing agricultural production and aesthetics, and it should help commercially increase city revenue. As a result, concentrating on semi-urban lakes benefits individuals and entire urban and rural areas. The reconnaissance survey and preliminary study clearly show the lake's current state. The current meter method was used to determine the velocity of the inflow into the lake to calculate the discharge of each influx. The preliminary investigations provide information on the existing state of the lake. As a result, creating a questionnaire was essential to conduct this survey quickly (Pope Paul 1998). The whole research method is displayed in Fig. 4.

Seventy-four households were chosen from a 5 km buffer zone around the lake. The methodology is divided into two parts: (i) preliminary research and (ii) quantification of lake benefits.

Preliminary study of candidate lake

The preliminary investigation provides information about the lake. The lake's intake and discharge had been measured (Fig. 5). A visual survey will be used to determine the total amount of water entering the lake. The lake's water quality was assessed using water analysis and in-situ tests.

Water quality

Water samples were collected from Kavoor Lake on a monthly basis between June and November 2020. In each sample, three mixed water columns were examined at depths of 0.5 m, 1 m, and 2 m. Several studies have been conducted to explore the importance of lake water quality management (Carey et al. 2021; van Wijk et al. 2021; Ward et al. 2022; Haig et al. 2022; van Oosterhout et al. 2022). The samples were stored in plastic bottles that had been rinsed with metal-free soap, thoroughly rinsed multiple times, saturated in 10% nitric acid for 24 h, and then rinsed with ultrapure water. All water samples were kept in a refrigerator at 0 C for transit to the laboratory and later for processing and analysis. Table 1 lists the parameters used in this study for water quality analysis.

Discharge measurement

Three inflows and one outflow were connected to the lake. The discharge of the inflows was calculated for this study using the current meter method (Tazioli 2011). The following methods were used to assess the discharge.

a b

Fig. 2 Existing condition of the lake **a** east side **b** west side

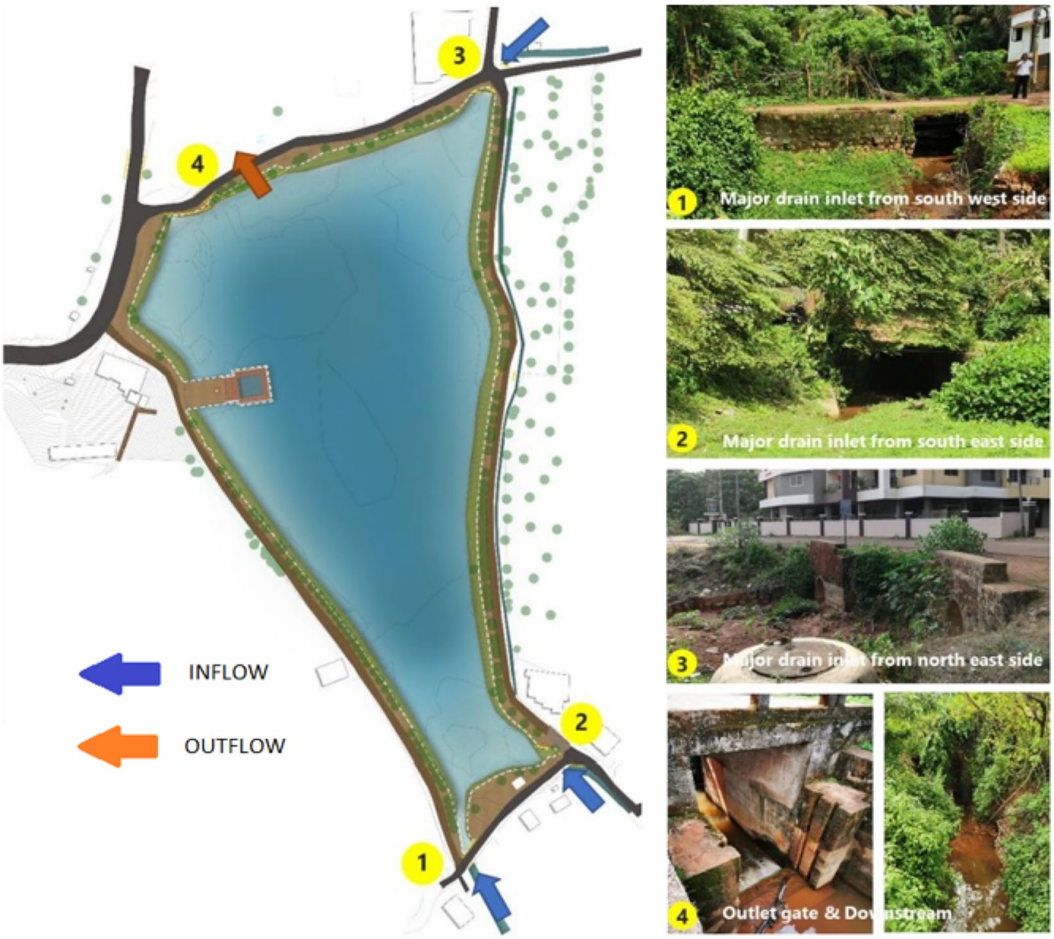


Fig. 3 Details about the lake. **a** Inflow and outflow details. **b** Drainage location details. (1) A major drain inlet for the southwest side. (2) Major drain inlet on the southeast side. (3) Major intake from the north side. (4) Downstream outlet gate

The release (Q) can be calculated if the mean water velocity (V) is normal to the flow velocity (V) and the cross-sectional area (A) of the water flow is known. The discharge can be determined using the following equation:

$$Q = A \times V \tag{1}$$

Q = discharge of flow m^3/sec, A = area of cross section of flow (perpendicular to the predominant flow) m^2, V = average stream velocity m/sec.

Land use and land cover details

The SCS-CN technique was developed by the Soil Conservation Services (SCS) of the United States in 1969. This method computes the quantity of surface discharge (Lalitha Muthu and Helen Santhi 2015; Khare et al. 2017; Saini et al. 2018; Bal et al. 2021). The soil type/properties, hydrological soil group (HSG), land use/cover, and antecedent moisture conditions all have an impact on the CN (AMC). The number of curves goes from 100 to CN to zero. A CN number of 100 represents the impermeable catchment condition, while a CN value of 0 represents the indefinitely abstracting catchment condition.

The change in LULC has a substantial impact on the catchment's hydrological response (Tola and Shetty 2021). Because of the reduction in initial abstraction, which increases runoff volume, the runoff characteristics naturally fluctuate. As a result, it is essential to investigate changes in the catchment's runoff characteristics as a result of LULC alterations.

Questionnaire survey

The questionnaire covered the residents within five kilometers of the radius of the lake. The responses provided valuable information for the lake's restoration operation. A few studies used a questionnaire survey to collect

