Received: 14 December 2020 | Revised: 27 January 2023 | Accepted: 1 February 2023
DOI: 10.1002/wat2.1642

OVERVIEW

WIREs WATER WILEY

Domestication of water: Management of water resources in the dry zone of Sri Lanka as living cultural heritage

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Funding information
Deutscher Akademischer Austauschdienst, Grant/Award Number: 57059698; Volkswagen Foundation, Grant/Award Number: 88578

Edited by: Jan Seibert, Co-Editor-in-Chief

Abstract
In the dry zone of Sri Lanka, human-made reservoirs (locally called *tanks* or *wewas*) have served for the collection, storage and distribution of rainfall and runoff and provided irrigation water for the cultivation of paddy for 2400 years. This water management system is deeply inscribed in the rural communities utilizing and maintaining it. Local knowledge connected to the utilization of this system is regarded as a substantial part of the intangible cultural heritage of this unique cultural landscape. In the dry zone of Sri Lanka this system had spread from the fifth century BCE onwards from the hinterland of the ancient capital Anuradhapura throughout the entire dry zone and provides a prerequisite for paddy cultivation. From approximately the 13th century onwards, written sources give evidence, that a weakening of state bureaucracy led to a decline of the water management system. In the Colonial period, numerous reservoirs were restored and the implementation of new governance structures lead to a diminishing of water supplies and conflicts at a local level. In post-Colonial times, since the 1950s, the system had undergone rapid changes triggered by governmental and economic developments (e.g., land use change, migration). The rich local knowledge, serves in line with a high degree of adaptation to local conditions, as a corner stone for its resilience. A future sustainable management requires the integration of local knowledge in combination with modern techniques in education, planning, and application.

This article is categorized under:
Human Water > Water Governance
Water and Life > Conservation, Management, and Awareness

KEYWORDS
local knowledge, social–hydrological systems, water management in South Asia

1 | INTRODUCTION

The island of Sri Lanka is located in the Indian Ocean east of the southern tip of the Indian subcontinent. Sri Lanka is 65,610 km^2 in size and has functioned since antiquity as a strategic hub for the maritime trade between Middle and Southeast Asia. Today the Democratic Socialist Republic of Sri Lanka is a multireligious and multiethnic nation. In this paper we introduce the tank cascade system in the dry zone of Sri Lanka with its multifaceted history. The system started to evolve in the fifth century BCE in the hinterland of the capital Anuradhapura (377 BCE to 1017 CE) located in the north-central dry zone of Sri Lanka. Although the tropical climate of Sri Lanka is predominantly controlled by the monsoon, spatial and temporal rainfall pattern in the north central part of the island do not show a strong connection to the monsoonal periods. Further this area is characterized by a distinct dry period during the summer months. Intermonsoonal rainfall occurs during a small rainy season between March and May while the majority of the annual rainfall falls in October and November (Domrös & Ranatunge, 1993; Schütt et al., 2013).

In the dry zone of Sri Lanka, the storage of rainfall and surface runoff in human-made reservoirs has been practiced since ancient times and provides water for paddy irrigation throughout the year. During the two annual humid periods surface runoff is stored in these reservoirs, the so-called tanks or wewas, and is distributed during the dry period to the paddy fields located downslope. The tanks are generally aligned cascade-like along shallow valley courses, connected by canals and spillways, and create a complex system of floodwater harvesting, water storage and water distribution measures (Jayatilaka et al., 2003). The introduction of this system was one of the most important preconditions for the development of early urban societies in north central Sri Lanka, as knowledge of the storage and distribution of water for irrigation purposes was necessary to obtain an agricultural surplus for the growing population (Deraniyagala, 1998). Today, 30,000 small so-called village tanks are still in use in the dry zone of Sri Lanka (Melles & Perera, 2020). Thus for 2000 years the tanks have characterized the cultural landscape of north central Sri Lanka and have become an identity-generating part of rural everyday culture (Bebermeier et al., 2017). Tank-based irrigation as a traditional technique is also know and have been applied in South India, especially in Tamil Nadu since the Medieval period (Gunnell & Krishnamurthy, 2003; Mosse, 2008).

Issues related to water resource management have a long history in dry lands. With the onset of sedentariness in the fertile crescent, seasonal changes in water availability posed a particular challenge for agriculture, animal husbandry and domestic use. The development of techniques that allowed the management of water and thus "the domestication of water" (Gebel, 2004) is therefore a basic requirement for a sustained, adapted and successful settling of dry areas. These techniques, which aim to enable the collection, storage and distribution of rainfall and runoff for agricultural and domestic use especially in dry subhumid to semi-arid regions, are summarized as water harvesting systems (after Beckers, Berking, & Schütt, 2013; Oweis et al., 2001). These frequently complex landscape-engineering measures include wells and conveyance systems that transported water to the settlements via conduits, channels and aqueducts from perennial or periodical water sources such as rivers, dammed reservoirs, but also terracing systems that enhanced soil water storage and soil conservation (Beckers, Berking, & Schütt, 2013). In general, these landscape engineering measures were strongly adapted to particular natural settings and cultural conditions. Such conditions are not stable, but are on the contrary subject to constant change and phases of upheaval, indicating resilience of these systems against external (e.g., climate change and war) and internal forces (e.g., phases of political upheavals).

By sustaining water for irrigation and domestic use these systems built a corner stone for the livelihood of farmers and represent a substantial part of the tangible and intangible cultural heritage of entire regions (Abeywardana et al., 2017). Their great cultural-historical value is documented through their recognition as UNESCO world heritage sites, like, for example, the *Subak* system of Bali (Indonesia) as integrated hydrosocial system, shaping terraced paddy landscapes. The Subak system is composed of rice fields connected by canals, tunnels and weirs, villages and an integrated remarkable system of water temples as centers for its governance and as an important aspect of religious life (Lansing, 1987). Another traditional water harvesting system, with UNESCO heritage status is the qanāt system, which is rooted in ancient Persia and from there distributed all over the Eurasian and North African semi-arid regions (Boucharlat, 2003). A *qanāt* chain serves for groundwater harvesting and consists of a subsurface tunnel that connects an aquifer with a foreland outflow facility. A set of vertical shafts enables access to the tunnel for maintenance measures (Semsar Yazdi & Labbaf Khaneiki, 2017).

In line with the implementation of these systems regionally specific governance structures developed with legal frameworks and particular rituals for the systems' use and maintenance, including their successive adaptation to changing physical and social settings: leading to the formation of technical and local knowledge systems sustaining the use of such water management systems (Folke, 2004). In the context of this paper we understand the term "local knowledge" as the knowledge system, that people of a given community have developed over time and continue to develop (Warburton & Martin, 1999). Traditional water harvesting systems, broadly regarded as sustainable systems (Ariyananda, 2020; Chinnasamy et al., 2021; Ghorbani et al., 2021), are currently endangered by several developments related to global change. Especially modern irrigation solutions like groundwater pumping are successively replacing traditional systems which subsequently get abandoned and the underlying knowledge gets forgotten (Beaumont, 1971; Gunnell & Krishnamurthy, 2003). Abandoned water harvesting systems tend to silt up, their infrastructure decays and becomes irreparable (Beckers, Schütt, et al., 2013). Further rural–urban migration, especially of young people, affects the system, as labor for maintenance tasks becomes scarce and operating and maintenance knowledge is lost (Köpke et al., 2019).

