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Traditional Dual Tank Water Management: A Study of Kolakanatham in Perambalur District, Tamil Nadu

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Abstract

Societies make rainwater harvesting structures to collect and store rain water to cater for their immediate and future needs. In a remote village in the Perambalur district, the people use the dual temple tank, nearly 350 years old, for their drinking purposes. This study tries to understand the traditional knowledge embedded in the dual pond structures, cascade aerators, and an open well connected with the ground aquifer inside the tank. This study delves into projected rainfall trends using NASA POWER data for 2050, revealing a noticeable increase and an assessment of pond water quality parameters demonstrating adherence to acceptable limits set by the Bureau of Indian Standards (BIS). However, despite meeting these standards, the water quality index deems the water unsuitable for direct human consumption, though it remains suitable for domestic household use. Moreover, analysis of land cover and land use changes by Sentinel2A data over the past 22 years underscores significant growth in settlement areas, indicative of a rising demand for water resources. The study proposes the restoration and utilization of the dual tank system as a potential solution to address this burgeoning water demand, offering a reliable water source and preserving traditional practices within the local community.

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Introduction

In India, rainwater harvesting for various purposes, such as drinking, agriculture, and sociocultural activities, is widespread.[1] Rural areas across the country are characterized by the ubiquitous presence of tanks and ponds, which serve as focal points of daily life. In South India, regions where perennial water sources are scarce and settlements are distant from rivers and tributaries, communities have relied on constructing artificial water-holding structures. Often based on traditional or indigenous knowledge, these structures are vital for meeting basic needs, especially during normal days and lean seasons. Local rulers typically facilitated constructing and maintaining these water storage facilities in collaboration with usufructuary communities.[2] The effective utilization and administration of water resources are important in regions such as Tamil Nadu, where reliance on monsoon precipitation is paramount. Historically, the region's inhabitants recognized the pivotal role of monsoon rains and developed water harvesting mechanisms tailored to the local topography.

Nonetheless, it is noteworthy that the precipitation patterns in Tamil Nadu exhibit annual variations.[3] In Tamil Nadu, the understanding of water storage in reservoirs and ponds, as well as its hydrological cycle, finds mention in numerous literary works from the Sangam period (300 BC to 300 AD), supported by archaeological findings and diverse rock inscriptions.[4] The majority of Tamil Nadu lies within the rain shadow region of the Western Ghats, resulting in limited rainfall from the South-west monsoon. Conversely, the Northeast monsoon, often accompanied by cyclones, brings intense rainfall in a short period. Over time, locals have developed unique hydrogeological structures by gaining knowledge through extensive observation of meteorological patterns, primarily for agricultural and drinking water needs.[5]

Before the British colonization in 1600 AD, local communities in Tamil Nadu autonomously managed tanks with a strong sense of ownership. However, the British colonial administration introduced centralized systems, leading to the deterioration of the well-established tanks. The establishment of the Public Works Department (PWD) during colonial rule transferred control of these tanks to governmental authority, causing the dissolution of traditional community stewardship.[1,6] Andhra Pradesh, Karnataka, and Tamil Nadu collectively possess approximately 150,000 tanks,[7] of which in Tamil Nadu alone, 39,200 tanks were present in the early 1980s. About 9,000 were categorized as system tanks, while 10,000 were referred to as ex-Zamin tanks. Both classifications encompass large tanks, many of which are currently administered by the PWD.

Additionally, around 20,000 tanks with a catchment area smaller than 40 hectares are under the jurisdiction of Panchayats (specifically, Panchayat Unions), commonly known as Panchayat tanks. In recent years, population growth, urbanization, and infrastructure expansion have further strained the declining traditional water management systems. Additional contributors to this decline include land use changes, deforestation, sedimentation, inadequate maintenance, infrastructure development, industrial pollution, agricultural activities, chemical fertilizers and pesticides.[3]

Presently, Tamil Nadu grapples with a water deficit exceeding 11%, a challenge projected to intensify in the foreseeable future. Given the absence of perennial rivers within the state, Tamil Nadu relies heavily on its neighbouring states for its water supply. In response to this pressing water scarcity issue, Tamil Nadu has embarked on initiatives to promote water recycling and the deployment of seawater desalination systems.[8] In this context, traditional knowledge of water harvesting holds promise for addressing the escalating water demand.

Among the diverse rainwater harvesting systems implemented in Tamil Nadu, the pond harvesting system stands out as a significant and extensively utilized method. Pond harvesting systems offer several benefits for sustainable water management and agricultural development. This technique helps mitigate flood risks by minimizing floodwater quantity and reducing peak flow. Moreover, it plays a crucial role in groundwater recharge, replenishing aquifers and ensuring long-term water availability. Regarding water supply, pond-harvesting system outperforms roof top rainwater systems due to their larger scale, enabling the collection and storage of more rainwater for various purposes. Additionally, it contributes to energy savings and emissions reduction, particularly when strategically located at lower levels, thus promoting environmental sustainability. Economically, this technique offers widespread benefits, especially in irrigation and income generation for farmers, making it a valuable tool for enhancing agricultural productivity and livelihoods.[9,10] The indigenous customs related to temple tanks in Tamil Nadu have profoundly impacted contemporary water management initiatives in the study area.[11] The indigenously developed water management practices offer crucial insights into sustainable water management and conservation.

The present study is about the traditional knowledge of a dual tank system, a sophisticated water storage and distribution method where the first tank acts as a reservoir replenishing groundwater, and the second tank stores runoff water. This concept might have originated from contemporary water storage structures, particularly in arid areas that face water scarcity and fluctuating rainfall patterns. This management practice fostered a sense of ownership and responsibility among the local stakeholders. This is evident in modern water management practices. These structures are effectively used for flood control, storing surplus water in modern times. The above practice also signifies biodiversity, natural habitat, and water conservation. Henceforth, these indigenous water traditions provide valuable knowledge and insights to address contemporary water adversities by striking a harmonious balance between community demands and environmental sustainability. With this backdrop, this paper aims to explore the traditional 'Two Pond Water Harvesting System', its structure, water management, and its future potential as an alternative water source for the community.

Traditional Water Harvesting Practices in Southern India

The historical backdrop of the Sri Varadharaja Perumal temple at Kolakanatham, Perambalur district, Tamil Nadu and its water-storing structures provide important insights into the traditional water management practices and religious importance within the community. The temple was built 350 years ago, accompanied by a stone inscription that lists the land contributions. This emphasizes the long-lasting relationship between temples and tanks, which are crucial for religious and sociocultural activities. The temple tanks traditionally found in every hamlet functioned as reservoirs for collecting rainfall, recharging groundwater, and sustaining the surrounding ecology. The significance of these temple tanks is sustainable water management, highlighted by their hydrological functions, such as water storage during heavy rainfall and groundwater augmentation. Gaining insight into the historical background is crucial for a thorough understanding of the importance of traditional water harvesting techniques, such as the twin tanks, in effectively meeting water requirements and safeguarding cultural heritage in contemporary research.

Knowledge can originate from either scientific or traditional origins.[12] Traditional knowledge, in particular, has been characterized as a collective reservoir of knowledge, customs, and convictions that evolve through adaptive mechanisms and are passed down through generations via cultural transmission.[13,14] India's diverse terrain significantly influences the climate across its various regions, giving rise to distinctive summer, winter, and monsoon seasons. Numerous regions in India have cultivated unique water conservation practices due to reliance on the monsoon, water scarcity due to climatic conditions, and limited water sources.[15] Tamil Nadu is rich in traditional practices passed down through generations, encompassing diverse cultural, art, and spiritual aspects. These traditions play a significant role in shaping the identity and heritage of the region.[4] The different water harvesting practices are described in Table 1.