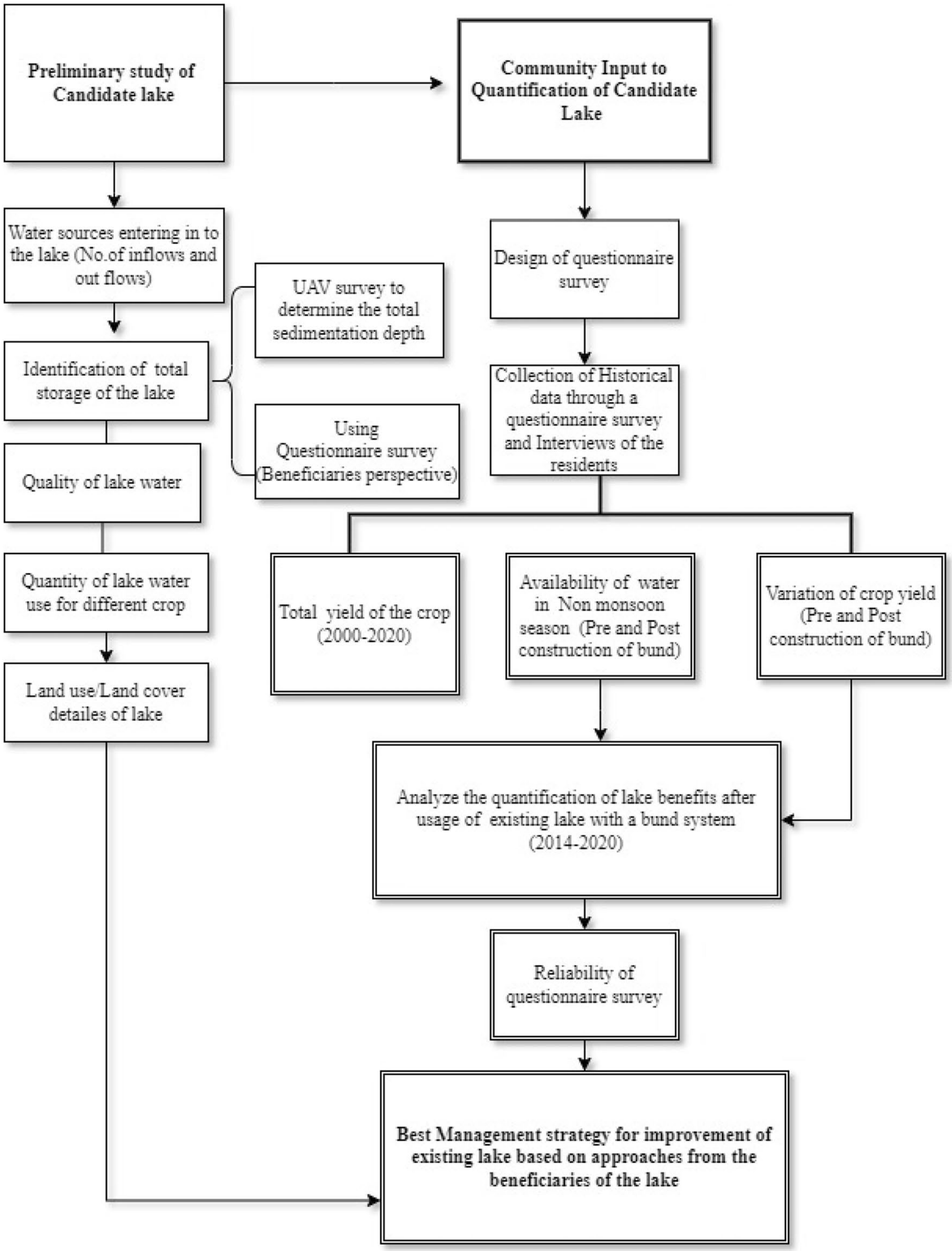


Fig. 4 Proposed methodology

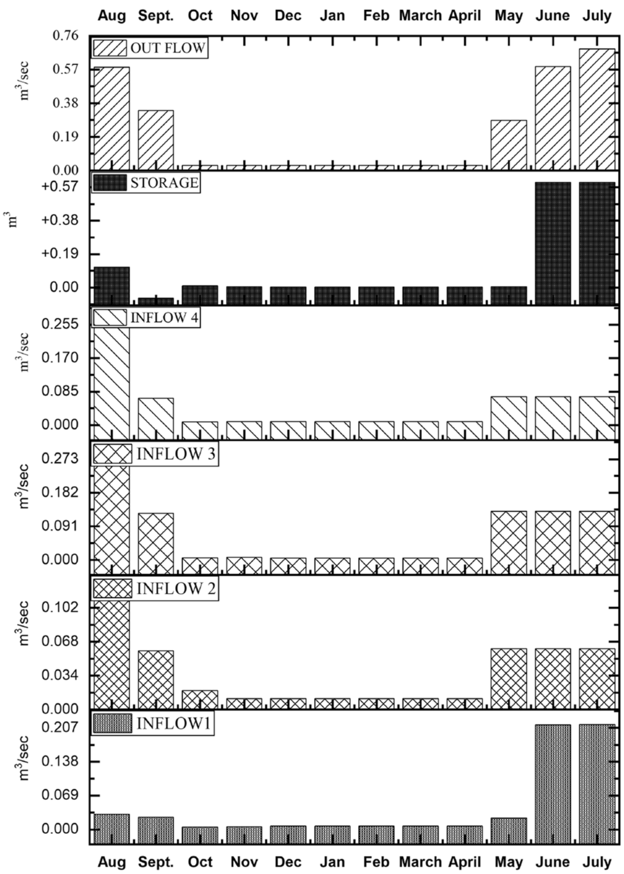


Fig. 5 Inflow, outflow, and storage details of the lake

suggestions from technical experts and senior members of the local body (Kumari et al.2021; Abubakar and Mu'azu 2022; Gizaw et al.2022). Table 1 contains a summary of the analysis methodologies. A similar study was conducted on the development of local adaptive capacity for watershed development (Singh 2018).

The questionnaire survey sample size

Expert and content validation were used to validate the preliminary draught of the survey questions. Some of the following equations were observed to calculate the sample size for the questionnaire survey and used to calculate the sample size for the questionnaire survey and to assess the study's reliability (Cochran 1997).

(i) Coachron formula for calculating sample size when the population is infinite is expressed as

$$n_0 = \frac{z^2 pq}{e^2}. \tag{2}$$

(ii) Coachron formula for calculating sample size when the population is finite

$$n = \frac{n_0}{\frac{1+(n_0-1)}{N}}, \tag{3}$$

where n_O = Sample size, p = population proportions = 0.5, q = 1 − p, e = acceptable sampling error, z = value at reliability level or significance level, N = population size.

The framed questions were asked to every lake beneficiary in this study (74 households). Some similar studies have been done using questionnaire surveys (Alemu et al. 2016; Lee et al. 2021; Wafula et al. 2022; Donacho et al. 2022; Zare et al. 2022; Basu et al. 2022).

Design of questionnaire survey

The study made use of both primary and secondary data. To collect a multi-scale data set and triangulate findings, a multimethod strategy employing qualitative and quantitative tools was used for preliminary data collection (Buchanan 1981). The method of selecting questions, stakeholders, and community members was identified in the study (Roopa and Rani 2012). The survey was administered to people of various ages and occupations (Preston 2009). The benefits of the lake restoration project were evaluated at the watershed and family levels. Over 10 months of fieldwork (October 2020–July 2021), six focus group discussions (usually with 3–4 farmers), household-level semi-structured questionnaires, key informant interviews, participant observation, and document reviews were used to collect data. All homes within the watershed were polled to represent all conceivable farmer types based on demography, location, asset

Table 1 Lake water concerned parameters and analysis method

S. no	Concerned parameter	Analysis method	Testing instrument
1	Air temperature	Mercury method	Thermometer
2	PH	Glass electrode method	PH meter
3	Secchi plate	Water transparency	Secchi disk
4	Total Dissolved Solids	Oven dry method	Evaporating disk
5	Nitrate	Absorption method	A spectrophotometer as per IS-3025
6	Salinity	Weight method	Electronic balance
7	Sodium	Absorption method	Flame photometer as per IS-3025

ownership, and social capital. The methodology of the work included field trips and public meetings. The first step was restoration planning, followed by discharge and depth of sedimentation inquiries. The general public's contribution to the lake's restoration was the third step.

Progressive farmers, government officials, and non-governmental organisation (NGO) workers were among the key informants who helped build a bigger view than just community concerns. Community input was analysed to understand further how the lake restoration was envisioned to strengthen the local adaptive ability to water scarcity. The Cronbach equation was used to perform the reliability test according to the point scale method (Tavakol and Dennick 2011; Trizano-hermosilla and Alvarado 2016; Taber 2018).

It is necessary to determine the quality and quantity of water generated within the lake. As a result, community surveys are more important. The primary goal of the study is to restore the water, but it also needs to understand the benefits of the lake. Everything must be scrutinised during the process. There are numerous locations, where different types of lakes can be found. However, because there is no database for identifying lakes, it is entirely dependent on community input to determine whether a lake is natural or man-made. Water scarcity occurs everywhere, and water availability is lower than in most areas, so determining water availability at the end of the summer is critical. Identifying the sediment deposited in the lake is an important aspect of the research. Because accumulation of sediment reduce the lake's storage capacity. It is necessary to calculate the total amount of sediment collected. Crop yield variation and water quality entering the lake are critical factors. The list of issues discussed during the community survey is shown in Table 2.

Internal consistency of questionnaire survey

The ordinarily utilized strategy for estimating inward consistency is computing the Cronbach Alpha coefficient (Tavakol and Dennick 2011). As indicated by this technique, for a given survey x, with k number of things, Cronbach's alpha (α) can be determined as internal consistency of the questionnaire survey had been measured using Cronbach equation (Trizano-hermosilla and Alvarado 2016).

The Cronbach equation alpha (α) can be determined using the following equation:

$$\alpha = \frac{N.\overline{C}}{V + (N-1)\overline{C}} \tag{4}$$

In condition, Eq. (4), Cronbach's alpha worth generally goes from 0 to 1. Here, N equals the number of items, the $\overline{c}$ is the average inter-item covariance among the items and $\overline{v}$ equals the average variance. To check the reliability of the questionnaire survey, Cronbach equation is the most widely used method. Although the equation has some limitations, it was the best method to determine the omega coefficient (Taber 2018; Akatsuka and Tadaka 2021).

Unmanned aerial vehicle (UAV)survey to determine the sedimentation depth

Unmanned aerial vehicles (UAVs), also known as drones or aerial robots, are flights are controlled remotely rather than by a human pilot. The DJI Phantom 3 Pro was used during the high-altitude aerial surveys (120 m above ground level) (Jayson-Quashigah et al. 2019; Alexiou et al. 2023; Goh et al. 2023). Nonetheless, it was outfitted with a 1/1.3" Complementary Metal-Oxide semiconductor (CMOS) sensor and a tiny Red, Green, and Blue (RGB) digital camera with a resolution of 12.4 megapixels. When viewed as an integrated system of parts (UAV, ground station, telemetry, etc.), each mission lasted between 8 and 15 min, depending on battery life, covered area, and wind conditions (Westaway et al. 2001; Alvarez et al. 2018).

