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Cascade Tank Water Quality Management: A Case Study in *Thirappane* Tank Cascade System, Sri Lanka

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ABSTRACT

Tank cascade system (TCS) is a series of tanks located in a meso-catchment and has been accepted as a Globally Important Agricultural Heritage System found in Sri Lanka. Ecosystem components of the TCS play a major role in purifying water within the system. This study attempted to investigate the water quality status and the farmers' willingness to rehabilitate the ecosystem components of the Thirappane TCS. Drinking and irrigation water quality parameters were tested in 34 locations and drinking and irrigation water quality indexes were calculated. Participatory rural appraisal and a questioner survey were conducted to gather social data. Water of TCS was observed to be appropriate for irrigation but not for drinking during the *Maha* cropping season. Based on the results of the Nitrate (as NO_3^-) and Total Phosphate (as PO_4^{3-}), water of TCS can be categorized as eutrophic. Presence of ecosystem features of tank cascade system, annual income of the respondents, satisfaction on the quality of water for drinking, and the awareness about the tank cascade system significantly influenced the participatory decisions of the community on the rehabilitation of TCS. This study shall be an example and an eye opener to formulate sustainable tank cascade management plan.

1. Introduction

A watershed system provides a range of valuable ecosystem services which can be categorized as provisioning of food, water, fibre and fuel; regulating droughts, flood and water purification; cultural covering providing humans with recreational, spiritual and aesthetic values and supporting services such as basic ecological properties/processes (eg. soil formation) [1]. Many of these functions are related to the water and its suspended and dissolved constituents [2]. Water purification is a vital function of an ecosystem. Therefore, understanding the ecosystem functions and promotion of eco-engineering structures and techniques is vital in water purification as those are no regret and multi beneficial approaches.

Sri Lanka is a tropical island demarcated into three main climatic zones wet, dry and intermediate. Rainwater harvesting with man-made small reservoirs or "*Wewa*"s

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(tanks) is the major source of water for irrigation and drinking in the dry zone of Sri Lanka. These tanks were built by the early inhabitants in a cluster arrangement aligned with the water flow and are now referred to as Tank Cascade Systems (TCS). TCS of Sri Lanka is a special kind of watershed within which a series of tanks are located one over the other in terms of water flow hydraulics aligned with respect to the natural flow of water. TCS also provides the production, regulatory, supporting and other cultural services similar to that of a general watershed. TCS has been acknowledged as a Globally Important Agricultural Heritage Systems (GIAHS) by the Food and Agriculture Organization [3] because this system is an improved agricultural system managed with time tested indigenous techniques and it comprises of outstanding landscapes of aesthetic beauty and resilient ecosystems. Proper functioning of ecosystem components and bio engineering structures such as the earthen dam (*We-kanda*), spillways (*Pita Wana*), sluice gates (*Sorrowwa*), valve pit (*BissoKotuwa*), upstream conservation bund (*isweti-ya*), upper peripheral gentle sloping land (*thaulla*), closer catchment (*wew ismaththa*), upstream wind barrier made of tree plantations (*gasgommana*), downstream wind barrier, located in between the sluice and paddy (*kattakaduwa*), and land strip around the hamlet for protection (*tisbamme*) warrant the improved quality, quantity and sustainability of the water of the TCS. The importance of these components is highlighted in many publications and attempts have been reported to prove those functions scientifically [4,5]. The application of eco-engineering components and the use of existing structures need to be fully utilized as these are non-regret approaches and have multiple benefits. This time tested system of rainwater harvesting is a sound adaptation strategy to face consequences of climate change and variability related issues.

However, at present the system is degraded due to changes in land use pattern, improper land management practices, and the lack of due consideration for the ancient ecosystem components and the structural components by the present planners [6]. Moreover, population rise, urbanization and modernization might have impaired the services of TCS. Changes in agricultural practices such as heavy dependence on increased amount of inorganic fertilizer, pesticides and cultivation neglecting soil conservation [7] may have direct impact on TCS where main land use is in agriculture. It is evident that agro chemicals improve the crop productivity while leading to soil contamination and transfer of contaminant to food chains causing several human health problems [8]. One such health issue is Chronic Kidney Disease of unknown aetiology (CKDu) prevailing in both dry and intermediate zones of Sri Lanka. Dry and intermediate zones of the country are the home of these ancient TCS in which more number of patients are reported and many of them are farmers. Aetiology of CKDu is still a mystery, however it is hypothesized that the agro chemicals might be the cause for CKDu [9]. This manuscript does not aim to discuss the aetiology of CKDu but attempts to investigate the present status of water quality and farmers' perception on possible water quality improvement and thereby to introduce best management practices for the farmers in order to minimize the impairment of water quality of the TCS. Abeysingha *et al.* [6], have shown that if ecosystem components of TCS are rehabilitated, spreading of CKDu could be controlled, even with a control measure such as the application of recommended doses of inorganic fertilizers. As a basic step, the water quality status of the entire cascade need to be understood to formulate a proper watershed management plan. In such watershed management plan, the stakeholder commitment, participation and their perception on the rehabilitation of TCS are vital. Therefore, this manuscript attempts to discuss the water quality status both with respect to drinking and irrigation in the area during the major rain (*Maha*) cropping season and the community perception on rehabilitation of ecosystem components of the TCS in improving water quality status.