Materials and Methods

Study Area

One of the unique structures of water harvesting tanks for religious and drinking purposes is located at Kolakanatham village in the Perambalur district of Tamil Nadu (Lat 11.115894, Long 78.950294) (Figure 1). This village is located along the geo-heritage site at the Karai-Kolakkanatham section of the Perambalur district. (No 193 /150/CD/ Geological Heritage Site/TN/2015). The typical semi-arid climate of Perambalur district has scorching summers and mild chilly winters. March through May is the warmest time of year. The average maximum temperature during this time is 34°C, the average lowest temperature is 23°C, and the maximum temperature frequently surpasses 40°C. According to the India Meteorological Department, Chennai, in 2017, the actual rainfall recorded was 1005.5 mm, while in 2018, it dropped significantly to 533.2 mm, indicating a notable decrease from the normal rainfall expectations. Subsequent years witnessed varying degrees of rainfall, with 2019 experiencing 747.3 mm, 2020 recording 1102.4 mm, and 2021 noting a substantial increase to 1563.4 mm, exceeding normal rainfall levels.[19] Hence, an upward trend in rainfall patterns has been observed in the Perambalur district (Figure 1). This area is characterized by a lack of soil moisture and is classified as semi-arid. The primary economic activity of the community is agriculture. This village is predominantly inhabited by members of the lower caste social groups, such as SC (Scheduled Castes) and ST (Scheduled Tribes). This community exhibits a literacy rate of over 60%. However, water scarcity is prevalent in this region, which necessitates cultivating crops only during the rainy season.

Table 1: Different Traditional water conservation practices in Tamil Nadu

Traditional Water Harvesting Practices	Type of the System or Use of the System	Advantages	Location	Reference
Eri system	Eris are larger surface water storage structures mainly used for irrigation and fishing.	Large storage capacity of water	Tiruvannamalai District, Tamil Nadu;	Nandhini and Priya[3], Chakravarty[15]
Oorani	These are smaller surface structures, mainly lying along with residential areas, mainly used for drinking purposes. The name *Oorani* is widely used in southern Tamil Nadu.	Groundwater recharge and replenish aquifers	Pattikadu village in Thirukazhuk-undram block, Tamil Nadu	Chakravarty[15]
Kanmoi	These are larger water storage structures similar to the *Eri* system. These terms mostly prevailed in Southern Tamil Nadu.	Replenish ground -water resources, storing excess water. Its placement is strategically chosen to ensure the efficient collection and manag -ement of water flow from the canal.	Southern Tamil nadu	Ratnavel and Gomathinay -aga m[4]
Kulam	These are small dugout structures with four side walls or circular in size. Used specifically for storing drinking water.	Regulate water flow, reduce flooding and groundwater recharge	Tamil Nadu	Sivasubram -niyan[16]
Well	A well is a shaft dug into the ground to access water reso -urces. The width varies in diameter.	Groundwater recha -rge and replenish aquifers	Palar Basin, Tamil Nadu	Vaidyanat han[17]
Temple Tanks	"Temple tanks" are associated with the temples. Which has steps to reaching down to the water used for temple rituals and holy bath	Regulate water flow, reduce flooding and groundwater recharge	Madras city, Tamil Nadu	Ganesan[18]

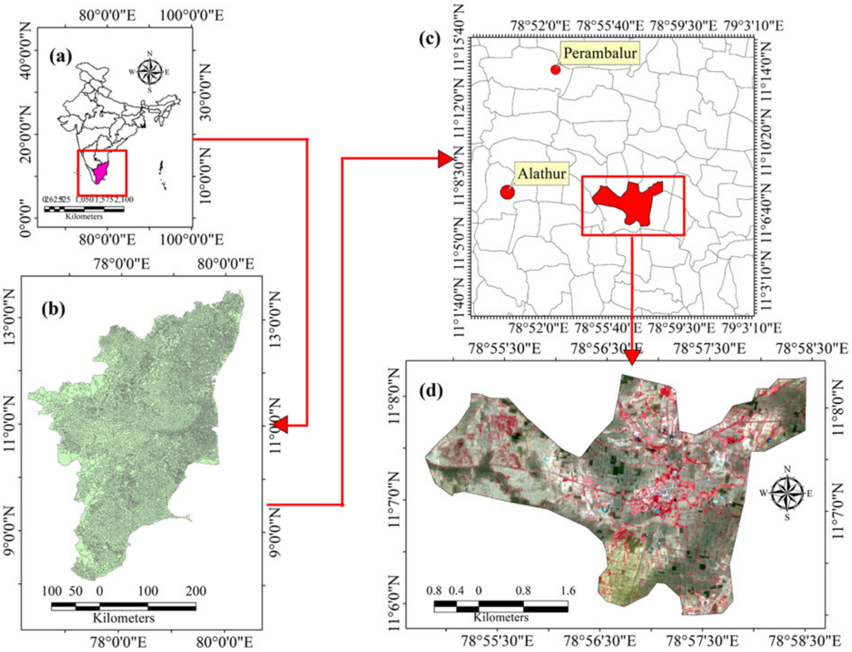

Fig. 1: Study Area

Water Sampling, Analysis and Water Quality Index

The water samples were collected from the southwestern temple tank in Kolakanatham village (The description of the tank is provided in section 4.0). The samples were collected from the secondary pond using polyethene bottles that had been pre-cleaned and sterilized. The bottles were submerged approximately ½ to 1 feet below the water surface for water sample collection, ensuring complete filling before tightly sealing with the cap. Water quality measurements were conducted monthly from July 2022 to June 2023. The basic physiochemical parameters like pH (Thermo Scientific Orion ROSS electrode), Dissolved Oxygen (RDO Optical Dissolve Oxygen Sensor), Biological Oxygen Demand, Electrical Conductivity, Total Dissolved Solids, Salinity (DuraProbe 4-Electrode Conductivity Cells) were measured using Thermo Scientific ORION Star A329 Meter. The Hardness, Alkalinity, Residual Chlorine, Iron, Turbidity, Chloride, and Iron (Jal Tara Water Testing Kit of TARAlife Sustainability solutions Pvt. Ltd., Delhi)

The Water Quality Index (WQI) is a singular metric used to assess water quality by integrating various parameters and complex data. Its primary aim is to offer a straightforward and concise representation of water quality for diverse applications. The Weighted Arithmetic Water Quality Index (WAWQI) evaluates water quality based on its purity level using commonly measured water quality parameters. The index offers a comprehensive assessment of the overall water quality status by incorporating various parameters and identifying the presence of pollutants.[20,21] The WAWQI method was employed to calculate the WQI in this study.[22,23] Eleven distinct water parameters were employed to derive the single index value of WQI. Subsequently, the obtained WQI values were interpreted and compared against the established standards for drinking water quality, as recommended by the Bureau of Indian Standards (BIS)[24] in 1983. The WQI is computed using the "Weighted Arithmetic Index method" as described below.[23]

$$\mathrm{WQI} = = \sum_{n=1}^{n} qn * Wn / \sum_{n=1}^{n} Wn \quad ...(1)$$

Where qn is the rating for the nth water quality parameter; Wn is the unit weight for nth parameters. And the sub-index quality rating in calculated using the following equation.

$$q_n = 100[(V_n - V_{io})/(S_n\text{-}V_{io})] \quad ...(2)$$

q_n = Quality rating for the n^{th} water quality parameter; V_n = Estimated value of the nth parameter at a given sampling station; S_n = Standard permissible value of n^{th} parameter V^{io} = Ideal value of nth parameter in pure water. V^{io} is taken as zero for drinking water except for pH = 7.0 and dissolved Oxygen =14.6mg/l. The unit weight was calculated using the following relation

$$W_n = K/S_n \quad ...(3)$$

Where W_n is the Unit weight for nth parameters, S_n is the Standard value for n^{th} parameters, and K is the Constant for proportionality.

