

Framework for the sustainable development of village tanks in cascades as an adaptation to climate change and for improved water security, Sri Lanka

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Abstract

The 2030 Agenda for Sustainable Development, adopted by all UN member states, provides a policy framework for achieving sustainable development goals. The 13th SDG: Climate Action is fully dedicated to ‘taking urgent action to combat climate change and its impacts’. Increasing storage is a key adaptation strategy in the water sector, and restoration and rehabilitation of ancient village tanks have been identified as one of the Nationally Determined Contributions in Sri Lanka. Though the country has engaged in the restoration of village tanks for nearly 170 years, only around 50% of the ancient tanks amounting to around 16,000 are restored and in working condition. Hence, this study aims to identify a strategy for restoring the abandoned tanks in the country towards achieving Sustainable Development Goals. The study reviewed the evolution of policies and approaches adopted in developing village tanks and identified conceptual and technical drawbacks in the existing normative assessment approach. New conceptual and decision-making frameworks were developed, incorporating design-level strategic considerations identified while following a multidimensional and transdisciplinary approach. The approach presented would be a viable strategy to develop village tanks in cascades as sustainable social–ecological systems.

Keywords: Adaptation strategies; Hydrological principle; Multidimensional approach; SDGs; Social–ecological systems; Transdisciplinary approach

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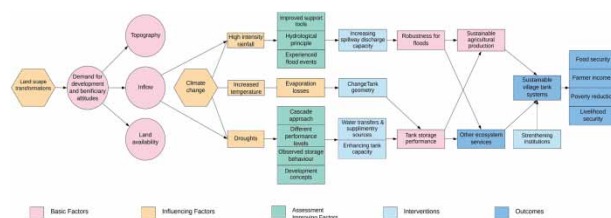
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Highlights

- Approaches used in developing village tanks for 170 years were reviewed.
- Overlooking global development concepts in assessment affects tank restoration.
- Sustainability and social–ecological aspects should be key determinants.
- The proposed transdisciplinary approach guides developing village tanks sustainably.
- Consistency of strategies and technical approaches with the policies are crucial for achieving goals and objectives.

Graphical Abstract



Introduction

The concept of sustainable development is a universally accepted norm in the development arena, and all countries and stakeholders are committed to achieving this ambition by way of Sustainable Development Goals (SDGs). Seventeen SDGs were adopted by United Nations member states in 2015, as part of the 2030 Agenda for Sustainable Development. Climate Action is the 13th SDG, and the official wording is to ‘take urgent action to combat climate change and its impacts’ (Council of Europe, 2015). The governments have identified Nationally Determined Contributions (NDCs) for adaptation to climate change by achieving the targets under this goal in line with the United Nations Framework Convention on Climate Change (UNFCCC). Climate change is a cross-cutting theme, and it affects water resources directly while significantly influencing several other SDGs such as no poverty, zero hunger, clean water and sanitation (United Nations, 2015). As one of the member countries, Sri Lanka is committed to making contributions towards both adapting to the effects of climate change and achieving SDGs.

As a majority of the rural population in the country depend on irrigated agriculture, the adaptation options selected to mitigate the effects of climate change for water and irrigation sectors would directly influence the degree of resilience of these communities. The availability of land and access to water to productive agriculture or agricultural labour are integral parts of the poverty alleviation strategy in the rural areas (Amarasinghe et al., 2005). Increasing water storage capacity is identified as one of the key adaptation options, and restoration and rehabilitation of all tanks in an abandoned state in the country have been identified as one of the NDCs in the irrigation sector (MoMD&E, 2016). The present restoration and rehabilitation endeavour of these ancient tanks began in the 1850s and is being continued even after around 170 years. According to

estimates, Sri Lanka has around 30,000 small-scale reservoirs of ancient origin termed minor tanks or village tanks, and around 16,000 such tanks are in working condition after restoration and rehabilitation (MoI, 2020). It implies that nearly half of the village tanks in the country are still in an unrestored condition.

Abbay (1877) has stated that the focus of the first attempt to restore village tanks in the country had been on irrigation water issues, and the government has supported the villagers to get the abandoned tanks restored. Subsequently, several approaches have been adopted to restore and rehabilitate the village tanks in the country (Ievers, 1899; Kennedy, 1933; Arumugam, 1957; Ponrajah, 1984) by following different assessment criteria in the various projects and programmes.

The responsibility of restoration and rehabilitation of these tanks has been shuttled among several parties starting from village communities, Provincial Irrigation Boards, Irrigation Department, Ministry of Agriculture and Food, Department of Agrarian Services, and again to Irrigation Department and back to Department of Agrarian Services in the 1980s (Begum, 1987). Presently, the responsibility of these tanks is with the Department of Agrarian Development, Provincial Councils, Irrigation Department and the Mahaweli Authority of Sri Lanka, depending on the jurisdiction and the linkage of these tanks to the major irrigation systems (Madar, 2005). The operation and maintenance of these systems right throughout have been the responsibility of farmers. Furthermore, the responsibility of the tanks located in the forest and wildlife reserves are with the Forest Department and Department of Wildlife Conservation, respectively. Therefore, the selection and development of these systems for restoration and rehabilitation have been carried out by different parties to meet their requirements with the available guidelines formulated for stand-alone tanks.

Varying cropping performances occurring due to water scarcities and the risk of breaching of bunds due to heavy inflows are two limitations associated with these systems. Despite such limitations associated with these water storage structures, the importance for the livelihood of rural communities and the sustainable regional ecosystems, heritage values, and other indirect benefits of them have been emphasised (Maddumabandara, 1985; Tennakoon, 2005). However, these factors have not been included in the assessment criteria. Furthermore, the effects of landscape transformations within the tank cascades and their vicinity have also been identified as a significant and influential factor of their restoration potential (Somaratne et al., 2005). Nianthi & Jayakumara (2010) have given several reasons for these tanks being abandoned, and the non-viable engineering perspective is also among the reasons given. The difference between the hydraulic engineering perspective and the ecosystems perspective associated with these systems has also been highlighted (Mendis, 2002).

