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# Ancient Tank Cascade Systems in Sri Lanka and DPSIR Framework for Conceptualizing Ecosystem-based Management Approaches

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**ABSTRACT**

The dry zone of Sri Lanka is the major agricultural area in the country. The major problems in this area are less rainfall and lack of water for agriculture. Ancient people identified the importance of water resource management for agriculture. Since the 5th Century B.C., several strategies have been implemented, including hydrogeology and ecosystems. Tank cascade systems (TCSs) are one of the strategies developed to overcome the challenges faced by communities in dry zones regarding water scarcity. It is declared as a Globally Important Agricultural Heritage by the Food and Agriculture Organization. However, TCSs were disturbed by the interruption of hydro-ecological balance due to natural and anthropogenic causes. Without a proper understanding of the effect relationships of TCSs destruction, it is hard to identify possible strategies for its sustainability. This paper reviews the ancient indigenous information about TCSs, the distribution of TCSs, ecosystem functions and services provided by the TCSs, and previous studies conducted about tanks and TCSs, and conceptualizes an ecosystem-based management approach for TCSs. The Driver–Pressure–State–Impact–Response (DPSIR) model was applied to recognize cause-effect relationships of TCSs. It describes demographic, socio-economic, environmental, and political drivers and recognizes possible responses such as restoration of TCSs, capacity building, institutional framework, livelihood involvements, and environmental interventions. The destruction of TCSs over the years has caused unsustainability in agriculture, food insecurity, and a recession in contretemps in Sri Lanka. As an ecosystem-based approach, the DPSIR model can be helpful for TCSs.

## 1. Introduction

The ancient kingdoms in Sri Lanka were initially formed in the country's North Central, and Southeast parts and were organized mainly in dry zones. The fertile soil in these areas facilitates the people to pursue subsistence agriculture as their main activity. However, agriculture in the dry zone suffers from a lack of rainfall for a shorter period (4 months from September to January) and prolonged drought periods (almost 8 months). The severity of the water scarcity intensified due to the low moisture retention capacity of the typical soil (Alfisols/Reddish brown earth) dominated in the area [1]. Thus, their major challenge was cultivating fields with limited water availability. The ancient kings embraced the challenge and ensured sustainable cultivation through water resource management. The undulating lands in the dry zone have permitted them to build a variety of tanks and conveying mechanisms as a successful water management strategy. The ancient hydraulic civilization was initiated in Sri Lanka in the 5th century B.C. [2]. The indigenous technologies utilized in this era were astonishing, and modern engineers still cannot understand some. The main mechanism of these tanks was to store water from rainfall and surface runoff. These manmade tanks either exist as an independent tank or as an interconnected system with several tanks. The latter is defined as tank cascade systems (TCSs) by [3] or "*Ellanga*" [4]. It is used for "storing, conveying through an ephemeral rivulet" [3]. As an outcome of such a system, it guaranteed uninterrupted cultivation in both the wet season (*Maha*) and the dry season (*Yala*).

Some of the tanks belonging to TSCs are still functioning and provide efficient irrigation facilities for the cultivated fields. It confirms the sustainability of the system [5-6]. The distribution of TCS is mainly concentrated in the North and North central parts (Rajarata) of Sri Lanka and was known as “the kingdom of thousand tanks”. A smaller amount of TCSs distributed in north-western, south, and south-eastern parts (*Ruhunu rata*) of Sri Lanka. About 15,000-18,000 tanks and 13,000 anicuts are distributed in Sri Lanka [7].

It is important to analyze the ecosystem functions and ecosystem services of TCSs to safeguard its sustainability. The ecosystem function is a result of the components, processes, and structure of a particular ecosystem, and ecosystem services are part of human well-being that contributes to provisioning, regulating, supporting, and cultural services [8]. The functions of the ecosystem are mainly explained hydrologically, biochemically, and ecologically. The TCSs are interlinked hydrologically and socioeconomically [9]. Therefore, understanding ecosystem functions and services is important to ensure the best use of TCSs and any expansion or rehabilitation of human well-being. However, a minute alteration to a single tank in the TCSs may cause implications to the livelihood of people in the command areas and to the whole ecosystem. Thus, the complete cascade should be assessed, and be aware of the system before any such modifications to the tanks in any contemplated TCSs.

Considering the evolution of studies regarding tanks in Sri Lanka, there is evidence since the British colonial period (1855-1897). However, the systematic studies were commenced since 1923 [10]. According to him, the outstanding documentation was started after 1933. The derivation of the term TCS was first introduced in 1985 by Madduma Bandara [3]. As the TCSs have been efficacious in the last two millennia in the dry zone of Sri Lanka, different modern studies were adopted to confirm their sustainability. These previous studies which have been based on several themes such as productivity, environment, socio-economic, ecological, hydrological, rehabilitation, information technology, networking, and studies on indices of sustainability for assessing TCSs have been discussed in “Previous systematic studies on tanks and TCSs”.

At present many disturbances on TCSs have become a threat to its sustainability. The hydrological balance of TCSs has been interrupted due to the construction of dams, agro-wells, spillways, and ad hoc de-silting of individual tanks [11]. As a result, the groundwater table has been severely reduced. Further, human settlements, encroachments, and unbalanced agriculture techniques have also intensified the problem. Thus, systematic management strategies and rehabilitation of TCSs by restoration and improvement are of prime importance to ensure their sustainability. However, the main challenge is to implement modern techniques and technologies in design, ensuring not disturb the ecosystem functions and services of TCSs. Therefore, ecosystem-based approaches for TCSs need to be implemented for sustainable agriculture, ecosystem services, and food security. The Driver–Pressure–State–Impact–Response (DPSIR) model can be applied to identify possible divers and pressures over the TCSs and possible strategies for the sustainability of the system. The DPSIR framework has not been applied to any of the studies in TCSs in Sri Lanka.

Therefore, the present review is based on published literature available in journals, books, and technical reports and attempts to compile the previous studies conducted on TCSs which have different perspectives, and to understand the need to manage the system. The first part of the article describes the ancient indigenous knowledge of TCSs, explaining the components and the uses of these components. Secondly, the distribution of TCSs, ecosystem functions, services provided by the TCSs, and previous studies of tanks and TCSs have been outlined. In the latter part, the DPSIR framework for conceptualizing climate change resilience, sustainable agriculture, ecosystems, and food security has been discussed.

## 2. The ancient indigenous knowledge and the components of TCS

### 2.1. History

The most ancient Sri Lanka chronicle (*Mahawansaya*) gives evidence that larger tanks were embraced during the ancient king’s era after invading the country by Aryans [11]. The Bassawakkulama tank in the North central part of Sri Lanka was the first tank by King Pandukabhaya who ruled the country in the 5th century B.C. [12]. Thousands of tanks were established thereafter by several kings in the Anuradhapura kingdom. After the foreign attacks by South India [13] this kingdom was destroyed. However, these conquerors established a new kingdom in Polonnaruwa. In this era, the most splendid ruler was King Parakramabahu (1153-1186), who constructed amazing amounts of tanks and other structures to convey water for irrigated agricultural fields. He developed 2376 small tanks, 163 large tanks, 3910 canals, and 165 anicuts. His Royal dictum was “Let not a single drop of rainwater allow to reach the sea without utilizing it for human welfare”. Later the kingdoms shifted towards the Northwestern province and many of the previous tanks were demolished [14]. Meanwhile, the ancient kingdoms established in Southeast parts of the country based on the Walawe basin similarly showed hydraulic civilization as in North Central and Northeast parts. In the reign of King Mahanaga and Kawnthissa, several involvements in tanks could be observed. The studies [12, 15] denoted that the tanks in the dry zone were arranged in an orderly manner using the slight elevation of the land which the lower tank can receive the overflow water from the immediately above tank. The term “cascade” was first introduced by [3] allowing most scientists and hydrologists to consider a tank rather than an individual unit but as an interconnected tank network. It revealed that 90% of these individual tanks are parts of a single cascade [3]. Overall, 30,000 tanks were distributed covering approximately 40,000 km$^2$ lands of the dry zone [16-17]. During the British colonial in the 19th century, ancient historical abandoned monuments were restored [11]. Currently, almost 10,000 tanks are in function [18, 5-6] including around 3,500 TCSs.