Nowadays local knowledge systems are widely regarded as corner stones for the implementation of coping strategies to increase the resilience of rural communities against climate change by adaptation measures (Pearson et al., 2021). Therefore, there is an urgent need to capture and preserve the local knowledge associated to the management and maintenance of the tank cascade systems. By providing a review on the tank cascade systems in Sri Lanka, shaping a unique hydraulic landscape, this paper aims to highlight the value and potential of integrating traditional water harvesting systems in strategies of coping with climate change and increase resilience for rural farming communities by maintaining and thoughtfully adopting these systems to future needs. We will introduce (a) the technical features of tank cascade systems, and (b) provide an overview of their history and transformation of the governance system. Further we introduce (c) contemporary challenges in regard to cope with climate change to increase the resilience of rural communities whose livelihood relies on tank-based irrigation.

The terms resilience and vulnerability are key terms when dealing with human-environment systems (Knitter et al., 2021), and are widely used in social and natural science, however, partly with different meanings. In the context of this paper we understand resilience after Holling (1973) as the buffering capacity of a system against external or internal perturbations (e.g., climate change or population growth) and respectively as the capacity of a system to recover from such perturbations (Holling, 1973) and disturbances (Adger, 2000). The concept of vulnerability describes the "threshold beyond which a society risks breakdown because of a lack of means to respond adequality to threats" (Knitter et al., 2021, p. 19). The synopsis of the definitions shows that the two concepts are closely linked to each other.

2 | DESIGN OF TANK CASCADE SYSTEMS AND SPATIAL DISTRIBUTION

Tanks are a characteristic landscape element in the dry zone of Sri Lanka. The highest density of tanks occurs in the heartland of the Rajarata kingdom, the first kingdom, of the island, corresponding to the hinterland of Anuradhapura (Abeywardana, Pitawala, et al., 2019). In this area densities of one tank per 1.2 km^2 are reached (Figure 1). This brief overview sketches the high degree of complexity and interconnectedness of the single components of these tank cascade systems and underlines the perception of scholars understanding the tank cascade systems as socioecological systems (Panabokke et al., 2002; Ratnayake et al., 2021).

The majority of tanks are organized in tank cascade systems by connecting single reservoirs with channels and spillways. Typically, the tanks increase in size in downstream direction (Figure 2a–h). Excess water is routed via spillways to the next downstream tank, preventing water loss and dam breaks (Itakura, 1995; Schütt et al., 2013). The tanks allow the storage of rainfall and runoff water during the rainy season and the distribution of water mainly for the cultivation of rice (Jayatilaka et al., 2003). The reservoirs are differentiated in major and medium, as well as in minor and micro irrigation works, as a function of the size of the tanks' water surface area and the size of the irrigated area (command area) (Murray, 2004 and literature cited herein; Bebermeier et al., 2017):

- Major tanks have a water surface area of >200 ha and a command area of >600 ha. The government administration is responsible for their maintenance.
- Medium tanks have a water surface area of 50–200 ha with a corresponding command area of 80–60 ha. The government administration is responsible for their maintenance.
- Minor tanks have a water surface area of 1–50 ha and a corresponding command area of less than 80 ha. Like the micro tanks (water surface area 0.1–1 ha, command area <1 ha) they are maintained predominantly by local communities.

Small or village tank systems represent the single elements of a tank cascade system, featuring their own typical structure (Figure 2i). According to the model by Tennakoon (1974), a typical village tank consists of five concentrically

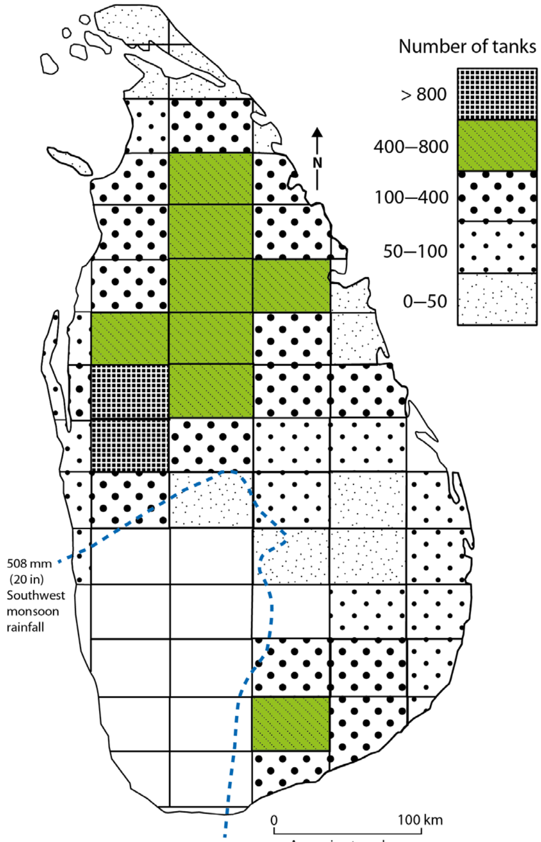

FIGURE 1 Distribution pattern of small tanks in Sri Lanka (modified after Cook, 1935; Domrös, 1974; Panabokke et al., 2002).

arranged zones, with the tank and the tank bund (dam) in the center (first zone) (Figure 3). Artificial swamp areas lie between the dam and the downstream paddy fields and serve for sewage treatment. The wetland-area of the so-called "*thaulla*" is located in the root zone of the tank; here upstream inflow is cleaned from pollutants and fines (Mahatantila et al., 2008). Tall grasses and softwood from the *thaulla* area serve as raw material for crafts (Jayasena & Selker, 2004). Fines—mostly silt and clay—deposited in the wewa are traditionally utilized as raw material for pottery.

The paddy fields directly located downstream the tank correspond to the second zone, which comprises the so-called "old fields," which commonly have a long cultivation history. The subsequent third zone connects to the old fields and comprises the so-called "field blocks," which were taken into cultivation in the context of land management programs mainly after 1935 (Tennakoon & Heathcote, 1980). The fourth zone is characterized by open parkland with isolated trees and bushes and surrounds the tank and the irrigated fields. This zone also contains the settlement, situated in a flood-safe location close to the bund (Wiel, 1995). The fifth and outmost zone comprises forested areas, enclosing the inner zones 1–4. In most recent times these areas are increasingly used for chena cultivation and highland farming (Tennakoon, 1974).

Forest tanks situated in peripheral areas provide water for wild animals in order to keep them away from the villages. Erosion control tanks are constructed in the head water areas as siltation basins to protect the main tanks of a cascade from siltation (Zubair, 2005). These latter two tank categories are not necessarily connected to a tank cascade.

Beside irrigation, the tank water is used for domestic needs, fishing and cattle watering (Mahatantila et al., 2008; Murray, 2004). From an ecological point of view tank cascade systems function as habitat and breeding ground for birds and aquatic species and provide ecosystem services, which are especially important for peasants relying on irrigation water of minor tanks. Vidanage et al. (2005) calculated the monetary value of ecosystem services of tanks in the Kala Oya Basin provided by water and aquatic resources to 425 US$ per household per year and almost 3000 US$ per hectare inundated land. Vidanage et al. (2005) clearly underline the importance even of minor to medium scale tanks especially for smallholders to secure subsistence and livelihood.

