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Revitalizing Traditional Tank Systems: Case Study Insights From Sri Lanka's Village Tank Cascade Systems for Climate Resilience and Water Governance

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ABSTRACT

Village tank cascade systems (VTCS) are a long-established form of water management in Sri Lanka's dry zone. However, their role in groundwater recharge, climate adaptation, and water governance remains insufficiently recognized in policy and planning. In this study, we examine the hydrological and institutional functions of VTCS in Sri Lanka's dry zone, with a focus on Vavuniya District. Using field validation, GIS-based cascade mapping, tank status assessment, and correlation analysis between tank water levels and nearby wells, the study identifies a strong hydrological relationship, most notably at Vavuniyakulam, where a correlation coefficient of 0.88 was observed. These findings highlight the significance of tanks in sustaining groundwater availability, especially during dry periods. However, decades of neglect, socio-political conflict, and fragmented institutional mandates have led to widespread degradation of tank systems and erosion of community-based governance structures. The study shows that VTCS offer critical ecosystem services beyond irrigation, including groundwater recharge, domestic water supply, climate buffering, and livelihood support. Drawing from the Vavuniya case, the paper argues for repositioning village tanks within national water policy and climate resilience frameworks. Revitalization efforts need to combine scientific assessment, participatory governance, local ecological knowledge, and institutional coordination to restore the multifunctional role of VTCS. The Vavuniya case offers wider lessons for dryland and postconflict regions where small-scale water systems remain central to groundwater security, rural livelihoods, and climate-resilient water governance.

摘要

“村级蓄水池级联系统”(VTCS)是斯里兰卡干旱地区一种历史悠久的水资源管理形式。然而，在政策制定与规划过程中，其在地下水补给、气候适应及水资源治理方面的作用尚未得到充分重视。本研究考察了斯里兰卡干旱地区(重点关注瓦武尼亚区)VTCS的水文与制度功能。通过实地验证、基于GIS的级联系统制图、蓄水池状况评估以及蓄水池水位与周边水井水位间的相关性分析，研究发现两者之间存在显著的水文联系——尤其是在Vavuniyakulam，观测到的相关系数高达0.88。这些结果凸显了蓄水池在维持地下水资源(特别是在干旱时期)方面的重要性。然而，数十年的忽视、社会政治冲突以及管理职能的碎片化，导致了蓄水池系统的普遍退化和社区治理结构的瓦解。研究表明，VTCS不仅能提供灌溉服务，还具备关键的生态系统功能，包括地下水补给、生活用水供应、气候缓冲及生计支持。基于瓦武尼亚的案例，本文主张在国家水资源政策和气候韧性框架中重新定位村级蓄

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水池。复兴这些系统需要结合科学评估、参与式治理、本土生态知识及制度协调， 以恢复VTCS的多重功能。瓦武尼亚案例为其他干旱地区及冲突后地区提供了宝贵经验, 在这些地区, 小型水利系统对于地下水安全、农村生计及具备气候韧性的水资源治理至关重要。

RESUMEN

Los Sistemas de Embalses en Cascada (SEC) son una forma de gestión del agua de larga tradición en la zona árida de Sri Lanka. Sin embargo, su papel en la recarga de acuíferos, la adaptación al cambio climático y la gobernanza del agua sigue sin estar suficientemente reconocido en las políticas y la planificación. En este estudio, examinamos las funciones hidrológicas e institucionales de los SEC en la zona árida de Sri Lanka, con especial atención al distrito de Vavuniya. Mediante validación de campo, mapeo de cascadas basado en SIG, evaluación del estado de los embalses y análisis de correlación entre los niveles de agua de los embalses y los pozos cercanos, el estudio identifica una fuerte relación hidrológica, especialmente en Vavuniyakulam, donde se observó un coeficiente de correlación de 0.88. Estos hallazgos resaltan la importancia de los embalses para mantener la disponibilidad de agua subterránea, sobre todo durante los periodos de sequía. Sin embargo, décadas de abandono, conflictos sociopolíticos y mandatos institucionales fragmentados han provocado una degradación generalizada de los sistemas de embalses y la erosión de las estructuras de gobernanza comunitaria. El estudio demuestra que los SEC ofrecen servicios ecosistémicos esenciales más allá del riego, como la recarga de acuíferos, el suministro de agua potable, la amortiguación del cambio climático y el sustento de las comunidades. A partir del caso de Vavuniya, este artículo aboga por la reincorporación de los embalses comunitarios dentro de las políticas hídricas nacionales y los marcos de resiliencia climática. Los esfuerzos de revitalización deben combinar la evaluación científica, la gobernanza participativa, el conocimiento ecológico local y la coordinación institucional para restaurar el papel multifuncional de los sistemas de embalses comunitarios en cascada (VTCS). El caso de Vavuniya ofrece lecciones más amplias para las regiones áridas y posconflicto, donde los sistemas hídricos a pequeña escala siguen siendo fundamentales para la seguridad del agua subterránea, los medios de vida rurales y la gobernanza del agua resiliente al clima.

1 | Introduction

1.1 | Traditional Small-Scale Water Storage Systems

Across many semiarid and subhumid regions of the world, traditional small-scale water storage systems have supported agricultural and rural water management for centuries. In Sri Lanka's dry zone, one of the most distinctive forms of such infrastructure is the village tank cascade system (VTCS). In South Asia, village tanks and ponds are particularly prominent in India and Sri Lanka, where they harvest monsoonal rainfall for irrigation, livestock watering, and groundwater recharge (Panabokke et al. 2002). India hosts an extensive network of traditional irrigation tanks, estimated at over 208,000 nationwide, many of which are concentrated in the southern states of Tamil Nadu, Karnataka, and Andhra Pradesh. Although these systems vary in scale and management, they share important functions with Sri Lanka's VTCS, particularly in supporting irrigation, livestock watering, and groundwater recharge (Palanisami et al. 2010; Nagarajan 2013; Panabokke et al. 2002). These shared functions make traditional tank systems relevant to current debates on rural water security, groundwater recharge, and climate adaptation. This paper focuses on the Sri Lankan VTCS experience through the case of Vavuniya District.

Despite their past success, many traditional water systems have declined in recent decades due to land-use changes, groundwater overextraction, neglect of maintenance, and growing climate variability. These trends have led not only to the physical deterioration of infrastructure but also to the erosion of institutional memory and local knowledge systems that once sustained it. Nevertheless, there is renewed policy interest in restoring such systems, particularly as part of nature-based solutions aligned with climate resilience and the sustainable development goals (SDGs) (Bebermeier et al. 2017; Shah 2009b; UN-Water 2018).

The Vavuniya District, located in Sri Lanka's northern dry zone, provides a compelling case for understanding how traditional water systems can be revitalized to meet contemporary challenges. The district faces conditions of water stress, agro-ecological fragility, and postconflict institutional disruption—circumstances that mirror those found in many dryland regions globally. Studying the operational status and governance of VTCS in Vavuniya offers valuable lessons on how to combine scientific tools, community participation, and policy frameworks to restore traditional infrastructure and enhance water security.

In light of these challenges, this study examines the VTCS in Vavuniya District as a lens to understand how traditional water infrastructure can support sustainable water management and climate resilience in postconflict dryland regions.

1.2 | Study Aim

The main aim of the study is to examine the current functionality, challenges, and restoration needs of VTCS in the Vavuniya District of northern Sri Lanka. Drawing on field-based observations, satellite imagery, and GIS mapping, it assesses the operational conditions of tanks, their contributions to agriculture and groundwater recharge, and their broader role in building climate resilience. The study seeks to identify key gaps and proposes strategies for restoring and managing VTCS to support sustainable water resource management in the region.

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While rooted in Vavuniya, the study addresses broader issues common to traditional water systems in dryland and postconflict regions globally. The VTCS represent a wider class of small-scale, community-managed infrastructure found across South Asia, sub-Saharan Africa, and parts of Southeast Asia. The pressures they face—ranging from climate variability and ecological degradation to institutional neglect and socioeconomic transitions—are not unique to Sri Lanka. By closely analyzing the status, challenges, and performance of VTCS in Vavuniya, this study offers insights that can inform the rehabilitation and adaptation of similar systems globally. The analysis also contributes to broader discussions on climate resilience, sustainable groundwater management, and the integration of traditional ecological knowledge into contemporary water governance frameworks.

2 | Literature Review and Theoretical Framing

2.1 | Traditional Village Tank Systems: Literature Review

The VTCS are distinctive traditional water management systems developed in the dry zone of Sri Lanka. Comprising a network of interconnected small tanks located within micro-catchments, the VTCS are designed to store, convey, and utilize rainwater for irrigation and other local needs. These systems rely on ephemeral rivulets and capture surface runoff during the monsoon seasons, making them vital rainwater-harvesting structures in regions with no perennial rivers (Madduma Bandara 1985).