UAV survey is the most advanced method for determining the sedimentation depth in a dry condition of the lake. By

Table 2 Lists of the issues discussed during the community survey

	Issues	Project aims
1	Source of water entering into the lake	The lake has three inflows. Community input is required to know the water source contributing to the lake
2	Vegetation covered in the lake	Total percentage of vegetation cover in the lake and type of vegetation cover in the lake
3	The necessity of lake water storage	The total benefits of the lake for nearby residents
4	Nature of the lake	The community input is taken to know the type of lake, artificial or natural lake
5	The total availability of water at the end of the summer season	The community input is taken to the availability of water at the end of the season
6	The total depth of silt deposited in the lake	The total quantity of sedimentation accumulated in the lake
7	Type of water entering the lake	Sewage entering the lake
8	The total quantity of productivity	The total variation of agricultural productivity post- and pre-monsoon

knowing the initial depth of the lake, this method estimates the total depth of sedimentation deposited in the lake. The depth measuring instrument became a transportable sounder with a satellite positioning device (Deeper Smart Sonar PRO + (WI − FI + GPS). The UAV survey was used to estimate the total sediment deposition inside the lake.

The following steps were taken during the UAV survey:

a) Using the UAV survey, locate the existing contour map (identify the RL of the existing lakebed)
b) Note the bottom RL of the existing lake using both maps; compare the two maps; and subtract the current level from the initial level.
c) The cumulative deference will show that overall sediment has been deposited inside the lake.

Quantification of lake benefits using community survey

The respondents' perspectives on the lake's use were also recorded. The respondents provided specific information about the lake's specific encroachment. The respondents' knowledge was beneficial in systematically recording significant outcomes to create the respondents' overall assessment. The collection of old data bases greatly improves the condition of existing lakes. They mentioned previous implementations. Many respondents stated that building a bund can solve future water scarcity issues as well as recharge nearby open wells. The residents were interviewed for a study on production variation over the last two decades. The majority of residents cited water scarcity as the reason for the shift from paddy to arecanut crops.

The total amount of water available for crop yield determines areca nut production. Finding a good source of water for crops is critical. The discussion that follows demonstrates the effect of lake water on crop yield after using the lake. The overall crop yield was estimated between 2000 and 2020, and crop yield variation was identified following the construction of the bund to the lake outflow. There is enough water available for crops to be migrated from paddy to arecanut, and the total variation in productivity must be calculated.

The productivity during the monsoon and non-monsoon seasons must also be determined, taking into account the lake water with and without the bund water.

The total productivity (Rs/ha)–total income of a farmer in growing crop

The study interviewed each household in the study area and collected data on each farmer's total income from farming fields in Rupees per hectare (Rs/ha), as well as their knowledge of the best water sources for improving agricultural production. Residents of the region grow a variety of crops with lake water as a major source. This region's primary agricultural products are areca nut and coconut.

Many people depend on the paddy crop as their primary source of income. To collect data on agricultural production using various water systems, a questionnaire survey was used. The permanent residents of that region provided insight into the variation of farm output. The total agricultural yield per unit of land is indicated by productivity. The total harvest includes the amount displayed, the market price, and any friendly exchanges.

Productivity of the crop: the total production from each farmer

Continuing to follow the usage of the existing lake, the overall output was determined. The questions should frame lake usage using bund (from 2010 to 2020). In production economics theory, physical productivity reflects the level of technological efficiency obtained from a given set of inputs. The study was based on agricultural output (Hatibu et al. 2006). This research does not focus on interplanetary production; rather, it focuses on the practicality of farmers in any area. This research contributes to the equation's advancement (Hatibu et al. 2006). Equation (5) yielded biological productivity:

$$\int_{i}^{n} \frac{\left(P_{im}R_{im} - C_{im}\right)}{A_{im}} \tag{5}$$

The farmer varies from i_1 to i_n crop varies from m_1 to m_n.

where P_{im} = productivity from the i^{th} farms of m crops, R_{im} = Rate of the production from the ith farmer of m crops, C_{im} = Cost for ith farmers to m crops, A_{im} = Area of ith farms of m crops.

Results

Preliminary study of lake

The lake is surrounded by three different inflows. The discharges from Inflow 1 are 0.116 m^3/s, while those from Inflows 2 and 3 are 0.114 m^3/s and 0.221 m^3/s, respectively. Inflows 3 and 4 meet at the same point, and the sum of the two is referred to as inflow 3. Peak discharge in the outflow point was 0.587 m^3/s in August and 0.687 m^3/s in June, according to the study. There was heavy rainfall of 1184 mm and 811.5 mm in June and July of 2020, respectively, and the maximum storage in June was 0.598 m^3 (Fig. 5). Monsoon season lasts from May to September. Even though, the monsoons are June, July, and August. Monsoon season storage is greater, then gradually decreases. According to initial results, the lake's overall storage capacity during the dry season could have been improved. During the non-monsoon season, there is no inflow contribution to the lake. Nonetheless, Inflows 1 and 2 produce significantly less inflow due to a smaller catchment area than Inflows 3 and 4.

Vegetation: total vegetation covered in the lake and type of vegetation

A study also looked back 50 years to find how plant types have changed over time, and how weeds have increased in the current scenario due to pollution. The lake was much different earlier, according to an 80-year-old local, when it used to attract exotic birds and insects, improving the beauty of the area. It varies seasonally in the current situation. Beneficiaries claim that creepers cover 15% of the lake's surface and periphery, and shrubs cover the lake's bottom; this lake has been in eutrophy for several years. The details of the vegetation found in the lake are depicted in Fig. 6. The lake contained four different phytoplankton classes, as represented by the percentages Cyanophyceae (34%), Bacillariophyceae (32%), Chlorophyceae (22%), and Desmidaceae (22%) (11%). There were four types of desmids present, with Cosmarium sp. being the most common. In terms of zooplankton density, Copepoda (34%) was followed by Rotifera (22%), Cladocera (27%), and Ostracoda (8%). Seasonal variations, as previously discovered, had an impact on plankton populations (Devi and Kumar 2013).

Quality of lake water: quality of inflows entering into the lake

The hydrological parameters' month-to-month potential gains were divided into three seasons: pre-monsoon (February–May), monsoon (June–September), and post-monsoon (October–January). The water in the lake was greenish throughout the year. The temperature of the air near the lake ranged from 24.6 °C to 33.5 °C, while the surface water temperature ranged from 23.7 to 32.5 °C. The pH of the water fluctuated somewhere between 3.6 and 7.0. The water appeared to be slightly acidic throughout the survey period. This is consistent with prior observations. During the storm season, the pH was higher than during the other two seasons. The overall straightness of water was low, with the smallest Secchi plate worth 4.5 cm recorded in April and the highest raised worth of 86.5 cm obtained in August during the top storm. Total Dissolved Solids (TDS) ranges from 62.90 to 146.90 mg/l. The greatest limit was observed during the pre-rainstorm period, which was caused by the spread and accumulation of broken-down solids.

The deteriorated oxygen level increased from 3.45 to 6.78 mg/l with higher calibres during the post-monsoon and lower calibres during the pre-monsoon. This could be due to more severe photosynthesis and oxygen depletion in the water during the post-storm period. The low value

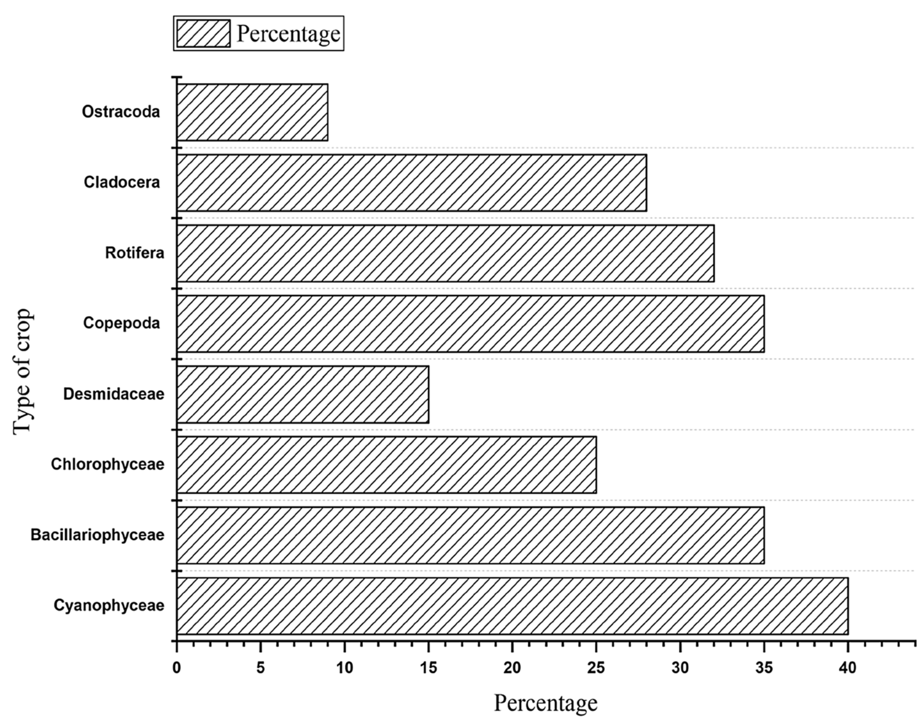


Fig. 6 Type of crop grown in the lake

of separated oxygen can be attributed to massive levels of regular pollution, most likely from squander contamination. Furthermore, as previously examined, poor qualities during pre-storm could be attributed to low oxygen breaking down and low water levels. During a storm, the ordinary proportion of nitrate was 2.31 mg/l, 4.69 mg/l during the post-monsoon, and 7.29 mg/l before the storm. Regardless, the month-to-month variations ranged from 1.80 mg/l in July to 12.50 mg/l in May.