### 2. 2 Structure and the main components

TCS is one of the oldest technologies in the world which is considered as an agricultural heritage. It has been explained as the 'lifeblood' among rural communities in the dry zone [19]. These watershed management structures, components, and technology developed two millennia during the ancient king's period astonished the present hydrologists and engineers. According to [3], the TCS comprises an interconnected tank network within respective micro-catchments, which are in a single meso-catchment to store and convey water from an ephemeral rivulet. However, [20] proposed to change the term "ephemeral rivulet" to "first-order ephemeral stream" or "second-order inland valley". Accordingly, an individual tank is in a micro catchment within a large meso catchment. These TCSs demarcated by a meso-catchment from 13-26 km$^2$ [21]. TCSs comprise around 2-30 tanks [22] and at least 2 tanks must be interconnected together to become a cascade. A study by [23] explains the TCSs as a sequence of tanks arranged orderly under a single common tank. Later, a Sinhala term for cascade was introduced with the meaning of "*ellan*" as hanging and "*gawa*" as "one after the other in orderly arrangement" [24].

A tank classification system can be done according to the form of the cascade, the size of the catchment/ watershed boundary, and the configuration of the main valley, main axis, and side valleys. Table 1 shows the proposed topological classification of cascades according to their size, form, shape, and general alignment [25].

According to the classification, cascades that are linear, with a form index higher than 1.5, and with a gentle slope in the main axis are hydrologically efficient endowed cascades [25]. Figure 2 illustrates the branched cascade and linear/slightly branched cascade systems.

Furthermore, according to the Agrarian Service Act No. 59 of 1979, tanks in the TCSs are categorized into major tanks, medium tanks, and minor tanks based on the command areas. The tanks with command area beyond 400 ha are considered major tanks, 80 - 400 ha as medium tanks, and less than 80 ha as minor tanks [10]. The upper tanks in the cascade are smaller than the lower tanks [26]. These are interconnected along the valley with canals and spillways.

**Table 1: Topological classification of cascades [25].**

| Level | | Category | Features |
|---|---|---|---|
| First level | Form | Linear/slightly branched | No/less number of branches in the main axis |
| | | Branched | With many branched main axes |
| | | Form index (ratio of cascade area to its length) | 1.15-2.55 |
| | Size class | Total extent of meso-catchment | Small (<2500 acres)<br>Medium (2500-5000 acres)<br>Large (5000-7500 acres)<br>Very large (>7500 acres) |
| Second level | Configuration of the main valley, main axis and side valleys | Nature of main valley and main axis | Long<br>Medium<br>Short |
| | | Slope of the main class | Gently sloping (better retention)<br>0-2%<br>Moderately sloping 2-4% |
| | | Number of side valleys | High-cascade density increase (reduce the ratio of catchment area: tank water spread area)<br>Low-cascade density decrease |

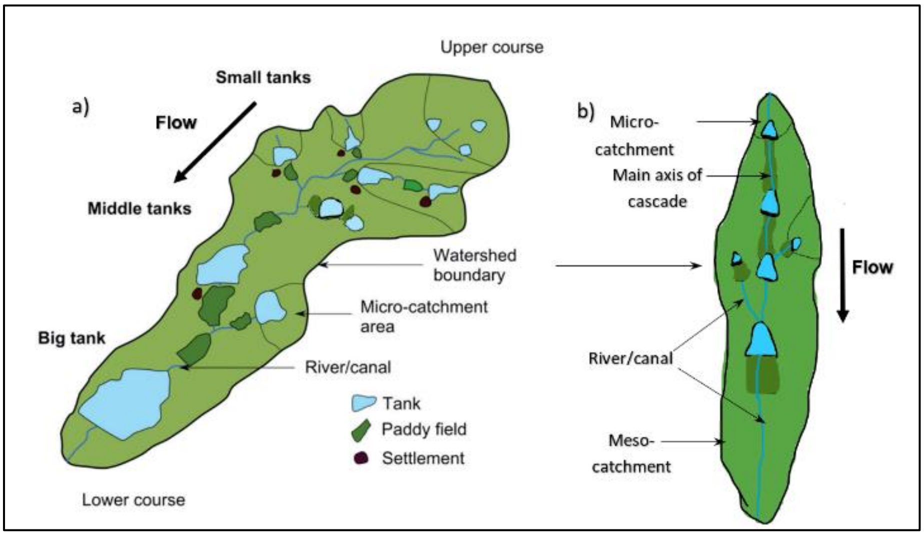

**Fig 1: Sketch of a) Branched cascade b) Linear/slightly branched cascade (modified after [11, 27]**

A TCS was designed with different important zones where each zone contributes a specific function or significance. The major zones such as tank bund and tank body, the path to cultivated lands/paddy fields, upper catchment, and residential area (hamlet) consist of several other sub-areas [21]. Among them, some important unique features of TCSs from upstream to downstream are catchment forest (*mukalana*), riparian/retention zone (*thaulla*), interceptor (*kattakaduwa*), tree belt (*gasgommana*), check dams (*potawetiya*), soil ridges (*iswetiya*), tank bund/dam, sluice gate (*biso kotuwa*), and paddy fields. Figure 2 depicts some of these features. Other than these components, silt trapping small tanks (*kuluwewa*) which were not utilized for irrigation purposes have been found inside the catchment [28]. Further, waterholes (*godawala*) are located in the inlet of the tank to provide drinking water for wild animals, control sediments, filter salts, and damage the embankment during floods [21]. The catchment forest (*mukalana*) is the uppermost part of the tank that maintains the groundwater table and collective efforts have been taken to protect this important zone by preventing any encroachments and deforestation [29]. The riparian/retention area (*thaulla*) is the upper periphery of the tank. It acts as an artificial wetland with different hydrophytes which helps to remediate pollutants from drainage water flowing from upstream [30]. The interceptor (*kattakaduwa*) lies between the paddy fields and tank bund/earthen dam having a similar width of its base. Its role is phytoremediation by absorbing several salts and metal pollutants from seepage water. The plants in this zone with well-established deep roots protect the soil preventing erosion and acting as a wind barrier. The tree belt (*gasgommana*) consists of a variety of trees along the tank which act as an inundation area. Reducing evapotranspiration, and acting as a wind barrier to reduce waves are its other benefits. Check dams (*potawetiya*) retain sediments coming from the upper catchment and are dominated by different semi-aquatic flora and fauna. Further, these store excess water from the upper catchment. The soil ridge (*iswetiya*) lowers soil erosion and siltation by preventing the addition of sediments into the tank.

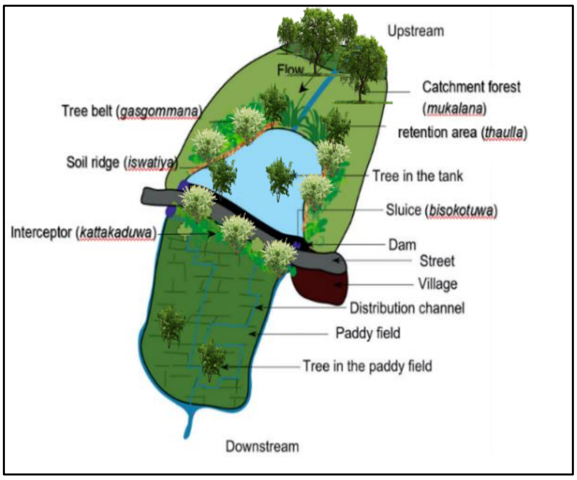

**Figure 2: Sketch of a typical tank in a specific micro-catchment (modified after 6, 27, 31)**

### 2. 3 Distribution of TCS

TCSs restricted to dry-subhumid regions of Sri Lanka [31] with annual rainfall variation of 800-2000 mm [32]. These are densely distributed in 100-500 m amsl elevation [33] and in gently undulating terrain with <4% slope and restricted in undulating terrains with 2-4% slope [25]. The rainfall pattern and the soil overburden also affect the distribution of TCSs. The 3 major cascade zones identified as

North and North-central, North-Western, and South and South-Eastern [34] covering five provinces. These 3 zones consist of 617, 255, and 177 cascades, respectively [35]. Of 25 districts in Sri Lanka, TCSs found in 8 districts (Mullaitivu, Vavuniya, Anuradhapura, Trincomalee, Puttalam, Kurunegala, Hambantota, and Monaragala). According to [11], the tank density in the North-western Province and the North-Central Province is a tank per 1.2 km$^2$. Figure 3 depicts the tank distribution map in Sri Lanka [36]. These are geologically placed in the Wanni and Vijayan complex [32].