Originating during the hydraulic civilization of ancient Sri Lanka, VTCS represent one of the earliest and most sophisticated forms of community-managed irrigation infrastructure (Mahatantila et al. 2008; Nanthakumaran and Palanisami 2010; Ratnayake et al. 2021). Constructed by early Sri Lankan kings, these systems were engineered to optimize the use of rainwater for agriculture, especially rice cultivation, which dominates land use in the dry zone. The basic design allows excess water from upstream tanks to overflow via sluices into paddy fields and natural depressions downstream. This water then continues its journey through the cascade, feeding subsequent tanks and facilitating multiple rounds of reuse and recharge (Panabokke et al. 2002; Galagedara et al. 2018; Dharmasena 2020).

The distinctiveness of Sri Lanka's VTCS lies in the way these systems evolved in response to the island's dry-zone geomorphology, soils, and monsoon regime. The dry zone is characterized by undulating terrain, shallow drainage lines, seasonal streams, and a marked contrast between wet and dry periods. These physical conditions allowed small tanks to be linked into micro-catchments, where runoff from upper tanks could be stored, reused, and gradually conveyed to downstream tanks and paddy fields. The reddish brown earth and low-humic gley soils common in the dry zone further shaped land and water use, supporting paddy cultivation in lower valley positions and other forms of agriculture on higher ground. Unlike isolated small reservoirs in many other regions, Sri Lanka's tank cascades developed as integrated socio-hydrological systems that combine water storage, sediment trapping, groundwater recharge, ecological buffering, and community management. This close alignment between landscape form, seasonal rainfall, soil conditions, and collective management is a key reason why VTCS are recognized as a distinctive feature of Sri Lanka's historical hydraulic civilization.

In recent decades, changing rainfall patterns have placed increasing stress on these traditional systems. Alterations in monsoon timing, reduced precipitation predictability, and increased intensity of extreme events are disrupting the balance between water availability and demand (Ranjith and Wijesekera 2020). These shifts have reduced water availability in dry regions while contributing to flooding in wetter zones. Rising temperatures and prolonged dry periods exacerbate water scarcity, posing significant challenges to agriculture and local water security (Eriyagama et al. 2010). Despite these challenges, VTCS are recognized for their potential to support climate change adaptation in rural areas. Their ability to harvest and store rainwater, recharge groundwater, and support agricultural livelihoods makes them a valuable resource in the face of environmental variability (Withanachchi et al. 2014; Galagedara et al. 2018). However, many of these systems have deteriorated due to siltation, reduced maintenance, and socioeconomic disruptions, especially in postconflict regions (Nanthakumaran et al. 2022).

Village tank systems are widely recognized in South Asia for their contribution to agricultural productivity, rural livelihoods, and groundwater recharge. In India, for instance, there are about 208,000 small reservoirs, accounting for around 60% of tank-based irrigation (Perera et al. 2021; Nagarajan 2013). These systems not only function as surface irrigation sources but also play a key role in recharging shallow aquifers through percolation and seepage, particularly during the monsoon season (Palanisami and Easter 2000).

Several studies have highlighted that rehabilitated tanks can improve water availability and enhance agricultural yields by 20%–30% (Molden 2007). In India (Kerr 2002) and particularly in South India (Batchelor et al. 2003), community-managed tanks integrated into micro-watershed development initiatives have enhanced groundwater recharge and supported crop production. However, outcomes have varied across different sites. Tamil Nadu provides a prominent example, with approximately 39,200 tanks of varying sizes and operational models (Nanthakumaran and Palanisami 2010). Of these, around 22% are managed by the Public Works Department (PWD), generally serving command areas greater than 40 ha, while the remainder fall under the jurisdiction of Panchayat Unions and are often community-managed (Nanthakumaran and Palanisami 2010). These tanks are typically aligned with the rice-growing season (September to January), offering supplementary irrigation in years when rainfall is delayed or insufficient (Molden 2007). Beyond irrigation, tanks support rural livelihoods, generate employment through rehabilitation works, and foster community engagement (Kerr 2002; Batchelor et al. 2003). Micro-watershed development projects have shown notable benefits in increasing water availability

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and groundwater recharge, particularly for smallholder and marginal farmers (Kerr 2002; Batchelor et al. 2003). These insights reaffirm the importance of tank rehabilitation, bund repair, and catchment restoration for long-term water security and rural resilience (Palanisami et al. 2009).

Outside South Asia, similar small-scale storage systems exist across sub-Saharan Africa, where they support water security under conditions of erratic rainfall and limited infrastructure (Venot et al. 2012). These international experiences position village tanks as nature-based infrastructure that are both scalable and locally adapted.

2.2 | Conceptual Framing: Common-Pool Resource (CPR) Theory

To frame the analysis of governance, degradation, and restoration strategies for VTCS, this study draws on the principles of CPR theory. CPR theory emphasizes how shared natural resources—such as village tanks, canals, or aquifers—can be sustainably managed through local-level cooperation, mutual trust, and well-defined rules, rather than relying solely on top-down state control or market-based allocation (Ostrom 2002).

The VTCS fit well within this conceptual tradition. It is an interconnected and interdependent resource system whose sustainability relies on community-led management of both water infrastructure and the surrounding landscape (Nanthakumaran et al. 2022). When the collective norms and informal institutions that sustained VTCS in the past begin to weaken—as in postconflict or rapidly modernizing regions—degradation accelerates. CPR theory helps explain how this breakdown in cooperation can lead to overuse, neglect, or collapse of such systems (Ostrom 2002).

In this study, CPR framing enables a deeper understanding of why some cascades continue to function well while others deteriorate, despite having similar physical characteristics. It also guides the interpretation of governance challenges and restoration efforts by emphasizing the need for participatory approaches, locally grounded institutions, and shared responsibility for resource stewardship. The integration of community knowledge, social memory, and adaptive governance mechanisms emerges as central to revitalizing these traditional systems in ways that are both socially embedded and ecologically sound (Bandara 2007; Nanthakumaran et al. 2022).

The Vavuniya case contributes to CPR theory by showing that the sustainability of traditional water systems depends not only on collective rules and local cooperation but also on the continuity of hydrological connectivity, institutional memory, and postconflict social recovery. In many CPR applications, the resource system is treated mainly as a shared social–ecological asset governed by local rules. The VTCS case extends this understanding by demonstrating that, in cascade-based water systems, governance failure is also expressed physically through broken tank linkages, abandoned channels, silted storage, and weakened surface–groundwater interactions. This means that revitalizing VTCS requires more than restoring collective action alone; it also requires reconnecting the hydrological system, rebuilding local knowledge networks, and aligning community institutions with state agencies. The Sri Lankan case, therefore, refines CPR thinking by emphasizing the combined importance of social cooperation, physical connectivity, and institutional continuity in sustaining traditional water commons.

3 | Traditional Tank Systems: Global and Regional Context

Traditional small-scale surface storage systems, such as village tanks and minor reservoirs, have been an integral part of water management across many regions of Asia, Africa, and even parts of Europe. These systems play a crucial role in meeting local water needs, particularly in areas with seasonal rainfall and limited access to perennial water sources. In Asia, they are particularly prominent in countries such as Sri Lanka, India, Japan, Myanmar, Thailand, and Cambodia, where they support agriculture and rural livelihoods (Begum 1987).

In South and Southeast Asia, tank irrigation systems have long served as common property resources, particularly in water-scarce and economically disadvantaged regions. These traditional systems enable local communities to manage and utilize rainwater efficiently for agriculture and domestic use. Sri Lanka's VTCS represent one of the most extensive and sophisticated examples of such traditional systems, adapted to the island's dry zone conditions.

Desilting tank beds, repairing bunds, and integrating tanks with local agricultural practices can improve water storage, groundwater recharge, crop productivity, and rural livelihoods (Dharmasena 2004; Molden 2007; Palanisami et al. 2009; Kerr 2002; Batchelor et al. 2003). These regional experiences underline the continuing relevance of traditional tank systems when they are supported by community participation, technical rehabilitation, and modern water governance frameworks.

4 | VTCS in Sri Lanka

Sri Lanka has a long and distinguished history of irrigation, particularly in the dry zone, where water scarcity has shaped centuries of agricultural and settlement patterns. Village tanks—small-scale reservoirs constructed to store rainwater—were extensively developed by ancient kings as a strategy to manage limited water resources for agricultural and human use. These tanks remain central to rural livelihoods and food production, particularly in areas where access to large-scale irrigation schemes is limited.