The storage function of the tanks buffers effects of climatic extreme events like floods and droughts (Emerton, 2005; Geekiyanage & Pushpakumara, 2013; Hewawasam & Matsui, 2022; Schütt et al., 2013). Already ancient chronicles

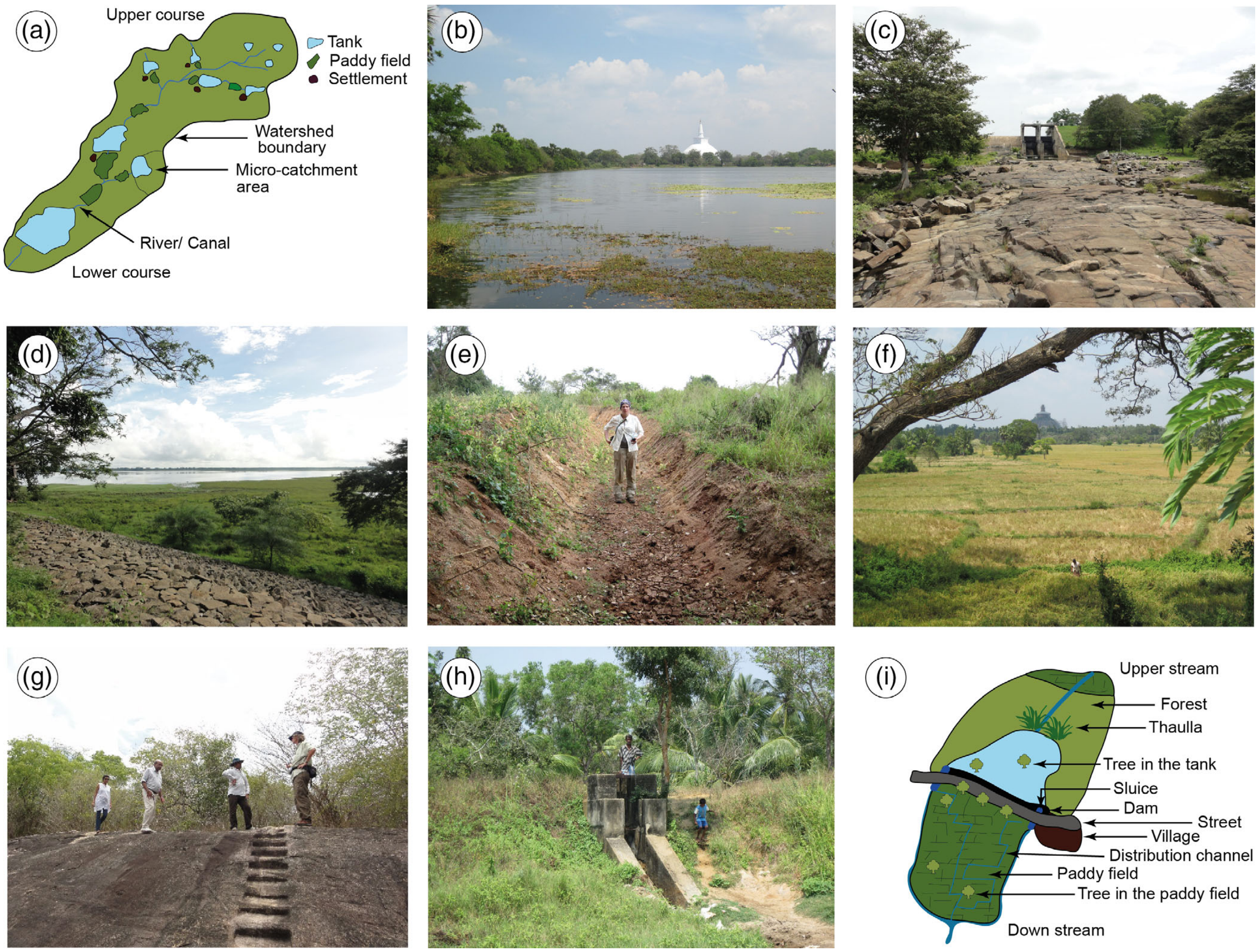

FIGURE 2 Function and elements of tank cascade systems in the dry zone of Sri Lanka (a) sketch of a typical village wewa cascade system (Schütt et al., 2013; modified after Panabokke et al., 2002), (b) Bassawakulama wewa west of Anuradhapura, (c) sluice of Kala Wewa, a major reservoir from which water is routed northwards to selected tanks in the hinterland of Anuradhapura, (d) stone cover at the dam of Nuwarawewa, Anuradhapura, (e) spillway, connecting tanks in the Rota Wewa system east of Mihintale, (f) view of paddy fields close to the Citadel of Anuradhapura, (g) bedrock outcrop, with sculptured stairs as an upstream boundary of an abandoned village tank north of Anuradhapura, (h) view of a bund with sluice at a village tank north of Anuradhapura, (i) sketch of a typical small or village tank system corresponding to a microcatchment (modified after Schütt et al., 2013) (source photographs: authors).

mentioned frequently droughts and resulting famines and clearly refer to an increase in investment in the irrigation infrastructure as coping strategy applied by ancient kings (Siriweera, 2004 in Jayawardana & Wijithadhamma, 2015; Geiger, 1912, pp. XXXVI 20, 75–79). Consequently, nowadays scholars highlight the potential of the tank cascades system to cope with the effects of climate change (Ratnayake et al., 2021).

3 | HISTORY AND TRANSFORMATION OF THE SRI LANKAN TANK CASCADE SYSTEMS AND ITS GOVERNANCE STRUCTURES

The reconstruction of the history of the tank cascade systems is largely based on the analysis of written sources (Abeywardana, Pitawala, et al., 2019; Diksith, 1986; Gunawardana, 1971) and has been an object of research since the beginning of the 20th century. A pioneer in this field was Parker (1909), who firstly succeeded in linking tanks mentioned in ancient texts to present-day existing tanks. Furthermore, scholars like Brohier (1935, 1979, 1997) and Gunawardana (1971) contributed substantially to the reconstruction of the development of the Sri Lankan

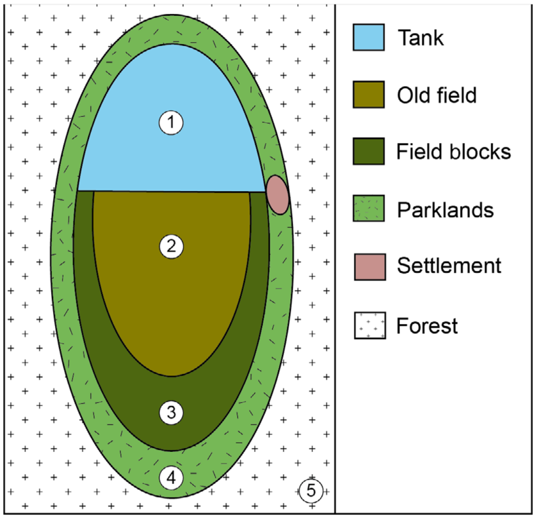

FIGURE 3 Schematic diagram of a typical dry zone village (modified after Tennakoon, 1974).