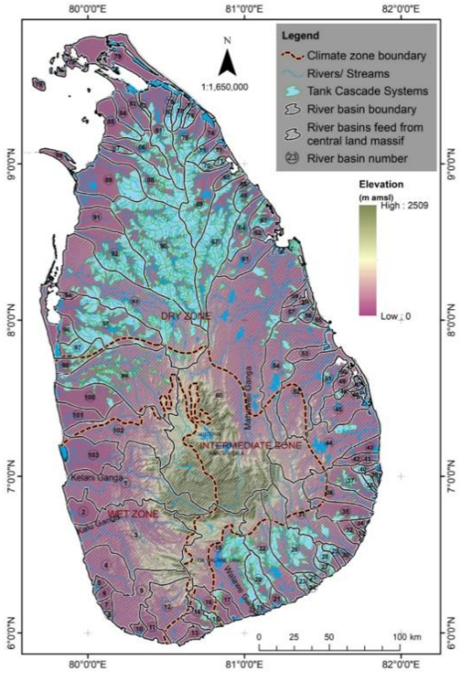

**Figure 3: Tank distribution (functioning and abandoned) in Sri Lanka [36]**

## 3. Ecosystem functions and services of TCSs

Wetland ecosystems include rivers, lakes, tanks paddy fields, etc. which provide several services that help in poverty alleviation and human wellbeing.

Tank ecosystems are examples of lentic ecosystems that have sluggish/still fresh water. With the hydraulic civilization based on the tank cascade ecosystem, in the dry zone of Sri Lanka, the ecological, and cultural quadruple—— the *Wewa* (tank), *Wela* (Rice/agriculture field), *Gama* (village), and the *Dagaba* (religious shrine) were built. Therefore, rural people rely profoundly on tanks for their livelihood activities [37] showing ecological harmony and socio-economic harmony [38].

TCS ecosystem includes catchment forests, aquatic habitats, different land use, and sophisticated water management systems [39]. The proper functioning of an ecosystem is important for the betterment of human well-being or human welfare. The structure, components, and processes are the basic features of an ecosystem. They provide vital ecosystem functions that are useful to humans called ecosystem services [40]. According to the ecological sensitivity assessment criteria, the TCSs can be included at a high functional level with sensitive ecosystems with high dynamic systems for ecosystem integrity [41]. TCSs provide hydrological, biochemical, and ecological functions. During seasonal peak rainfalls floodwater detention is reduced by floodwater retention. This protects wildlife, and especially the fisheries. Further, groundwater recharge is a key function provided by the catchment forests in TCSs. Replenishment of groundwater resources and maintenance of dependent ecosystems in discharge areas are important in this scenario. Groundwater discharge at seepage zones is identified as another function that maintains the tank base flow dependent on soil water regimes. Also, sediment retention by TCSs provides an improvement in water quality due to the reduced input of suspended sediments and associated sediment nutrients/pollutants. Pollution by excess use of agrochemicals [30-31] soil weathering [30], and water quality deterioration [31] are key problems. Retaining or delaying the release of nutrients (N and P) into water bodies may prevent potentially deleterious effects on water courses. Thus, eutrophication changes which adversely affect water quality can be avoided. The retention zone (*Thaulla*) in the upper stream of the tank acts as a wetland to precipitate N and P in soil and absorb other harmful metals by hydrophytes that grow in that zone. Further, C retention was functioning by organic matter accumulation, often as peat. Peat supports rare and valuable biological communities. Also, physical, and biochemical retention helps to keep the tank water quality due to the reduction of suspended or dissolved trace element loads. Trace element loads can have toxic effects on the tank ecosystem. Moreover, it prevents groundwater contamination and uncontrolled translocation of trace elements within the tank ecosystem. Similarly, physical, and biochemical remobilization of trace elements control the removal of trace elements, avoiding the danger of toxic effects on plants and re-contamination of tank water or groundwater. Wetland ecosystems in TCSs strongly influence the concentration of dissolved organic carbon (DOC) in runoff water, key features of water quality, and the aquatic ecosystem in areas with DOC-rich water (over 5 mg L$^{-1}$ DOC) by controlling the organic carbon concentration. The ecological ecosystem functions of TCSs are to maintain the ecosystem by overall habitat structural diversity, providing micro-sites for macroinvertebrates, fish, herptiles, birds, and mammals. This supports unique habitats for a variety of adapted organisms contributing to global biodiversity, supports recreation and quality of life. Also, it supports the food web by biomass production on-site or by detritus and/or organisms externally transported into the system. Biomass is imported via physical processes (water courses, overland flow, wind transport) and biological processes (via fauna, and anthropogenic means). Biomass is exported via physical processes and biological processes.

Ecosystems provide different kinds of services as explained by the Millennium Ecosystem Assessment report [42] and the Economics of Ecosystems and Biodiversity report [8], including provisioning services, regulating services, habitat services, and cultural /supporting services. and cultural /supporting services and cultural services. Among various natural ecosystems, the identification of ecosystem services from the perspective of inhabitants is vital for research development on sustainable use and management of natural resources [43]. The ecosystems in TCSs provide vast varieties of ecosystem services, explained according to the TEEB report [8]. TCSs are complex ecosystems and ecosystem services from TCSs are interconnected with various socio-economic and ecological components for villages [38]. Thus, village communities tend to depend strongly on TCSs for their livelihood activities [37]. Understanding the services of TCS-based ecosystems is important for any conservation, rehabilitation, and sustainable/wise use of water sources. Also, community-level valuation of ecosystem services offers a proper understanding of different perspectives of villages. However, many of the services provided by the ecosystem remain outside the market systems making it difficult to value them.

### 3.1 The provisioning services

Water for irrigation is the main service of the TCSs. Utilizing water for agriculture, the villages cultivate paddy, vegetables, and grains in lowlands and chena (shifting cultivation) in major seasons. This cultivation method undergoes a long fallow period. Traditional crops such as kurakkan (finger millet), maize, mineri (cereals), chilies, mustard, and vegetables such as pumpkin and hybrid varieties are cultivated [44]. Also, tank water is used for domestic needs and livestock use [31, 18]. Small tanks inside the forest (kuluwewa), cater to drinking water for wild animals and act as silt deposition beds [45, 14]. Fishing, medicinal plants for indigenous medicine, cattle grazing, collecting reeds, collecting fuel wood, flowers for worshiping (lotus-*Nelumbo nucifera*), and Water lily-*Nymphaea*) are some other services. Also, the clay deposited in the retention area (*thaulla*) is used for pottery; tall reeds (*Typha Angustifolia*), and grasses and softwood from this area are used for crafts and mats [46]. Also, services provided by the catchment forest, and shrubs were utilized as medicinal herbs for indigenous medicine [21]. Land use of TCSs is delineated as alluvial soils (alluvial humic gley soils) for paddy cultivation and Alfisols (reddish-brown earth soils) for shifting cultivation.