Hence, there is a requirement for investigating the evolution of the development approaches and identifying the causes for nearly half of the village tanks to remain in the abandoned state to develop them sustainably. In this background, the objective of this study is to identify a strategy for restoring the abandoned tanks in the country towards achieving SDGs. This paper presents: (1) review and analysis of the approaches followed in restoration and rehabilitation; (2) drawbacks identified in the present assessment approach for restoration and rehabilitation; and (3) proposed conceptual and decision-making frameworks on design-level strategic considerations with a multidimensional and transdisciplinary approach for sustainably developing these tank systems. In the discussion and conclusion sections, the rationale for developing the proposed approach and the importance of giving policy recognition and formal acceptance of such an approach to ensure sustainable development of the tanks as social–ecological systems are presented.

Methods

The study was carried out through document analysis and secondary data sources such as publications, guidelines, reports, and lessons learnt through experiences. The relevant matters were also discussed with key personnel of the Department of Agrarian Development. Considerations in restoration and rehabilitation were identified by reviewing the development approaches followed since the 1850s in the country, and schematic diagrams were developed for the restoration and rehabilitation approaches adopted during different periods. Guidelines and criteria adopted by different projects and programmes for selecting village tanks for restoration and rehabilitation were also analysed.

Findings related to the studies on village tanks were reviewed, and the adaptability of them in the assessment approach was identified. The evolution of global development concepts, technological improvements, and social and environmental factors, those that can significantly affect the development of these systems, were identified and reviewed. The factors that have not been included in the development approaches and gaps in respective guidelines and criteria were identified. The effects of influential factors that can prevent restoration and the provisions available to incorporate improved technological, social, and ecological factors to the design-level considerations were also identified.

A conceptual framework with a multidimensional approach was developed for restoring the tanks in cascades incorporating the factors identified in the study. A decision-making framework was then developed to assess the tanks with restoration or upgrading potential. The factors identified that substantially influence the sustainable development of village tanks in cascades to be an adaptation option for climate change and improved water security were also incorporated in the framework.

Results

The results section consists of: the analysis of restoration and rehabilitation approaches of village tanks; existing findings, concepts and concerns relevant to the process; and the additional factors required to be incorporated in the technical assessment of the village tanks. Finally, the conceptual framework and decision-making framework developed for assessing the restoration potential of village tanks are also presented.

Restoration and rehabilitation approaches of village tanks

Different restoration and rehabilitation approaches for developing village tanks have been adopted in the country over around 170 years since its inception in the 1850s. This period can be designated as the modern era of the development process as its beginning goes back to ancient times.

The period from the 1850s to the early 1930s can be considered the first stage of the development of village tanks in the modern era. The focus of the approach during this period (Figure 1) was on increasing the irrigated land area of the country for meeting the food requirements of the people while increasing revenue through land tax (Ievers, 1899).

The technical assessment of tanks for restoration had been based on rules of thumb such as bund heights and water depth in the tanks. Accordingly, three classes of tanks have been identified. The first and second class tanks have water depths of 12.5 ft (3.8 m) and 10 ft (3.0 m), respectively, and were provided with a freeboard of 6 ft (1.8 m). Tanks with a water depth of 8 ft (2.4 m) have been classified as third class and were provided with a freeboard of 4 ft (1.2 m) (Ievers, 1899). These freeboards have been provided as rules

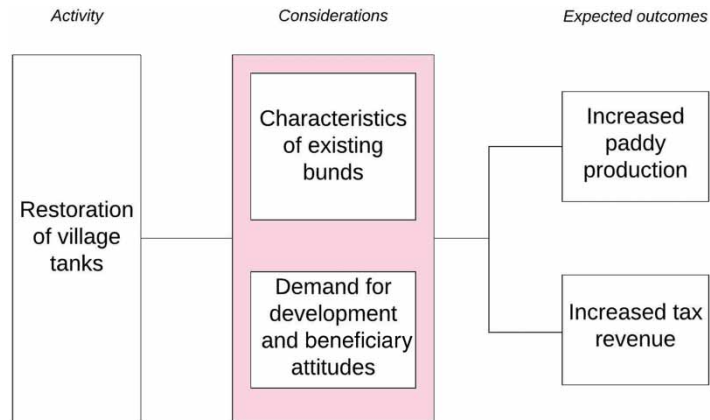


Fig. 1. Schematic diagram of the development approach adopted in the first stage of the modern era (1850s–early 1930s).

of thumb due to the absence of hydrometric data. Under these criteria, only the tanks with bund heights over 3.6 m had been selected for restoration.

The first systematic study on the development of village tanks has presented a methodology for investigation, survey and design. With this scientific method presented by Kennedy in 1933, the second stage of the development of village irrigation works in Sri Lanka began and continued till the early 1980s. During this stage, the approach was governed by the policies of the Executive Committee for Agriculture and Lands accepted in 1932 (Kennedy, 1933), and the focus of restoration of the village tanks was mainly on paddy production and preventing the emigration of communities from their villages. A schematic diagram derived for this approach is shown in Figure 2.

The approach considered four factors: the inflow characteristics, topography, land availability and the demand for development. Hydrological impacts due to the existence of tanks in the upstream and cultivation data of the tank to be developed have been considered in a Preliminary Schedule of Village Tank report. Proposals for tank restoration had been based on engineering surveys and designs provided in the Full Investigation Report. Later, these two documents have been combined and formed into the

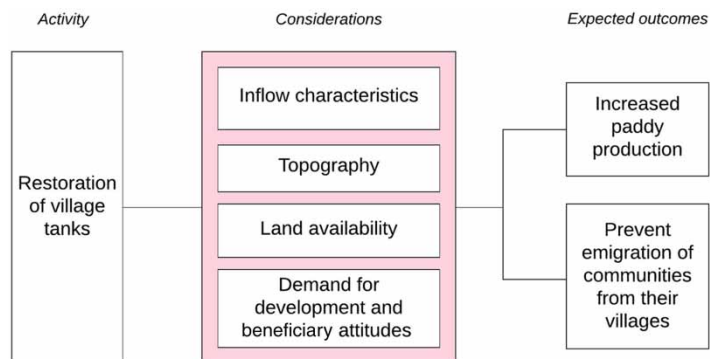


Fig. 2. Schematic diagram of the development approach adopted in the second stage of the modern era (mid-1930s–early 1980s).

Preliminary Investigation Report (PIR) while maintaining the original approach (Arumugam, 1957). This approach had been continued until the 1980s with these additions.