The average concentration of sulphate in the lake was 8.01 mg/l due to the immersion of manures from agricultural runoff and nearby waste from the catchment region. The sodium concentrations varied only slightly between seasons, ranging from 26.60 mg/l to 46.80 mg/l. This contrasted with observations made in polluted waters, where significant variations in the sodium centre were observed throughout the year. Potassium concentration does not vary seasonally (4.50–5.73 mg/l).

Quantity of lake water used for different crop yields

The total irrigated area by the lake is 2000 hectares, with coconut accounting for 40% (800 ha), areca nut compensating for 35% (700 ha), and paddy rice accounting for 25% (500 ha).

The daily water requirement for coconut per hectare is 60,000 L/day, which equates to 48 million cubic meters for 2000 ha of coconut cultivation (Mm3). From June to February, 12,960 mm^3 of lake water produced coconuts. In the field, however, it was discovered that the daily water requirement for coconut per hectare is 36,000 l/day. As a result, the total amount of water consumed for coconut yield was 6804 mm^3. The water requirement for vegetables per hectare is 100,000 l/day, while rice requires 50 mm^3. Rice crops were grown using 13,500 mm^3 of lake water. A total of 33,264 mm^3 of lake water was used for crop cultivation in addition to all crop water requirements.

Land use and land cover

In LULC research, natural resource management, and environmental monitoring and protection, remote sensing image-based methods for detecting changes in land use and land cover are widely used.

In 2004, the water body decreased slightly, while the built-up area increased by 11.94%. During that time, there was 16.42% less bare soil available. The water body increased by 1.22% in 2012, the built-up area increased by 12.92%, and the vegetation increased by 69.44%. Water area was 0.13% in 2021, built-up area was 37.75%, bare ground decreased by 4.42%, and vegetation increased by 37.7%. This is due to increased crop productivity as a result of increased water availability. According to the findings, the built-up area and vegetation increased by 25.66% and 2.64%, respectively, between 2004 and 2021. Because of the effects of urbanisation, the bare soil and water body decreased by 27.7–0.47% (Figs. 7, 8). The growing population near the coastal city has an impact on water overuse.

Community input to improve the existing lake: lake restoration

In the absence of historical data, a community survey method was used to collect historical data. Most residents have been monitoring the lake for 30–40 years. The study identifies that the lake's existing condition needs to be restored; after the tremendous usage benefits, the lake's beneficiaries identified that it is necessary to rejuvenate the lake and supply the water to more beneficiaries.

Community input: selection of respondents

The study visits many homes to gather ideas for improving the existing lake. The majority of participants are aged 40 to 60 and have lived in the area for at least a year. A few respondents are aged 60–80 (35%). Figure 9 displays the age group in more detail. People of all ages were present. Those aged 40 to 70 are more likely to share information and express a strong desire to restore the current lake. Individuals under the age of 30 who are preoccupied with daily tasks and are unaware of restoration work. During the fieldwork, the following key points were discussed.

Water sources entering the lake

The study also identified various sources of water entering the lake. The respondents were questioned about the lake's major source. According to the majority of respondents in the 20–30-year age group and the 70–90-year age group, catchment surface water was the primary source of water for the lake. The opinions of those aged 30–70 were mixed, but the majority of respondents said groundwater flux is the lake's primary source. According to a 90-year-old respondent, groundwater flux is the lake's primary water source. Although community perspectives varied, the majority believed that groundwater flux was the source of the lake (Fig. 10). More than 40% of those polled believed that agricultural runoff enters the lake, and that Inflow 1 carries a significant amount of domestic sewage.

The nature of the lake

Beneficiaries in the area have been extremely helpful in determining whether lakes are natural or man-made. The lake was thought to be natural by 90% of those polled.

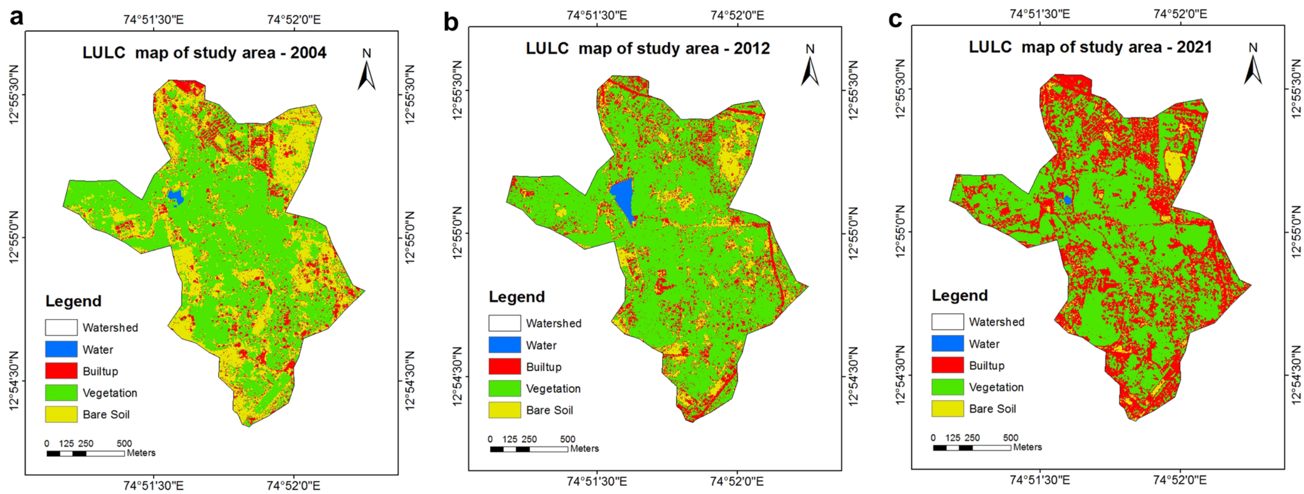


Fig. 7 Land cover details of the study area in the year of **a** 2004 **b** 2012 **c** 2021

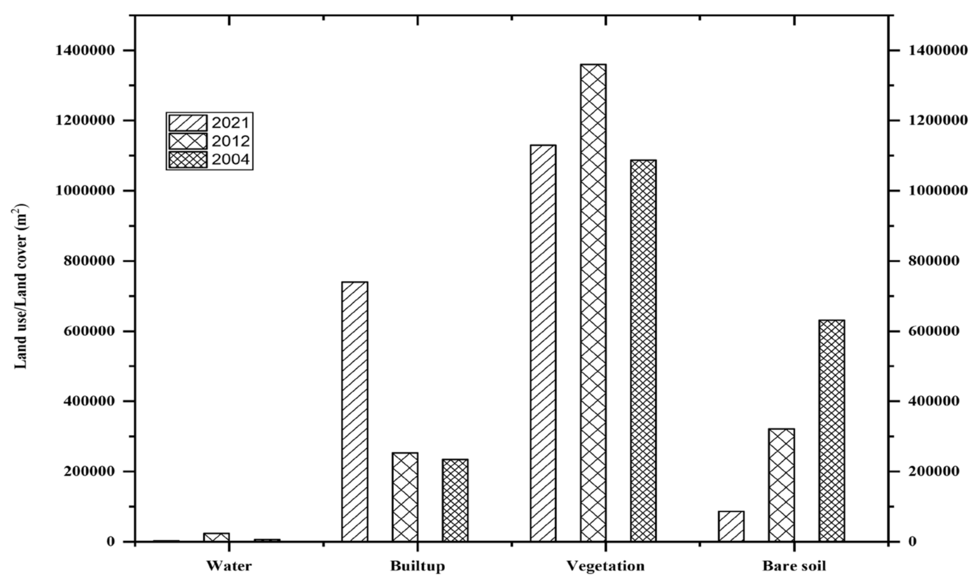


Fig. 8 Land cover details of the study area

Similarly, despite the lack of evidence, some people believe the lake was man-made. While the majority of respondents over 40 agreed that the lake was built, some under 40 suggested that it was created artificially.

Sedimentation deposition in the lake

The amount of silt deposited within the lake can be identified during the field visit, but an estimate of overall sedimentation is required. In this study, participants were asked to estimate some values based on their knowledge. However, scientific methods, such as UAV surveys, were used to precisely locate the deposition. Figure 11 shows a summary of the community input as well as its statement on sedimentation depth, indicating that silt accumulation is a challenging component. According to the 20-year-old respondents, the lake has a depth of 5 m, while the 20–30-year-old respondents believe it is 3–2 m. According to the 40–60-year-old respondents, the sedimentation depth is 3–4 m, as confirmed by a visual assessment of the lake during the dry season. The study received mixed responses from people aged 70–90 about lake sedimentation. Male respondents made up 75% of the responses in the 20–40 age group, but in the 40 to 70 age group, 40% of female respondents and 60% of male respondents were identified.