According to the Department of Agrarian Development (DAD), approximately 14,421 small-scale reservoirs, commonly referred to as village tanks, are operational across Sri Lanka (DAD 2012a). Classified as minor irrigation systems, these tanks typically support command areas of up to 80 ha (GoSL 2000). Despite their modest size, they make a significant contribution to national food security, accounting for roughly 28% of the country's paddy production (Bronzoni 2015). While

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many of these tanks remain functional, a considerable number have been neglected or abandoned, particularly in remote or postconflict regions (Withanachchi et al. 2014). Sri Lanka's geography is broadly divided into three agro-climatic zones based on annual rainfall: the wet zone (more than 2500 mm), the intermediate zone (1750–2500 mm), and the dry zone (less than 1750 mm) (DAD 2012a; FAO 2011). The dry zone, which covers more than two-thirds of the country's land area, is where most of the village tanks are concentrated. Key provinces within this zone include the North Central (Anuradhapura), North Western (Kurunegala), Northern (Vavuniya), and Eastern (Ampara) provinces. Communities in these areas depend heavily on tank irrigation, particularly for cultivating rice during the two main cropping seasons—*Maha* (September to March) and *Yala* (May to August)—which are driven by the northeast and southwest monsoons, respectively (DAD 2012a; Bronzoni 2015).

In many areas, especially those without access to major irrigation canals, village tanks are the only reliable source of water for crop cultivation. They also provide water for livestock, domestic use, and, in some cases, small-scale drinking water schemes. Their multipurpose utility and decentralized nature make them an essential part of rural infrastructure (DAD 2012a; Bronzoni 2015; Withanachchi et al. 2014).

In recent years, collective action within village tank cascade systems (VTCS) has emerged as a vital mechanism for responding to environmental and social challenges. These community-based approaches have been instrumental in strengthening local adaptation to climate change, supporting livelihood resilience, enabling disaster preparedness, and promoting social cohesion (Galagedara et al. 2018; Withanachchi et al. 2014; Kerr 2002).

However, despite their ecological and socioeconomic importance, village tanks face several persistent challenges. Many operate beyond their designed command capacity, and variability in catchment characteristics—such as area, shape, and rainfall distribution—leads to uneven water availability. These limitations contribute to declining agricultural productivity and increase the vulnerability of rural communities to climate risks (Dharmasena 2000).

Although significant efforts were made to restore large tanks in the early 20th century and to rehabilitate smaller tanks until the 1980s, there remains a limited understanding of the storage behavior of these systems over space and time. Existing water balance models often fail to capture the dynamic and interconnected nature of village tank systems across regions. Furthermore, the absence of a robust monitoring system—especially for smaller tanks—hampers efforts to assess their performance and plan for their sustainable use (Perera et al. 2021).

The cumulative effect of these challenges is a decline in the reliability and effectiveness of tank irrigation in many parts of Sri Lanka. Addressing this requires not only technical interventions but also community engagement, institutional support, and scientific assessment to restore and sustain the tank systems for future generations.

5 | Study Area and Methodology

5.1 | Overview of Vavuniya District

The study was conducted in the Vavuniya District, situated in the Northern Province of Sri Lanka, which is part of the country's dry zone. This region is characterized by low and unevenly distributed rainfall, ranging from 800 to 1200 mm annually, primarily during the northeast monsoon (October to January). The annual evaporation rates range from 1700 to 1900 mm, resulting in a net water deficit (Panabokke et al. 2002). Mean annual temperature ranges from 26°C to 34°C (District Secretariat, Vavuniya 2020), contributing to high evapotranspiration losses and seasonal drying of tanks and wells, particularly from May to August.

Vavuniya covers a total area of 1967 km^2 and shares borders with the districts of Anuradhapura, Mullaitivu, and Mannar. Approximately 39% of the land is used for agriculture, while 45% is covered by forest, which plays a crucial role in regulating the local climate and surface runoff (District Secretariat, Vavuniya 2020). Agriculture is the primary livelihood activity, particularly paddy cultivation, supported by both minor irrigation tanks and shallow wells. The district has around 21,000 ha of paddy land, of which 11,000 ha are irrigated using village tanks. Additionally, approximately 10,000 ha are planted with perennial and upland crops, such as coconuts and mangoes, often irrigated with water from open dug wells (District Secretariat, Vavuniya 2020; Sudusinghe et al. 2016).

The district's soils, predominantly reddish brown earth and low-humic gley, are classified as Alfisols (USDA) or Luvisols and Lixisols (World Reference Base) and are generally well-suited for agriculture (Panabokke 1996; Ratnayake et al. 2016). However, limited and unreliable access to irrigation water remains a significant challenge. While tanks generally provide adequate irrigation for crops during the *Maha* season, water availability is often insufficient during the *Yala* season, posing severe constraints on crop production and livelihoods (Dharmasena 1989).

Surface water in Vavuniya is primarily sourced from village tanks, which may exist as isolated systems or as part of tank cascade networks. According to the DAD (DAD 2012b), the district contains 756 village tanks, with particularly high density in the Vavuniya North Division. While many tanks remain operational, a significant number are underutilized or abandoned due to damaged infrastructure, siltation, or encroachment. Preliminary DAD data indicate 69 cascades across eight Agrarian Service Centres (ASCs)—Omanthai, Kanagarayankulam, Nedunkerny, Madukanda, Cheddikulam, Ulukulam, Pampaimadu, and Kovilkulam—each containing varying numbers of tanks depending on terrain and topography. Field studies and recent research by Nanthakumaran et al. (2022) further documented the structure, functioning, and management practices of these VTCS, confirming the spatial distribution and operational challenges reported by DAD.

Village tanks serve multiple purposes, including irrigation, livestock watering, domestic use, and recharge of shallow aquifers that support upland farming and household water supplies. However, unregulated groundwater extraction, primarily through the proliferation of tubewells, has exceeded

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the natural recharge capacity of aquifers. This overexploitation has contributed to groundwater depletion, further intensifying the already fragile water security situation in the region.

5.1.1 | Hydrological Context of the Tank Systems

The hydrology of the Vavuniya District is primarily governed by its seasonal rainfall pattern, shallow aquifers, and extensive village tank networks. Earlier investigations in this region (Tharani et al. 2015) revealed a strong interdependence between surface water stored in tanks and the underlying groundwater systems. During the northeast monsoon, percolation from tank beds contributes to groundwater recharge, while during the dry season, the stored tank water and recharged shallow aquifers help sustain nearby wells and local water availability (Chowdhury and Behera 2018; van Meter et al. 2016). However, increasing dependence on tube wells and unregulated groundwater extraction has placed additional pressure on shallow aquifers, weakening the beneficial link between tank storage and groundwater availability (Panabokke and Perera 2005; Shah 2009a; Chowdhury and Behera 2018). These findings underscore the importance of considering both hydrological and hydrogeological linkages in formulating regional water policies. Effective revitalization and management of tank cascade systems, therefore, require an integrated policy framework that synchronizes surface and groundwater management with land use and community-level water governance.

5.2 | Data Sources and Field Method Used

The methodology adopted in this study integrates three related strands of investigation: hydrological analysis of tank–groundwater interactions, identification and validation of VTCS, and assessment of the declining performance of village tanks in the Vavuniya District. These components build on earlier field-based studies on surface water–groundwater interactions (Tharani et al. 2015), cascade identification and validation in Vavuniya District (Nanthakumaran et al. 2022), and the performance of village tanks under changing climatic and management conditions (Nanthakumaran 2025). While these earlier studies provide the empirical foundation for the present analysis, the key sampling procedures, analytical steps, and validation methods are summarized here to ensure that the manuscript can be read as a standalone study.

The overall approach combined spatial analysis, field validation, community consultation, tank status classification, paddy cultivation trend analysis, and statistical assessment of tank–well relationships. This mixed-method approach was used to assess both the physical condition of VTCS and their hydrological linkages with shallow groundwater systems. It also enabled the study to connect field-level evidence with broader questions of tank rehabilitation, groundwater sustainability, climate resilience, and water policy. In this way, the methodology was designed not only to document the present status of village tanks in Vavuniya but also to identify the practical and institutional conditions required for their revitalization.

The study on identifying VTCS in Vavuniya District was conducted in three phases. In the first phase, the DAD, with the support of the Natural Resource Management Centre, Department of Agriculture, prepared a draft cascade map using GIS tools and satellite imagery. The initial mapping exercise helped identify the spatial distribution of tanks and the potential connectivity among them based on elevation, drainage, and proximity (Figure 1). A digital elevation model (DEM) and slope profiles were used to support the initial identification of cascades. Draft cascade boundaries were cross-referenced with topographic maps and drainage patterns to assess connectivity and identify areas of potential impact. A total of 69 cascades comprising 514 village tanks were identified across eight ASCs, including Omanthai, Kanagarayankulam, and Kovilkulam.

In the second phase, field validation was conducted with a multidisciplinary team comprising DAD officials, local farmers, and subject experts. This participatory process involved site visits, transect walks, and key informant interviews with village elders and farmers to verify whether the tanks functioned as cascades or had become isolated due to natural or human-induced disruptions. Particular attention was given to water flow between tanks, the condition of connecting channels, and the presence of structural or land-use changes affecting connectivity. The field validation took place in August 2018.