The hydrological assessment method was improved in the 1980s (Ponrajah, 1984). The updated hydrological design guidelines include the unit hydrograph method for flood assessments and iso-yield curves for the estimation of seasonal yields of the stand-alone irrigation works in small catchments with the hydrometric data then available (Ponrajah, 1984). These guidelines are used to restore and rehabilitate village tanks in the various programmes and projects implemented since then.

Meantime, the concerns on the development of village tanks have changed, thus beginning the third stage of village tank development in the modern era. The focus of these projects and programmes have been gradually changed to food security, farmer income, poverty reduction and livelihood security without confining only to agricultural production but with those objectives achieved through increased agricultural production. Furthermore, the term ‘rehabilitation’ has been used to express both restoration and rehabilitation.

Figure 3 illustrates this development approach, including the four primary considerations and the link of intermediate and long-term outcomes. The assessment of tanks has been carried out using criteria such as existing irrigation areas, cropping intensity, additional irrigable land available, the number of people benefited and the Economic Internal Rate of Return based on individual tanks. Thus, the tanks with limited irrigation areas could not satisfy the economic evaluation criteria, resulting in the smaller tanks not being selected for restoration in general. This approach has also led to selecting the tanks within cascades on an *ad hoc* basis affecting the functionality and robustness of the tank systems.

Main considerations and the criteria adopted for the selection of tanks in some major rehabilitation projects and programmes after the 1980s are summarised in Table 1.

Most of these projects have given the highest priority to the schemes which would yield maximum financial returns relative to the investment. The village tanks that had been abandoned long ago and those that require extensive rehabilitation did not receive priority due to higher cost. On the other hand, the inherent seasonal water shortages that result in low agricultural production have made them less attractive for financing as the return on investment is low. For instance, the estimated Economic Internal Rate of Return has been 7.4% in minor irrigation compared with 15.4% in medium-sized irrigation in the North Central Province Rural Development Project (ADB, 2006).

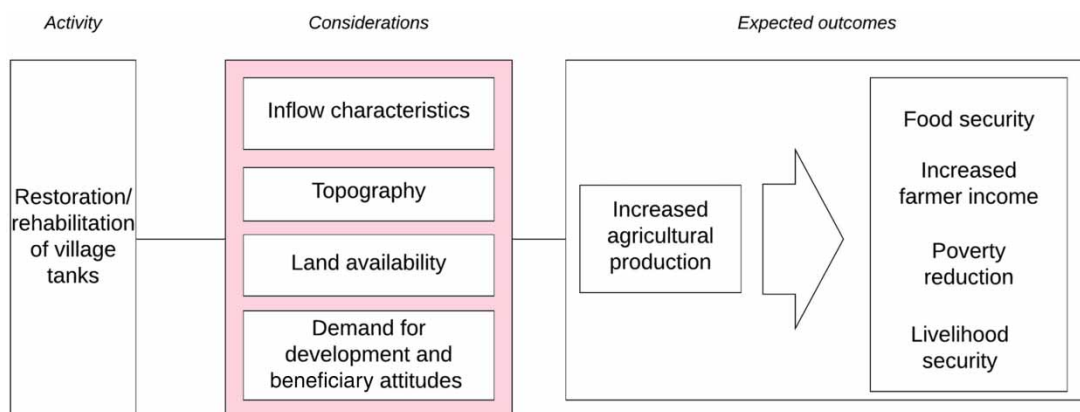


Fig. 3. Schematic diagram of the development approach adopted in the third stage of the modern era (early 1980s–to date).

Table 1. Considerations and criteria adopted in the selection of tanks for development under different projects and programmes.

Consideration	Criteria	Project
Command area	Should not be less than 20 acres (8 ha)	VIRP; PRDP; ADZAP
	Should not be less than 10 acres (4 ha)	NIRP
	Less than 50 acres (20 ha)	NFFHC
No. of farmer families	Should benefit at least 10 families.	VIRP; PRDP; NIRP
Tank capacity	Useful storage of the tank should not be less than 3 acre-feet per acre, 2.5 acre-feet per acre, and 1.5 acre-feet per acre of command area in the dry, intermediate, and wet zones, respectively	VIRP; PRDP; ADZAP
Hydrological endowment	Should not exceed 70% of the yield potential of the tank computed from iso-yield curves of the Irrigation Department	VIRP
	The tank should have a record of being filled at least three times during the last 5 years, or hydrologic studies indicate comparable yield for damaged tanks	PRDP
Closeness to settlement	Minor tanks located close to the settlement villages	ADZAP
EIRR and investment	Investment cost per acre not to exceed Rs. 10,000 (US\$ 1,400 per ha) on average and the economic internal rate of return (EIRR) for each tank is at least 15%	ADZAP
	Improvement on works not to exceed a base cost of Rs. 30,000 (US\$ 750 equivalent) per ha in 1991 prices	NIRP
	EIRR above 12%	VIRP; NCPRDP

VIRP, Village Irrigation Rehabilitation Project (1981–1985) (World Bank, 1981); PRDP, Puttalam Rural Development Project (1981–1985) (World Bank, 2015); ADZAP, Anuradhapura Dry Zone Agricultural Project (1981–1985) (Begum, 1987; ARTI, 1991); NIRP, National Irrigation Rehabilitation Project (1991–1998) (World Bank, 1991); NFFHC, National Freedom from Hunger Campaign (Begum, 1987); NCPRDP, North Central Province Rural Development Project (1997–2005) (ADB, 2006).

Rehabilitation of village tanks is one of the primary functions of the ongoing foreign-funded projects, namely, the Climate Resilient Integrated Water Management Project (CRIWMP) and Climate Smart Irrigated Agriculture Project (CSIAP) in the country. *Wari Saubagya* is another ongoing programme that envisages the rehabilitation of 5,000 village irrigation works with government funds. It indicates that the restoration of village tanks would be possible within the available financial resources if the tanks get qualified through the selection criteria adopted.

Existing findings, concepts and concerns relevant to the restoration of village tanks

The strategically distributed nature of the tanks along rivulets in the form of tank cascades has been revealed by a study carried out on the spatial distribution of these systems (Maddumabandara, 1985). However, the hydrological linkages of the tanks within the cascades have not been considered expressly during the technical assessment in major restoration and rehabilitation attempts. Though the necessity of adopting the cascade approach in rehabilitating headworks of minor irrigation works is mentioned in the recently published guidelines (ID, 2020), no clear guidance is provided. Hence, the design-level considerations in the hydrological assessment are still based on individual tanks.