UAV survey to determine the sedimentation depth

High-resolution remote sensing imagery has been used by unmanned aerial vehicles (UAVs) as a tool for natural

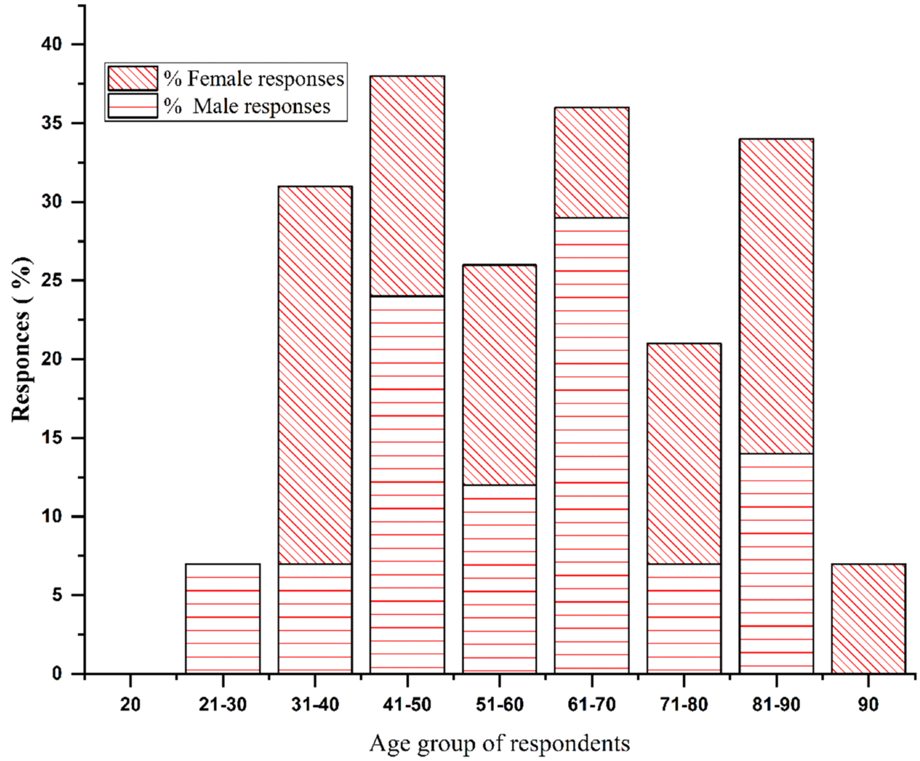


Fig. 9 Respondents' age group

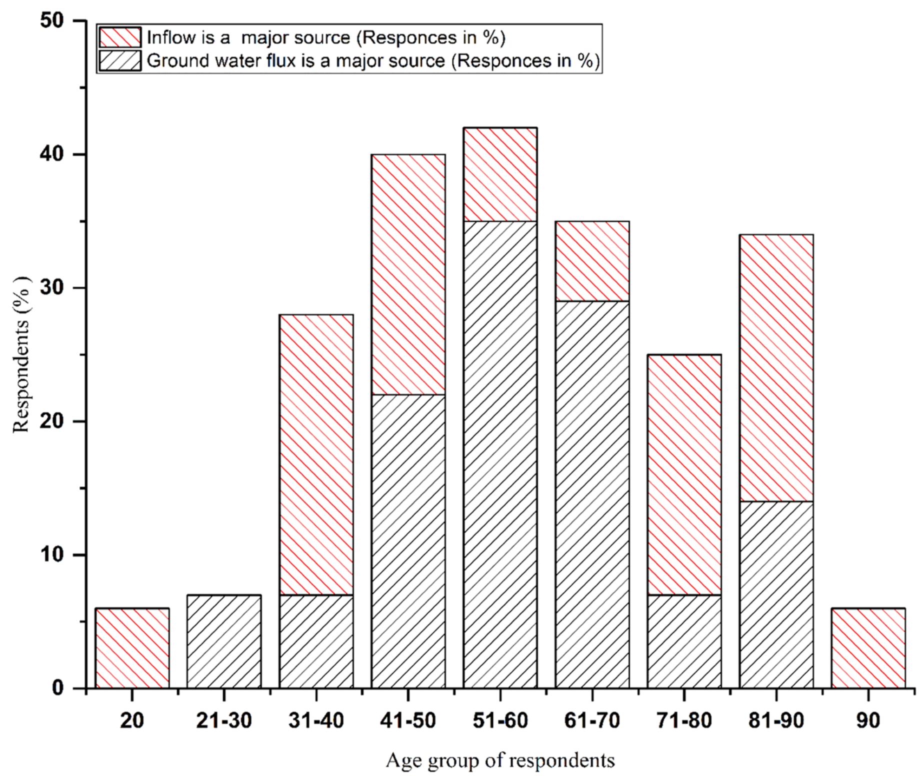


Fig. 10 Type of water entering the lake

resource environmental management. The lake's water is removed, and the surface bed profile of the lake is determined using UAV images (Fig. 12). The maximum deposited RL is 29.54, and the lake bottom surface is RL 24. As a result, the total estimated depth of sedimentation is 5.54 m,

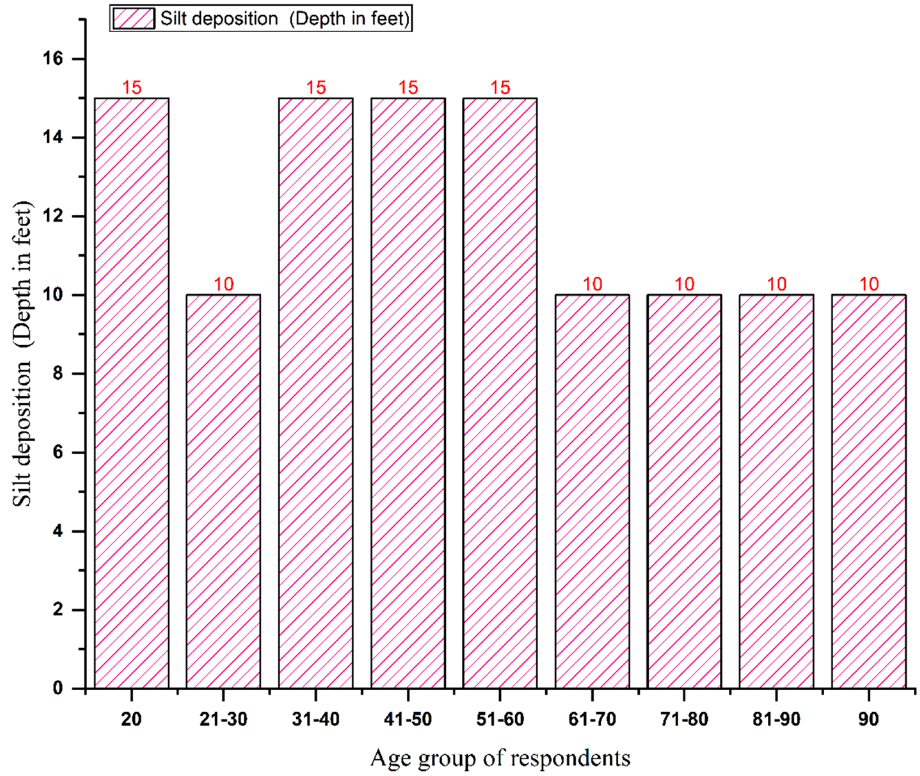


Fig. 11 Total depth of silt deposition of the lake

which is more in line with the value derived from community input.

Quantification of lake benefits: improvement of productivity after usage of lake water with bund (during the years 2010–2020)

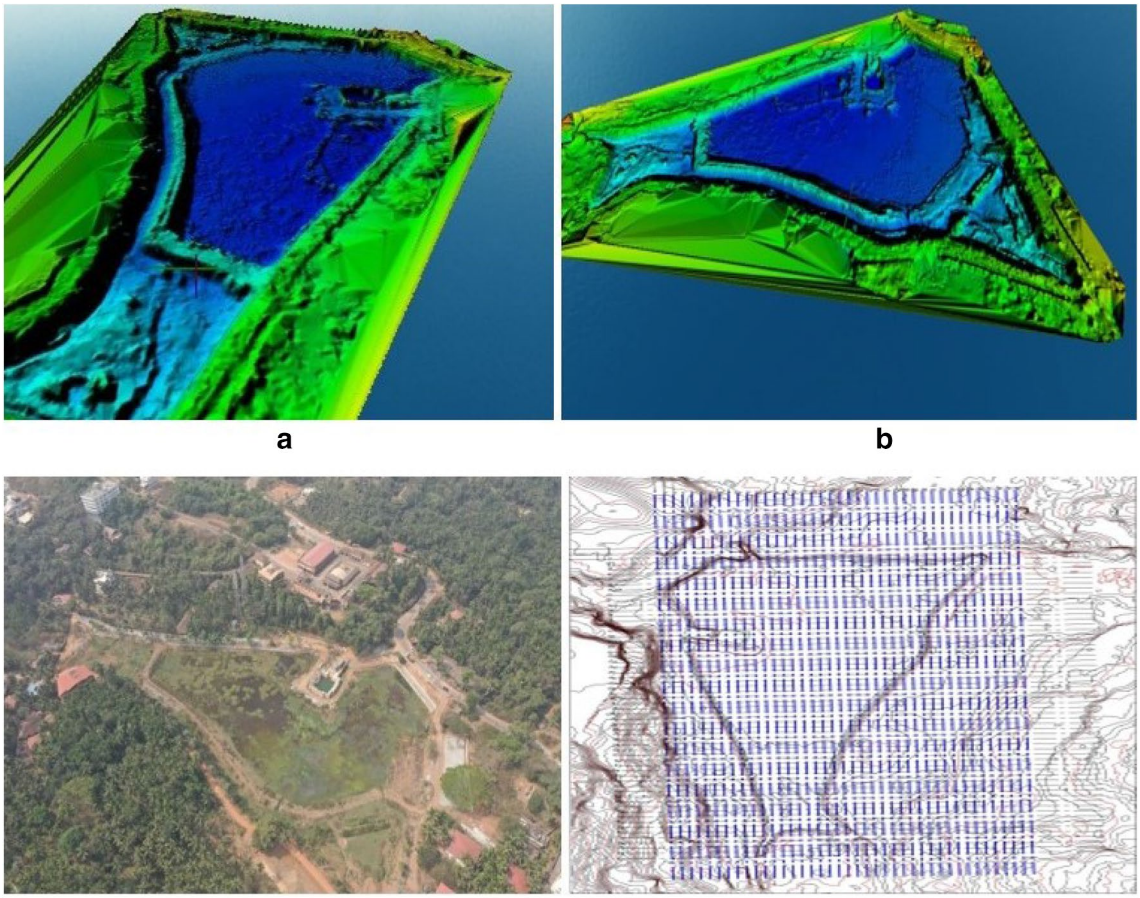
During the summer, there is a severe water shortage. Because of water scarcity, lake users are concerned about increasing lake water storage. As a result, they realised the value of lake water storage and constructed a bund for the outlet discharge water (700 m from the outlet). According to information gathered from lake beneficiaries, from 2000 to 2010, the beneficiaries relied on alternative water sources, such as an open well and a small pond. According to the study's findings, paddy earns less than areca nut and coconut. If they want to reap more benefits from paddy, they must rotate crops three times a year. According to the information gathered in this study, farmers are not selecting three crops for the year due to water scarcity, resulting in a decrease in the farmers' total annual income.