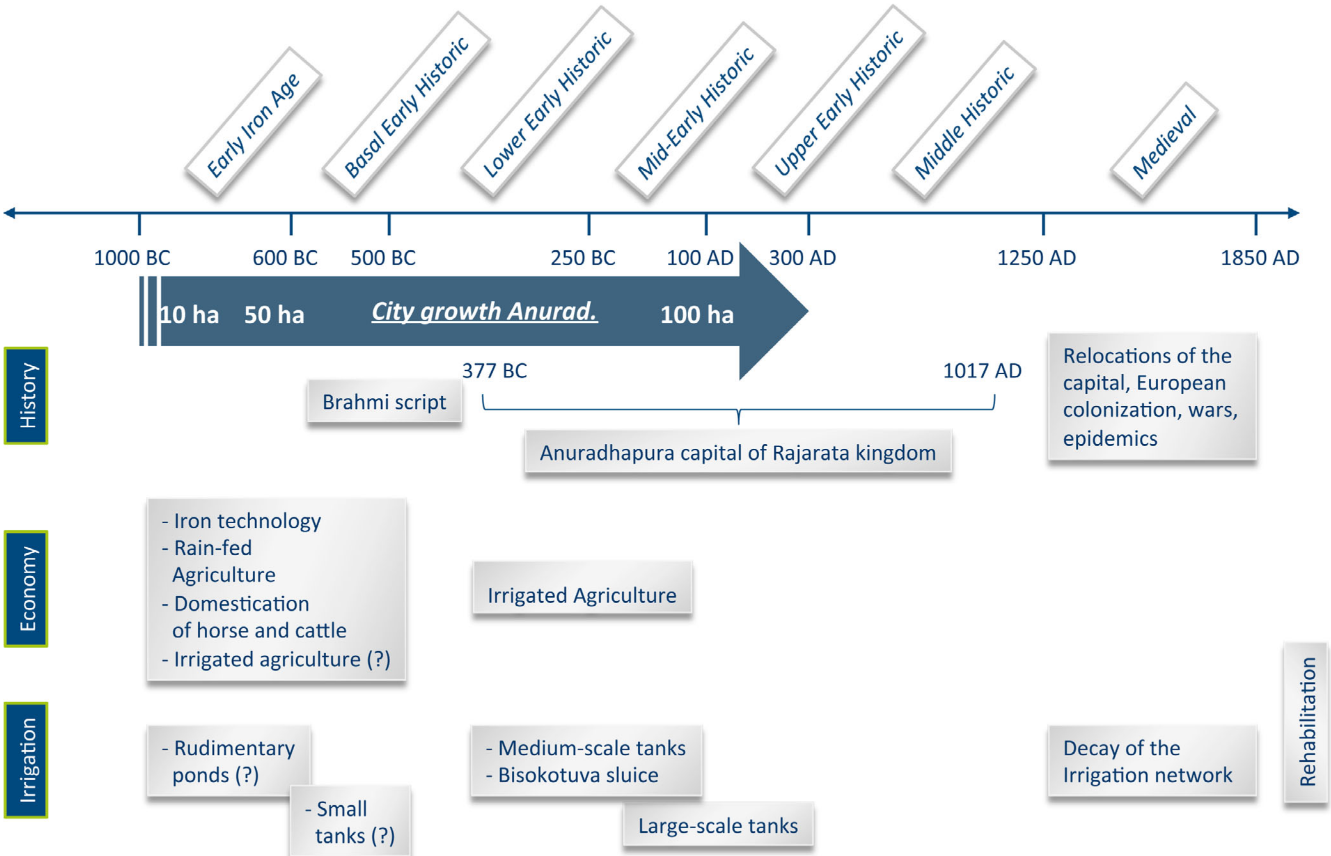

FIGURE 4 A short history of the tank cascade system (arranged according to Deraniyagala, 1992; Panabokke, 2009).

tank cascade system. A systematic qualitative and quantitative analysis of ancient sources based on ancient chronicles of Sri Lanka and epigraphic sources introduced by Abeywardana et al. (2018); Abeywardana, Pitawala, et al. (2019) reconstructs the historical development of the tank cascade system. In the following we will briefly summarize the development and transformation of the tank cascade system and its governance structures through time (Figure 4).

3.1 | Development of the tank cascade systems during the Anuradhapura period (377 BCE to 1017 CE)

During the Early Iron Age (900–600 BCE) a village-based agricultural and pastoral society had developed in the dry zone of Sri Lanka. The livelihood of these Early Iron Age settlers was based on rainfed agriculture, animal husbandry of cattle and horses and the knowledge of iron production (Deraniyagala, 2004). Panabokke (2009) hypothesized, that rudimentary human-made ponds were used for water storage, but this hypothesis is not underlined by empirical evidence. The introduction of the tank cascade system coincides with the founding of the first royal capital Anuradhapura in 377 BCE. The hinterland of the ancient capital Anuradhapura was the center for the development and diffusion of the water harvesting system throughout the dry zone of Sri Lanka from the fifth century BCE onwards (Abeywardana, Pitawala, et al., 2019) (Figure 5a). The tank Abhayavapi is the first tank mentioned by written sources in 437–367 BCE (Geiger, 1912, pp. X/84–88). The construction of the major and medium tanks west of the ancient city center, namely the Basawakulama tank, Perimiyankulam tank and Tissa tank, is dated to the early first century BCE (Abeywardana, Pitawala, et al., 2019) (Figure 5). The Nuwarawewa tank is first mentioned during the reign of King Gajabahu (113–135 CE). Further ancient records report the construction or presence of numerous other major irrigation works until the second century CE. In the second century CE the number of references to the tank cascade systems in the written sources is distinctly higher than in the previous and subsequent centuries (Abeywardana, Pitawala, et al., 2019). This peak is associated with parallels between the expansion of the tank cascade system and the urban monastic development of Anuradhapura. At the end of the second century CE the initial expansion phase of the tank cascade system resulting in numerous major and medium-sized irrigation works in the dry zone of Sri Lanka had been completed (Abeywardana, Pitawala, et al., 2019; Gilliland et al., 2013). This went along with the development of