2. Material and Methods

2.1 Study Site

The *Thirappane* cascade system (TCS) is located about 25 km south of *Anuradhapura* city in Sri Lanka. It is one of the typical of hundreds of irrigation tank cascade systems that are found in the dry and intermediate zones of Sri Lanka. *Thirappane* tank cascade system is mainly comprised of five tanks, *Vendaramkulama*, *Badugama*, *Bulankulama*, *Meegasagama* and *Allisthana* tanks (Figure 1). In this tank system, command area of one upstream tank is a part of catchment of the next downstream tank and ultimately all water of these tanks are emptied to *Thirappane* tank, a larger tank. Administratively this area covers *Thirappane* Divisional Secretariat Division and *Thirappane* Agrarian Service Division of *Anuradhapura* district. According to available statistics in the Divisional Office of the Department of Agrarian Development, there are three farmer organizations in the TCS. It is observed in this TCS, the modernization has `changed the sustainable traditional farming practices and also the human encroachments have disturbed the eco-system components of the TCS. Figure 2 shows some prominent structural and ecosystem components of *Meegasagama* tank which is a

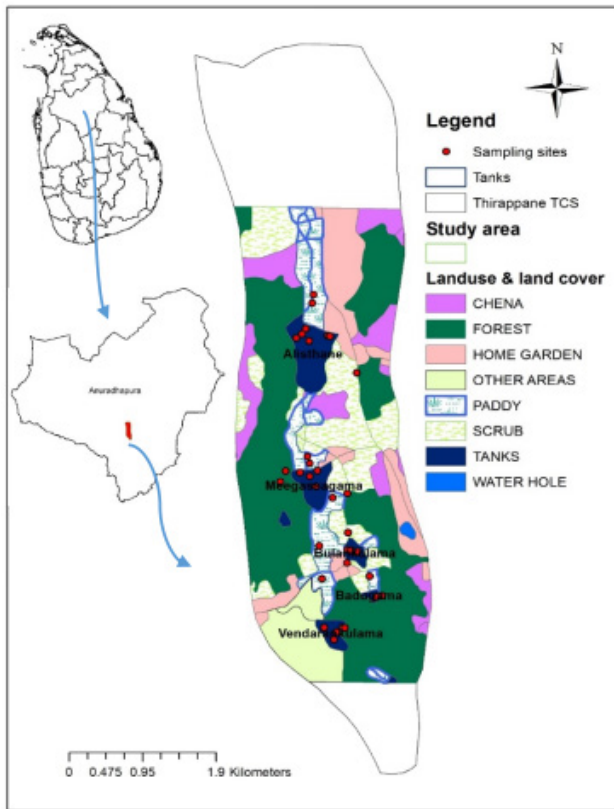part of TCS and the map was made during the dry season.

Figure 1. The geographical locations of *Thirappane* Tank cascade system, studied area, tanks, land use, land cover and the water sampling points. The direction of water flow is towards north.

Figure 2. Part of *Thirappane* tank cascade showing Meegassagama tank and its prominent components (Google Earth map taken during dry season)

2.2 Water Quality Survey

Five main tanks (*Vendaramkulama, Badugama, Bu-lankulama, Meegasagama* and *Allisthana* tanks) and their catchments and command areas were selected to monitor the water quality status in the TCS. The selected area of water quality monitoring represented the entire TCS except for the most downstream section of the TCS. Community in the area supported to select 34 sampling points which include the tank water spread area, catchment and the command area. Attention was drawn to represent the entire tank water when particularly choosing water sampling sites of the tanks. Surface water quality sampling sites of these five tanks, their catchments and command areas are shown in Figure 1. However, as per the definition of TCS, the command area of one upstream tank becomes the catchment area of the next downstream tank. Water was sampled during the early hours of the day (around 9.30 to 10.30) on 10th January 2019 (Fist sampling), 11th February 2019 (Second sampling) and 28th April 2019 (Third sampling). Two samples were taken from each of these 34 sites and analysed separately. However, sampling was limited to three times because of the non-availability of water in the sampling sites because of the prevailed drought and the higher evapotranspiration. First sampling day represented the full supply level and water levels of the area were medium during the second and third sampling times according to the community feedback. Sampling sites have to be little shifted during the third time sampling due to the water level receding. During this time, the major cropping season of the dry zone, the *Maha* (October to March) has been commenced and the most of the initial cultivation practices have been finished. This area receives a total average annual rainfall of about 1,445 mm and also the area receives more water during October to March period especially from the North East monsoon rains.