Yield productivity of crops

From 2005 to 2020, agriculturists in the catchment area shifted from paddy to areca nut. According to the questionnaire survey results, around 85% adopted paddy as their main crop in 2000, but that figure has since dropped to 10% by 2020. The primary reason given by the respondent for this redirection is the decreased accessibility of water. Respondents stated that arecanut trees require more water, resulting in a greater reliance on water. The main goal of rerouting water for commercial crops is to increase profits while decreasing labour. However, this did not begin to impact residents' water availability until 2010. After 2010, using a lake outlet with a bund resulted in unpredictability in production (Fig. 13). Despite a drop in annual rainfall following 2010, productivity increased from 120,000 to 220,000 Rs/ha. Annual rainfall varied from 1000 to 5000 mm between 2000 and 2010. However, productivity was significantly lower during this time period, because beneficiaries were completely dependent on rainfall for crop yield and had no other options. The water from the bund provided enough water for agricultural work and increased productivity after it was built between 2010 and 2020. Crop yield has also been related to rainfall over the last two decades (2000–2020) (Fig. 13). Rainfall has been consistent from 2000 to 2020, ranging from 4000 to 6000 mm, according to the findings. Nonetheless, productivity increased significantly after the bund was used (from 2010 to 2020).

Source of water: lake water harvesting with bund system

Water scarcity reduces crop yield, so lake beneficiaries decided to construct a bund to control the lake's outlet flow during the monsoon season. It can also be used during the



a b c d

Fig. 12 Details of UAV survey. **a** 3-D Map of Kavoor lake using UAV survey. **b** 3-D Map of Kavoor lake in Horizontal direction. **c** Top view of the lake. **d** Contour Map used to estimate sedimentation depth

non-monsoon season. The monsoon rainwater collected on the lake's downstream side, and this technology is essential in dry to semi-dry regions with 200–750 mm of precipitation. The results show that production was closest to Rs.500/ha from 2000 to 2003, after which it will be drastically increased. The output of agricultural fields increases after the lake outlet conservation system is used. Areca nut production increased following the installation of the lake outlet bund system. Areca nuts, unlike paddy fields, require all pre- and post-monsoon water. The water requirement of areca nut begins when the rainy monsoon season ends and continues until the next monsoon season begins. Paddy and areca nut productivity increased between 2015 and 2020. Total productivity increased to Rs.7000 per hectare.

Quantity of productivity pre- and post-construction of bund: water source for different agricultural productivity

Paddy yield has dropped significantly over the last two decades, from 67,699 Rs/ha in 2003 to 79,259 Rs/ha in 2005, a decrease of 27.36% overall or 16% monthly. Between 2005 and 2010, paddy output fell by 55,233 and 57,530 Rs/ha, respectively. Between the years 2000 and 2012, the overall yield fell by 20% per year. The primary cause of increased productivity from 2010 to 2020 is the construction of the bund to discharge water; farmers also shifted to commercial crops during this time period. However, the yield of areca nuts has increased significantly (176,306 Rs/ha in 2005, 208,162 Rs/ha in 2010, 24,358 Rs/ha in 2015, and a current low yield of 318,935 Rs/ha in 2020). The production of areca nuts increased between 2010 and 2020 (Fig. 14).

The areca nut yield in 2006 was 151,851 Rs/ha, and it increased to 208,162 Rs/ha in 2010, going to represent an overall increase rate of 37.083% or a 10.12% annual increase rate. Paddy productivity was higher in the early years of 2000. It is approximately 97,531 Rs/ha. Paddy production fell by 37.8% and 2020. Paddy yield of paddy fell by 20.45% to 2012, and the result identified that paddy yield increased by 37.88% to 2020. However, the use of a lake as a storage structure and the adaptation of the bund structure are the

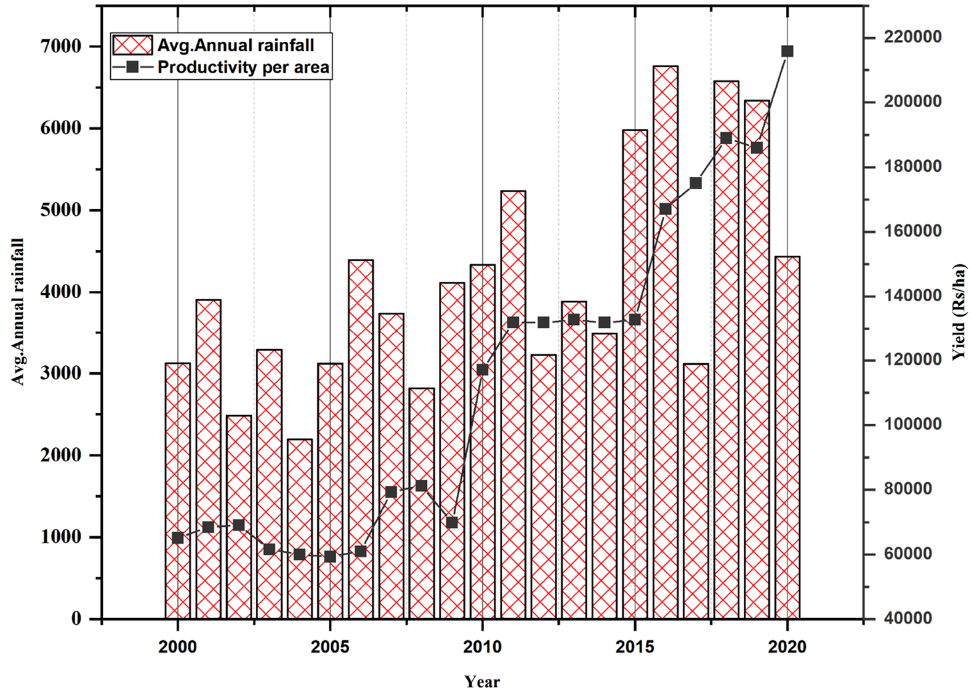


Fig. 13 Total productivity of the area in the years 2000 to 2020

reasons for increased output of paddy and areca nuts. From 2010 to 2020, the percentage of areca nut and paddy productivity increased (Fig. 14).

Over three seasons, the average profits from paddy ventures were lower than those from areca nut and coconut. As a result, farmers are exposing themselves to the work required to improve lake storage capacity and maintain water collection methods.

Because of the terrain and laterite formation of the soil, massive dams are not preferred for coastal Karnataka. During the summer, the bund's stored water is used for agricultural purposes. The findings demonstrate that water harvesting with a canal bund can boost output while also providing a water source and harvesting lake to improve the groundwater table for future use. Non-monsoon season agricultural yield increased from 2012 to 2020 after the bund system was implemented. Lake restoration with a bund system is an improvement that allows for water storage outside of the crop field, allowing for strategic supplementary irrigation. However, only a few farmers have used this technique, primarily for areca nut and paddy fields.

Seasonal variation of productivity pre- and post-construction of bund for lake outlet: monsoon and non-monsoon productivity after using bund construction for lake outlet

The efficient usage of lake water in the cop production increased in monsoon and non-monsoon seasons from 2010 to 2020 (Fig. 15).