In the third phase, the validated cascades were categorized as functioning, isolated, or abandoned based on field observations and local knowledge. The status of tanks was assessed in terms of physical condition, usage, rehabilitation history, and surrounding land use. To examine the hydrological linkages between tanks and wells, the water levels in tanks and wells were monitored biweekly between August 2013 and January 2014 at three cascade sites: Vavuniyakulam, Paddanichchepuliyankulam, and Pandarikulam. A total of 65 wells were sampled—21 near Vavuniyakulam, 21 near Paddanichchepuliyankulam, and 23 near Pandarikulam. Pearson correlation coefficients (r) were computed to assess the relationship between tank water levels and corresponding well water levels.

The study on declining performance of village tanks is based on the methodology described in Nanthakumaran (2025), published as Chapter 33 in *Tank Cascade Systems of Sri Lanka: A Globally Important Agricultural Heritage System* (CRC Press). The performance of Tank Cascade Systems (TCSs) in the Vavuniya District was assessed using the extent of paddy cultivation during the *Yala* season as the principal performance indicator, as cultivation during the *Maha* season primarily relies on direct rainfall rather than stored tank water.

Data on the extent of paddy cultivation were obtained for 10 years (2014–2023) across eight ASC areas. Information on rehabilitation interventions—such as desilting of tanks, repairs to sluice gates, and pipelines—implemented between 2019 and 2020 was compiled from project reports and verified through field observations. Climatic data, particularly rainfall records, were also analyzed to identify drought years, with 2017 and 2018 identified as periods of severe drought that adversely affected TCS performance.

The annual extent of paddy cultivation during the *Yala* season was compared across the eight ASC areas to determine temporal

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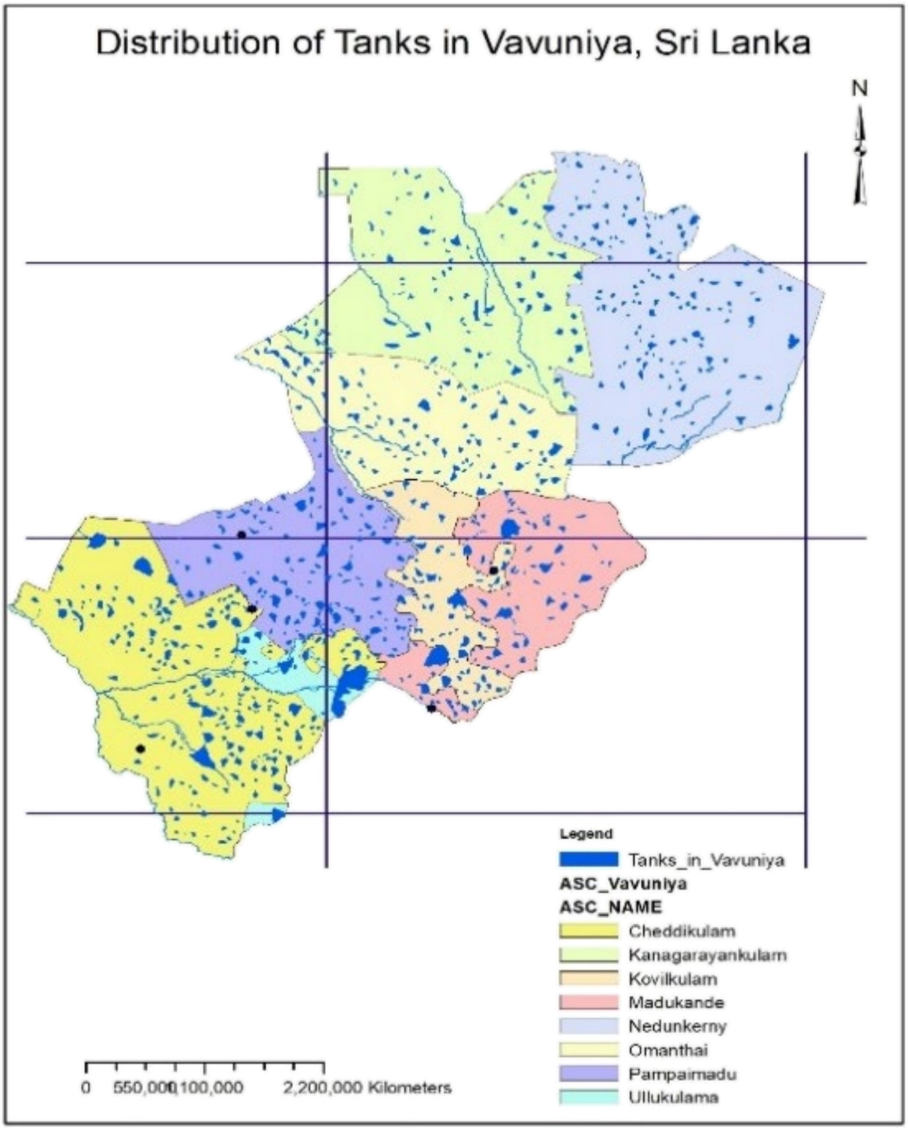

FIGURE 1 | Location map of Vavuniya District, Northern Sri Lanka, showing the distribution of village tanks and identified cascade systems.

trends in TCS performance. The analysis integrated data on the number of tanks rehabilitated and prevailing climatic conditions to evaluate the relationships among rehabilitation activities, drought events, and resulting variations in system performance.

The study has some limitations. The tank–groundwater correlation analysis was based on biweekly water-level measurements from three representative tank systems over 6 months from August 2013 to January 2014. The analysis, therefore, captures seasonal tank–well interactions during the monitored period but does not fully quantify long-term recharge volumes, sedimentation rates, or changes in aquifer storage. Similarly, the extent of paddy cultivation during the Yala season was used as a practical performance indicator for tank systems. However, it may also be influenced by factors such as farmer decisions, labor availability, input costs, and local market conditions. These limitations are acknowledged, but the combined use of GIS mapping, field validation, farmer knowledge, tank status assessment, paddy cultivation trends, and hydrological correlation provides a robust basis for identifying restoration needs and policy implications.

Overall, the approach outlined above enabled the study to document the current status and performance of VTCS in Vavuniya, while also examining their hydrological interaction with local groundwater systems, as elaborated in the following Results section.

6 | Results

6.1 | Status of Village Tanks and Cascade Validation

The VTCS across eight ASCs in Vavuniya, including Cheddikulam, Pampaimadu, Kovilkulam, Madukanda, Nedunkerny, Omanthai, Ulukulam, and Kanagarayankulam, were investigated as detailed in Nanthakumaran et al. (2022). Using GIS tools, satellite imagery, and field validation with local farmers and senior community members, the study identified 756 village tanks in the district. Among these, 69 tank cascades comprising 514 tanks were validated in the field, with 111 tanks classified as isolated and 131 identified as abandoned (Table 1 and Figure 2).

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TABLE 1 | Number of village tank cascades identified and field-validated in Vavuniya District, Sri Lanka.

ASC division		Number of cascades identified in the desk study	Number of cascades validated in the field	Total number of tanks in the cascades	Number of isolated tanks	Number of abandoned tanks
Name	Area (km^2)					
Cheddikulam	428	16	13	90	22	43
Pampaimadu	235	16	14	124	14	28
Kovilkulam	111	05	07	82	03	05
Madukanda	137	04	03	49	08	03
Nedunkerny	336	07	10	47	07	30
Omanthai	289	17	11	68	24	10
Ulukulam	86	07	05	35	02	02
Kanagarayankulam	372	08	06	19	31	10
Total	1994	80	69	514	111	131

Source: Nanthakumaran et al. (2022).