### 3.2 The regulating services

The tank ecosystem regulates a variety of services such as climate regulation, mitigation of climate change, carbon sequestration, maintaining air quality, pollution control, erosion prevention, land degradation regulation, flood control, drought control, biogeochemical cycling, groundwater recharge, pollination, and biological control. These ecosystems are fully reliant on hydrological conditions. The occurrence of TCSs retard the inflow of large reservoirs, reducing flooding and drought in the river basins. Both mass C storage in wetland soils and biomass sequestration and the source and sink of greenhouse gases (GHGs) through net GHG productions and annihilations can be seen in these wetland ecosystems. Regulation of climate change occurs by means of sequestering and discharging a major amount of fixed C in the biosphere. Also, the evaporated water from tanks cools the environment and may influence regional temperature and precipitation. The wetland trees capture large amounts of $CO_2$ which also helps to maintain air quality. In the case of pollution control, the retention areas in this ecosystem regulate bioremediation and phytoremediation. The nitrate concentration is reduced by more than 80% in these ecosystems [8]. The excess nitrogen amounts added by fertilizers from cultivated lands, and plant biomass nitrogen or directly nitrogen from the atmosphere. Several components such as tree belts (*gasgommana*), interceptors (*kattakaduwa*), check dams (*potawetiya*), and soil ridges (*iswetiya*), prevent erosion and regulate land degradation. The tank body controls flood during heavy seasonal rainfalls. Ecosystems regulate biogeochemical cycling [47]. It is the cycle of chemical transportation and transformation that is influenced by the diverse hydrological conditions of the ecosystem. The chemical mass balance in tank ecosystems regulates the transformation of chemicals. There the ecosystem acts as a source of chemicals to the atmosphere, as a sink for chemicals from the atmosphere. Groundwater recharge is regulated by catchment forests in the ecosystem. Further, these ecosystems regulate pollination by providing habitat for pollinators. The biological control of insects is regulated in this ecosystem by bats and some bird species (palm swift, owls, flycatchers, black robin, etc.). Mosquitoes are controlled through dragonflies and bats to avoid malaria and dengue.

### 3.3 The habitat/supporting services

The tank ecosystems provide habitats for species. As an example, the tree belt (*gasgommana*) provides habitats for terrestrial species and during floods for fish and other aquatic species. Also, the part devoted to birds (*kurulu paluwa*), is a land adjacent to the bund of the tank and end of the rice field [35]. The yield in this part is not harvested and remains for the consumption of birds. It is a good example of maintaining biodiversity while tracking it to conserve it. Other than that, soil formation and nutrient cycling are supported by the system. Ecosystems with biodiversity and important habitats such as endangered Asian elephants (*Elephas maximus* L.), and resident and migrant water birds in TCSs are common.

### 3.4 The cultural services

According to TEEB [8] cultural services of wetland ecosystems are spiritual and inspirational, recreational, aesthetic, and educational. Tank cascade systems are linked with local societies in terms of many religious activities, values, and norms. As an example, *kem* systems (spiritual way of crop protection), rituals such as *gammadu*, *daha ata sanniya* for wishing prosperity for villages, chanting by religion for mental health, commencing work based on auspicious times [17] are some of the cultural services in use. The temple is one of the key organizations in the village. Folk poetries based on their experience, and spirituality, were used by different groups of people during specific activities such as farming, riding boats, and protecting cultivation from wild animals during night. There are opportunities for recreational activities (boat riding, bird watching) due to the aesthetic values of the ecosystem. However, still, most of these opportunities are not fully utilized for local and tourist attractions. Also, educational visits are possible to gain knowledge of engineering values as well as ecological values.

## 4. Previous systematic studies on tanks and TCSs

Previous studies before introducing the definition of TCS, were confined to individual tanks rather than TCSs. The studies of tanks and TCSs in Sri Lanka have been based on different themes such as the nature of the system and the management, geological and geographical, socio-economic, climatologic and ecological, biodiversity, hydrology, water quality, water budgeting, sediments, rehabilitation, and studies on indices of sustainability for assessing TCSs, information technology, and networking. Further, the evolution of TCS studies in different eras of Sri Lanka was reviewed [10]. In this paper, some of the systematic studies after 1985 have been listed in Table 2.