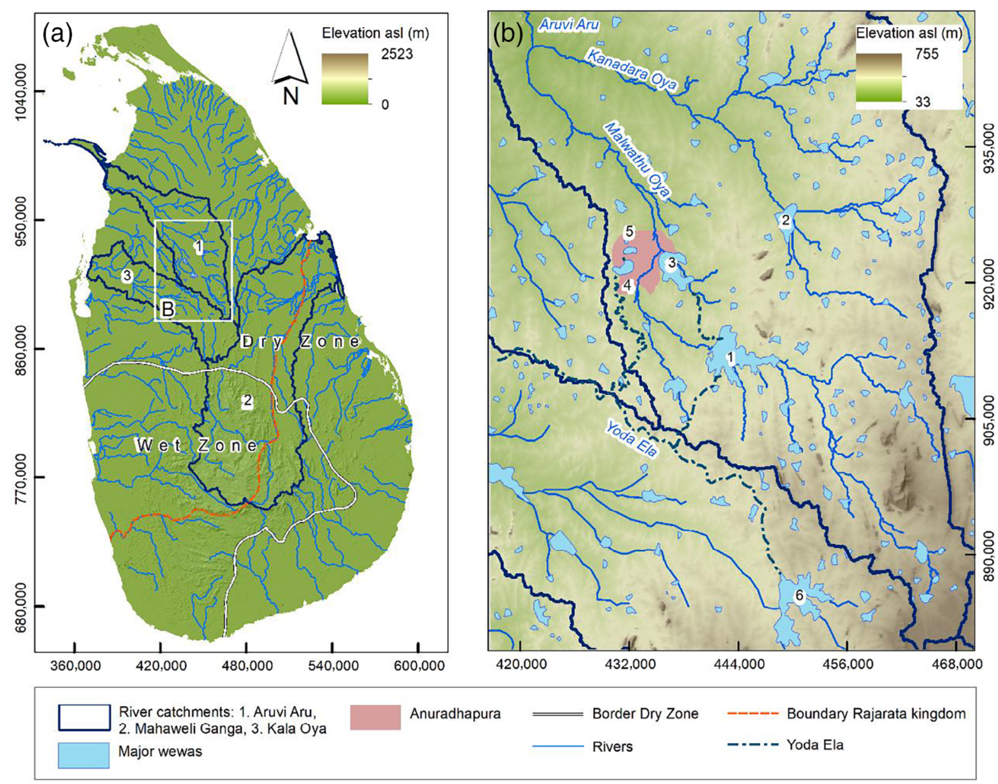

FIGURE 5 Digital elevation model (DEM) of Sri Lanka, with the river network, major wewas, the location of the Aruvi Aru, Kala Oya and Mahaweli Ganga catchments and the boundary of the Rajarata kingdom; (b) digital elevation model (DEM) of the hinterland of Anuradhapura and its large tanks: (1) Nachchaduwa wewa, (2) Mahakanadarawa wewa, (3) Nuwara wewa, (4) Tissa wewa, (5) Basawakkulama wewa. Kala wewa (6), situated in the Kala Oya catchment, receives water via a channel from the Mahaweli Ganga and water from Kala wewa is diverted through the channel of Yoda Ela to different tanks within the Aruvi Aru catchment (after Saase et al., 2020). *Data source*: DEM (Shuttle Radar Topography Mission [SRTM] 1 Arc-Second Global 30 m × 30 m, 2015); catchment, tanks, rivers, channel, Anuradhapura (Survey Department of Sri Lanka, 2007).

governance structures for the utilization and maintenance of the tank cascade systems (Abeywardana, Pitawala, et al., 2019) (see Section 3.3). Since the second century CE the monasteries became increasingly involved in the administration of the tank cascade systems as documented by numerous records on grants of irrigation works to Buddhistic communities (Abeywardana, Pitawala, et al., 2019; Strickland et al., 2018). They functioned as centers of knowledge and in general contributed to an increase in written records.

Between the third CE and the eighth CE the ancient written records document the diffusion and expansion of the tank-based irrigation technique from the hinterland of Anuradhapura throughout the whole dry zone of Sri Lanka (Abeywardana et al., 2018; Gilliland et al., 2013). One central project of this period was the implementation of a supraregional channel network connecting the catchments of Mahaweli River, Kala River, and Malwathu Oya River and enabling the routing of water from the catchment of the Mahaweli River via the catchment of the Kala Oya River to the catchment of the Aruvi Aru (Gunawardana, 1971) (Figure 5a). The headwater area of the perennial Mahaweli River catchment is situated in the central highland, an area receiving precipitation from the south west monsoon. In consequence, the Mahaweli River catchment has generally a high capacity to provide a surplus of water for catchments situated in the dry zone, which are mostly disconnected from the precipitation of the south-west monsoon (Domrös, 1974; Schütt et al., 2013). This system of trans-catchment routing of water was established in the eighth century CE at the latest (Abeywardana, Pitawala, et al., 2019; Chulawamsa, 1953, p. XLVIII/148; Gunawardana, 1971). A reconstruction of this supraregional canal network is based on the combination of information from written sources and evidences from constructional remains (e.g., canals) (Brohier, 1997; Parker, 1909): starting from the damming of a tributary of the Mahaweli River close to its divide, water was routed crossing the divide of the Kala River to the Kala Wewa, from which it was further distributed to the major tanks, namely Tissa Wewa, Nuwarawewa and Nachchaduwa situated in the hinterland of Anuradhapura.

The construction of this supraregional canal network falls in the Middle Historic Period (300–1250 CE) in which Anuradhapura had increasingly achieved supraregional importance (Coningham, 2006; Deraniyagala, 2004). The expansion of the ancient capital of Anuradhapura in line with population growth in its center as well as in its hinterland resulted in an increased demand for water (Coningham et al., 2007; Deraniyagala, 2007). This supraregional water transfer connecting the hinterland of Anuradhapura to water resources in the headwater area of the Mahaweli River has to be understood as a measure reducing drought risks, as droughts are repeatedly reported for the Middle Historic Period in the written sources and, thus, as an additional water supply (e.g., Geiger, 1912, pp. XXXVI 20, 75–79). Also, the construction of large-scale reservoirs in the hinterland of Polonnaruwa and in the catchment of Kala Oya need to be understood as a strategy to reduce exposure to droughts and stabilize food production (Abeywardana, Pitawala, et al., 2019). By assessing the dependency of water level changes on precipitation Saase et al. (2020) show that present-day average precipitation is appropriate to fill the major tanks in the environs of Anuradhapura at least annually, allowing the conclusion, that the tanks in the hinterland of Anuradhapura function efficiently in their system boundaries.

The period between the 8th and 11th century CE is characterized by an increase in political instability as a result of numerous invasions by groups from South India (Codrington, 1994; De Silva, 1959). Ancient sources report the restoration of dilapidated tanks (Chulawamsa, 1953 XL/48/9, LI/121, EZ.1, pp. 230), indicating that the invasions went along with a destruction of infrastructure (Abeywardana, Pitawala, et al., 2019).

During the 9th to 10th centuries CE, an increasing number of laws and official announcements appears in the ancient written sources, suggesting a development toward more bureaucratic and centralized water management structures. Abeywardana et al. (2019, p. 99) assume that this development was a "measure intended to counter destruction by the invaders and continue the management after destruction."

The Rajarattha kingdom collapsed during the reign of King Mahinda V (reign 981–1017 CE) and its capital Anuradhapura was intentionally destroyed by Chola invadors from India. In line with this conflict also many of the major irrigation works in Anuradhapura's hinterland were destroyed or fell abandoned, while the minor tanks along the tank cascade systems continued functioning (Gilliland et al., 2013; Karunanada, 2006; Murphey, 1957).