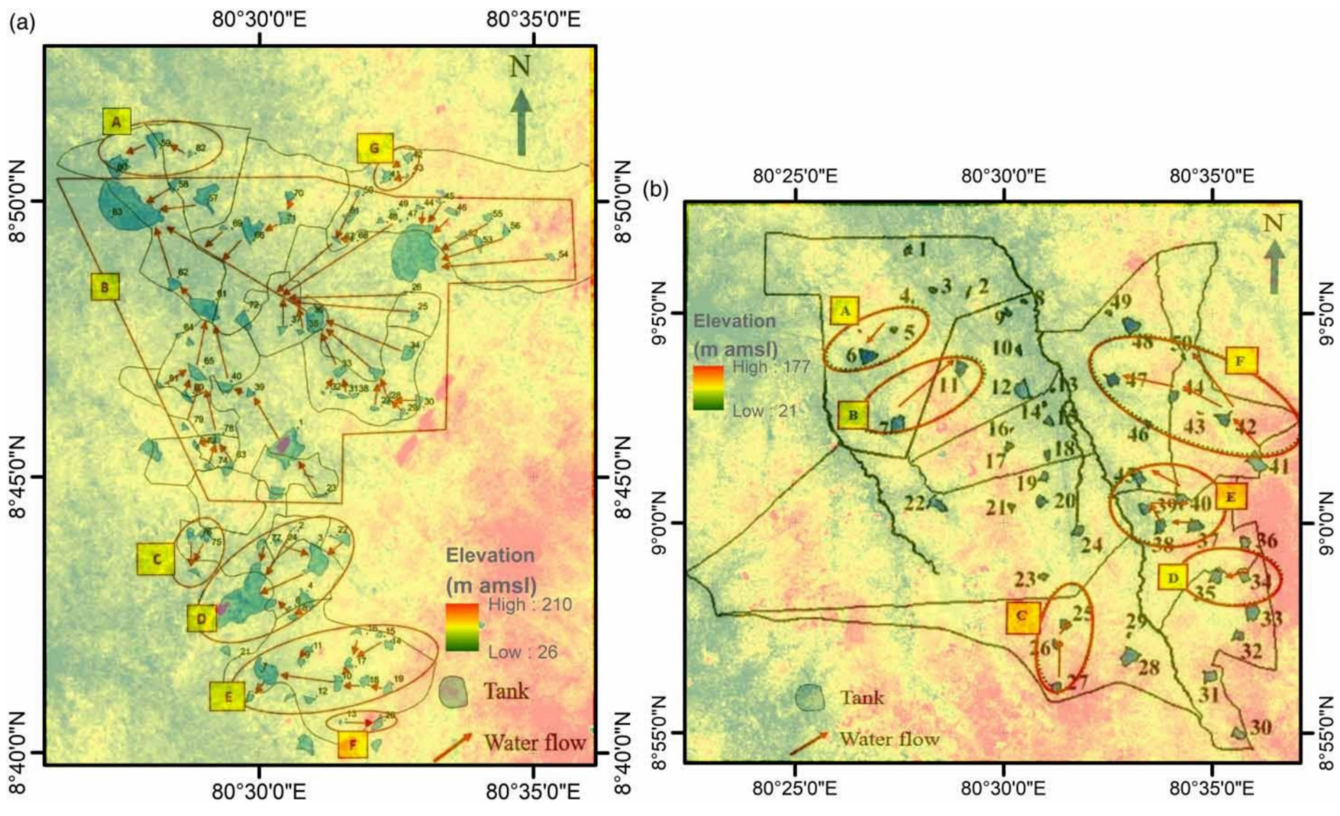

FIGURE 2 | Validated cascade systems in the 2018 field study. (a) Kovilkulam ASC area, showing seven cascades comprising 82 tanks, and three isolated tanks; (b) Kanagarayankulam ASC area, showing six cascades comprising 19 tanks and 31 isolated tanks. Arrows indicate the direction of surface water flow between connected tanks within each cascade.

The validation process revealed spatial differences in tank distribution and functionality. For instance, Kanagarayankulam ASC had 31 isolated tanks—the highest among all ASC divisions. This region, located in the northern part of the district, was heavily affected by Sri Lanka's civil conflict (1983–2009), which led to large-scale displacement and disruption of farming activities. The absence of routine maintenance, coupled with overgrown vegetation and silted channels, has led to severe degradation of tank systems. Many abandoned tanks could potentially be restored to harvest seasonal rainwater if supported by targeted rehabilitation programs.

Table 1 presents a summary of the number of cascades identified, field-validated cascades, total tanks, and the proportion

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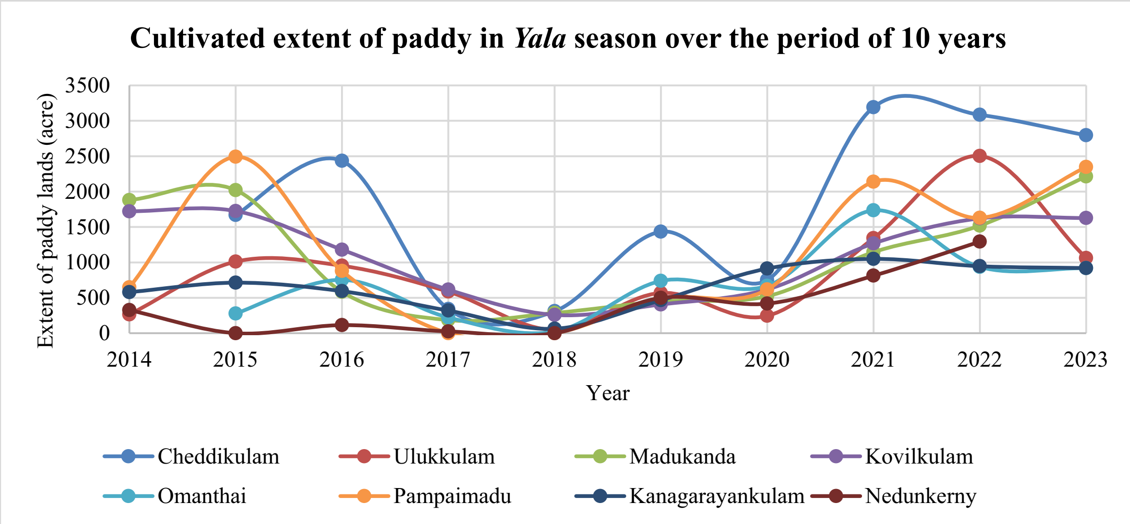

FIGURE 3 | Ten-year trend in the extent of paddy cultivation across eight Agrarian Service Centre (ASC) areas in Vavuniya District. Data show interannual variability in cultivated area, influenced by rainfall availability, tank functionality, and seasonal water stress.

of abandoned or isolated tanks across the ASC divisions. The case of Kanagarayankulam, where settlements now surround numerous tanks and no longer function as components of a connected cascade, exemplifies the long-term effects of war-related disruptions on rural water management and infrastructure. The lack of tank maintenance, natural siltation, and degraded water channels has led to fragmentation within cascades, limiting their effectiveness as interconnected water systems. While some efforts have been made to map these tanks, further research is needed to trace historical water flow paths and understand the reasons behind the fragmentation. This should include consultations with key stakeholders and elderly farmers who possess knowledge of traditional hydrological linkages.

The overall performance of VTCS in Vavuniya has declined, particularly during the *Yala* season. A key indicator is the decline in paddy cultivation, which has dropped steadily from 2014 to 2020. However, rehabilitation projects implemented between 2019 and 2020, involving desilting and repairs to sluices and pipelines, led to notable improvements in 2021 across most ASCs. Exceptions include Omanthai, Nedunkerny, and Kanagarayankulam, where fewer tanks were rehabilitated. Severe droughts in 2017 and 2018 also contributed to the earlier decline in performance (Figure 3).

In conclusion, the status of village tanks in Vavuniya reflects a mix of potential and vulnerability. While they remain crucial for agricultural and domestic water supply, the challenges of maintenance, siltation, abandonment, and overextraction of groundwater require urgent and integrated interventions. These systems can be revitalized through scientific assessment, local knowledge, and coordinated rehabilitation efforts that consider not only technical needs but also the socioeconomic context, especially in postconflict regions.

6.2 | Hydrological Linkages Between Village Tanks and Groundwater

The interaction between surface water stored in village tanks and the groundwater levels in adjacent wells is a key factor influencing the overall water balance and sustainability of irrigation systems in the Vavuniya District. To assess this hydrological linkage, a focused study was conducted on three representative tanks: Vavuniyakulam, Pandarikulam, and Paddanichchepuliyankulam, as described in Tharani et al. (2015). Water-level data for the Vavuniyakulam tank were collected periodically from the Provincial Irrigation Department. Water levels in Pandarikulam and Paddanichchepuliyankulam tanks were measured periodically at the sluices, while corresponding rainfall data were obtained from the Department of Meteorology. The study monitored 21 wells near Vavuniyakulam, 23 wells near Pandarikulam, and 21 wells near Paddanichchepuliyankulam, with biweekly measurements collected between August 2013 and January 2014 (Figure 4).

The relationship between surface water in tanks and groundwater levels in adjacent wells was quantified by calculating the correlation coefficient (r) between the two variables. The analysis revealed strong positive correlations, with coefficients of 0.88 for Vavuniyakulam, 0.72 for Pandarikulam, and 0.69 for Paddanichchepuliyankulam. The particularly high correlation at Vavuniyakulam ($r = 0.88$) indicates a strong hydraulic connection between tank water storage and adjacent groundwater levels. Furthermore, 86% of the wells within the Vavuniyakulam command area exhibited correlation coefficients greater than 0.8, confirming that groundwater levels respond directly to fluctuations in tank water storage (Tharani et al. 2015).

6.3 | The Peraru Village Tank: An Innovative Multifunctional System

The Peraru tank in the Vavuniya District serves as an innovative example of how traditional village tank infrastructure can be adapted to meet modern water demands. In addition to irrigating local command areas, the tank has been incorporated into a pipe-borne water supply scheme, providing raw water for treatment and distribution to nearby communities.