Cropping performance or the agricultural production of village tank systems is the most prominent factor in the assessment criteria. However, the cropping performance of most of the tanks rehabilitated under several projects has shown a lower performance than expected (Somasiri, 2000). Furthermore, the working tanks in Hambantota District have shown different regional and temporal variability in terms of water existence and cropping performance (Perera et al., 2020a). Though these are evidence that the storage behaviour and the agricultural performance of the tanks are varied, the existence of different performance levels is not accepted in the assessment. Hence, only the tanks with higher agricultural potential are selected, targeting higher returns. Nevertheless, the existence of tanks with different traditional names implies different functions associated with the tanks such as domestic and cultural uses (*Pin weva*), preventing desertification, conservation of micro-ecosystems, groundwater recharge, water for livestock, benefits for the wildlife (forest tanks) and silt trapping (*Kulu weva*), in addition to the tanks of which the primary function is agriculture. However, these concerns are not addressed in the present assessment criteria.

Empirical methods are excessively used in the hydrological assessment of village tanks due to the paucity of actual data. Uncertainties associated with such assessments are a major drawback and could cause lower performances experienced than expected (Somasiri, 2000). The proposed selection criteria for village tanks based on the modelling approach in the North Central Province Rural Development Project had not succeeded due to the high cost involved (ADB, 2006). However, Perera et al. (2016) have presented a systematic methodology to incorporate actual data to assess water reliability of the tanks using a simple five storage states, as there is no mechanism available to estimate the storage of most of these tanks. Hence, reliance on observed storage state behaviour data instead of simulation model results influenced by the limited data availability and the uniqueness associated with these tanks would improve the assessment.

The principle behind the development of these village tank systems remained to be answered for a long time. Perera et al. (2020b) has revealed that the formation of a series of tanks is a technique used to regulate the inflows during heavy rainfall events as the technologies available were limited. Furthermore, these systems have been defined as ‘village tank cascade is an autogenic runoff harvesting technique consisting of strategically located series of bunds in shallow valleys of a small catchment for storing water while increasing the ability to regulate peak flows experienced over time’ (Perera et al., 2020b) following the hydrological principle behind the development of these systems.

Besides, there are several global concepts that could be applicable in developing these systems. The concepts of development declared by the United Nations have been changed over time by including various aspects (United Nations, 2020). The focus on the development of economic and other material resources that existed in the second development decade (1971–1980) has changed in the third development decade (1981–1990) by adding the importance and recognition of ecological aspects. Later, the sustainability concept was included in the Millennium Development Goals (2000–2015) by way of ensuring environmental sustainability. The development concept has continued to evolve, and the Agenda 2030 with 17 SDGs was declared by the UN in 2016. Following the Agenda 2030, Sri Lanka is also committed to achieving SDGs, and legal provision for this purpose has been provided by enacting the Sri Lanka Sustainable Development Act, no. 19 of 2017. The concepts such as ecological restoration and climate change adaptation have been taken into account in some of the rehabilitation projects and programmes implemented on a pilot scale by the International Union for Conservation of Nature (IUCN), United Nations Development Programme (UNDP), Non-Governmental Organisations (NGOs) and other interested parties in recent (IUCN, 2015; MoMD&E, 2019).

Furthermore, these Cascaded Tank-Village Systems in the Dry Zone of Sri Lanka have been designated as Globally Important Agricultural Heritage Systems (GIAHS) by the Food and Agriculture Organization (FAO) of the United Nations in 2018. With this, it is expected to follow the GIAHS' dynamic conservation approach, which emphasises the balance between conservation, adaptation and socio-economic development in developing these systems. Furthermore, social–ecological systems thinking is also one of the guiding development concepts in natural resource management, and the systems in which cultural, political, social, economic, ecological, technological and other components interact are referred to as social–ecological systems (The [Resilience Alliance](#), 2010). The concept emphasises the 'humans-in-nature' perspective in which ecosystems are integrated with human society, such as village tank systems. However, none of these concepts has been systematically incorporated in the assessment criteria adopted to select village tanks for development.

Farmer participation in rehabilitation and operation & maintenance of these systems is practised through the Farmer Organisations, the smallest institutional arrangement at the field level. Therefore, assuring their formal involvement in the assessment stage to obtain the details of historical events related to the design and operation of these systems would facilitate filling the gap of the paucity of observed data. Furthermore, reorganisation of existing Farmer Organisations established based on individual tanks would be essential for managing the entire cascade by ensuring a holistic approach at the field level. These institutions are also required to be strengthened by giving formal recognition through amendments in the relevant statutes and ensuring the engagement of other stakeholders in the community.

Finally, the assessment process can be further upgraded by using improved support tools such as GIS, DEMs, and hydrological models that enable properly carrying out a hydrological assessment by incorporating the hydrological principle behind the development of these systems, which is not possible with the methods currently used.

Landscape transformations taken place over the years have also been identified as one of the influential factors that affect the restoration of village tanks. A study carried out on the effect of landscape transformations on restoration potential of village tanks in cascades has revealed five causes that could prevent the development: restoration and upgrading of tanks in the downstream, expansion of the command area of some tanks absorbing bunds in the downstream, declaration of lands having tank cascades as protected areas, being located in the tank bed or catchment area of major reservoirs, and being in the command area of major irrigation schemes (Perera *et al.*, in preparation). Hence, restoration and rehabilitation of all the ancient tanks would not be a pragmatic approach as the original environment under which they have been built has undergone several changes.

Accordingly, several considerations could be incorporated into the assessment process of village tank systems to restore them as an adaptation option for climate change. Furthermore, following historical evidence and studies reveal that several interventions are also needed to develop village tank systems sustainably while improving their performance under climate change.

Udawattage (1985) noted the breaching of 78 out of 488 tanks that were rehabilitated under the Integrated Rural Development (IRD) Project in Puttalam District during the high rainfall event in 1984. The breaching of 982 minor tanks and diversions and 967 tanks were also recorded during floods in 2011 and 2014, respectively (MIWR&DM, 2018). Thus, these tanks are associated with a high risk of bund breaching during heavy rain events due to inadequate spillway capacities and weak bunds. Hence, enhancement of the spillway discharge capacity of village tanks with the limited space available is vital. Adopting Type D Piano Key Weir spillway is an effective structural intervention to overcome

this problem (Jayatillake & Perera, 2017). Perera *et al.* (2020c) have also revealed the effectiveness of this spillway technology to increase the robustness of tanks in cascades for floods.