Rainfall and Temperature

Long-term rainfall data (in millimetres) spanning from 2001 to 2021 were acquired from freely available global sources provided by the National Aeronautics and Space Administration's Worldwide Energy Resource Prediction (NASA POWER) project.[42] A linear analysis approach was employed to examine the seasonal trends of rainfall over the specified study period, spanning from 2021 to 2050. Linear analysis allowed for the identification of trends, patterns, and correlations in rainfall data over time, which is helpful in understanding the dynamics of hydrological processes and their impact on the objectives of this research. The analysis was conducted using Minitab version 21.2, with the selected model type being the linear trend model. The linear trend equation modelling rainfall is estimated, which can be concisely expressed as follows.

$$Yt = f(t) \quad ...(4)$$

(Where Y denotes the climate variable under scrutiny, and t signifies the year).

Satellite Data

This investigation utilized satellite imagery from Sentinel2A. This study analyzed a satellite image captured on 14 April 2023 at 11:54 a.m. UTC. The Copernicus Open Access Hub, the primary platform for acquiring Sentinel-2 Level-1C user products (https://scihub.copernicus.eu/), supplied the imagery. L1C grains or tiles are orthorectified and spatially registered images of 100 square kilometres. The UTM/WGS 1984 projection is employed to present the images. The tile S2B_OPER_MSI_L2A_DS_2BPS_20230816T094132_S20230816T051547_N05.09 (Supplementary Table 1) was selected for further analysis due to its coverage of our study area.

Based on the provided information, it is evident that the sentinel image is a high-resolution image that provides precise insights into the characteristics of land use and land cover over the test region. Furthermore, it will enable us to determine the current state of water harvesting in the research region.

Landuse and Landcover (LULC) change Analysis

Four bands with a resolution of 10 meters have been chosen to determine the land use pattern within the study region. These bands are referred to as Band-2, Band-3, Band-4, and Band-8, as indicated in Table 3. All four bands have been integrated into the ArcGIS environment, specifically utilizing the data management tool. The final result of the map was obtained by applying the maximum likelihood classification algorithm. The LULC map has identified five distinct types: water bodies, agricultural land, barren land, settlement, and vegetation (Supplementary Table 1, 2). The importance of land use and land cover in landscape dynamics stems from its enormous effects on biodiversity, ecosystem services, and environmental health. Therefore, effectively managing and utilizing them is crucial for achieving sustainable land use and reducing environmental deterioration.

The importance of land use and land cover in landscape dynamics stems from its enormous effects on biodiversity, ecosystem services, and environmental health. Therefore, effectively managing and utilizing them is crucial for achieving sustainable land use and reducing environmental deterioration. Moreover, the operation and efficiency of classic tank systems are greatly impacted by land use and land cover. Hence, it is imperative to adopt sustainable land use practices and conserve natural land cover to uphold the well-being and effectiveness of these systems.

Typical Dual Tank System land use patterns are highly interdependent. Typically, land is classified into five categories: agricultural, residential, and water bodies, including dual tank systems, vegetation, and currently fallow. When these patterns are quantified, they usually show a balanced distribution, which shows that the society values its natural resources and knows how to live sustainably. The change map illustrates the expansion of human settlements and the decrease in both the size and permanence of the conventional tank. It illustrates the significant expansion of human settlements as a result of the rising population rate. It is clear that as the settlement area expands, traditional ponds no longer remain perennial.

Settlement Growth

The identification of settlement growth can be facilitated through the utilization of arithmetic population growth. The subsequent equation has been utilized to determine the magnitude of the arithmetic progression of a settlement.

$$\text{Arithmatic growth Settlement} = (\text{Settlement area}_{Present} - \text{Settlement area}_{past}) / \text{Settlement}_{Past} \times 100 \quad ...(5)$$

An arithmetic growth rate has been selected to analyze settlement growth because it is based on its simplicity and practicality, especially in cases when growth happens consistently. In contrast to exponential growth, arithmetic growth does not involve compounding effects. Instead, it involves a constant amount of growth added over each period, making it easy to calculate and understand. This method is particularly valuable for making short-term forecasts or when managing communities undergoing consistent, gradual growth in population or development. Using arithmetic growth, planners and researchers can construct unambiguous, linear models that enable direct analysis and decision-making, enhancing the ability to predict resource and infrastructure requirements more efficiently.

This dual tank system influences the spatial pattern of land use and land cover as the water in the tank is used for domestic purposes and to irrigate agricultural land. This region is part of the Deccan plateau, so it's hard to cultivate crops without water. On this ground, the land use map plays an important role in regulating dual tank systems.

The annual growth rate of settlement has been calculated by dividing the total increase by 22 years. The interval of arithmetic expansion of settlement has been determined as 22 years based on prior satellite images, which indicate that most settlements experienced growth between 2001 and 2011. However, we have extended the time frame by an additional ten years to facilitate the research.

The study of settlement growth is crucial as it directly influences population dynamics, urban planning, resource management, and economic development. As human settlements grow, they create a greater need for water, which can result in a decline in water quality and changes to the natural water cycle. This presents substantial issues for managing water resources. In addition, the growth of settlements puts pressure on the current infrastructure, requiring the development and improvement of transportation, utility networks, and social services. This also raises issues about sustainability.

Water quality analysis and the calculation of the water quality index were conducted to gain insight into the current state of water quality, aiding in effective water management. Additionally, an analysis of rainfall patterns and LULC changes was performed to assess the future potential of the tanks, particularly highlighting the impact of settlements on dual tanks. This analysis provides valuable information for managing water resources in the future.

Dual Tank System of Kolakanatham

Structure and Elements

Sri Varadharaja Perumal's temple and temple tank are closely associated as water is crucial for religious and sociocultural activities. When used exclusively for temple activities, temple tank water is called *Theppakkulam* (Temple tank). Since daily rites must be performed at regular times, the *Theppakkulam* must hold water year-round. Temple tanks are rarely polluted since locals cannot use them. In water-scarce locations like Kolakanatham village, temple tanks are transformed into potable water.[25] Based on landscape, natural water availability, and construction materials, hydrological structures, components, and dual tanks system performance were commissioned.[26] Three hydraulic locations were traditional for temple tanks. During severe rains, the first reservoir stores water and improves groundwater. Second, efficiently stored runoff water can be used for summer droughts and flood management after heavy rains. Third, land-water interactions with surface and groundwater assist the ecosystem.[22]

Structure of the Temple Tank

The temple tank is a square shaped water body which measures 18 meters per side and has a depth of 3 meters. Stepping stones provide access to three sides of the tank (Figure 2A). A conduit is integrated into the bund on the fourth side. The bund's water-front features a revetment wall composed of permanent stone structures. It safeguards the banks against erosion and subsidence during intense rainfall, flooding, and tidal waves resulting from the interaction between air and surface water in the tank. Elevated stone walls safeguard the water from wandering animals. A rectangular well featuring a brick and stone wall is situated at the centre of the tank, measuring 6 meters in length and 5 meters in width. The well is accessible solely during summer when the tank is depleted. The temple tank features a water conduit, stepping stones, and a revetment wall. The primary tank retains water, and the secondary tank processes and replenishes groundwater. Water purity is preserved through sedimentation and aeration within the tank system. Canals transport catchment discharge water to the primary tank via gravitational flow. The well connected to the secondary tank supplies water from subterranean aquifers during arid seasons.

Aquatic Channel Conduit

The conduit is situated atop the tanks and is enclosed by the bund (Figure 2B). This water tubing links tanks like an umbilical cord. The 'U shaped conduit construction functions as a tunnel made of elongated stones featuring a central depression. The prepared stones possess the appropriate margins for limestone mortar-bonded stone slabs. The tube measures 30 cm in width and conveys clarified water from the primary to the secondary tanks.