The power of the royal house of the Rajarata kingdom was in the 10th century CE not only destabilized by external forces, but also by internal developments referring to the administration of tanks. In this context Strickland et al. (2018) discuss the complex hydraulic economy with its multifaceted relationships between royal authorities and Buddhistic monasteries, which successively increased their impact on the hydraulic landscape through the donation of land, tax exemptions and income related to the tank cascade systems as factors destabilizing the dry zone society. Additionally, in the decades before the collapse of the Rajarata kingdom, famines and crop failures characterized the 10th century during the reign of King Kassapa V (r. 914–923 CE) and King Mahinda IV (r. 956–972 CE). These facts are controversy interpreted: Seneviratna (1989, p. 55) concludes on a "major breakdown of the irrigation system", while Gilliland et al. (2013) assume that the time between 1000 and 1100 AD corresponded to a rapid increase of the south-west monsoon intensity, resulting in severe droughts in the dry zone and an increase in cyclonic storms during the north-east monsoon (Jung et al., 2004, cited in Gilliland et al., 2013). Recapitulatory, it can be concluded that multiple and partly interdependent developments contributed to the abandonment of Anuradhapura and the coinciding decay of the major tanks in its hinterland.

In summary, with the collapse of the Rajarata kingdom and its ancient capital Anuradhapura governmental and religious (Buddhistic monasteries) administrative units in charge for the management of the tank cascade systems disappeared. Presumably as a consequence of the vanishing governance structures, the large tanks were left abandoned and their infrastructure decayed. Contrastingly, it is assumed that medium and minor tanks in the hinterland of Anuradhapura have continued to be utilized by local villagers (Gilliland et al., 2013; Karunanada, 2006; Murphey, 1957), although Bohier (1935) indicated a reduction of their effectiveness as tanks and canals were affected by siltation and fell partly into disuse (Brohier, 1935).

3.2 | Development of the tank cascade system during the Polonnaruwa period (1017–1235) until the beginning of the colonial period (1576)

In 1070 CE the Singhalese King Vijaya Bahu (1055–1110 CE) succeeded to defeat the Chola and developed Polonnaruwa, located about 80 km south-east of Anuradhapura, as his new capital. Polonnaruwa, a former military outpost of the Rajarata kingdom (Sastri, 2000), is situated in the center of a fertile paddy land and had already been equipped with major tanks since the eighth century CE. The Polonnaruwa period is regarded as the great flourishing period of the Singhalese kingdom (Domrös, 1976). This was particularly the merit of King Parakrama Bahu I. (1153–1186 CE) who significantly expanded the irrigation system (Domrös, 1976). His reign is credited with the construction of about 200 tanks and a significant expansion of the canal network. The massive investments in the irrigation infrastructure resulted in a flourishing paddy cultivation, generating production surpluses which were exported to India (Domrös, 1976). With the end of the reign of King Parakrama Bahu I, a period of political instability had begun, marked by renewed clashes with Chola troops from southern India and the conquest of Sri Lanka by the Indonesian kalinga ruler Magha (1215 CE). The final abandonment of Polonnaruwa in 1235 heralded the decline of the ancient Sinhala kingdoms (Domrös, 1976). It is largely assumed that in line with this development, a weakening of state bureaucracy led to a decline of the water management systems (Melles & Perera, 2020; Sha et al., 2013). Furthermore, in 1360 the relocation of the capital out of the dry zone to Kotte, located in the south-west of the island close to the modern town of Colombo, indicates a loss of relevance of paddy cultivation and tank-based irrigation (Domrös, 1976). In line with this development, likely already starting in the 10th century malaria became endemic in the dry zone (Peebles, 1990). It is assumed that the interplay of the different developments finally led to decreasing population in the dry zone after the abandonment of Polonnaruwa (Peebles, 1990).

From 1505 onwards, European interests in Sri Lanka's natural resources, first of all spices, and its strategic hub position usher a new era in the history of the island (Domrös, 1976). In 1597 the Portuguese annexed the Kingdom of Kotte and became the rulers of the south-western part of the island. In 1658 Sri Lanka became a Dutch colony and in 1815 the whole island became a British crown colony.

3.3 | Development of governance structures between the Anuradhapura period and the 19th century CE

Ancient sources provide valid information on the organization and governance of major tanks in ancient times (Abeywardana et al., 2018; Abeywardana, Schütt, et al., 2019). From the beginning of the second century BCE these sources report on the private proprietors of tanks (*Parumaka vapihamika*) and different professions related to irrigation agriculture such as flow operators (*Naguli*), officers in charge of canals, proprietors of ferries (*Parumaka Thota Bojhaka*), proprietors of the pasturelands and proprietors of tanks (*Parumaka vapihamika*) (Abeywardana et al., 2018). Tanks were granted to monastic communities (the *Sangha*) by private individuals and kings. From the first century BCE onward a tax system developed, focusing on taxation of water from tanks and canals (Abeywardana et al., 2018). Tank owners generated revenues from tanks and canals, share of water, share of fish caught in the tanks/canals and income from the pasturelands neighboring the tanks (Abeywardana et al., 2018).

Ancient records clearly show that already at this early stage the noble class and the monastic communities were involved in the management of the tank cascade systems (Abeywardana, Pitawala, et al., 2019; Abeywardana, Schütt,

TABLE 1 Categories of official notices on irrigation in ancient sources (Abeywardana et al., 2018).

Category	Percent of share of analyzed sources (%)
Taxation	31
Nature conservation	23
Free flow of water from canals to paddy fields/villages	10
Protect 12 great reservoirs	10
Water management of tanks/canals	8
Protect river dams	6
Prevent illegal fishing in tanks	6
Protect ponds/tanks	4
Ensuring labor at tanks	2

et al., 2019; Seneviratna, 1989; Strickland et al., 2018). This period also corresponds to the transition of Anuradhapura from a rural village settlement to the first capital of the Rajarata kingdom (Coningham, 2013; Deraniyagala, 2007) with a fortified inner center, the so-called *Citadel*, and a belt of monasteries east of the citadel (Bandaranayake, 1974; Silva, 2000; Wagalawatta et al., 2015). Seneviratna (1989) notes that the Buddhistic communities gradually became an important stakeholder in the governance and management of tanks. Their power in the administration and governance reached a peak by the end of the 10th century CE (Gunawardana, 1979). At the same time the water management system had been transformed from a decentralized, village-based system to a centralized system managed by the state and clergy (Abeywardana, Pitawala, et al., 2019).

After abandonment of Anuradhapura, between the 13th century CE and the beginning of the early 19th century, the management of small tanks was predominantly in the hands of village communities. Paddy farmers cultivated lands that they leased from the Kandyan kings. They were obliged to maintain irrigation facilities as a service in exchange for the land lease, called *rajakariya*. In this arrangement, local village councils consisting of influential village elite and an irrigation headman, the so-called *Gamarala*, administered water matters concerning their settlement unit with only occasional exchanges with the representatives of the king. The irrigation headmen were mostly of upper social strata and resided in the village, which strengthened both their influence and also their accountability (Abeywardana, Pitawala, et al., 2019). In times of war, the kings interfered more with the self-controlled production of rice and influenced administrative decisions regarding irrigation in order to ensure sufficient food for the army. In peaceful times, however, they allowed the village residents to administer the irrigation and the agriculture independently (Pfaffenberger, 1990).