Improving hydrological endowment of these systems by water transfers from major water resource development works has already been recognised as one strategy to increase water availability. Weli Oya Diversion Project, Mau Ara and Daduru Oya Reservoir Projects, Uma Oya Multipurpose Development Project are examples where this practice has been adopted. Hence, water transfers could be adopted as an improving intervention where possible.

Sedimentation is another major issue with village tanks which leads to the reduction of the tank capacity, reduction of sub-surface flow into the tank, blocking of the sluices and filling the dead storage with silt causing tanks to dry up ceasing the availability of water for domestic and other uses (Dharmasena, 1992). The occurrence of high-intensity rainfalls and frequent and prolonged dry periods due to climate change worsens the situation. Dharmasena (1994) has presented the concept of partial desilting as a solution and for improving tank geometry to reduce evaporation losses. Depending on the cost involved, selective desilting is identified as a possible improvement intervention while preventing the risk of disappearing tanks due to siltation. Furthermore, increasing the capacity of the tanks by upgrading the headwork components where possible could also be considered an improving intervention during the restoration and rehabilitation of the tanks while modifying the cascades.

Additional factors required to be incorporated in the technical assessment

In the light of the above, the additional factors identified as required to be incorporated in the prevailing assessment approach are summarised below.

- Influence of landscape transformations within or in the vicinity of tank cascades
- Effects of climate change
- Hydrological assessment with the cascade approach instead of the individual tanks
- Acceptance of the distinct performance levels of the tanks in a cascade in terms of storage reliability and agricultural outputs
- Reliance on observed storage state behaviour data and experienced flood events
- Hydrological principle behind the development of village tank systems
- Evolution of global development concepts and goals
- Use of improved support tools now available to assess the tank systems
- Stakeholder engagement in the assessment process
- Adaptability of new spillway technologies and storage enhancement strategies to improve the flood and drought resilience of the tank cascades
- Water transfers to and from the cascade and interceptions of the cascades by transfer canals
- Necessity of desilting tanks to ensure functionality and sustainable existence
- Strengthening field-level institutional setup by reorganising and amending the statutes to suit the cascade-based management

These factors are grouped into two, i.e., influencing factors and improving factors. The improving factors are further categorised into two: assessment or intervention based on their influence in the process.

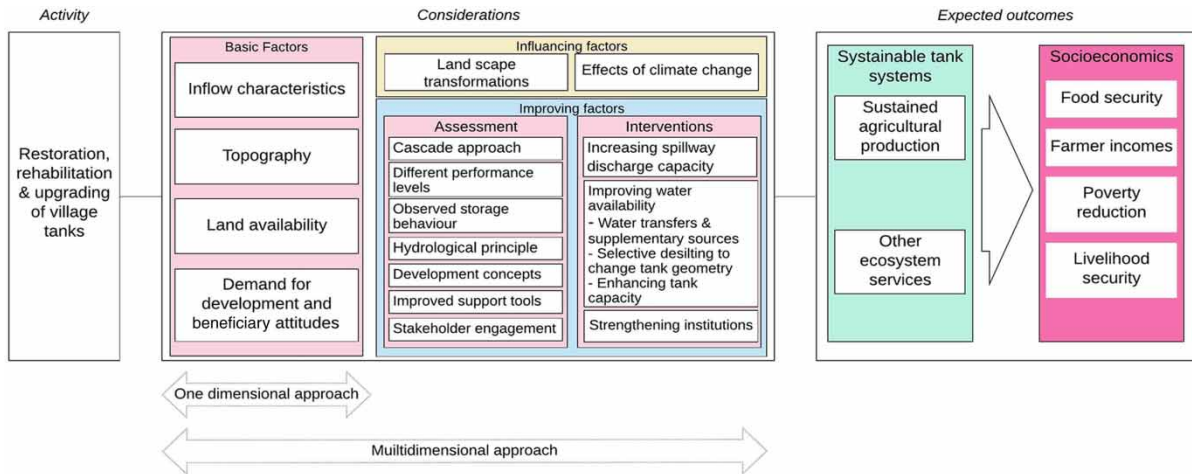


Fig. 4. Proposed conceptual framework for the sustainable development of village tanks.

Proposed conceptual framework for the development

The proposed conceptual framework, which incorporates the factors identified, is shown in [Figure 4](#).

The inclusion of improving and influencing factors to the existing framework has significantly upgraded the development process of village tanks while ensuring the multidimensional approach. Therefore, the terms restoration and rehabilitation alone could not adequately express the sustainable development of these village tank systems, and the term upgrading was added to represent the activity appropriately. The addition of improving factors related to the assessment and interventions to the basic factors in the framework guides the development of these systems sustainably under climate change and influences of landscape transformations. The assessment considers facts, principles, assessment tools and stakeholder engagement, while the intervention options include improving spillway discharge capacities for the safety and the reliability of water supply. Apart from the inclusion of engineering considerations under interventions, strengthening the existing field-level institutional setup to suit the cascade-based approach is also added for effective management, operation and maintenance to ensure the sustainable existence of these systems. Incorporating these considerations would direct the development of village tank systems towards sustainable social–ecological systems by which the socio-economic objectives would be achieved through agricultural production and other ecosystem services.

Proposed decision-making framework

The decision-making framework developed following the conceptual framework consists of a two-stage process, namely, the screening tanks for restoration and the assessing hydrological aspects related to the safety and services provided by the tanks. The framework consisting of seven decision points and 24 steps directs the design-level strategic considerations related to the restoration of tanks within a cascade.

Figure 5(a) shows the framework developed for screening the tanks for restoration in the design process. It consists of two decisive sections, namely, identifying the status by delineating the layout of the tank series within the cascade and the effects of landscape transformations.

Steps 2–6 facilitate identifying the existing hydrological linkages of tanks in the cluster and water transfers through diversions and feeder canals using improved support tools. The identification of hydrological linkages of the tanks within the cascade enables carrying out hydrological assessments following the cascade approach. The formulation of a schematic layout of the tank series in step 6 facilitates distinguishing the restored and unrestored tanks systematically at step 7. Based on the responses during the stakeholder consultations, Questions 1 and 2 direct the assessment process into two routes, as shown in steps 8 and 9. If all the tanks in the cascade are restored, and there are no requests from beneficiaries or identified needs for upgrading tanks, the assessment is terminated, as shown in step 8.