Principal Reservoir

The primary tank is rectangular, measuring 13,200 square meters and 2 meters in depth, surpassing the dimensions of the secondary tank. The tank bunds are constructed of earth. Bunds are broader, taller, and more robust to endure substantial water retention. Indigenous trees such as *Ficus religiosa*, *Tamarindus indica, Mangifera indica, Strychnos potatorum, Terminalia arjuna, Neolamarckia cadamba,* and *Phyllanthus emblica* with their robust root systems reinforce tank bunds, guaranteeing the stability of any structures erected upon them. The primary and secondary tanks are linked by a sculpted stone conduit that traverses the northern bund. A sporadic stream delineates the southern embankment of this reservoir. The northwest inflow channel of this tank collects surface runoff from the catchment area via a singular channel. The primary tank functions as a storage, sedimentation, or pre-treatment vessel.

Redirecting Watershed Runoff

Water harvesting involves the collection of runoff for beneficial utilization, as stated by Critchley and Siegert.[27] During the seasonal monsoon, transient water sources are limited, prompting rural inhabitants to conserve rainwater for future use. A prevalent method involves redirecting seasonal streams through an intricate system of canals to facilitate gravity-fed water flow into storage reservoirs. The catchment area is often situated away from residential zones, which consist of rainfed agricultural land.

The catchment's surface runoff rainwater traverses as a five-meter-wide stream that might suddenly increase its velocity. Precipitation descends into the little riverine stream along the gradient. This mainline is more substantial because of the influx of water from adjacent fields via small streams. A canal diverts water to the tank through a narrow, winding pathway from this point. Water from this conjoining junction will be directed to the main tank and the adjacent minor riverine stream.

A complex system of gravity-driven canals transports water from seasonal streams to the reservoir in conventional water harvesting. Water enters the channels and main tank from the surrounding area. Curved conduits transport water to the reservoir. Water moves effortlessly along canals that conform to the landscape. Embankments adjacent to streams mitigate erosion and regulate water flow. The dual pond system effectively captures and holds seasonal stream waters via properly positioned pipes. The residents consume and irrigate using the ponds. Traditional structures exemplify the indigenous community's ancestral proficiency in utilizing natural resources to fulfil water requirements.

Water Treatment Process

Primary Treatment

The water treatment methods have evolved historically worldwide, which was rudimentary in structure and had expected clean water results. The knowledge of reducing the turbidity level from the sources of runoff water is an old age phenomenon. The early settlers of Harappan allowed the river to divert its silt-laden water and pass through several interconnected small reservoirs to allow sediments to settle down.[28]

The running water in the stream undergoes a roughing treatment process intended to eliminate big and settleable material from raw water in the channel by meandering before the water reaches the reservoir. Where streams carry suspended and floating debris, such as leaves or branches, the heavier objects tend to move along the bottom during high flow periods. The water abstracted from the turbid streams reduces the carrying capacity of the load at sedimentation tanks.

Plain sedimentation allows for removing suspended solids in the raw water by gravity and the natural aggregation of the particles in a basin without coagulants. In tropical countries, plain sedimentation effectively helps the turbidity of runoff water carried with heavy soil erosion be settleable. The viscosity of water is reduced because high temperatures improve the sedimentation process. The storage reservoirs serve several purposes in natural water treatment by reducing turbidity, attenuating sudden fluctuations in raw water quality, and improving the quality by reducing the number of pathogenic bacteria.[29] The seasonal thermal or continuous chemical waterbody stratification substantially affects the water quality of sedimentation of suspended particles, including pathogens and hydrophobic chemicals adsorbed to the particles.[30]

Water storage is a physical treatment of the received runoff water when collected in the primary tank. When fresh water is stored for a certain period, harmful organisms can be eliminated by deposition. Galvis[31] noted that harmful protozoans like *Schistosoma cercariae* generally do not survive 48 hours of storage. The number of faecal coliforms and streptococci is considerably reduced when the raw water is stored. Moreover, the storage allowed the settleable solids content, the expected removal ratios were up to 80-90 percent, and the sedimentation tanks could improve water quality.[32]

Through the primary treatment process, the water from the canal gets cleaned by the sediments, and large particles are settled. This is sent to the secondary treatment tank through a conduit followed by a cascade tank.

Secondary Treatment

Cascade Aerator

After the rainwater reaches the primary tank, the physical sedimentation-free clear water will pass through a stone conduit to the secondary tank (Figure 2C, 2D). While flowing from the openings of the stone conduit to the secondary tank, the water flows through a well-built stone structure constructed like footsteps, which act as an aerator for the steady stream of water. When the water flows through the stepped cascade aerator structure, the change in the form of energy from one step to another creates turbulence. As the water moves downstream, the air and water mix, causing bubbles to rise and gas molecules to diffuse into the liquid phase. The stepped cascade hydraulic structure minimized the nitrogen content, increased the oxygen level, and dissipated the force of water.[33]

Obstacles like falls, rises, hits, and strikes caused by cascade structures cause a physical disturbance in the smooth flow of water and allow it to mix with atmospheric gases. The dissolved gases such as carbon dioxide oxidize dissolved metals such as iron (Fe), Hydrogen Sulphide (H_2S), and volatile organic chemicals (VOCs) are removed.[31] The maximum exchange productivity depends on the gaseous and liquefied substance interaction on the stepped frictional surface. The oxygen added through aeration could increase the palpability of water by removing its flat taste. This aeration is performed by cascade aerators, which consist of a series of steps over which the water flows.[34]

The present study describes how natural aeration and sedimentation were essential in water purifying in traditional water treatment procedures, such as those observed in ancient civilizations like the Harappan period.[35] Removing dissolved gases and increasing oxygen levels[36] using cascade aerators is essential to modern water treatment These old water structures mimicking natural processes may have inspired the current cascade aerators, which follow these ancient techniques. Turbulence is induced by the tiered cascade structure described in the current system to improve gas exchange between the air and the water. This procedure can lower the nitrogen concentration, raise the oxygen levels, and remove dissolved pollutants. This traditional method is consistent with modern cascade aerators that purify water via physical processes and sun radiation. Cascade aerators preserve historical characteristics while offering the best filtration by combining modern and ancient water treatment methods.

The secondary tank, which received the clear water after a certain period of sedimentation, aeration, and exposure to sunlight through the water, underwent the natural water treatment process. The water will stay in the secondary tank for a reasonable period until summer. The village people use the water from the second tank for drinking and religious purposes until the tank dries in summer. The ground surface of the tank is a non-permeable hard-rock area, which holds the water without losing the quantity by seeping into the underlying area. The rocky surface area is opened to create a rectangular open well connected with the permeable underground area in the middle of the tank. Groundwater recharge is the renewal or replenishment of water in the groundwater system, which is recharged during rainy days.[37]

The temple tank enables natural groundwater replenishment, which supports sustainable water management. First, impermeable bunds and revetment walls keep rainfall inside the tank, prevent overflow, and stimulate aquifer water penetration. A well in the tank bed connects surface water in the tank to the groundwater aquifer. Water percolates through the well into the aquifer during rains, and tank refilling restores groundwater. A vast network of conduits and canals transfers surface water into storage structures by catching rainfall runoff. By collecting and storing rainwater runoff, the tank reduces surface water flow and recharges groundwater, especially during strong rains. The tank's design and the region's explicit natural topographical features help to recharge groundwater. The stored water percolates into the aquifer by being placed on a porous rock substratum. The temple tank's wells, channel networks, revetment walls, and impermeable bunds promote natural groundwater replenishment. By collecting, storing, and allowing rainwater to enter the aquifer, the tank ensures groundwater supplies for future generations.