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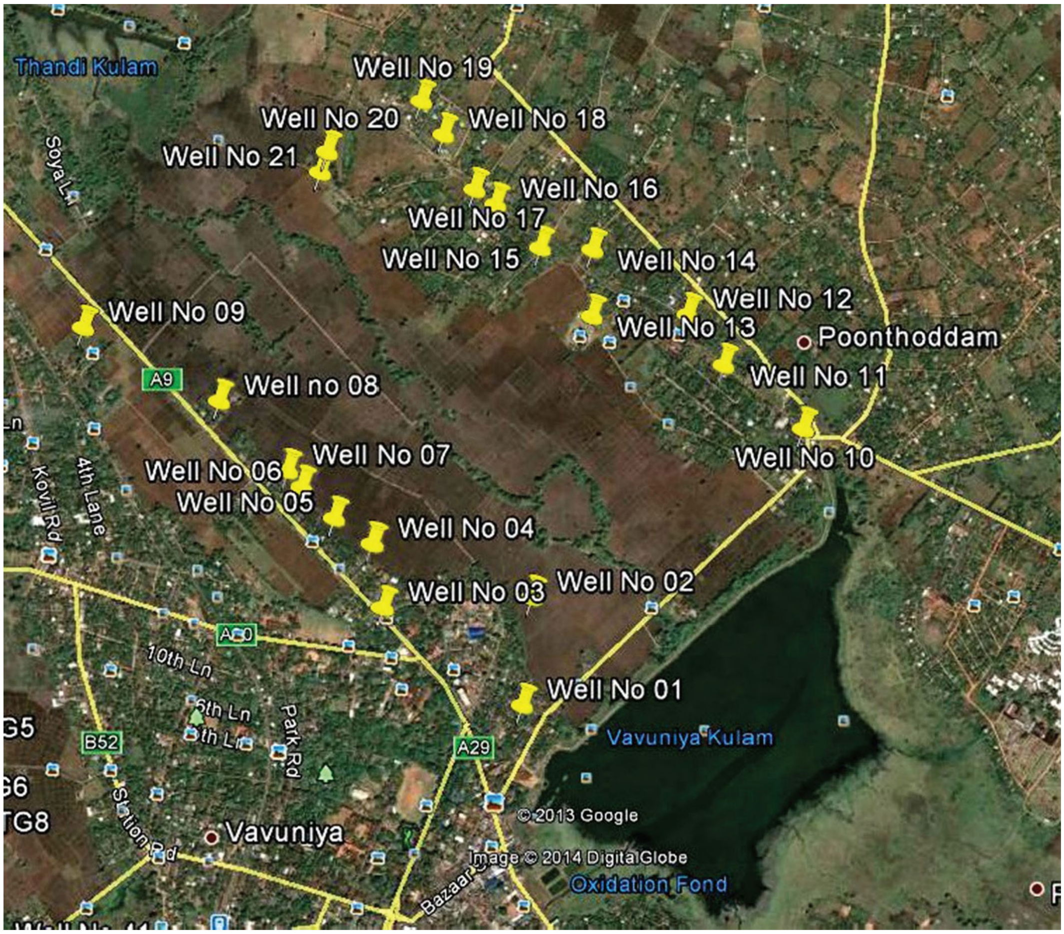

FIGURE 4 | Location of selected village tanks and associated groundwater monitoring wells in Vavuniya District.

Located at 8°50′8.00″N and 80°27′13.00″E, the Peraru tank functions as both an irrigation reservoir and a drinking water source. Due to its relatively good water quality, the National Water Supply and Drainage Board (NWSDB) in Vavuniya now treats and distributes its water through the public supply network, making the tank a vital regional asset.

Under the *Dry Zone Urban Areas Water and Sanitation Project* supported by the Asian Development Bank (ADB 2008), a 1.5-km earth dam was constructed across the Peraru stream in 2009, forming a 215-ha reservoir that expands to 280 ha at high flood level. The system is designed to deliver 20,000 m^3 of treated water per day by 2030, serving an estimated 88,000 people across 6250 ha.

The Peraru tank exemplifies the adaptive potential of Sri Lanka's ancient hydraulic systems, demonstrating how their rehabilitation and integration can strengthen water security in the dry zone. It also highlights the importance of catchment protection, water quality monitoring, and coordinated management to balance the use of water for agriculture, domestic purposes, and ecology. This case reinforces the broader view that VTCS are inherently multifunctional, capable of supporting climate resilience, sustainable water supply, and community well-being through integrated management approaches.

7 | Discussion

7.1 | The Relevance of Tank Systems for Climate Resilience

Climate change is increasingly disrupting hydrological cycles, particularly in tropical regions, where altered rainfall patterns, rising temperatures, and increased evaporation are affecting water availability and reliability. These impacts are particularly severe for rain-dependent agricultural communities, which are increasingly vulnerable to both droughts and floods. Village tanks, functioning as rainwater-harvesting structures, offer a valuable means of adaptation by supporting local water management and enhancing resilience.

Shifts in rainfall timing and distribution have made farming more unpredictable. Traditional cropping patterns are under pressure due to shorter rainy seasons and prolonged drought. Village tanks help mitigate these risks by capturing and storing seasonal rainfall, which can be used for irrigation during periods of water stress. Their presence supports crop survival, improves food security, and reduces the risk of crop failure.

VTCS function as a local climate buffer, capturing monsoonal rainfall and redistributing it gradually through surface flow, seepage,

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and percolation. This role is especially critical in dry zones where rainfall is seasonal and evaporation rates are high. The Vavuniya case reaffirms this role: Well-performing tanks helped maintain water levels during the dry *Yala* season, while degraded or isolated tanks contributed to water stress and crop failure.

For farmers relying on tank-based irrigation systems, these changes are particularly significant. Climate projections indicate that dry zones will become drier and hot weather will intensify, further stressing freshwater availability (Eriyagama et al. 2010; IPCC 2014; IPCC 2018). Under these conditions, increasing the capacity of local water storage systems is essential. Village tanks, with their capacity to harvest and conserve water at the micro-catchment level, are being increasingly recognized as a practical and low-cost adaptation strategy (Bebermeier et al. 2017; Climate Change Secretariat, Ministry of Environment, Sri Lanka 2010; United Nations Climate Change Secretariat 2019).

The Peraru tank exemplifies how village tanks are increasingly being adapted for multiple purposes—including treated water supply for domestic use—demonstrating their evolving multifunctionality in response to climate and social pressures. Importantly, the role of tanks extends beyond agriculture. They also support the drinking water supply, livestock needs, and ecological functions, such as preserving wetland habitats. The multiple uses of tank systems make them particularly relevant in integrated watershed management approaches. By ensuring year-round water availability, village tanks reduce the need for overreliance on groundwater extraction, which has become unsustainable in many regions.

The stress on village tank systems is compounded by increasing evaporation losses, degradation of catchment areas, and siltation, which reduce the effective storage capacity. As temperatures rise, these systems are further compromised unless they are regularly maintained and scientifically managed. Rehabilitation of tanks must, therefore, be accompanied by broader catchment conservation efforts to ensure sustainability.

Understanding the spatial and temporal behavior of tank storage under changing climatic conditions is essential. Studies have shown that such knowledge is crucial for effective restoration and long-term planning (Perera et al. 2021). Strategies to improve the resilience of these systems include desilting, structural repair, strengthening sluices, and re-establishing water flow linkages between tanks within a cascade.

In summary, village tanks offer a time-tested and locally embedded strategy for adapting to climate change. Their role in capturing rainfall, replenishing groundwater, and supporting rural livelihoods makes them an indispensable part of resilience planning in water-scarce regions. However, to realize their full potential, a concerted effort is needed to restore, maintain, and integrate them into broader climate and water governance frameworks.

7.2 | Conjunctive Water Use and Recharge Functions

Village tanks not only serve as vital sources of surface irrigation but also play an important role in groundwater recharge, particularly in semiarid and dryland regions (Chowdhury and Behera 2018; van Meter et al. 2016). By capturing surface runoff, these tanks help reduce water loss and increase the availability of water for subsurface infiltration. Their permeable beds allow stored water to seep into the ground, thereby recharging shallow aquifers and contributing to the sustainability of groundwater-dependent agriculture (Sakthivadivel 2009).

The strong correlation observed between tank and well water levels, such as $r = 0.88$ at Vavuniyakulam (Tharani et al. 2015), supports the view that VTCS contribute significantly to groundwater recharge. Tanks facilitate natural infiltration and support shallow aquifers that supply water for domestic use, livestock, and upland cultivation (Bakker et al. 1999). This finding reinforces the case for promoting conjunctive use strategies, where tank rehabilitation is explicitly designed to enhance groundwater recharge rather than focusing only on surface irrigation.

Research has shown that tanks constructed in areas with alluvial soils and high permeability are particularly effective in enhancing recharge rates. During the monsoon season, these tanks retain rainwater, allowing it to percolate slowly into the subsurface and replenish groundwater reserves. Groundwater stocks in these regions tend to remain relatively stable, as wells are recharged both from tanks and through percolation in irrigated rice fields (Palanisami and Easter 2000).

For instance, studies in southern India have demonstrated that tanks contribute significantly to groundwater recovery, accounting for up to 30% of annual aquifer replenishment (van Meter et al. 2016). This function becomes particularly crucial in regions where overextraction of groundwater has led to declining water tables. In such cases, tanks serve as natural recharge structures that help stabilize groundwater levels and mitigate the adverse effects of excessive withdrawals (Shah 2009a).