The availability of water during the non-monsoon season has also substantially increased the restoration of lake water with bunds (Fig. 15). Throughout the year, during the monsoon and non-monsoon seasons, lake water availability remained constant. Production increased from 47,012.34 Rs/ha to 86,049.38 Rs/ha between 2000 and 2010. Water scarcity during the non-monsoon season will result in low agricultural output between 2000 and 2010. Non-monsoon crop production increased by 10.38% and 2010. After the bund was built, total crop yield increased by 16.38% and 2020. Productivity levels were above average during both the monsoon and non-monsoon seasons between 2000 and 2010. However, productivity levels in both seasons increased between 2010 and 2020 (Fig. 15). Bund construction for agricultural use contributes significantly to increased productivity during the non-monsoon season. Despite receiving less rainfall than average, non-monsoon season production increased from 2010 to 2020.

Management strategy for improvement of the existing lake

Sedimentation has also reduced the lake's depth. The majority of respondents agreed that residue removal is required for the Lake. Respondents in the mid-80s and 90s shared information about the lake's existence and importance in everyday life. According to the feedback of people in their 80s and 90s, the lake was well-maintained and productively used on a daily basis. Beneficiaries began to pollute in the

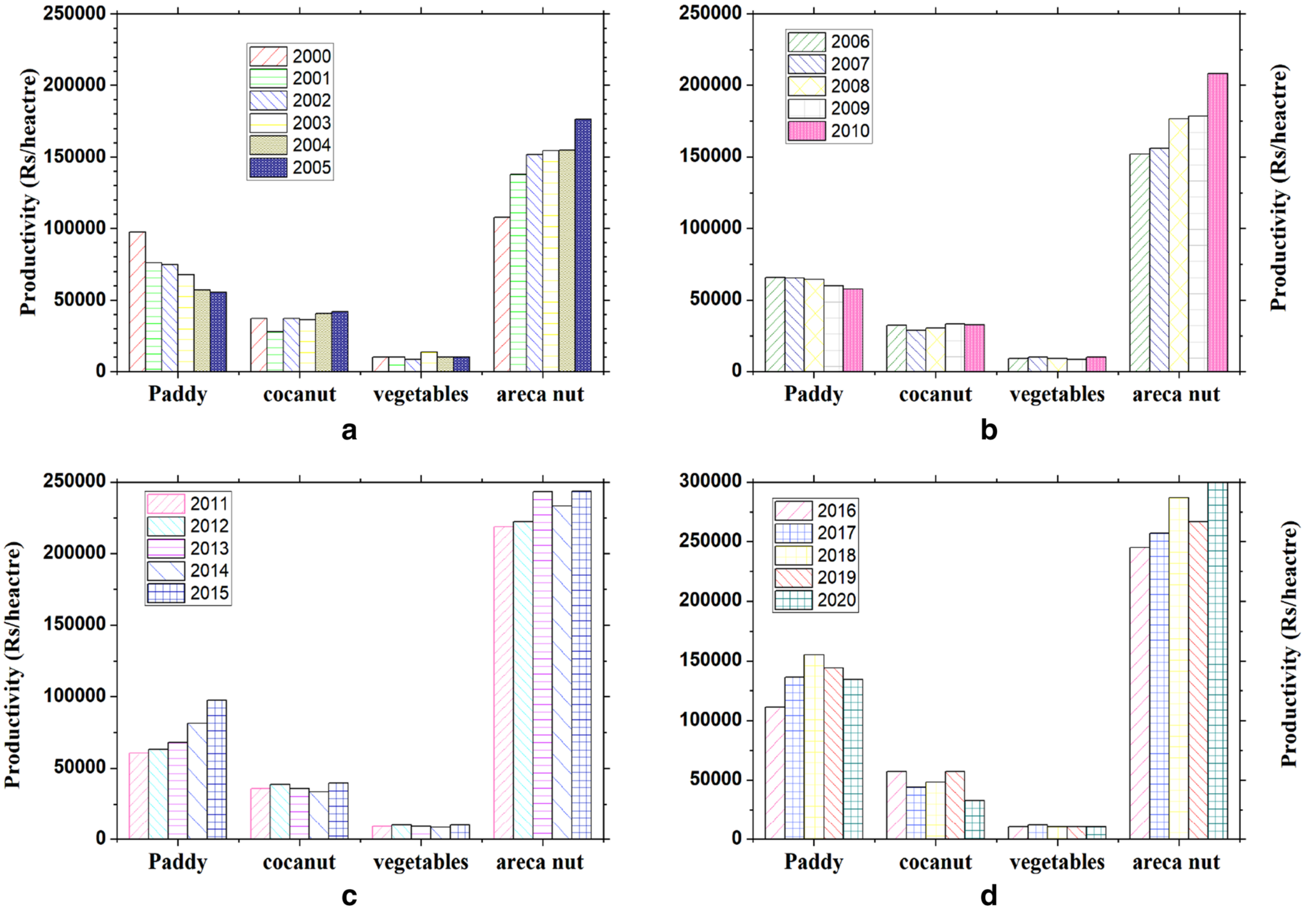


Fig. 14 Variation of crop productivity in the years **a** 2000–2005 **b** 2005–2010 **c** 2010–2015 **d** 2015–2020

long run, such as washing clothes, bathing animals, and so on. This activities contaminated the water. Sewage materials, in turn, influence water capacity limit step by step. Because that area is more reliant on lake water, restoring the lake will benefit all respondents. More habitats rely on lake water, so clean water is required for the natural environment.

Beneficiaries claim that creepers cover 15% of the lake's surface and periphery, and shrubs cover the lake's bottom; the lake has been eutrophicated for several years, so the study recommended removing the top vegetation for quality purposes.

Most communities in this area rely on this water for agricultural purposes, particularly paddy fields and areca nut trees. The respondent's main concerns are rejuvenation and the use of the lake for groundwater recharge. If the lake's sedimentation is removed, water storage will increase as the profundity expands. It will help farmers grow paddy. Because 70% of respondents said they use water for agriculture, lake water aided in groundwater recharge near open wells.

Increased access to profitable markets is critical for investment in lake water harvesting to have an impact on poverty reduction. This study found that increasing cash income is a top priority for farmers. The most pressing action needed to maximise the benefits of the existing system while encouraging wider adoption would be to connect crop and livestock producers working in semi-arid areas. The markets and marketing strategies to obtain high returns on their investments in water harvesting, such as removing sediment deposition from the lake so it can store more water. The results show that the sediment deposited in the lake is 10 to 15 feet deep. The removal of sediment and restoration of the lake with the construction of a bund across the flow of water can be used to improve groundwater recharge. As a result, the municipal authority should remove the silt deposition and increase the lake's capacity to provide more water for agricultural use. It can also save the existing water source for future use.

Integrating lake harvesting with the bund could be an essential capital investment in semi-arid areas, increasing market linkages and water availability. In 2010, the lake's

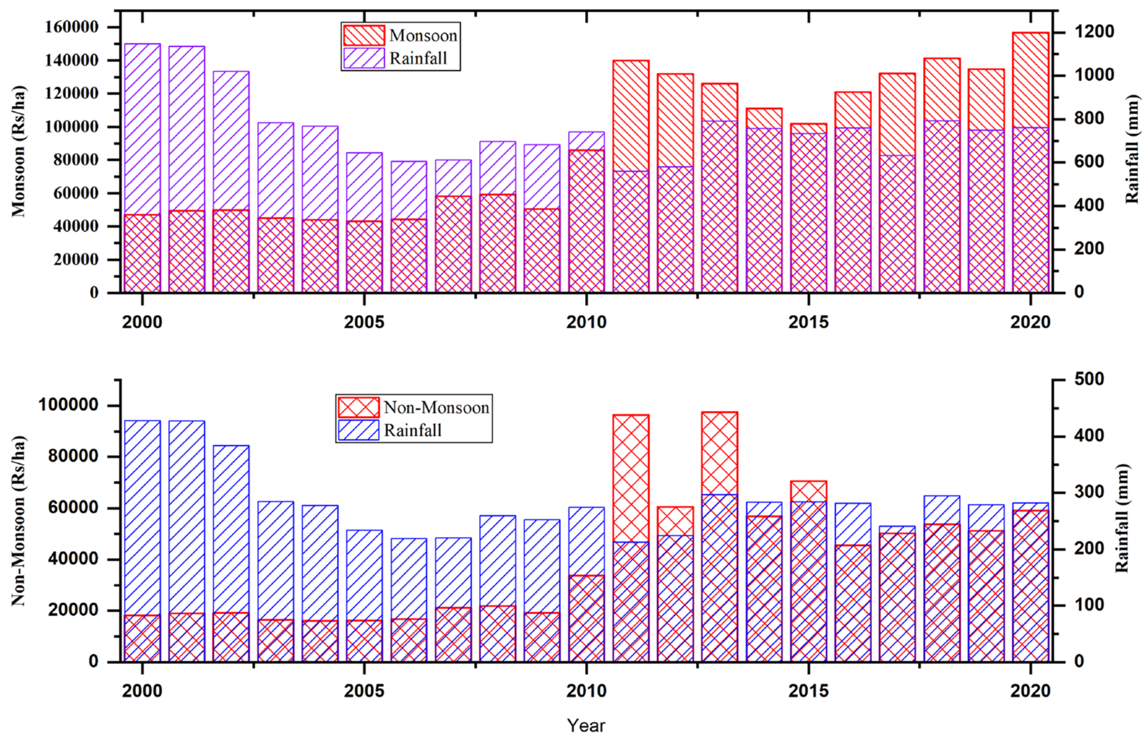


Fig. 15 Monsoon and non-monsoon productivity

beneficiaries used water sources to increase crop yield. However, because of the increased labour demand for paddy, increasing paddy production through canal water irrigation only occasionally increases the return on labour. Despite the fact that the structure has yet to generate a profit, they continued to grow the crop due to decreased water availability. The study identifies the drastic changes in yield after using the lake, shifting crops from paddy to arecanut. The areca nut and paddy yields increased after the bund was built in this area. The bund system and tank rejuvenation will provide more water to generate and help the locality, as well as improve groundwater recharge in the area. According to the study, bund construction aided in many ways in improving production, as other water sources could be stored for future use. The community demands that the responsible authority build a bund in the study area.