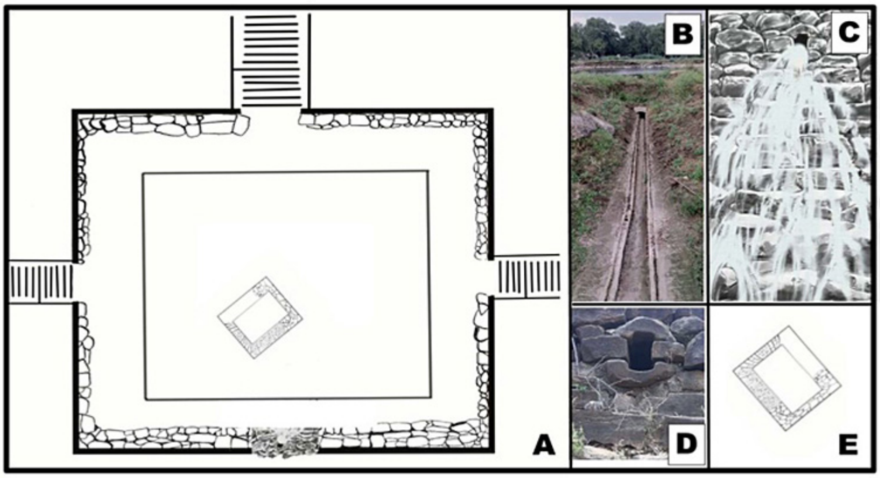

Fig. 2: Different Components of Dual Tanks (2A: Structure of the temple tank; 2B: The Conduit -water channel; 2C & 2D: Cascade Aerator; 2E: The Well

The Well Water
The well is situated on the central surface of the secondary pond, and its depth is 3 meters. The rectangular well connects the surface and subsurface of the pond (Figure 2E). When the water in the secondary tank dried up in the summer period, the water in the well was the source of life for the people. Even in the most prolonged drought, the water springs up from the corner of the well, where the well is connected to an underground aquifer. The tank with the well in the bed acts as a medium to link with the underground aquifer as a natural recharge.[18]

So, the open well supplies water during the hot summer period, and it is supported by underground springs, which display connectivity with aquifers. The well in the secondary tank effectively supplies the village with water during drought. The ability of the well to reconnect with the underlying aquifer and refill water supplies, even in the absence of surface water in the tank, is crucial. In the event of summer or prolonged droughts, when the water on the surface of the secondary tank evaporates or decreases, the well supplies the residents with drinking, cooking, and sacred water. The well connectivity to the sub-surface aquifer ensures long term water availability. The well also facilitates infiltration of excessive surface water by accessing the aquifer. The aquifer system thereby ensures water provisioning even during dry spells. A well in the dual pond water system facilitates natural recharging through the interconnectedness of surface and groundwater resources.

Overall, the temple tank construction is vital to water harvest and treatment in the study region. First, the tank's square design and depth maximize water storage capacity, allowing rainwater collection and retention. This design makes water gathering easier, especially after heavy rains, which meets community water demands. Bunds and revetment walls around the tank serve several roles. They shield the tank from erosion and subsidence during severe rain and floods, preserving its structure. The bunds' elevated stone walls protect the water from wandering animals and other contaminants. Water quality must be protected to keep gathered water safe for drinking and religious usage. The water channel at the top of the tank connects water management system elements. It transfers water from the primary tank to the secondary tank for effective water treatment. The conduit's diameter and materials maximize water flow, reducing pollution and loss. The primary tank also stores and pre-treats. Its rectangular form and huge surface allow it to store catchment rainwater. Suspended solids settle in the main tank before additional treatment. The sedimentation removes turbidity and particulates in the harvested water, improving water quality. Natural water treatment takes place in the conduit-connected secondary tank. Water is aerated and exposed to sunlight to reduce microbial contamination. As the well is connected to subsurface aquifers, the secondary tank ensures consistent water even during dry spells, ensuring water supply sustainability in the study area. The temple tank's shape, bunds, conduit, and interconnected tanks are indigenously designed to support water harvesting, treatment, and storage, meeting the study's goal of sustainable community water management and supply.

To summarize, the dual pond system involves a variety of phenomena related to water treatment, including water harvesting, sedimentation, aeration, etc. Before the water may be used for drinking or any other purpose, it must undergo each process. A well in the secondary reservoir further emphasizes the underlying relationship between aquifers and surface water bodies. This is because the well provides a consistent flow of water even when the weather is dry since it helps to restock the system with groundwater. The dual pond system's integration of water filtration and management procedures and reliance on natural recharge mechanisms make it an environmentally friendly and long-lasting water supply option.

Results and Discussion

Pond Water Quality

In the context of pH levels, a marginal increase is observed during the summer, particularly in June, when the water quality surpasses the permissible limit set by the Bureau of Indian Standards (BIS) at 8.7 ± 0.28. The pH level remains within the standard limit of 6.5-8.5 for the other months of the year. Similarly, electrical conductivity exhibits elevated values during summer (401.04 ± 0.54; 401.76 ± 0.79 μs). Dissolved oxygen (DO) levels fluctuate from 5.5 ± 0.57 to 8 ± 0.14 mg/l throughout the year. However, DO levels are notably lower during the summer compared to other seasons. This observation aligns with a study in a fish pond in Thanjavur, Tamil Nadu, where DO levels ranged from 7.63 to 6.7 mg/l, with the lowest levels recorded during the summer.[35] The biological oxygen demand (BOD) remains consistent throughout the year, ranging from 4.5 ± 0.42 mg/l to 5.6 ± 0.42 mg/l. This is in accordance with findings from a which focused on the water quality of Ponnamaravathy in Pudukkottai district,[36] Tamil Nadu, where BOD values ranged from 1.9 to 7.8 mg/l, consistent with the current study's results. Total dissolved solids (TDS) range from 184 ± 1.41 to 943 ± 1.41 ppm. The highest TDS concentration, 943 ± 1.41 ppm, is observed in April during summer. These values conform to the

BIS standards, which specify a range of 500-2000 ppm for TDS in pond water, indicating compliance with the established standards. Salinity values range from 0.1705 ± 0.0021 to 0.284 ± 0.0014 psu throughout the year, with the lowest values occurring in January, corresponding to the post-monsoon season. Hardness levels in the dual pond system vary from 93.5 ± 2.12 mg/l to 164.5 ± 3.54 mg/l, consistently falling below the permissible limit set by BIS. Similarly, another study also observed the highest hardness levels during summer.[38] Ammonia, residual chlorine, and iron levels exhibit no significant variations throughout the year.