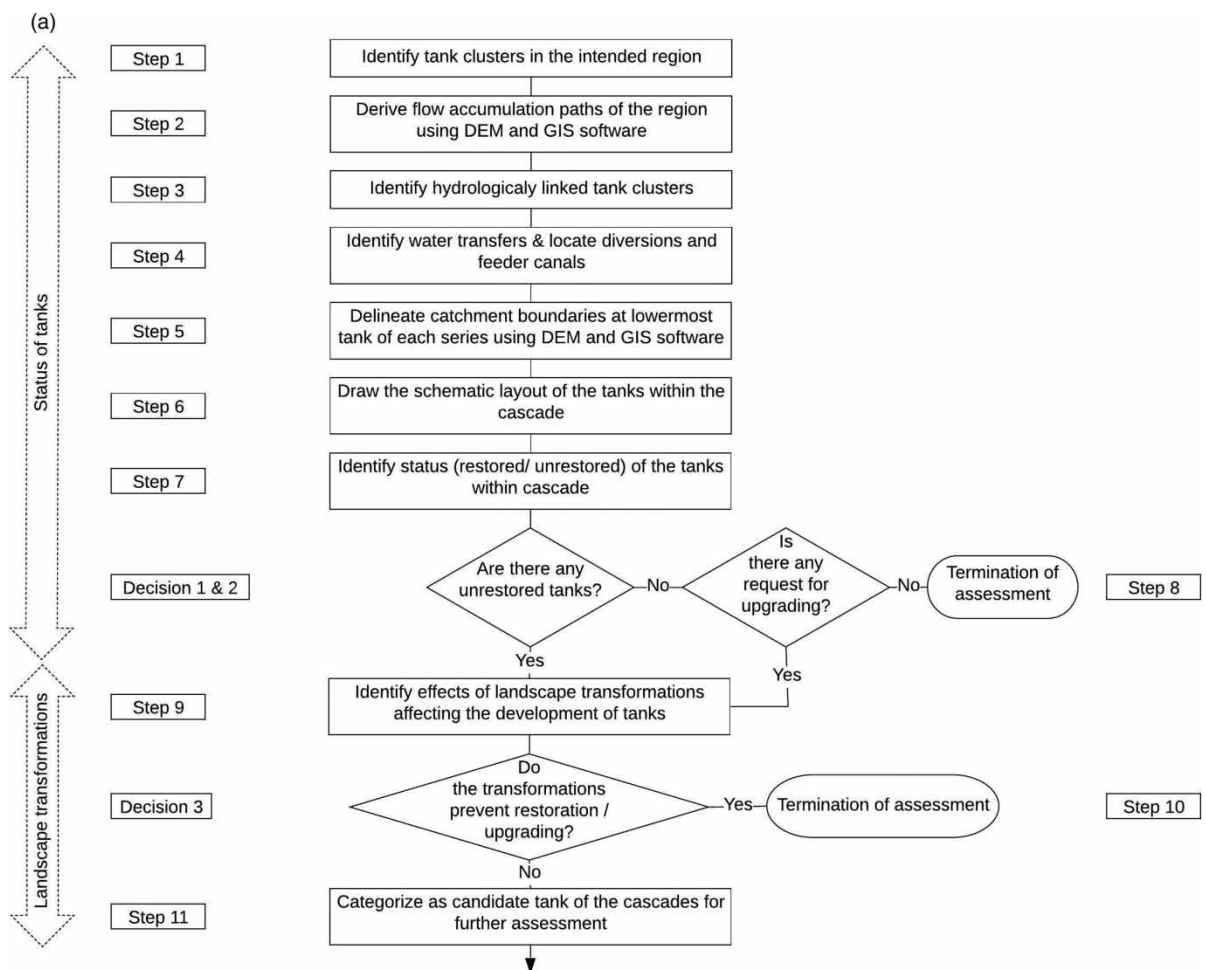


Fig. 5. (a) Proposed decision-making framework for screening tanks for restoration. (b) Proposed decision-making framework for assessing hydrological aspects of tanks within a cascade. (continued.)