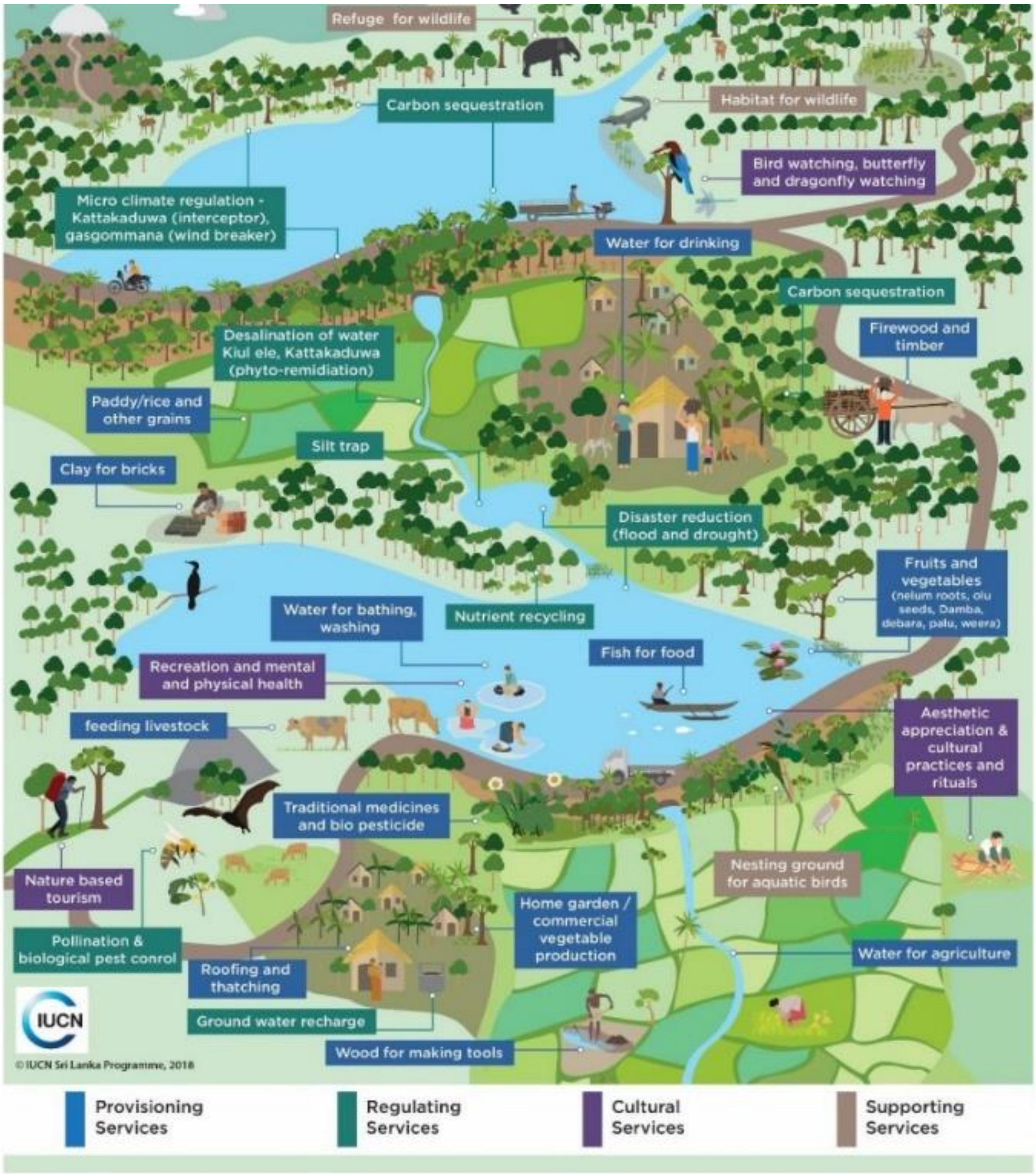

**Figure 4: Illustration of ecosystem services generated from the TCSs [48]**

**Table 2: Systematic studies based on tanks and TCSs in Sri Lanka since 1985**

| **Theme of the study** | **Key findings/reviews** | **Focused location /TCS** | **Reference** |
|---|---|---|---|
| Nature of the tanks/TCSs and their management | Studied the catchment ecosystems of selected village TCSs in the dry zone. It observed that the tank size and capacity increase from the upper to the lower of the cascade. | Dry zone of Sri Lanka (*Toruwewa* and *Kadiragama* Cascades) | [3] |
| | Highlighted the importance of treating the network with respect to irrigation management. | Small valleys in the dry zone | [49] |
| | Indicated the re-using technique in cascade systems. Further, discussed the importance of managing the system with modern techniques with minimum harmfulness. | Anuradhapura in Dry Zone | [39] |
| | Identified the general characteristics of 310 small TCSs and their topology. Two level topologies have been proposed (The first level as form and size class; the second level as configuration of main and side valleys. | Anuradhapura district (*Thirappane, Maha kanamulla, Ulagalla, Gangure wewa, Thimbiri wewa* TCSs) | [25] |
| | Evolutionary studies on characteristics of TCS in Sri Lanka and qanats in Iran | - | [50] |
| | Transformation of agricultural systems in Dry zones and their sustainability and demonstrated the value of protecting indigenous agricultural systems.<br>Water management and governance systems in the dry zone of Sri Lanka | Anuradhapura, Dry zone | [51-52] |
| | The nature of the *Malwathu oya* cascade and key problems encountered have been identified. It was recognized as a system with good hydrological endowment. | *Malwathu oya* cascade I | [53] |
| | Spatial distribution pattern analysis of tanks in cascades in the *Deduru Oya* river basin | *Daduru oya* catchment | [54] |
| | Differentiated the water management pattern in different socio-cultural groups | - | [55] |
| | Studied the *Kappiriggama* cascade system and problems in the system | *Kappiriggama* cascade, Dry zone | [56] |
| | TCSs belonging to 3 regions were studied to differentiate the cascade characteristics of each region. | Anuradhapura, Pallegama and Hambantota representing the Rajarata, Uva-wellassa and Ruhuna-magama | [57] |
| | A review of small TCSs and their management and governance emphasizes a polycentric governance system which is considered the best to adopt. | - | [58] |
| | Discussed the environmental conditions, social and institutional settings of small TCSs and their sustainable management for Agricultural Resilience | Dry Zone | [59] |
| | Identified village tank systems based on GIS mapping, remote sensing, interviews, and field studies. | Vavuniya | [60] |
| Hydrology | Small tanks higher than 3 acres of catchment/acre-foot storage can achieve a full supply level of 40-70 in the *Maha* (wet) season indicating favorable irrigation potential. It discussed the runoff estimated model. No runoff was created unless the catchment soil met with pre-saturated conditions. | Nachchaduwa, Dry zone | [61] |
| | The tank catchment area initially gains a significant amount of water to saturate soil before any runoff in 150 mm rainfalls. It proved that Reddish Brown Earth soil moistens 1.5 m soil depth to the field capacity level. It discussed the runoff estimated model. | *Maha kanamulla*, Dry zone | [62] |

| | | | |
|---|---|---|---|
| | Studies based on groundwater in tanks and TCSs found that the safe limit of agro-wells is 3600 in 50 TCSs. Further, he found that a higher number of agro-wells are in the middle catchment region of the cascade. | 50 cascades in Anuradhapura | [63] |
| | Discussed the sources of water in a tank in TCS, i.e., direct rainfall, runoff, drainage return flow, and spill water from the upper tank. To characterize the hydrological endowment, it discussed CI (cropping index) as a reliable measurable index. CI is defined as the ratio of the area cultivated during the wet season (Maha) and the total command area. From the upper to lower end of the main valley, the CI of small tanks in TCS increased. Further, a hydrological simulation model for a cascade was developed. | - | [25] |
| | Estimated the aquifer parameters, and annual average recharge and developed a nomograph for sustainable use of agro-wells in the cascade system. | *Meegassagama* tank in *Thirappane* TCS | [64] |
| | The study identified disaster control by monitoring and estimating water levels of TCSs. | - | [65] |
| | Implemented a digital elevation model to delineate depending on food and drought vulnerability. | Hambantota | [66] |
| | Integrated surface and groundwater management model for runoff, percolation, evaporation, groundwater availability, crop water use assessment | *Nachchaduwa* major tank watershed in the Anuradhapura district | [67] |
| | Discussed socio-technical aspects of water management in TCS and large dam systems. Comparatively, TCS has been identified as a sustainable system and recommended for rural areas of developing regions. | - | [68] |
| | Developed a spatial modeling approach based on GIS to recognize the conditions and the impact of small TCS on groundwater potential. Found that the groundwater potential of TCS has been reduced due to human intervention. | Parts of cascades in Vavuniya | [69] |
| Water balance | A water balance model was applied to a linear TCS in four seasons (2 wet and 2 dry) based on rainfall, tank water level, evaporation, water problem, and drainage flow in command areas. It was the first study to evaluate drainage return flow (upstream and downstream tanks) from the total cascade. The drainage return flow in the Maha season varied in the mid-main valley, lower main valley, and lower side valley at 23%, 29%, and 12%, respectively. | *Thirappane* cascade system in Anuradhapura (six tanks namely *Vendarankulama, Badugama, Bulankulama Meegassagama, Alisthana, and Thirappane*) | [23, 70] |
| | Hydrological aspects - Water balance | | [71] |
| | Formulated dynamic hydrologic components of an irrigation tank cascade system. | Anuradhapura | [26] |
| | Developed a model of optimization by the “WEAP” computer-based tool regarding water balance | *Pihimbiyagollawa* tank cascade system | [72] |
| Productivity | TCSs have several technologies such as drought management, rainwater harvesting, groundwater recharge, soil moisture balance, erosion control, ecological balance, social leadership, and cultural and spiritual development, and they nurture animal husbandry and inland fishing. | Anuradhapura in Dry Zone | [39] |
| Geographical and Geological | Tanks, paddy fields, watersheds, and canals are the main features. Geologically the area comprises Precambrian crystalline rocks, with granitic gneisses and quartzites. | - | [73] |
| Socio-economic | A household survey was conducted to understand the physical, socio-economic, and institutional | Cascade systems in the | [44] |

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| | evolution of the sample tank cascade systems in the Walawe basin. The changes in TCSs, tank-based communities and their relationships with tanks, problems associated with TCSs, and changes in socio-economic and hydrology were discussed. In terms of socio-economic changes highlighted by population growth exceeding the carrying capacity of the TCSs and the basin. | Walawe basin (*Kadawarawewa* cascade, *Aluthwewa* cascade, *Metigathwala* cascade system) | |
| Climatologic and ecological | Ecological zones were identified in a TCS namely, a) tank bund and tank bed, b) irrigation canals and paddy fields, (iii) catchment forest, d) village and their components were discussed. | - | [21] |
| | Recognized environment-related issues and indicated the possible solutions. | *Kappriggama* Tank cascade | [73] |
| | Focused on resilience in Climate change, mitigating drought, for human wellbeing. | - | [9] |
| | Preparation for water scarcity by understanding the tank storage capacity, facilitating water management, and adjustments for cropping patterns | Hambantota | [74] |
| | Focused the status, scope, and challenges in disseminating the climate-smart agricultural (CSA) practices to the cascades or tank clusters. | *Neliwewa, Ralapanawa, Rambewa* cascades in Puttalam district | [75] |
| Biodiversity | Discussed the biodiversity in TCSs with endangered species, Asian elephants, resident, and migrant water birds. Forest ecosystems in the dry zone resemble tropical dry mixed evergreen forests. Similar species are found in tropical dry mixed evergreen forests and TCSs. | - | [21] |
| | It described the TCS as one of the wealthiest sources of wetland biodiversity in Sri Lanka. | - | [76] |
| Water quality | Analyzed surface water quality by means of Sodium adsorption ratio, residual sodium carbonate, E.C.), pH Na, K, Mg, Ca, available $PO_4^{3-}$- P, alkalinity, and nitrate-nitrogen ($NO_3^-$ -N). The water quality (with low salinity and sodium hazard) was at standard levels for irrigation. | *Ulagalla* cascade, Anuradhapura | [77] |
| | Spatial and temporal variation of water quality of a small TCS in Monaragala district was investigated. According to the Canadian Council of Ministers of the Environment (CCME) index, it revealed that the water quality was marginal in the dry season than wet season. Further, the water quality deteriorated from upper to lower in TCS. | Thanamalwila (*Sinhalayagama, podi wewa, Maha wewa, Bagamuwa wewa*) | [78] |
| | Water quality assessment based on nutrients and heavy metals (N, P, K, and Cd). | *Mahakanumulla* tank cascade | [79] |
| | Assessed selected water quality parameters in 3 tanks and drain channel. Nutrient variation was observed in the tail part of the cascade with higher amounts than in the head parts. | *Meegasagama, Alistana* and *Thirappane* of Thirappane TCS | [80] |
| | A review on whether the restoration of tanks would prevent the occurrences of CKDu in dry zone and intermediate zone. | - | [81] |
| | Assessed the water quality of the tank and the role of plants in the retention area (*Thaulla*). It revealed the chemicals were retained in the *Thaulla* area due to retention ability. | *Malagane* Cascade | [82] |
| | The Empirical Bayesian kriging (EBK) method was indicated as the best method to interpolate groundwater quality parameters. | *Ulagalla* Tank Cascade | [83] |
| | Applied Analytic Hierarchy Process (AHP) and GIS-based water quality zoning procedure. Indicated the irrigation suitability for sustainable agricultural production. | *Ulagalla* Tank cascade | [84] |
| Indices of sustainability | Modified the existing parameters (21) for sustainable indexing of village TCSs. Based on the sustainability index (S.I.), 2 parameters were developed i.e., Physical-environmental, and socio-economic. The SI ranges between 0–100. It indicates the sustainability of a TCS/individual tank i.e., very low sustainability (0–25)/ low sustainability (25–50)/ moderate sustainability (50–75) or high | - | [85] |