Table 2 a: Physiochemical Properties of Pond Water

	Pre-monsoon		Monsoon		Post Monsoon		Summer		BIS Standard
	July	September	October	December	January	March	April	June	
pH	7.2 ± 0.14	7.55 ± 0.07	7.2	7.8 ± 0.14	8 ± 0.14	7.95 ± 0.07	8.45 ± 0.21	8.7 ± 0.28	6.5-8.5
Electrical conductivity (µs)	337.71 ± 6.52	361.135 ± 1.44	283.14 ± 1.10	271.745 ± 1.68	351.16 ± 1.47	335.965 ± 0.78	401.04 ± 0.54	401.76 ± 0.79	300
Dissolved oxygen (mg/l)	8 ± 0.14	7.33 ± 0.33	7.525 ± 0.09	7.84 ± 0.40	7.4 ± 0.14	7.55 ± 0.07	5.65 ± 0.21	5.5 ± 0.57	5
Biological Oxygen Demand (mg/l)	4.63 ± 0.38	5.23 ± 0.16	5.3 ± 0.28	5.6 ± 0.42	5.55 ± 0.35	5.35 ± 0.35	4.5 ± 0.42	4.7 ± 0.28	5
Total Dissolved Solids (ppm)	385 ± 1.41	290.5 ± 0.71	191.5 ± 0.71	230	184 ± 1.41	195.5 ± 0.71	943 ± 1.41	868.5 ± 0.71	500-2000
Salinity (PSU)	0.197 ± 0.0014	0.284 ± 0.0014	0.184 ± 0.0014	0.2 ± 0.0014	0.1705 ± 0.0021	0.1955 ± 0.0007	0.1825 ± 0.0007	0.192 ± 0.0014	NM
Hardness as $CaCO_3$ (mg/l)	152.5 ± 0.71	146.5 ± 2.12	127.5 ± 2.12	93.5 ± 2.12	105.5 ± 4.95	159 ± 12.73	139.5 ± 4.95	164.5 ± 3.54	300
Ammonia (mg/L)	1	1	1	1	1	1	1	1	0.5
Residual chlorine (mg/L)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2-1
Iron (mg/L)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Turbidity (NTU)	21.5 ± 2.12	23 ± 4.24	15.5 ± 4.95	15.5 ± 3.54	14 ± 2.83	21 ± 1.41	18	20.5 ± 0.71	5-25
Chloride (mg/L)	20 ± 1.41	18.5 ± 0.71	22 ± 1.41	21 ± 2.83	23.5 ± 2.12	23.5 ± 3.54	20.5 ± 2.12	21.5 ± 2.12	250-1000
Water Quality Index (WQI)	125.013	125.60111	122.9065	123.2527	122.5861	125.0842	123.1498	124.1221	

Conversely, turbidity remains consistently high, with recorded values ranging from 15.5 ± 4.95 NTU to 23 ± 4.24 NTU in the recent study. This range aligns with the findings with another study, which reported turbidity values ranging from 20 to 35 NTU.[38] Chloride content fluctuates from 18.5 ± 0.71 mg/l to 23.5 ± 3.54 mg/l over the year, consistently remaining lower than the BIS water quality standard. Table 2a presents a comprehensive overview of the various physiochemical characteristics of the pond water. The findings from the aforementioned study indicate that the physicochemical quality of waterfalls is within the permissible limits set by BIS standards. Consequently, the water quality in the dual tanks is suitable for household use, thereby reducing the reliance on alternative water sources.

The current investigation's findings on water quality in the dual pond system are compatible with and verified by previous research, contributing to a cohesive account of water management. The variations in the water quality parameters, such as pH, electrical conductivity, and dissolved oxygen in the summer season, are consistent with data from analogous environmental settings, such as fish ponds in Thanjavur, Tamil Nadu.[38] Similarly, the sustained levels of BOD and TDS align with the findings reported in previous studies,[39] which examined water quality parameters in Ponnamaravathy, Pudukkottai District, Tamil Nadu. Furthermore, the turbidity, salinity, hardness, and chloride content results align with earlier studies, providing a better understanding of the temporal changes in the water quality. The comparison with the literature provides a reliable understanding and emphasizes the need for continuous monitoring to ensure safe drinking water complies with water quality standards. Though the water quality index reveals that water is unsuitable for direct consumption, circumstance-specific water treatment methods can address the issue. A better understanding of the changes in water quality allows us to inform decision-making and develop a sustainable management approach in the present dual pond system. WQI provides a simplified representation of water quality based on multiple parameters. In this case, the highest WQI values were observed in September (pre-monsoon) and March (post-monsoon), with values of 125.60 and 125.08, respectively. This indicates relatively bad water quality during these months. The increase in WQI during these periods can be attributed to factors such as lower levels of BOD, turbidity, salinity, and chlorine in the water, which indicate improved water quality.

Table 2b: Water Quality Index (WQI) level and Water Quality Status (WQS) based on Weighted Arithmetic Index WQI method[23]

WQI	WQS
0-25	Excellent
26 -50	Good
51- 75	Poor
76 – 100	Very Poor
>100	Unsuitable for Drinking

Conversely, the lowest WQI values were observed in October (monsoon season) and January (post-monsoon), with values of 122.90 and 122.58, respectively. The calculated water quality index (Table 2b) consistently exceeds 100 throughout the entire year, indicating its unsuitability for drinking purposes. Although the waterfalls are within limits established by the BIS, they do not meet the criteria for safe drinking water.

Nonetheless, it remains suitable for general household use. It is noteworthy that the water quality index is elevated due to inadequate maintenance of the pond. Factors such as sedimentation, algae growth, pollutant accumulation, and vegetation management can significantly impact pond water quality if not addressed through regular maintenance practices. Sedimentation can lead to nutrient and contaminant release, while unchecked algae growth can result in toxins and oxygen depletion. Pollutant accumulation from runoff and inadequate vegetation management further exacerbate water quality issues. Improved maintenance practices have the potential to enhance the water quality, thereby rendering it more suitable for drinking purposes. Effective maintenance measures such as sediment removal, nutrient control, pollutant source management, and vegetation control are crucial for mitigating these concerns and ensuring the health and sustainability of pond ecosystems.

Rainfall Pattern

A Trend Analysis

Figure 3 shows Kolakanatham yearly rainfall data (millimetres) from 2001 to 2021. Annual precipitation varied significantly over this period. The wettest year was 2021, with 1348.74 mm of rainfall. In 2016, this dataset's lowest annual rainfall was 416.6 mm, suggesting a dry year. Time correlates positively with Kolakanatham rainfall patterns, indicating an increased trend in annual precipitation. This trend affects the local ecosystem, water supplies, and traditional water-gathering technologies. Sustainable water resource management in the region requires understanding these patterns and their effects. The Kolakanatham region's higher rainfall trend throughout the chosen period shows climate change's strong influence. Using the historical average yearly dataset and descriptive statistical analysis, 2021 had the lowest precipitation with 1348.74 mm, followed by 2005 at 1112.70 mm. The green-shaded part of the trendline shows the predicted trajectory for the next 29 years, up to 2050, assuming minor climate-related changes. Remember that rainfall (Y) strongly correlates with time (t).

Additionally, the linear trend equation for rainfall is estimated as $Y_t = 727 + 6.08 \times t$. According to this model, rainfall is rising (Figure 4). The study measured accuracy using MAPE (Mean Absolute Percentage Error) at 23.6%, MAD at 174.4, and MSD at 47,339.1. The projection assumes minor climate-related factor changes, confirming past trends. According to the linear trend equation, annual rainfall increases over time. Several factors make long-term rainfall estimates unreliable. Future climate conditions may not follow historical tendencies, causing uncertainty. The projection model's linear trend equation may simplify climate systems and overlook non-linear phenomena or abrupt weather patterns. The accuracy measurements (MAPE, MAD, MSD) show how well the model fits historical data but don't account for future events or climate change. The estimate has uncertainties; thus, including various scenarios may provide a more accurate and complete picture of future rainfall trends.

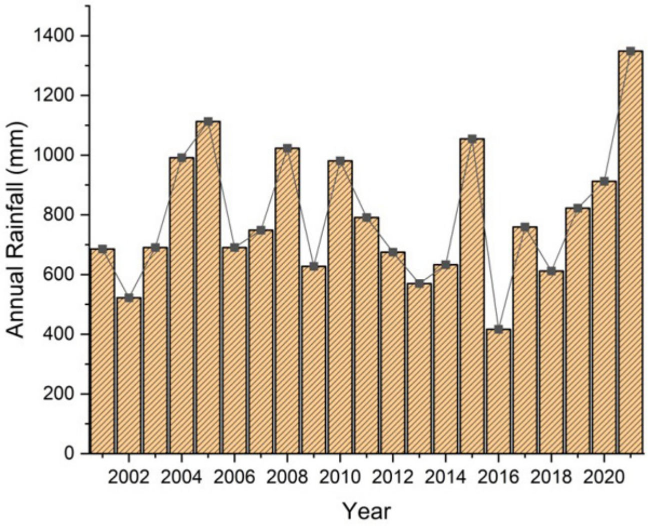

Fig. 3: Annual Rainfall

The accuracy assessment measures (MAPE, MAD, MSD) are crucial to rainfall trend analysis dependability. MAPE measures the average percentage difference between observed and forecasted rainfall amounts to assess the accuracy of the trend analysis model. MAD and MSD measure the size and dispersion of errors between actual and forecast rainfall levels, respectively, indicating trend analysis consistency and dependability. The rainfall trend analysis results are more credible because the study approach is transparent and rigorous. Trend analysis is more accurate and reliable with lower MAPE, MAD, and MSD values, whereas greater levels may reveal model limits. This chart shows that Kolakanatham's annual rainfall has increased over time. This rising tendency follows climate change tendencies, where higher atmospheric temperatures increase evaporation and precipitation. Deforestation, urbanization, and land use changes may also affect regional weather patterns. Climate change affects regional rainfall patterns, reflecting a global phenomenon of altered hydrological cycles due to greenhouse gas concentrations.