The relationship between tank irrigation and groundwater use has evolved. Due to the reduced reliability of tanks alone, farmers increasingly supplement tank irrigation with wells. A comparative study conducted across Madurai, Sivagangai, and Coimbatore districts evaluated three scenarios: tank-only, tank with wells, and wells-only. The study found that well irrigation provided the most reliable water supply and the highest crop productivity, followed by the tank-and-well combination, with the tank-only scenario yielding the least reliable outcomes. This variation was primarily attributed to the consistency of water availability from wells (Nanthakumaran and Palanisami 2010).

Even in areas where well irrigation predominates, village tanks continue to play a significant role in groundwater recharge (Chowdhury and Behera 2018; van Meter et al. 2016). In such regions, tanks function primarily as percolation ponds, allowing stored water to seep into the subsurface and indirectly support wells. Where tanks are combined with wells, the wells often provide supplementary irrigation when tank water is insufficient, ensuring more reliable water availability for crops. Across these semiarid and dryland areas, the contribution of tanks to maintaining groundwater levels remains evident and valuable, highlighting their continued importance in sustaining groundwater-dependent agriculture (Palanisami and Easter 2000).

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Over time, the siltation of tank beds has significantly reduced both the infiltration capacity and storage volume of village tanks, thereby diminishing their potential for groundwater recharge (Reddy et al. 2018). The gradual accumulation of sediments not only lowers the effective storage but also restricts percolation through the tank bed, weakening the hydraulic connection between surface and subsurface systems. To restore and sustain the recharge function of these tanks, regular desilting, maintenance of sluices and feeder channels, and proper catchment management are essential (van Meter et al. 2016).

While the direct link between the degradation of traditional water harvesting systems and groundwater depletion remains to be studied (Chowdhury and Behera 2018), there is growing recognition that enhancing the productivity of wells through improved groundwater recharge can offer substantial benefits to tank-dependent farmers (Palanisami et al. 2009; Shah and Raju 2002). In many tank-dominated, drought-prone areas, the decline of tank infrastructure disrupts connections between surface and groundwater systems, reducing overall water availability and increasing the vulnerability of local ecosystems and agricultural production (Chinnasamy and Srivastava 2021). These results indicate the need to design tank rehabilitation explicitly to enhance both surface and groundwater systems.

Strengthening this link requires a comprehensive understanding of how tanks and aquifers interact, particularly in rain-fed and dryland contexts. Experiences from India demonstrate that community-based groundwater recharge initiatives, such as the MARVI project in Rajasthan and Gujarat, can be highly effective and sustainable (Jadeja et al. 2018). These efforts demonstrate that a transdisciplinary approach involving farmers, local communities, researchers, NGOs, and government agencies is critical to addressing the complex challenges of groundwater management (Maheshwari et al. 2014). Identifying appropriate recharge methods and suitable locations can substantially increase recharge efficiency and improve water availability for irrigation and domestic use (Chinnasamy et al. 2015).

7.3 | Institutional and Postconflict Challenges

The findings also highlight the legacy of Sri Lanka's civil conflict, particularly in northern areas such as Kanagarayankulam, where tanks were abandoned and cascades were broken (Figure 2). Decades of war led to displacement, the deterioration of infrastructure, and the erosion of community-based management systems. These challenges continue to affect the functionality of village tanks and the communities that depend on them.

Postconflict restoration of tanks is, therefore, not only a technical task but also an institutional and social challenge. Rehabilitating cascades in such areas requires attention to resettlement dynamics, knowledge recovery, and capacity building among both local communities and governance bodies. The need for multi-agency coordination—across irrigation, agrarian, and rural development departments—is particularly pronounced in postconflict contexts, where overlapping responsibilities and institutional gaps can hinder progress. Furthermore, persistent issues such as siltation, catchment degradation, and encroachments continue to limit the full potential of these systems. Over time, the degradation of catchments and tank infrastructure has weakened the functionality of many tanks. Inadequate institutional coordination, lack of timely maintenance, and resource constraints have all contributed to the deterioration of this traditional system.

Addressing these challenges requires integrated water resource management approaches that combine hydrological restoration with institutional strengthening and community participation. Successful examples of such approaches have demonstrated that tank desilting and bund repairs can significantly enhance recharge capacity, with positive impacts on over 1000 ha of farmland (Palanisami et al. 2009). In postconflict areas like Vavuniya, institutional revival must accompany physical rehabilitation. This requires long-term commitment, coordination among agencies, and the inclusion of local knowledge holders who may have been displaced but still retain valuable insights into how these systems once functioned.

7.4 | Integration of Local Knowledge and Participatory Governance

Field investigations in Vavuniya highlighted the significant role of local ecological knowledge, particularly that of experienced farmers and village elders, in validating cascade structures and interpreting seasonal water patterns. This knowledge base, accumulated through generations of practice, remains underutilized in formal tank planning and rehabilitation efforts. A key insight is the need to reintegrate community participation into water system governance through participatory mapping, monitoring, and decision-making processes. Empowering local institutions and farmer groups to co-manage tanks can improve maintenance, enhance equity in water distribution, and revive the collective custodianship that has sustained VTCS for generations. Their continued relevance depends on effective rehabilitation, community management, and supportive policy frameworks to ensure their sustainability and contribution to food security and rural livelihoods.

Given their community-based nature, village tanks also facilitate collective action and local governance, which are essential components of successful adaptation and sustainability. Empowering local communities to manage these resources enhances ownership, knowledge sharing, and responsiveness to local environmental risks. Integrating local knowledge and participatory approaches into tank governance can revitalize the social foundations of VTCS while strengthening their technical and environmental performance. Overall, this reinforces the relevance of CPR principles, while also showing that VTCS governance depends on more than local cooperation alone. The Vavuniya case indicates that successful revitalization requires the simultaneous restoration of community institutions, hydrological connectivity, and institutional coordination across government agencies.

8 | Broader Lessons and Policy Implications

VTCS are a time-tested form of community-managed infrastructure that continues to support dryland agriculture, rural

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water supply, and groundwater recharge. The Vavuniya case illustrates that although many tanks remain operational, their broader functionality and potential are increasingly constrained by physical degradation, institutional fragmentation, and limited incorporation of community knowledge. Building on the field findings, this section synthesizes key insights to guide VTCS revitalization in Sri Lanka and comparable dryland and postconflict contexts.

8.1 | Lesson 1: Reframe VTCS as a Decentralized Infrastructure for Climate Adaptation

There is a need to reframe village tanks as essential infrastructure for climate adaptation and resilience. Although small in scale, these systems can provide decentralized and locally appropriate responses to climate variability and dry season water stress. Unlike large dams and centralized canals, VTCS are embedded in the social and ecological fabric of rural communities. Their small individual storage volumes are offset by their ability to scale laterally through cascades. In regions affected by erratic monsoons, frequent droughts, and extended dry spells, VTCS provide irrigation, livestock watering, domestic supply, and groundwater recharge—all without significant ecological disruption. However, they remain poorly integrated into national or regional climate resilience frameworks. For VTCS to realize their full potential, they should be recognized as critical infrastructure in climate planning and promoted in policy as decentralized buffering systems for rain-fed and marginal farming regions.

8.2 | Lesson 2: Integrate Surface and Groundwater Governance Through Conjunctive Use

The hydrological findings from Vavuniya highlight the value of integrating surface and groundwater management. A strong correlation between tank water levels and well recharge ($r = 0.88$ at Vavuniyakulam) demonstrates the interdependence of the two systems. Nevertheless, in many regions, policy and governance frameworks continue to treat surface and groundwater as separate entities, often under the purview of different agencies. This separation leads to planning inefficiencies and can result in unsustainable outcomes, especially in water-scarce areas. A shift towards conjunctive use is required, supported by hydrogeological mapping that can identify tanks with high recharge potential. Locally led water user groups should be supported in co-managing tanks and wells through integrated water budgets grounded in both hydrological evidence and community experience.

8.3 | Lesson 3: Address Social and Institutional Legacies in Postconflict Regions

This lesson emerges from the postconflict dynamics of northern Sri Lanka. Areas such as Kanagarayankulam bear the marks of prolonged disruption—displacement, institutional breakdown, and the abandonment of traditional infrastructure. In such contexts, the rehabilitation of tanks is not only a technical challenge but also a social and institutional one. Postconflict recovery programs must go beyond infrastructure repair to include livelihood restoration, reconciliation, and capacity building. Effective tank revitalization in these areas requires strong interagency coordination, the inclusion of resettled communities, and mechanisms for rebuilding trust and local governance. Where infrastructure and social cohesion have both been weakened, tank rehabilitation can serve as a platform for reconnecting people with resources, institutions, and each other.