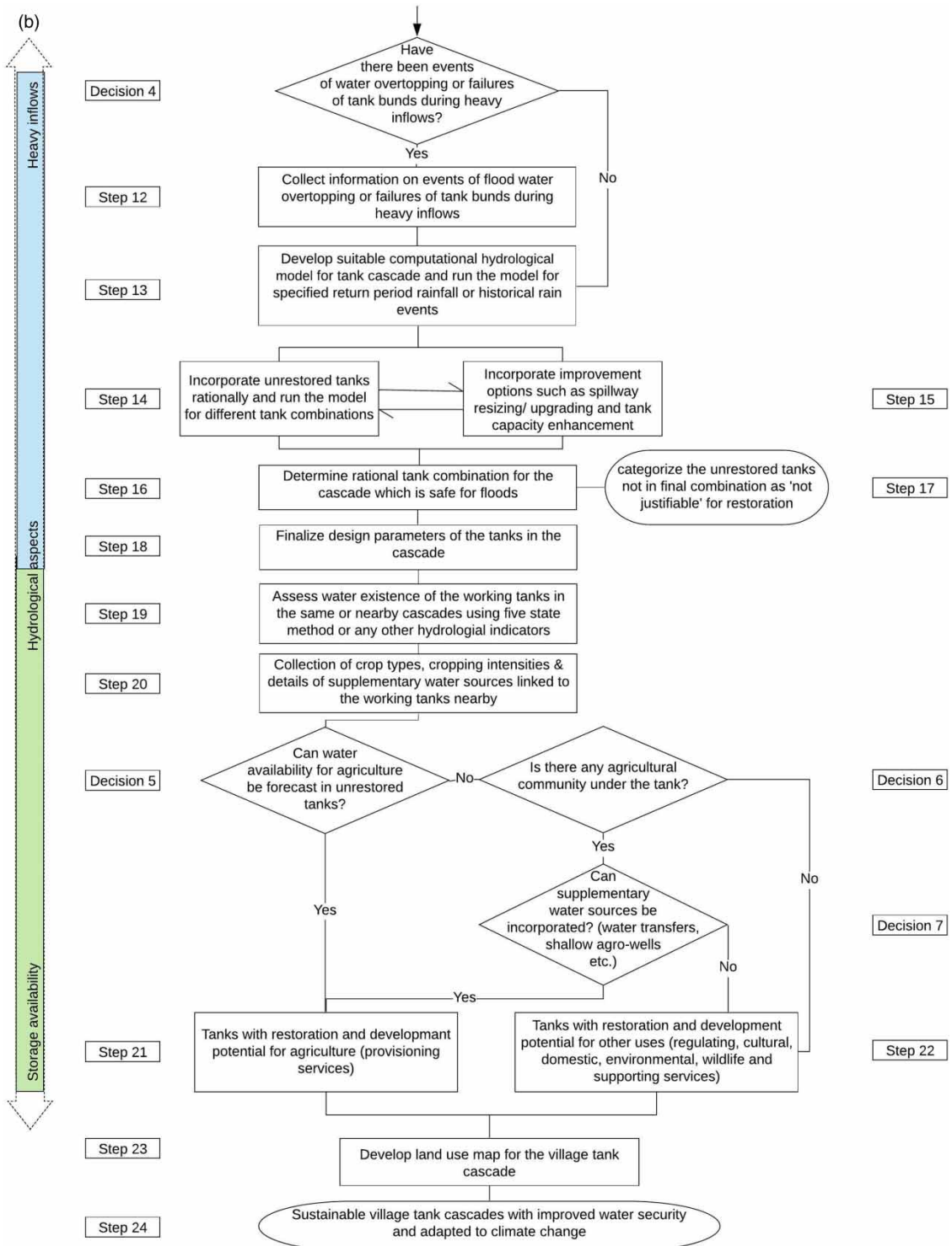


Fig. 5. continued.

If there are any unrestored tanks or needs for upgrading, step 9 directs to identify the effects of landscape transformations on the development. Question 3 that follows investigates the influence of landscape transformations as the development of tanks located in the protected areas such as wildlife sanctuaries and forest reserves are generally restricted. If the landscape transformations do not allow restoring or upgrading the tanks, the assessment of those tanks will have to be terminated as in step 10 and categorise them as *unrestorable*. Inclusion of an inquiry on the effects of landscape transformations in the framework facilitates estimating the number of tanks that should be excluded from the restoration process. The rest of the tanks in the cascade are candidate tanks for further assessment for development (step 11). Screening of tanks with development potential in a cascade is accomplished at this stage, and assessing the hydrological aspects of the tanks follows.

The framework shown in [Figure 5\(b\)](#) guides the assessment of hydrological aspects of tanks within a cascade mainly under two conditions, namely, during heavy inflows and dry spells.

Question 4 in the framework leads the hydrological assessment towards floodwater overtopping or failure of the bunds during heavy inflows. If such events had occurred, collecting information on them (step 12) through consultation of the village community is required. The information would facilitate computer simulation of the flow behaviour and verifying the model results of the tank cascade.

The development of suitable computational hydrological models will enable simulating the behaviour of the tanks for historical rain events and identifying the behaviour of the tank combinations for the predicted events. Development and execution of a suitable computational hydrological model for historical rain events, rain events expected with specified return periods and rainfall intensities predicted allows investigating the behaviour of the cascades incorporating the uncertainties associated with climate change as shown in step 13. Steps 14 and 15 enable the selection of rational tank combination with improving interventions such as incorporating unrestored tanks as if they are restored, upgrading of spillways and capacity enhancement of tanks without expanding the upstream inundation. A few trials carried out with these two steps enable determining a rational tank combination that will be safe for the floods by following the hydrological principle behind the development of these systems, as shown in step 16. Any unrestored tanks not included in the rational tank combination are suggested to be categorised as *not justifiable for restoration* (step 17). Step 18 facilitates the determination of optimum design parameters such as safe design rainfall, spillway characteristics and freeboard requirements of the tank series following the hydrological principle behind the development of ancient tank cascades.

The identification of rational tank combination resilient to flood inflows leads to assess the levels of water availability of tanks for different uses (steps 19–22). Step 19 suggests the accommodation of actual storage behaviour data using five storage states method ([Perera et al., 2016](#)) or any other recorded or observed storage data available to minimise uncertainties associated with the estimated data. Step 20 directs to collect experienced cropping data and details of supplementary water sources linked to the working tanks nearby. Question 5 that follows leads to investigating and predicting the cropping performance of unrestored tanks based on the storage state data analysis and cropping performance data acquired in both steps 19 and 20. These data aid to accept different cropping performance levels of the tanks. If the cropping under tanks after restoration can be predicted, those tanks should be identified as restorable tanks for agricultural purposes, as depicted in step 21. Question 6 inquires about the social considerations if the predictions indicate water shortages in tanks. Suppose there are settled communities under the tanks; in that case, the possibility of access to supplementary water sources such as water transfers and shallow agro-wells are to be considered for making a recommendation on restoration for agricultural purposes, in addition to the interventions on cropping practices as shown in Question 7.

If adequate water cannot be anticipated for agriculture or communities are not settled, restoration for other uses is recommended. Where communities are settled and adequate water cannot be anticipated for agriculture, by all means, restoration for other uses should be recommended in consultation with the communities as in step 22.

The development of a land-use map (step 23) for the cascade, including the primary function of the tanks identified, mitigates the possible conflicts on the management of water resources among the tanks, which may occur sooner or later. Thus, following steps 12–24, while answering questions 4–7 of the decision-making framework, directs the assessment of hydrological aspects for evaluating the restoration, rehabilitation or upgrading potential of tanks within the cascades in a sustainable manner.

Discussion

Presently, the tanks having command areas up to 80 ha are considered village tanks, and hence, the size of the village tanks falls in a much wider range with bund heights varying from 1.2 to 6 m consisting of a large number of smaller tanks. However, the tanks with bund heights of 3.6 m or above had been selected for restoration in the first stage of the development of village tanks in the modern era, and it implies that comparatively larger tanks had been selected for development during the early efforts of restoration. Continuation of an agricultural production-based approach on individual tanks has restricted selecting these large numbers of smaller tanks in an abandoned state for restoration. Therefore, the development of these systems sustainably should begin from the design-level considerations.

In this background, the proposed decision-making framework was developed incorporating the existing findings, present development concepts, possible improving factors and the influencing factors as design-level considerations, broadening the scope of the normative assessment approach.