Surface water resources depend on rainfall for groundwater recharge, runoff replenishment, and pollution dilution. Water quality, streamflow, and ecosystems, including wetlands and riparian zones, are maintained. Rainfall replenishes reservoirs, ensuring human water demands are met. It helps maintain the hydrological equilibrium of a region, ensuring the long-term sustainability of surface water bodies for ecological, social, and economic purposes. Understanding rainfall's many roles is essential for water resource management and conservation.[40] Recognizing the potential for traditional water harvesting methods with rising precipitation levels helps modify water management practices. Dual-tank rainwater harvesting systems are effective for capturing and storing rainfall. Systems that manage surplus rainfall, runoff, and groundwater recharge can be restored and maintained by communities. Installing dual tank systems in homes and public buildings can boost water availability. These systems can collect and store rainwater for residential, irrigation, and livestock usage and buffer drought seasons. Based on the trend analysis, the rainfall pattern is rising, indicating an increase in average rainfall over time. Traditional water harvesting devices that recharge with rainfall may be used as precipitation increases. Rainfall is essential to rejuvenating and sustaining such systems.

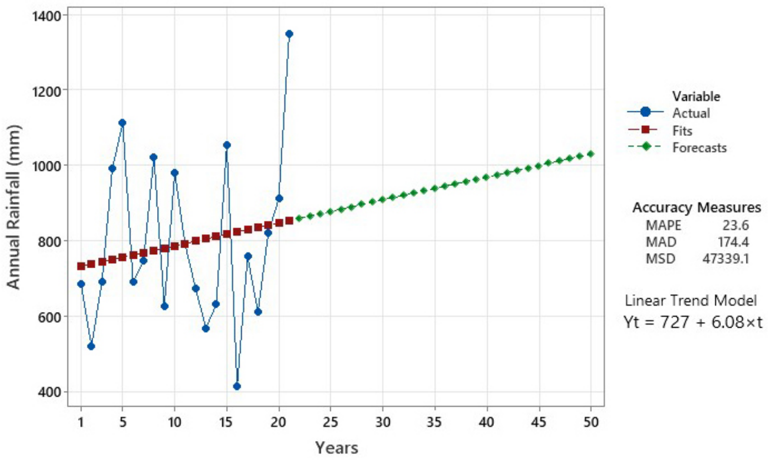

Fig. 4: Trend Analysis Plot for Annual Rainfall for the period 2001-2050

Changes in Land use Land cover (LULC)

The LULC of the study area was determined using a Sentinel-2 satellite image with a spatial resolution of 10 meters. The data analysis indicates that around 34% of the area is characterized by agricultural land, while settlement occupies 3.3%. Additionally, barren terrain accounts for 19% of the total area (Table 3, Figure 5). Alterations in LULC may significantly affect the functionality and effectiveness of traditional water harvesting structures, disrupting the hydrological system and deteriorating water quality. So, sustainable land and water management practices are crucial to mitigate these impacts and ensure the continued functionality of this structure.

Table 3: Area under different LULC facies

LULC Class	Area in sq. km.	% of area
Settlement	0.29	3.31
Water	0.05	0.64
Vegetation	0.94	10.72
Agricultural land	4.81	54.81
Barren land	2.67	30.50

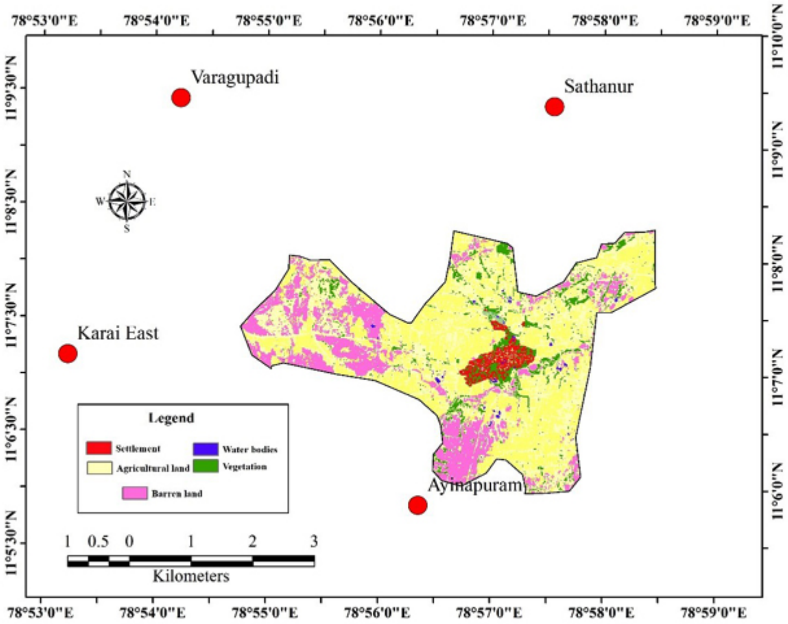

Fig. 5: LULC Pattern of the village

Impact of Settlement on Dual Tank

The spatial distribution of human settlements has experienced significant growth between 2001 and 2023. The spatial-temporal settlement changes in the study region are depicted in Table 6 and Figure 6. To facilitate the analysis, the settlement area is converted to square meters. The arithmetic growth rate approach was employed to ascertain the pace of settlement growth over the past 22 years (Table 4, Figure 6).

Table 4: Growth of settlement in the last 22 years

Year	Settlement area (m^2)	The growth rate of settlement in the last 22 years	Per year growth of settlement
2001	168795	72.44%	3.29%
2023	291086		

The expansion of human settlements substantially affects the need for water. This results from the escalating demands for consumption driven by an expanding population, coupled with the supplementary water necessary for crop cultivation. Population growth, land use change, and changes in the climate are causing uncertainty in future water availability. As a result, there is a greater reliance on exploiting groundwater resources to fulfil the expanding demand. The data indicates a significant increase in the rate of settlement growth within this particular geographical area. Consequently, an ample potable water supply is needed to support a substantial population. The significance of traditional dual tanks is noteworthy in this context. Our primary objective is to explore alternatives for future sustainable development rather than focusing on present-day answers.

The demand for drinkable water is directly influenced by the observable expansion of human settlements, which may be linked to the rising population and developing infrastructure. Consequently, there has been a surge in pressure on existing water supplies and supply infrastructure. The surge in demand often surpasses the capacity of conventional water sources, leading to challenges in guaranteeing an adequate and reliable supply of potable water. The importance of traditional twin tanks, namely those in Kolakanatham hamlet, becomes particularly notable in this setting. Traditional water-collecting technologies have been effectively utilized to meet the water needs of growing towns. The standard dual tank system consists of a main tank that collects and stores rainwater and a secondary tank that helps reduce pollutants through sedimentation and oxidation processes. The applied setup ensures a reliable supply of clean water throughout the year, especially when water availability is restricted. The twin tank system has several functions in mitigating the impact of urban expansion on water consumption. These objectives encompass increasing storage capacity two-fold, enhancing water quality, advocating for sustainable water management practices, and accommodating the rise of the population. To summarize, the growth of settlements increases the need for potable water, highlighting the importance of implementing efficient and eco-friendly water management systems. Utilizing dual tanks is a pragmatic approach that provides several advantages. They enhance storage capacity and water quality, promote sustainable practices, and can accommodate population development. Consequently, they offer a reliable water source for growing settlements.