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| | sustainability (75–100). | | |
| Sediments | Sediments were obtained in five sediment cores from four different tanks. Carbonates were found in sediments correspond to calcites. It gave a clear indication of the transition of weathered bedrock to the overlying sediments. The TCSs have been constructed in valleys with fluvial accumulation. Retention areas (*thaulla*) in the inflows of the tank are suitable sediment archives. | *Rota wewa* cascade, Anuradhapura | [27] |
| | Analysis of sediments of tank ecosystem and water pollution. | *Malagane* Tank Cascade (Daduru Oya basin) | [30] |
| | Determined the temporal and spatial variation of tank sediments | - | [31] |
| | Investigate sediment characteristics related to Functions and characteristics of VTCS | | [86] |
| | Assessment of physico-chemical parameters in the retention area (*Thaulla*) for management purposes. It revealed the importance of the retention area for the sustainability of tank water quality as well as quantity. Found P retention and the soil properties resembled the wetland soil. | *Ulankulama* Tank at Anuradhapura, | [87] |
| | Provided information on Sedimentological data of two tanks in Anuradhapura | Anuradhapura North | [88] |
| Rehabilitation | Introduced 3 criteria for selecting small tank rehabilitation under 4 categories. These 3 criteria were, *Maha* cropping intensity (CI), ratio of tank catchment area to water spread area, and the ratio of command area to water spared area. Also, it stressed the integrated development of the catchment, tank highlands, and command area. | Anuradhapura district (15 TCSs including *Maminiyawa, Thirappane, Maha kanamulla, Ulagalla, Gangure wewa, Thimbiri wewa* | [25] |
| | Review models of three different organizations in rehabilitating TCSs and selected best practices and proposed recommendations for rehabilitation. | | [89] |
| | A proposed multidimensional decision-making framework for screening tanks for restoration and for assessing hydrological aspects of tanks within a cascade. | - | [90] |
| Economic valuation | To value the TCS benefits total economic value concept has been used. These were compared with tank rehabilitation costs to suggest the policies. | Hambantota | [91] |
| Ecosystem services | Discussed the ecosystem services provided by the TCSs | - | [92] |
| Information Technology | To systematical explanation the Information Technology assisted networking program was introduced. Also, a GIS-based model was used to forecast sustainability. | *Rambawewa* in Puttalam District | [93] |

## 5. DIPSIR framework and conceptualization of ecosystem-based management approaches for the sustainability of agriculture, and food security

The TCS has been sustainable over millennia proving that it is one of the best techniques to synchronize the ecological, hydrological, and socio-economic activities and to reuse water efficiently. Ecosystem degradation of TCSs is intertwined mainly with anthropogenic activities and climate change. Well-operational TCSs are identified as a major strategy in food and livelihood security [94]. The TCSs have enhanced the food security of village communities since hydraulic civilization through generations, by generating harmony between ecology and society. Tank cascade ecosystems could overwhelm destructive climatic conditions such as droughts and floods. This ensured the sustainable agriculture, food security, and sustainability of ecosystem services provided. Sustainable agriculture production includes crops, aquaculture, livestock, and poultry. Combine supply of the basic requirements such as water and land, genetic materials, agriculture inputs (seeds, fertilizer, etc.), and agricultural services (insurance, extension, finance, etc.) confirm the food security through sustainable agriculture [95]. [41] has made several recommendations to promote food security, human well-being, and ecosystem health based on a baseline assessment. Also, [95] stated that the introduction of a sustainable food system will ensure the food and nutritional needs of the present as well as future generations. [96] has mentioned several interventions for the sustainability of TCSs and poverty alleviation and their outcome indicators. However, of the remaining TCSs, nearly 50% are dilapidated or abandoned [97]. The harmony between these components has been weakened due to the malfunctioning of the system [39]. Hence, ecosystem-based approaches are vital to identifying sustainable agriculture, ecosystem services, and food security.

The Driver–Pressure–State–Impact–Response (DPSIR) framework is one of the useful tools to provide information based on cause-effect relationships. It identifies human–ecological system interactions and activities and is associated with an ecosystem-based management approach. The DPSIR framework was introduced by the Organization for Economic Co-operation and Development (OECD) and later implemented by the United Nations and the European Environmental Agency [98]. In literature, evidence found DPSIR framework has been utilized in forest management [99], water problems [100], and coastal environment management [101]. Figure 5 depicts the typical DPSIR framework. Researchers have utilized this framework to provide requirements for policy reforms [102]. However, it has also been criticized by researchers due to some ambiguities in the concept [103].

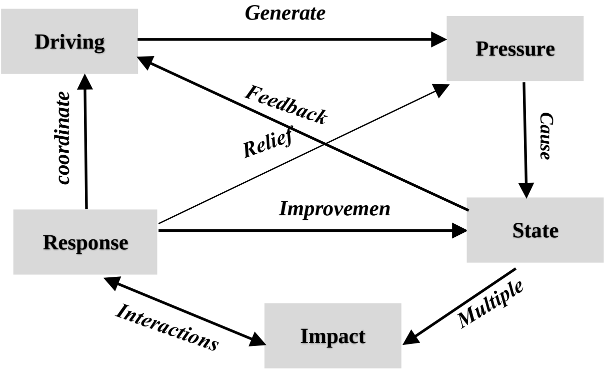

**Figure 5: DPSIR conceptual framework [100]**

The DPSIR framework begins with driving forces (ex: population increase) through pressure (ex: deforestation and forest degradation) to state (ex: ecosystem destruction) and impacts (ex: biodiversity reduction) leading to responses (ex: forest restoration and afforestation).

The DPSIR framework can be used to conceptualize the management approaches to ensure sustainability in agriculture and food security through different strategies. The DPSIR framework for a TCS ecosystem is given in Figure 6, which summarizes and visualizes demographic, socio-economic environmental, and political pressures, states, impacts of changes in the tank ecosystem, and possible responses in a simplified form.

### 5.1 Drivers

Drivers are the key reason for changing the ecosystem. The causes can be demographic, socio-economic environmental or natural, and political. The population increase, deforestation, and encroachments are demographic divers whereas, intensive agriculture, chemical fertilizer misuse/overuse, unplanned construction of dams, spills and agro-wells, and unplanned desilting processes are some of the socio-economic drivers that cause pressure in the tank cascade ecosystem. Further, climate change is natural or environmental driver which directly affects the sustainability of the ecosystem causing stresses on water resources. Effects from climate change fluctuations have caused water scarcity or floods which highly effect on cultivation. Political drivers are changes in policy decisions and un-stabilized political conditions.