The development of these ancient tank systems as an adaptation option for climate change is a challenge due to uncertainties associated with the effects of climate change. However, several adaptive measures were included in the proposed framework considering the implications of climate change on village tank systems, as detailed studies are not possible due to the paucity of data. Adopting high-intensity rainfalls based on recently observed events instead of focusing on the design return periods of rainfall obtained from available intensity depth frequency relationships is suggested as one of the strategic approaches to make these systems robust for floods. This alternative approach would be rational as the catchment areas of the cascades are small. Adopting the cascade approach with the hydrological principle and spillway improvements are the other interventions to improve flood resilience. Increasing tank capacities, reducing evaporative losses by improving tank geometry and changing cropping practices are the interventions included in the framework to address water scarcities. Accordingly, the proposed interventions allow modifying the cascades when selecting the rational bund combination by relocating, resizing, inclusion, disregarding and eliminating tanks to increase the adaptive capacity to climate change.

Furthermore, the acceptance of different functions and performance levels of the tanks within a cascade allows restoration of the tanks for different uses instead of confining them for agricultural purposes. Hence, adopting the framework avoids selecting the tanks within cascades on an *ad hoc* basis for development and gradually vanishing a considerable number of tanks in cascades allowing the conservation of these GIAHS. The use of observed storage behaviour data to assess the

performance of tanks reduces uncertainties, and the approach facilitates identifying suitable tanks within the cascades to develop command areas under them. It also allows adopting appropriate cropping practices to reduce the vulnerability associated with agriculture. Furthermore, the selection of rational bund combination allows restoring the tanks without agricultural potential and the tanks located in the protected areas where agricultural practices are prohibited. Accordingly, the approach provided in the framework ensures the restoration of tanks for other ecosystem services, though they are located in forest or wildlife reserves. Therefore, adopting this approach as an effective strategy requires reconsidering the current practice of not allowing restoration of tanks within the wildlife and forest reserves with the involvement of the relevant disciplines. Permitting restoration of those tanks will serve wildlife habitats, biodiversity, prevention of desertification, and maintain ecological equilibrium. Those are non-production yet economically important values of water storage with broader landscape benefits.

The proposed framework envisages the engagement of stakeholders from the beginning of the design level by collecting information through them on the availability of unrestored tanks and the upgrading needs. Gathering information on experienced flood events, issues related to water scarcities and cropping practices are the other occasions where this approach ensures stakeholder engagement. Furthermore, critical decisions such as restoration of tanks only for other uses due to the water scarcity are to be taken in agreement with the communities.

In addition to the stakeholder engagement at the design level, their involvement is essential for effective management, operation and maintenance of the system to ensure sustainability. Therefore, the proposed framework considers the strengthening of institutions as an improving intervention at the design level. Reorganising the existing field-level farmer organisations to suit the cascade management, strengthening the legal framework required for the effective functioning of the institutions and providing provisions for other stakeholders to participate actively in managing the cascade are some policy considerations that could improve the directions provided by the framework to ensure integration of social component with the ecological system.

As the proposed framework provides restoring tanks for agriculture and other ecosystem services, restoration may not be viable under the prevailing economic internal rate of return (EIRR) criteria. Hence, shifting away from the current selection criteria dominated by EIRR is needed by giving due recognition for all benefits. According to the investments made on the rehabilitation of village tanks in the country since the 1980s and the current national policy on village tank development, financial resources could not be considered a major constraint for the restoration of these tanks. However, if such a constraint exists, priorities of development can be based on the criteria such as maintaining regional equity and addressing the hot spots or adoption of stagewise development consistent with government policies.

Accordingly, the proposed framework for the development of village tank cascades consists of social and ecological factors and the technical considerations that interact with each other. Hence, the proposed framework ensures a multidimensional approach while crossing the boundaries of several disciplines. In light of the above mentioned, it is justifiable to replace the prevailing one-dimensional technical assessment approach with the proposed decision-making framework that ensures a multidimensional and transdisciplinary approach for developing the village tank systems. As the study mainly focused on the design-level strategic considerations in developing the ancient village tank systems as an adaptation to climate change and for improved water security, the issues related to the implementation stage need to be studied separately.

Conclusion

The study critically reviewed the approaches adopted in the restoration and rehabilitation of ancient village tanks in Sri Lanka for the last 170 years starting from the 1850s and identified the main drawbacks which have caused nearly half of these tanks not being selected for restoration. The main drawbacks identified are the prevailing one-dimensional normative assessment approach focusing on agricultural production and non-inclusion of some important technical, social, and ecological factors.

Besides, the global development concepts, the technological improvements related to engineering solutions and assessing mechanism that have undergone several changes since the 1980s are not expressly incorporated in the prevailing technical assessment approach. Therefore, though the concepts of sustainable development, ecological restoration and adaptation for climate change exist, the economic evaluation dominates the selection of these tanks for development. Hence, adopting a development approach that allows appropriate space for all relevant disciplines is required to develop these ancient tank systems sustainably.

The multidimensional approach proposed through the decision-making framework will enable consideration of the multifunctional nature of the tanks, current status, factors influencing the systems and possible improvement options while following the hydrological principle behind the development of village tank cascades. The additional factors included in the assessment have significantly broadened the design-level strategic considerations applied in restoring village tanks. The inclusion of stakeholder engagement and ecological considerations in the proposed framework would resolve the contradictory notions among different parties in assessing the importance of village tanks and investment in developing them. Therefore, restoring village tank systems as social–ecological systems, ensuring a transdisciplinary approach would be the strategy to develop them sustainably.

This transdisciplinary approach leads to the systematic identification of the restoration potential of village tanks along with their specific functions. Accordingly, the inclusion of the proposed decision-making framework into the assessment process along with the formal recognition would bridge the gaps between existing policies and practices adopted in restoring village tanks as an adaptation option for climate change. Adopting the proposed approach would also reinforce the possibility of developing village tank cascades as sustainable social–ecological systems while ending the tank restoration process implemented over 170 years in the country.

The findings indicate the necessity for reviewing the current economic evaluation criteria used in the development of village tanks and developing novel criteria that recognise the social–ecological aspects of these systems. Furthermore, it is also recommended to carry out specimen studies on relevant hydrological parameters for small catchments to enable effective simulations of the hydrological behaviour of the tank series with computational hydrological models. Finally, the study emphasises the importance of the consistency of strategies and technical approaches with the policies to meet the intended goals and objectives.

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Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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