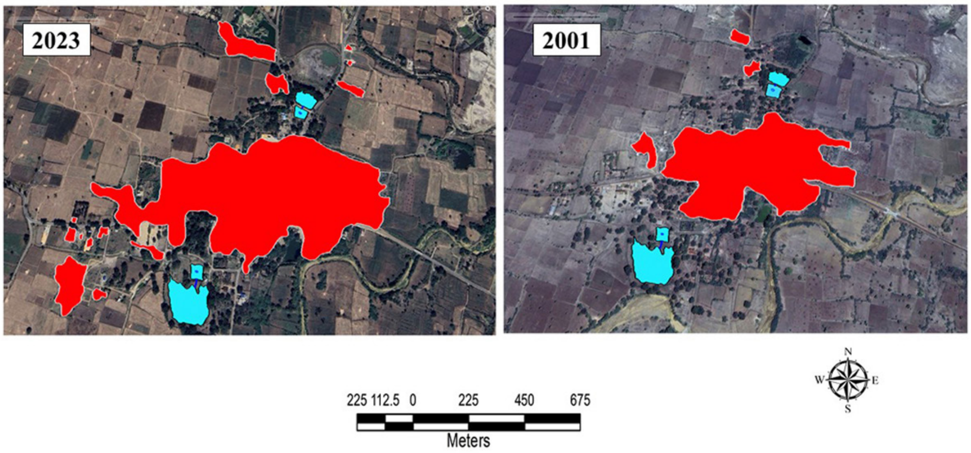

Fig. 6: Settlement encroachment from 2001-2023

Management of Water Resources using a Dual Tank System

The Sri Varadharaja Perumal Temple tank collects rainwater, recharges aquifers, and supports local ecosystems. The community strictly adheres to the norms to ensure the temple's ritual purity and operational performance. The twin tank system's design, maintenance, catchment area selection, and water treatment techniques reflect indigenous knowledge of the natural environment and its unique hydrological processes. This integrated approach to water management results in more effective and inclusive practices by protecting cultural heritage, as well as community engagement and ownership. The people preferred traditional water sources to cook rice and dal, which are softer and tender and enhance the taste of the food. Lee and Visscher[41] discovered that water collecting produces both consumable and visually pleasing water. When ambient rainwater is stored on the surface and combined with soil, it has a low mineral concentration. These structures were sustained via community involvement, not favoured authority. Their ethical role is to preserve and protect community resources like water and water-saving infrastructure. Despite the lack of official legislation managing these infrastructures, water governance was passed down and interwoven into their lives. Local water conservation and management restrictions have helped maintain drinking water hygiene. They separate drinking water and other daily-use water sources into two groups. These sources are deeply rooted in the communities' culture and history, making them sacred and essential for religious festivals. To reduce pollution, washing clothes, cleaning utensils, and swimming were restricted near water sources. The Kolakkanatham village in Perambalur, Tamil Nadu, explains how to pick a water catchment region, divert water to a storage pond, and filter it into a drinkable terminal end-use pond. This study emphasized the importance of rainwater gathering in dry places with limited groundwater resources. Indigenous knowledge and management provide insights into past conservation practices and modern technological solutions. Incorporating information and management into the community's life and culture will improve water management planning and policies. Policymakers can improve water conservation and planning efforts by incorporating local expertise into a holistic strategy that recognizes and applies this knowledge. Despite modern water delivery systems and environmental degradation, traditional water sources are important to many communities due to their cultural, social, and economic value.

Future Research Perspectives

This study suggests several promising research options. The long-term consequences of climate change on historic water systems must be studied to provide a sustainable water supply throughout climates for resilience against extreme weather events like floods and droughts. The use of hydrological models to evaluate and improve traditional water harvesting systems across climates may improve their design and efficiency. The effective water collection and natural groundwater replenishment allow the classic dual tank system to adapt to climate change precipitation patterns. Dual tanks depend less on external water sources than deep tube wells and surface reservoirs.

To be effective and sustainable, traditional water collecting systems must be recognised for sustaining local biodiversity and ecosystem services and studied in connection to land use changes. Finally, policy and governance frameworks for sustainable traditional water harvesting and community-based management models may ensure fair water access and community participation in decision-making. Traditional wisdom and modern science may be used to create resilient and adaptive water management methods for global environmental changes and water shortages.

Dual tank systems can improve functionality and sustainability without sacrificing their conventional style with the following.

i. Smart monitoring systems track water consumption trends, including quality and amount. These data can enhance water management by detecting leaks, pollution, and blockage promptly.
ii. Water quality can be improved by ozonation or UV disinfection at the point of use to eliminate harmful bacteria in stored water.
iii. Permeable pavements surrounding tank bunds will increase groundwater recharge by collecting rainfall runoff.
iv. Installing solar-driven water distribution systems can minimise energy usage and operational costs by raising water levels from lower to higher tanks.
v. Creating digital platforms to engage local stakeholders in water conservation and management activities for twin tank systems.

Creating biofiltration and green infrastructure around the twin tank system can improve water quality and storage capacity.

Conclusion

The one-year water quality monitoring of the dual tank system revealed several notable findings, with several parameters meeting or exceeding established standards. Throughout the monitoring period, parameters such as pH, ammonia, residual chlorine, and iron consistently remained within acceptable limits set by the BIS. Hardness levels also consistently fell below the permissible limit, demonstrating the system's ability to maintain water quality standards. Total dissolved solids (TDS) also fluctuated within the acceptable range throughout the year, with the highest concentration observed in April still conforming to BIS standards. Moreover, chloride content consistently remained below the established limits. These findings indicate the effectiveness of the dual tank system in maintaining water quality parameters within acceptable levels, highlighting its suitability for household use and reducing reliance on alternative water sources. The study also demonstrates a discernible upward trend in the village's population from 2001 to 2021, resulting in increased water demand. Analysis of the rainfall data suggests that assuming constant parameters, precipitation levels are projected to rise until 2050.

Furthermore, the study conducted one year of water quality monitoring, revealing that the water quality is suitable for household purposes. Utilizing a dual tank can significantly diminish the dependence on various water sources. These readily accessible tanks, often located close to residential areas, offer a reliable year-round water supply, reducing the need for people to travel long distances or rely on seasonal sources.

Moreover, tank water proves cost-effective, negating expenses linked to well-drilling water transportation. Such a shift also aids in conserving local ecosystems by minimizing over-extraction from traditional sources and enables communities to manage their water quality efficiently. Additionally, during droughts, these tanks can serve as essential water reservoirs, enhancing resilience in water-scarce regions. By using dual tank water, communities gain greater control over their water supply, promote traditional water harvesting practices, and empower themselves to manage water resources sustainably, thus contributing to overall water security and resource preservation.

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Conflict of Interest
The author(s) do not have any conflict of interest.

Data Availability Statement
This statement does not apply to this article.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions
All authors contributed to the study conception and design. Karuppaiya Ramesh, Apurba Koley, Niladri Das, Arunkumar Patchaiyappan, Tapas Bagdi and Srinivasan Balachandran performed material preparation, data collection, and analysis. Ramesh K. wrote the first draft of the manuscript, assisted by Apurba Koley. All authors read and approved the final manuscript.

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