### 5.2 Pressures and state

Due to some drivers, pressures on the environment and tank ecosystem could be identified. As a result of the population increase, the demand for provisioning services (water, food, fuelwood/biomass energy, fiber) of TCSs has increased. Due to the high demand for these, high landscape conversion has occurred pressurizing the environment and tank ecosystem.

Also, deforestation due to the rapid settlement of people even caused a hydrological imbalance, biodiversity, and malaria outbreaks [104]. Tanks, tank bunds, and canals have been destroyed owing to settlements [105]. Increased settlements may cause rapid waste disposal problems, creating soil pollution and water quality deterioration. Intensification of agriculture has increased water demand and has increased water withdrawals for irrigation. Further, it promotes nutrient and pesticide drainage from agricultural lands. The addition of these compounds has caused the prolific growth of invasive alien species such as *Eichornia crassipus*. Intensification also generally causes pressure on fauna and flora. Unplanned agro-wells due to agriculture may over-exploit the water in shallow aquifers and may dry up during dry periods and deteriorate the water quality.

As an example, droughts/ prolonged dry periods due to climate change will worsen problems related to increasing demands for water, groundwater recharge, aquatic biodiversity, endangering wildlife, fishing activities, etc. Due to droughts, the tanks may be dried up. Also, increasing temperature will cause eutrophication due to the high demand for oxygen in water resources, and the high mortality rate in aquatic species. The potential effects of climate change affect water balance and the variability over space and time. Precipitation, evaporation from the surface, soil moisture retention, groundwater recharge, and water resources including rivers, lakes, and tanks are the key components that are vulnerable to climate change. Frequent floods and rapid changes in rainfall distribution and intensity. Also, floods will increase soil erosion and deposition of sediments in retention areas and tank bases.

Agriculture is one of the basic processes that is sensitive to climate change. Among the ecosystem services provided by TCSs, water for irrigating paddy lands is one of the foremost inputs. At present, nearly 246,540 ha of paddy-cultivated areas are irrigated by using operational TCSs [36]. It is nearly 35 percent of the total irrigated paddy lands in Sri Lanka, and TCSs account for 191,000 MT paddy yield annually [106]. As the staple food in Sri Lanka, rice yield and productivity ensure sustainable household and national-level food security.

Policies developed and changes would pressure the livelihood of rural populations who depend on agriculture. Policy incoherence has resulted in mismanagement of TCSs [107]. Since 1979 Agrarian Services Act No 58 has been amended several times and in 2000 Agrarian Development Act was introduced [108]. In 1987 amendment No.13 to the Constitution of Sri Lanka decentralized and devolved as a provincial council mandate thus creating barriers to managing minor irrigation systems creating duplication of the mandate in the Department of Agrarian Development in the Central Government. Therefore, the decentralization was not effective as expected. Hence Provincial departments were seriously affected due to lack of technical and financial resources.

### 5.3 Impact

The GDP contributed by the agriculture sector has declined over the years, visualizing lower land productivity. Statistics showed that the country has been dependent on food imports for a long time [95] depicting destabilization in self-sufficiency. Self-sufficiency is an essential aspect of human well-being. Finally, it identifies their resilience to the vicissitudes of life. If the society suffers from food shortages, then children with malnutrition and retardation in education and health services could be observed in that society. Food insecurity is a major problem in Sri Lanka. Among the people who are insecure in food, 30.1% are severely insecure whereas 39.3%, 21.7%, and 8.9% are moderately, mildly, and marginally insecure, respectively [109]. Furthermore, low birth weight and stunted growth in under-age 5 groups is around 16% each [110]. The prevalence for all selected chronic illnesses is clearly increasing with age [111]. Political instability, and inadequate financial resources, are the key causes of food insecurity.

Due to the drivers and pressures over TCSs biodiversity within agricultural landscapes, tanks, and adjacent landscapes (*Gasgommana, thaulla, iswetiya*) has declined. Some chemical and microbiological pollutants due to the over-application of chemical fertilizers and misuse, cause health problems to humans. The evidence of CKDu in Sri Lanka has been increasing at alarming rates. It has turned into a major health problem in North Central, North-Western, and Uva, provinces [112].

### 5.4 Response

DPSIR framework points out the possible strategies to safeguard the sustainability of TCS ensuring food security. These strategies can be divided into restoration of TCSs, capacity building, institutional framework, livelihood involvements, and environmental interventions.

The rehabilitation of the TCSs is one such management strategy that will ensure the sustainability of the system. Also, the rehabilitation and restoration of TCSs is essential for the food and livelihood security of rural farming communities in the

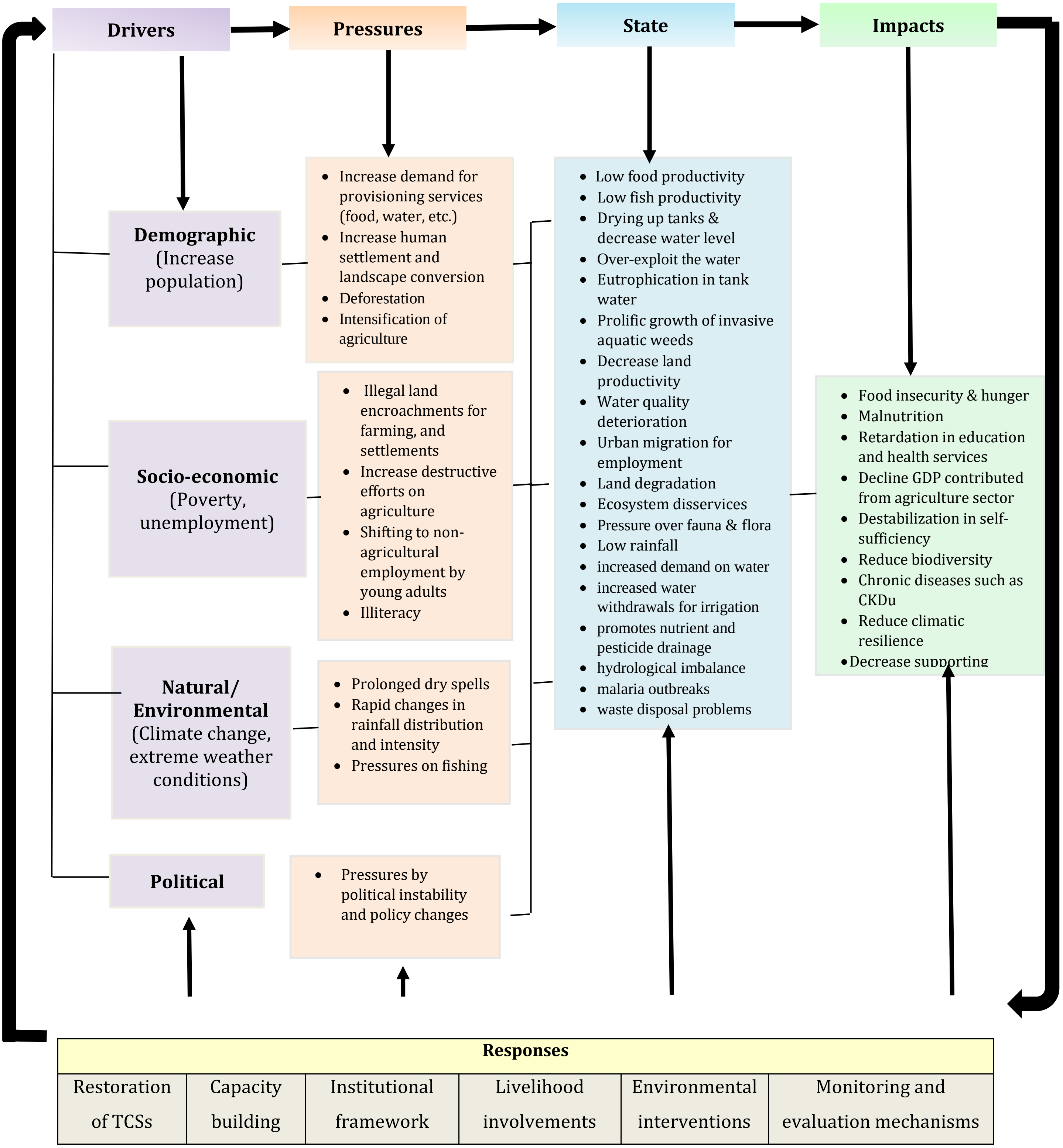

**Figure 6: DIPSIR framework for Tank cascade system**

dry zone. This is because a large percentage of food production in the dry zone is achieved from irrigated agriculture. Tank/TCS rehabilitation means either the restoration of an abandoned tank/group of tanks or, the improvement of a working tank/group of tanks. Further, [25] explained a broader classification of rehabilitation actions. The final goal of tank rehabilitation is to ensure the improvement of its performance. A rational approach should be adopted in selecting tanks to rehabilitate. Also, [90] has identified several selection criteria for the rehabilitation process and a multidimensional framework for developing tank cascades. These processes should go through a cost-effective rehabilitation. Further, rehabilitation practiced as site-specific work should be implemented with a master plan [113].