Discussion

The case for tank restoration can be made from both a commercial and equity and stability perspective. When compared to building new irrigation systems, canals, or tanks, restoration costs per unit are minimal. The preservation and enhancement of these structures is directly related to future food security.

As the initial assessments of the restoration process, community participation has become mandatory for any restoration project. The overall findings from the study and benefits of the lake are that the quality of water is acidic in nature, so it is not suitable for drinking, and the remaining parameters, such as potassium, sodium, nitrogen, and TDS values, are all within the allowable limits, allowing it to be used for agricultural purposes. After using the bund, 20 years of data are analysed, and variations in crop yield productivity are identified. The crop yield increased dramatically after the bund was used. However, the lake's current condition provides more benefits to lake users. The study suggests that the lake's restoration can be used lake water for a long time and is more beneficial to the beneficiaries, as is typical with rising water demand.

Preliminary studies

A few studies use seepage metre analysis to provide more precise measurements of groundwater flux (Blanchfield and Ridgway 1996; Rosenberry 2008; Kalbus et al. 2006; Martinez 2010; Kennedy et al. 2010; Lien and Ford 2014; Solomon et al. 2020; Lee et al. 2020). The groundwater flux was measured using the same procedure as in the previous study, and the result was 0.0182 m^3/s. As a result, some studies contend that studying the interactions between groundwater and surface water is critical to effective water resource management (Winter 1999; Sophocleous 2002). However, according to a similar study, the current metre method is used to calculate the discharge (Gerla 1999; Yuan and Forshay 2020).

The inflows and outflows data, as well as the equation of the water balance method, were used in this study to determine the total storage of the lake. The findings refute claims that increased internal Phosphorous loading causes poor lake water quality. At the same time, previous research has focused on recognising that high hypolimnetic water deficits cause oxygen, taste, and odour problems, as well as increased manganese and iron concentrations. The findings could imply that changes in land cover and longer growing seasons could increase manure utilisation, resulting in the draining of conduits, streams, and lakes, increasing the risk of eutrophication and biodiversity loss (Bhateria and Jain 2016). These findings take into account lake water quality analysis (Gupta and Dey 2013; Kumara and Vijaya Kumar 2011).

The catchment area contributes more nutrients to the lake water. Agricultural nutrients contain more phosphorus than forest nutrients. The deterioration of lake water quality was caused by an increase in internal phosphorous loading. Land cover change and longer growing seasons may increase manure utilisation, resulting in the draining of conduits, streams, and lakes, increasing the risk of eutrophication and biodiversity loss (Bhateria and Jain 2016). This parameter results in the lake water becoming eutrophicated. Previous research, on the other hand, has concentrated on the quality analysis of lake water (Gupta and Dey 2013; Kumara and Vijaya Kumar 2011). For the pilot lake, similar approaches were used. The lake's water benefits the lake in a variety of ways, including agriculture.

The lake's beneficiaries are more concerned about how the lake's water quality affects nearby crop yield and the ecosystem. The data suggest that water quality monitoring is an essential component of a lake management programme, and community perceptions provide valuable conservation support as well as information for ecosystem management. In the community prediction, the sedimentation depth is assumed to be 3 to 6 m. Using UAV surveys, some work has been done to determine sedimentation depth (Larson et al.2018; Moreno et al. 2022). Similar methods were used to estimate sedimentation depth; the result is 5.54 m, which is closer to the value gathered from community input.

Community input for lake benefits

Due to the lack of historical data, the study relied on a questionnaire survey of the beneficiaries. While previous research focused on data collection, such as through questionnaire surveys, these findings show that data collection through questionnaires provides dynamic documentation for future studies. A previous study found that a natural lake is more vulnerable to eutrophication than an artificial lake (Shenai and Quadros 2014). In general, reservoirs that are subjected to uncontrolled nutrient enrichment are more vulnerable to eutrophication than natural bodies of water.

People are generally perplexed by the formation of lakes. A few small studies provide information on artificial and natural lakes. When a natural lake is subjected to human enrichment, it is more susceptible to eutrophy (Shenai and Quadros 2014). In addition, according to a similar study, if a reservoir is subjected to uncontrolled nutrient enrichment, it is more susceptible to eutrophication than a natural body of water.

According to field studies (Sharip et al. 2019), natural lakes have significantly more algal variety than artificial lakes; based on a questionnaire survey and the lake's more eutrophy condition, the result suggests that the lake is natural.

Sediment deposition is a massive problem for lake management. The lake's beneficiaries are given a general idea of the depth of sedimentation. The research shows that desolation is an important factor in the restoration process. While previous research has focused on the internal Phosphorous (P) release caused by sedimentation, it slows eutrophication recovery and lowers lake water quality (Pettersson 1998). Questionnaires and UAN surveys, for example, were used to quantify total sedimentation. 2 to 5 m of sediment deposition, according to the respondents. Using a UAN survey with a resolution of 0.5 m, an accurate surface map of the lake bed and bottom surface profile data were obtained. The deduction provides 5.52 million, which is nearly identical to the answers gathered by the beneficiaries.

Rice is a major Kharif cereal crop grown along the coast of Karnataka (Jakkeral et al. 2018). The study (Khush 1984) explained the rice crop paddy field growing pattern. However, according to this study, rice crop cultivation has been drastically reduced in coastal Karnataka due to a lack of water availability.

The study shows that increasing the depth of the lake benefits lake users more. The observed increase in water consumption is effectively used in the construction of a bund for the lake's outlet. The analysis supports the theory that water storage expands the recharge zone in the surrounding area. Instead of concentrating water, the bunds diffuse it. They also reduce the amount of water that enters the system, allowing for greater penetration than open wells. Runoff does not easily damage or destroy bunds. Farmers may be confident that sufficient runoff will be collected to produce a crop even if rainfall is irregular or below average (Critchley et al. 1991). If lake water is not supplemented with groundwater, one of two things will happen: crop production will either fail completely or substantially (Nanthakumaran and Palanisami 2011).

The bunds save water, which helps to improve the groundwater table. According to the findings, the increase in areca nut production is due to paddy's lack of water availability. As a result, there is more water available. Beneficiaries also moved on to commercial crops, such as areca nut and some side crops. It's worth noting that a study chose crops based on cost and return availability of water (51.67%), with water deficit crops coming in second. Therefore, the areca nut increased rate from 2012 to 2020 is 195.74%. The findings show that rainfall in the 4000 to 6000 mm range remained constant from 2000 to 2020. Nonetheless, bunds increased productivity significantly (2010–2020). It is widely acknowledged that rainfall has no effect on productivity, particularly in 2001 and 2002, when productivity was 60,000 Rs/ha and 80,000 Rs/ha, respectively. In 2016, the average annual rainfall was 3000 mm, but productivity was 180,000 Rs/ha. Rain had no effect on productivity, according to the findings.

However, from 2000 to 2010, residents harvested crops from other sources, such as open wells or small ponds. After 2010, the study region's locality adopted a water source as a bund to improve productivity. Because of sufficient water availability, 80% of household respondents said they used paddy as the main crop in the first year after switching to areca nut as an entire crop. This study backs up the theory of groundwater recharge from the lake (Brauns et al. 2022). A similar study discovered that developing check dams increased agricultural production (Rao et al. 2017).

Conclusions

Community input has been used in the current work to improve the existing lake for future use. Summarizing all of the responses provided a good idea of restoration. After compiling all of the results and analyses, a portion of the development team concluded that the lake should be restored. The study tracked down complex transformation procedures such as the depth of sedimentation deposited in the lake and inflow diversion, the storage capacity of the lake, outflow study, and suggestions for improving the lake capacity, so that more water can be stored. It aided a larger portion of the community.

The study found that bund construction improved productivity in a variety of ways by allowing other water sources to be stored for future use. As a result of the continuous water supply from the monsoon and non-monsoon bunds, crop production increased from 16.84% to 19.84% between 2013 and 2020.

From 2000 to 2012, the overall yield decrease rate was 20.45% per year. The overall increase rate of paddy from 2000 to 2020 is 37.083%, with an annual increase rate of 10.12%. In the last two decades, the areca nut yield has increased by 195.74%.

The community's involvement in lake restoration projects helps to improve the groundwater table near the lake's surface. The bund is one of the techniques that farmers can use to improve production in that field by preserving the surface water. This study was primarily concerned with quantifying lake benefits in terms of crop yield. More research is needed to determine the lake-level contribution near open wells and healthy aquifer systems.

Funding This research did not benefit from any budget; it is the result of the personal author's research work.

Data availability All data used for the analysis of this study will be in the public domain and available free of charge.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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