Official announcements compiled from ancient texts and epigraphic sources mainly dating to the nineth century CE provide insights in the different aspects requiring regulation (Table 1). Issues related to taxation are most frequently mentioned (with 31%), followed by aspects of nature conservation (23%), free flow of water from canals to paddy fields (10%) and protection of the 12 great reservoirs (10%) (Abeywardana et al., 2018).

As stated by Melles and Perera (2020), traditional water governance comprises political, institutional, social, economic, and administrative entities. For the tank cascade systems, they conclude that political and institutional structures between rulers and villagers functioned within the traditional social fabric, while Buddhistic monasteries and responsible officials in the villages were in charge of compliance and implementation of the policy framework.

3.4 | Irrigation system under British rule (1815–1948)

Right after Sri Lanka became a British colony in the early 19th century the British abolished the village councils and thus the *rajakariya* system (Uphoff et al., 1990), ignoring the complex system of entitlements and obligations at the heart of *rajakariya* that advantaged the farmers. The British colonizers failed to notice that this system gave smallholders the option of refusing services if, for example, their parcel of land was too small for the intended effort, as rights and obligations were traditionally tied to land and not to persons: an administrative system that was new to the British (Leach, 1961; Pfaffenberger, 1990). In relation to this, Mosse (2008, 944) points out, that management of water required "a kind of flexibility and negotiability in social systems," feature which had in the past proven to be "incompatible with colonial or post-colonial systems."

After the rajakariya system was replaced, the management of the irrigation system was adapted to British legislation and administrative practice. This process was accompanied by the adoption of new and often contradictory laws to restructure the irrigation sector. On the local level these political requirements often resulted in total confusion and rejection (Pfaffenberger, 1990). At a local scale this lead to a vacuum in terms of officially responsibilities for the maintenance of village irrigation facilities in Sri Lanka between 1832 until the foundation of the Irrigation Department in 1887. During this period of time, the British also designed the institution of the Farmer Committee, which resembled the village councils with a more inclusive and democratic design and intended to improve community involvement, according to the British planners (Panabokke et al., 2002).

In the following decades colonial politics initiated a revitalization (Peebles, 1990) of the dry zone by the implementation of colonization schemes based on the Land Development Ordinance (1935). The colonization of the dry zone by landless peasants from the wet zone was until the 1970 of high priority of Sri Lankan politics (Peebles, 1990). For instance, the Gal Oya colonization—including the restoration and rebuilding of irrigation tanks—realized the creation of 120,000 acres irrigated farm land (Uphoff, 1982) on which until 1953 about 25,700 colonists had been settled (MacFadden, 1954). In the following years, further colonization schemes were initialised in the dry zone (Peebles, 1990). In terms of local knowledge, the colonization of the dry zone marks a restart: as the colonists originated from the wet zone and, thus, had not been acquainted to dry zone farming including technical aspects as well as aspects of traditional governance. In contrast, in the so-called traditional villages (*purana*) traditional practices and governance structures were continued (Abeywardana, Schütt, et al., 2019).

Comparing the British Colonial management approach of the tank cascade systems in Sri Lanka with the one of the tank systems in southern India, parallels are observable. Also in South India peasants lost their obligation to invest own labor in the maintenance of tanks. As a result, in the 19th century a general crisis of traditional tank irrigation occurred in South India and a successive installation of village institutions being legally forced to organize the maintenance of tanks started (Mosse, 2008). Reviewing the overall relationship between colonial rule and water management it can be pointed out, that the control over water supply was regarded as measures of disciplinary state exercise (Mosse, 2008). Grounded on a technocratic self-understanding scientific engineering of systems was "crucial to the self-representation of colonial government," but frequently ignored the social complexity of the traditional systems (Mosse, 2008, p. 945).

3.5 | Irrigation system after independence

In 1948 Sri Lanka reached independence. In the subsequent years Sri Lanka succeeded in establishing a democratic system, which lead in 1972 to the foundation of the Democratic Socialist Republic of Sri Lanka. In 1958 the Paddy Lands Act (The Paddy Lands Act, No. 1 of 1958) was passed, inspired by socialist influence. The act attempted to withdraw power from village irrigation headmen (*vel vidanes*) in order to protect paddy field tenants from exploitation. But since this act was mainly designed by landholders, it reinforced existing power relations leading to a degradation of (a) leadership, (b) discipline and, consequently, (c) the maintenance of minor irrigation schemes (Perera, 1997; Pfaffenberger, 1990).

In 1979, the role of *vel vidane* was officially reintroduced (Gamaathige, 1991; Uphoff et al., 1990). In this administratively chaotic time, many villagers distrusted the ever-changing regulations of the British and continued to stick to the old and trusted *vel vidane* system voluntarily, which mitigated total administrational chaos. Still, the arbitrary change of accountability and customs led to the decay of canals, diminishing water supplies and conflicts in the villages (Panabokke et al., 2002).

In the 1980s, the Farmer Organization, as existent today, came into operation and offered a mix of both the communal Farmer Committee and the individual *vel vidane* system, incorporating both irrigation approaches (Panabokke et al., 2002). Knowledge about the various rights and duties of the *vel vidane* is present in many of the traditional villages in the dry zone. For instance, it is still in the collective memory, that the *vel vidane* received a proportion of the harvest from each farmer, vice versa he was responsible for the coordination and supervision of maintenance work at the tank and opened the sluice. At the beginning of the cultivation period, he decided on the type of seeds and the cultivation schedule (Abeywardana, Schütt, et al., 2019).

In the following years conflicts between the group of the Sinhalese (holding the majority) and the Tamil minority increased, resulting between 1983 and 2009 in a civil war between Tamil separatists and the Sinhalese-dominated central government. The war significantly impacted the population, social and physical aspects and the economy (Avtar et al., 2014). Also, the irrigation infrastructures were affected and their restoration was one of the post-war challenges in order to increase livelihood conditions of people who had been displaced by war and started to return to their villages

(Avtar et al., 2014). Among numerous restoration projects also the Asian Development Bank approved a 2.5. million US $ grant to rehabilitate tanks and irrigation canals and consequently livelihood conditions of people displaced during war times especially in the North of Sri Lanka (Asian Development Bank, Sovereign Project 44 201-012).

4 | RECENT CHALLENGES

As introduced in the previous section, the irrigation-based agriculture in the dry zone has rapidly changed since the 1950s, being characterized by a general decline in the importance of tank systems to the village community and society (Abeywardana, Pitawala, et al., 2019; Sha et al., 2013). Today rural communities face several overarching challenges impacting their overall resilience and vulnerability, including:

1. the spread of the chronic kidney disease of unknown etiology (CKDu), resulting in severe restrictions on the livelihood of whole families and, at a community scale and in severe concerns regarding the environmental security of rural life, as unsafe drinking water is suspected to represent one cause of this disease (Köpke et al., 2019) and
2. socioeconomic tensions as a consequence of general conflicts resulting from "conflicting political interests between the central state and local communities" (Köpke et al., 2019, p. 633). These comprise, among others, a lack of response by government policies to major socioeconomic threats to the rural population (e.g., climate change and resulting harvest loss) (Köpke et al., 2019; Withanachchi et al., 2014).