8.4 | Lesson 4: Revitalize and Institutionalize Local Ecological Knowledge

Field investigations in Vavuniya confirmed that elderly farmers and long-standing residents possess a rich, detailed understanding of tank behavior, seasonal flows, and cascade connectivity. These insights often complement or even replace formal hydrological data, particularly in areas with limited monitoring infrastructure. However, such knowledge remains undervalued in most formal planning and design processes. Revitalizing VTCS will require a more deliberate effort to embed participatory methods into rehabilitation programs. This includes participatory mapping, monitoring, and decision-making, along with training community-based water stewards—such as Bhujal Jaankaars—to observe and report on rainfall, tank levels, and well conditions. Empowering local institutions with the tools and authority to co-manage water resources can substantially improve long-term maintenance and foster a sense of ownership and responsibility.

8.5 | Lesson 5: Leverage Modern Technology and Data Tools for Tank System Monitoring

Scientific tools and data systems also play a crucial role. While VTCS are based on traditional principles, their continued effectiveness depends on access to accurate, real-time information. In Vavuniya and similar districts, the absence of reliable data on storage volumes, sedimentation, and groundwater response limits the ability to target investments and monitor outcomes. Modern technologies—such as remote sensing, drone-based surveys, and hydrological modeling—can provide cost-effective insights over large areas. Developing integrated tank information systems at national and district levels, combining GIS data, performance indicators, and usage metrics, would support more informed decision-making. Linking these systems with agricultural advisory services could help farmers utilize available water more effectively, particularly amid seasonal uncertainty. Satellite imagery, supported by appropriate analytical tools, can also help identify tanks at risk from siltation or catchment degradation and support the prioritization of rehabilitation efforts.

8.6 | Lesson 6: Strengthen Policy Coherence, Interagency Coordination, and Funding Support

The scaling of VTCS restoration efforts requires an enabling policy and institutional environment. Fragmented mandates, underfunded programs, and institutional ambiguity continue to hinder the replication and expansion of successful models.

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Policy frameworks should support interdepartmental coordination—particularly among irrigation, agrarian services, and rural development agencies—and allocate dedicated funding lines for minor irrigation in national and provincial budgets. At the same time, community-led restoration activities such as desilting, bund repairs, and channel clearing should be supported through government schemes. VTCS revitalization must also be explicitly embedded within national water policy, disaster risk reduction strategies, and development agendas aligned with the SDGs.

In summary, the lessons from Vavuniya extend well beyond Sri Lanka. They apply to water-insecure regions across South Asia, Africa, and other dryland and postconflict contexts where small-scale water systems remain essential to rural livelihoods. Revitalizing VTCS requires a convergence of traditional knowledge and modern science, institutional reform and community agency, and sustained financial and policy commitment. When appropriately supported, VTCS can serve as powerful instruments of climate resilience, groundwater security, and rural sustainability in some of the world's most vulnerable regions. These lessons and policy insights must be accompanied by targeted research to fill critical knowledge gaps and guide effective restoration.

9 | Research Gaps and Future Directions

While the importance of VTCS in water management and climate adaptation is increasingly recognized, several critical research gaps remain, particularly in the Vavuniya district. These gaps hinder the development of effective, science-based interventions to sustainably restore and manage tank systems. Key areas requiring further investigation include the following:

9.1 | Tank Functionality and Degradation

- Limited Understanding of Abandoned Tanks: Although 131 tanks have been identified as abandoned, there is insufficient data on the specific causes of their disuse. Detailed studies are needed to explore the roles of siltation, structural deterioration, lack of maintenance, and socioeconomic disruptions—particularly in postconflict areas—in contributing to abandonment.
- Effects of Siltation and Catchment Degradation: The extent to which siltation and catchment degradation impact tank storage and performance remains under-researched. Quantifying these effects is crucial for prioritizing rehabilitation measures and evaluating their long-term sustainability.

9.2 | Climate and Hydrological Interactions

- Impact of Climate Variability on Tank Functionality: There is a lack of empirical research on how altered rainfall patterns, increased evaporation, and extreme weather events are affecting the performance of village tanks. A better understanding of these dynamics is essential for designing resilient water management systems.
- Unquantified Contribution to Groundwater Recharge: Although qualitative evidence suggests that VTCS makes a significant contribution to groundwater recharge, no detailed studies have quantified this contribution in the Vavuniya region. This limits the ability to integrate surface and groundwater management strategies effectively.

9.3 | Technology and Monitoring

- Underutilization of Advanced Analytical Tools: Although GIS has been used to map tank locations and cascades, more advanced tools, such as remote sensing and hydrological modeling, remain largely untapped. These technologies could be employed to predict tank performance, assess storage variability, and support strategic planning.
- Lack of Data on Crop Yields and Water Use Efficiency: There is limited information on how tank-based irrigation affects crop yields and water use efficiency in the region. Without such data, it is difficult to assess the full agricultural value of the tank systems or to optimize their management

9.4 | Ecology and Economics

- Neglect of Biodiversity and Ecosystem Services: The role of village tanks in supporting local biodiversity and ecosystem services is largely unexplored in Vavuniya. Investigating these aspects could strengthen the case for tank conservation from both ecological and socioeconomic perspectives.
- Insufficient Economic Analysis of Rehabilitation Efforts: Although tank rehabilitation is frequently recommended, there has been limited evaluation of the cost-effectiveness and economic feasibility of large-scale rehabilitation projects in the region. Such assessments are necessary to guide policy and investment decisions.

Addressing these gaps will require a combination of scientific research, field-based assessments, and participatory engagement with local communities. A coordinated approach involving government agencies, academic institutions, and non-governmental organizations is essential to generate actionable knowledge and ensure the long-term sustainability of tank-based water management systems in Vavuniya and similar dry-zone regions.

10 | Conclusions

Village tanks remain an indispensable component of water management in Sri Lanka's dry zone, particularly in districts such as Vavuniya, where seasonal rainfall is often insufficient to meet the agricultural and domestic water needs of communities. As demonstrated in this study, the VTCS represent far more than a traditional irrigation structure. It is a multifunctional system that supports rural livelihoods, facilitates groundwater recharge, buffers against climatic variability, and sustains

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ecosystems central to community well-being. This study documented the current status of VTCS in Vavuniya, highlighting patterns of degradation, partial functioning, and localized restoration efforts. It confirms the continued relevance of tanks for rural water security and groundwater recharge, while also exposing the limitations of fragmented governance and physical decline. This wider significance is also reflected in the recognition of Sri Lanka's Cascaded Tank-Village System as a Globally Important Agricultural Heritage System (GIAHS) in 2017 (Dharmasena 2016).

However, the functionality of these systems has been significantly weakened due to a combination of siltation, catchment degradation, insufficient maintenance, and the socioeconomic disruptions caused by prolonged conflict. One significant consequence of this deterioration is the growing disconnection between surface and groundwater systems, which has led to declining water availability, increased pressure on aquifers, and a marked reduction in crop productivity, particularly during the *Yala* season, when water stress is most acute. Without systemic interventions, these problems will likely deepen in future dry seasons, placing greater pressure on aquifers and increasing risks to the livelihoods of marginal farmers. The evidence from Vavuniya reinforces the urgent need for integrated water management approaches that link tank restoration with community stewardship and institutional coordination.

The hydrological findings confirm the strong interdependence between tanks and wells, with field data demonstrating the groundwater recharge function of village tanks. When tanks are rehabilitated systematically and guided by local ecological knowledge, they can support agricultural productivity and strengthen resilience to seasonal drought. The relevance of these findings extends beyond Vavuniya, as similar pressures are experienced in many dryland and postconflict regions across South Asia and sub-Saharan Africa. This points to the need to integrate traditional water systems into climate adaptation strategies, disaster risk reduction frameworks, and rural development agendas.

Reviving village tanks, however, cannot be limited to physical restoration activities such as partial desilting or structural repairs. A holistic and sustained approach is required—one that combines scientific assessment and monitoring, participatory governance, institutional coordination, and long-term policy support. These interlinked components are essential to re-establishing the functionality and sustainability of VTCS.

Equally critical is recognizing VTCS as a form of nature-based infrastructure that complements modern technologies while providing community-anchored water security solutions. When valued appropriately, these systems offer a path towards more inclusive, resilient, and context-specific water management practices.

The study provides new empirical evidence on the relationship between tank functionality, groundwater recharge, and community-led management in a postconflict, dryland context. It demonstrates how traditional systems, when supported by data and inclusive governance, can bridge the gap between legacy infrastructure and future climate resilience planning.

By positioning Vavuniya as a case study with broader applicability, this research contributes to the growing recognition that traditional water systems can support contemporary climate and water governance agendas when they are scientifically assessed, locally managed, and institutionally supported. The broader policy implication is clear: VTCS should be treated not only as heritage irrigation structures but also as decentralized water infrastructure that can strengthen groundwater recharge, dry-season water security, livelihood resilience, and community-based adaptation. If restored, supported, and integrated into comprehensive water governance frameworks, VTCS can offer scalable, climate-resilient water solutions for vulnerable rural communities in Sri Lanka, and comparable dryland regions.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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