During the last few decades, TCSs have been under rehabilitation process by Government and non-governmental agencies [107] after introducing the Agrarian Services Act No 58 of 1979 [11]. The village irrigation rehabilitation project (VIRP) during the period of 1981-1985 has selected tanks that have not less than 8 ha command area and at least 10 farmer beneficiary families for restoration. The NIRP, National Irrigation Rehabilitation Project (1991–1998) has selected tanks with not less than 4 ha command area. Also, under the Green Climate fund, the United Nations Development Program is funded for the rehabilitation of TCSs [36]. Recently, the program *Wari Saubagya* targeted the rehabilitation of 5,000 tanks under the government allocation [90]. The problems encountered in destructed TCSs were rectified under these projects. Of 488 tanks in Puttalam 78 were rehabilitated by the Integrated Rural Development (IRD) Project [114]. Three stages of rehabilitation work in the modern era have been identified by [90] with the expectations of increasing agricultural production. Further, he has mentioned that the two terms restoration and rehabilitation are not enough for the sustainability of the TCSs, thus the term upgrading is appropriate for further development. Recently, the Climate Smart Irrigated Agriculture Project (CSIAP) sponsored by the World Bank has identified hot spot areas in the North, Northcentral, Northwestern, South, and Southeastern parts of Sri Lanka. The key components of this project are managing water for irrigation, agriculture production and marketing, and contingent emergency response. Rehabilitation of irrigation systems including tank cascades and individual tanks, operation and maintenance of irrigation systems, and implementation of watershed treatment are some of the activities under managing water for irrigation. Developing climate-resilient practices and technologies are under climate-smart agriculture. The emergency response component allows adverse economic and social impacts caused by a natural disaster or a crisis.

As another strategy, capacity building such as training on water conservation, water conservation measures, efficient irrigation techniques, water demand management strategies, awareness of the environment and the wise use of resources, and establishment of local governance structures such as environmental protection committees can be implemented. The “wise use” is defined as maintaining of ecological components of wetlands to cater to ecosystem services for the well-being of its stakeholders and poverty alleviation [42]. The restructuring of farmer and fisheries associations existing in the village and developing a group of experts who have experience in water management and fisheries is important. To avoid youth migrating from rural to urban can be reduced by establishing youth-dominant societies to ensure active participation in ecosystem conservation. Also, establishing green concept and sustainable village concepts will enhance the community involvement towards sustainability within the village. The trainings on different value-added products that are readily available inside the village will reduce the post-harvest losses and marketing problems. The awareness of entrepreneurship may reduce poverty and the livelihood of rural communities. Further, developing a research task force and prioritizing the research, and providing an exchange mechanism to the researchers through, newsgroups, websites, joint projects will help to disseminate the results. Developing institutional mechanisms to share reliable water resource information may also help to manage the system. Introducing rainwater harvesting methods will be another strategy of efficient water utilization practice. Further, the introduction of new degree programs, and short courses, can improve the knowledge of water management concepts. Awareness of communities for wise use of water resources and other resources may improve their livelihood. Stakeholder engagement and participation in all the above-mentioned activities are a very important response that helps with capacity building.

The institutional framework is very important in policies related to environmental management such as water for irrigation and domestic uses, aquaculture, ecosystem, climate change, and forestry. In Sri Lanka, several policies and legal plans have been implemented. The State Land Ordinance No. 8 of 1947 defined the right to the flow, management, and control of water in a public lake or stream. In 1964 Water Resource Act No. 29 defined the water resources, soil conservation, water pollution, use of water resources, and integrated plans for conservation, utilization, control, and development of water resources. Further, there was the Flood Protection Ordinance (No. 3 of 1924) and, the Agrarian Service Act. (No. 58 of 1979), National environmental act (No 47 of 1980), Irrigation ordinance (No 32 of 1946). New policies should be introduced for a rational system for water allocation by prioritizing the demand for water during water shortages, and only to essential services. Policies should be provided to punish ecosystem illegalities such as illegal logging, illegal encroachments, and illegal farming. The sudden and unrealistic implementation of new policies in recent years such as banning chemical fertilizer usage completely had caused community protest leading to yield reduction and food insecurity. Policy enforcements should be formed to ensure farmers' rights to manage and utilize cascade ecosystems.

The livelihood involvement is very important to reduce the pressures on the cascade ecosystem. Although the villages are aware of the importance of maintaining the TCSs, any kind of degrading the system (over-exploitation) will not cease until any alternatives or livelihoods are offered. However, the in-kind contribution of villages has estimated their contribution towards the restoration of tanks and well-managed systems [115].

Environmental interventions to conserve and manage TCSs can be practiced via managing forest catchment (*mukalana*) in the upland, adjacent tree belt (*gasgommana*), and interceptor (*kattakaduwa*) by reforestation. Agro-forestry is also another way to reduce the pressures on ecosystems. Adaptation measures can be implemented for the changes in rainfall and thermal regimes by climate change. Perennial crop cultivation through intensive and efficient irrigation techniques (sprinkler irrigation for field crop cultivation), promotes conservation techniques such as cultivating with mulches, alley cropping, and intercropping, promotes integrated farming with crops and animals, strengthening the organic matter application in farming, breeding drought resistance varieties (coarse grains, pulses, and oil seed crops), breeding rice varieties for short age with high yields, breeding crop varieties for pest and disease resistance, high temperature tolerance, are possible strategies to adopt climate change. Usage of environmental monitoring and warning systems may forecast the changes of climate in a short period to the farmers. Regular Monitoring and evaluation mechanisms to assess the performance, impact, and effectiveness of TCS are also important as responses to address driving forces, pressure, state, and impacts of TCSs.

## 6. Conclusion

The historical Tank cascade systems in Sri Lanka are considered as a technology that ensures sustainable agriculture and food security. It is important to identify the ecosystem services provided by the TCSs and safeguard the system for long-term usability. There are several studies conducted previously on TCSs under different themes. These have been focused on the nature of the system and the management, productivity, geological and geographical aspects, socio-economic aspects, climatologic and ecological aspects, biodiversity, hydrology, water quality and water budgeting, sediments, rehabilitation, indices of sustainability for assessing TCSs, information technology and networking and evolution of tank cascade studies in different eras. All these studies have shown the importance of TCSs as a promising component in sustainable agriculture. The various anthropogenic activities, climate change, political instability, and inadequate financial resources, are the key causes for the destruction of TCSs. Recently, several tank rehabilitation programs were implemented in the dry zone. However, these programs would not be successful if it is not properly planned and implemented. Therefore, it is vital to conceptualize the drive, pressure, state, impact, and responses of the system to properly manage the system. The DIPSIR framework is a method to identify the cause-effect relationships in TCSs. Thus, this tool will identify the vulnerability of the system exploring the drivers, pressures, state, and impacts, and help to make appropriate management decisions and to formulate policies as responses. A long-term sustainable program with the collective efforts of the Government and individuals would resilient the tank cascade systems to overcome future food insecurity by sustainable agriculture.

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