These challenges lead to a socioeconomic marginalization of rural communities as a consequence of too little attention being paid by policymakers to strengthen their livelihood (Köpke et al., 2019). Farmers' livelihoods are inextricably linked to the tank cascade systems. In consequence, a major challenge lies in strengthening of the system's resilience in view of climate change and, thus, strengthening the resilience of farmer communities by applying integrated approaches (Withanachchi et al., 2014). Respective development cooperation projects targeting on these goals are, for example, funded by the United Nation Developing Programme (UNDP). In general, the projects follow integrated approaches of water management by operating on a catchment scale and taking the interconnectedness of the village irrigation systems, agricultural practices, the local knowledge of farmers as well as capacity building into account (UNDP Proposal FP016, 2016). Melles and Perera (2020) show that the tank cascade system is vulnerable not only to climate change, but also to rapid societal changes due to modernization, market changes, education levels, and inconsistent management decisions.

Current challenges are also due to inadequate and top-down interventions in irrigation infrastructure by professionals and engineers (Abeywardana, Schütt, et al., 2019). Numerous scholars have identified a lack of the integration of the farmers' local knowledge and experience into such decisions as being a major issue (Abeywardana, Schütt, et al., 2019; Köpke et al., 2019; Melles & Perera, 2020). The farmers perceive that this poor management in line with the occurrence of floods and dry spells as a factor increasing their vulnerability to crop failures. The spread of cash crops such as guava is another challenge for village communities, as guava farmers use the land and water resources of the villages but do not participate in agricultural community activities. Beyond, changing land use activities also change the behavior of wildlife, resulting, for example, in conflicting land use between farmers and wild elephants (Abeywardana, Schütt, et al., 2019).

Taking a meta-perspective, the main challenges for future sustainable development of tank-based irrigation in Sri Lanka are as follows: (a) increasing transparency and participatory approaches in decision making processes between involved administration units of different hierarchies and local small and stake holders, (b) establishing coordinated actions between responsible administrative units of different hierarchies, and (c) implementing actions which are well adapted to the needs of local communities (Abeywardana, Schütt, et al., 2019). Against this background it is assumed that well-elaborated and well adopted measures and technical solutions are needed to transform the tank-based irrigation system in the dry zone of Sri Lanka to modern socioeconomic and environmental conditions in order to establish a base for its sustainable development.

5 | CONCLUSIONS

This paper illustrates the development and transformation of the tank cascade systems since the fifth century BCE. Referring to Mosse (2008), the paper contributes to introduce the complex historical, sociological and regional dimensions of water management in Sri Lanka under different political and social systems. Summarizing the major outcomes are:

After the initial implementation of tank cascade systems in the north central dry zone of Sri Lanka starting in the fifth century BCE, the tank cascade systems have persisted different systems of rule, climatic phases of varying monsoon intensities and droughts, the abandonment of major system's components after the end of the Polonnaruwa kingdom, and finally a resettling of its core distribution area by colonists from south-west Sri Lanka, not being familiar with the system. Over the centuries governance structures were transformed from a community-based local system into a centralized bureaucratic system, with nowadays again community-based structures in form of Farmer Organizations. Regardless of these developments, the systems are still in use today pointing to their resilience against external and internal forces of change, which is from our perspective based on three corner stones:

1. The *synergy of tank ecology*, *social capital and institutional structures* results in secure property rights to land and water and subsequently in an engagement of rural communities (by providing labor), ensuring their successful operation and maintenance (Sha et al., 2013).
2. *Local knowledge* as living intangible cultural heritage is preserved in the rural communities of the traditional villages (*purana*) and covers, for example, mitigation strategies to buffer the effects of water shortage during droughts, the overabundance of water during floods and the management of wild animals (Abeywardana, Schütt, et al., 2019; Köpke et al., 2019; Withanachchi et al., 2014).
3. A high degree of adaptation to particular natural settings and cultural conditions, which frequently have been transformed through time. Walker and Salt (2012) characterize these systems as complex adaptive systems (CAS). As a result, the tank cascade system is deeply inscribed in the physical landscape and the societies utilizing and refining these systems (Bebermeier et al., 2017).

The tank cascade systems are deeply interwoven with the landscape in the Sri Lankan dry zone, including the socioeconomy and the ecosystem. Knowledge and consideration of the complex interrelations between the different system's components and actors is claimed as a cornerstone for rehabilitation and restoration measures targeting on an increase of livelihood conditions of famers with regard to climate change (Ratnayake et al., 2021). Restoration projects as, for example, funded by the UNDP already account to this claim and contribute to a resocialization of water management, which is seen by Linton (2014, p. 118) as adding many “opportunities for future research and practise.” In this context local knowledge as a resource for mitigating effects of climate change is highly recognized in the younger past (Ghorbani et al., 2021; Naess, 2013; Pearson et al., 2021). Here the approach of integrated watershed management provides a conceptual model and tool boxes. It allows to combine the different facets mentioned as it considers the capacity of the landscapes as a whole, the needs of the population while including the ecology and socioeconomic development—and as it acts strictly participatory (Förch & Schütt, 2006; Schütt & Förch, 2007; Thiemann et al., 2018).

Especially in drylands, water management practices have frequently been part of the cultural heritage for generations—including both technical knowledge and governance structures. This leads to our concluding statement: If we want to practice sustainable water management and the sustainable management of natural resources we need to consider and integrate local knowledge—which is mostly deeply rooted in the culture—and combine it with modern techniques in education, planning and application.

AUTHOR CONTRIBUTIONS

Wiebke Bebermeier: Conceptualization (lead); funding acquisition (equal); project administration (equal); writing – original draft (lead); writing – review and editing (lead). **Nuwan Abeywardana:** Writing – review and editing (supporting). **Maija Susarina:** Writing – original draft (supporting). **Brigitta Schütt:** Conceptualization (equal); funding acquisition (equal); writing – original draft (equal); writing – review and editing (supporting).

ACKNOWLEDGMENTS

Numerous project partners, students and sponsors supported this study. We are grateful to Prof. Dr. Kay Kohlmeyer (Hochschule für Technik und Wirtschaft Berlin) and Prof. Dr. Chandana Rohana Withanachchi (Rajarata University, Sri Lanka) for introducing the tank cascade systems to us in 2010. Warm thanks go to Jun.-Prof. Dr. Julia Meister (Universität Würzburg) for providing digital sketches as a basis for Figures 1 and 4, in the framework of her master thesis (2011, Physical Geography, Institute of Geographical Sciences). We also thank Dr. Katharine Thomas for an English language check. Open Access funding enabled and organized by Projekt DEAL.

FUNDING INFORMATION

This research was funded by the project "Tank cascade systems as an ancient measure of integrated Watershed Managements in the dry zone of Sri Lanka" Volkswagen Foundation grant number 88578 (2015–2020) and the project Master Landscape Archaeology at the University of Peradeniya (DAAD, 2016–2019, grant number: Az. 57059698).

CONFLICT OF INTEREST STATEMENT

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study

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How to cite this article: Bebermeier, W., Abeywardana, N., Susarina, M., & Schütt, B. (2023). Domestication of water: Management of water resources in the dry zone of Sri Lanka as living cultural heritage. *WIREs Water*, e1642. https://doi.org/10.1002/wat2.1642