The collected water samples were tested for various important water quality parameters and some parameters were derived based on the results of the laboratory tested parameters. As physical parameters, turbidity, temperature and colour and as physico-chemical parameters, EC and pH were tested using standard methods. As chemical parameters, chloride (as Cl^-), total alkalinity (as $CaCO_3$), free ammonia (as NH_3), nitrate (as NO_3^-), fluoride (as F^-), total phosphate (as PO_4^{3-}), sulphate (as SO_4^{2-}), HCO_3^- (as $CaCO_3$), CO_3^{2-} (as $CaCO_3$), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were measured using standard methods [10]. Moreover, Na, Ca, Mg, K, Cu, Cd, Pb, As, Cr, Mn, Zn, Ni, Hg, Fe and Al were also tested as metallic elements using Inductively Coupled Plasma Optical Emission Spectroscopy

(ICP-OES, Thermo, icap7400DUO MFC) following the method [10] in all sampling points.

Other than the above-mentioned parameters, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Sodium Percentage (SP), Kelly's ratio (KR), Magnesium hazard (MH) and Permeability index (PI) were also determined to test the suitability of water especially for irrigation.

Residual Sodium Carbonate (RSC) index was calculated from the difference of total carbonate and bicarbonate with total calcium and magnesium [11].

$$RSC\ index = [HCO_3^- + CO_3^{2-}] - [Ca^{2+} + Mg^{2+}] \quad (1)$$

SAR was calculated from the ratio of sodium to calcium and magnesium [12].

$$SAR = \frac{Na^+}{\sqrt{\dfrac{Ca^{2+} + Mg^{2+}}{2}}} \quad (2)$$

Sodium percentage (Na %) was calculated using the following formula,

$$Na\,(\%) = \left(\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + K^+}\right) \times 100 \quad (3)$$

The Kelly's ratio was measured using the expression [13],

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (4)$$

The Magnesium hazard (MH) was calculated using the equation [14],

$$MH = \left(\frac{Mg^+}{Ca^{2+} + Mg^{2+}}\right) \times 100 \quad (5)$$

Permeability index was calculated using the following equation

$$PI = \frac{Na^+ + \sqrt{HCO_3^-\ x100}}{(Ca^{2+} + Mg^{2+} + Na^+)} \quad (6)$$

All ionic concentrations are expressed in meq/L when calculating SAR, RSC, KR, MH and PI. Following Brindha & Kavitha [15]; Houatmia *et al.,* [16], this study calculated the Irrigation water quality index (IWQI) and also the Drinking water quality index (DWQI) only for the tank water considering the FAO and SLS guidelines respectively.

Irrigation water quality index IWQI

$$IWQI = \Sigma(Wn \times Qn) \quad (7)$$

Wn = Unit weight of the nth parameter

Qn = Quality rating or sub index corresponding to the nth parameter

$$Wn = \frac{K}{Sn} \quad (8)$$

K = Proportionality constant which is computed by

$$K = \frac{1}{\sum_{i=1}^{n} \dfrac{1}{S_n}} \quad (9)$$

$$\sum_{i=1}^{n} \frac{1}{S_n} = \frac{1}{S_{pH}} + \frac{1}{S_{EC}} + \frac{1}{S_{Ca}} \ldots + \frac{1}{S_n} \quad (10)$$

Sn = Standard permissible limit in water for the nth parameter

$$Qn = 100 \times \frac{[Vn - Vi]}{[Sn - Vi]} \quad (11)$$

Where

Vn = measure value of the nth parameter in water at a sampling location

Vi = ideal value of the nth parameter in water (0 for all parameters).

Study used EC, MH, RSC, SAR, Na %, NO_3^- and PI for the calculation of IWQI and the highest suitability limits were taken from the [15] and [17]. Similar calculation method was used to calculate the DWQI. Turbidity, pH, EC, NH_3, NO_3^-, SO_4^{2-}, PO_4^{3-}, Alkalinity, TDS, Na, Al, Ca, Cl, COD, Cu, Fe, F, Mn, Mg, Zn were used in calculating the DWQI and highest desirable limits of SLS 614 [18] were used and where there is no Sri Lankan (SLS) standard, study used the WHO drinking water guideline (2011).

2.3 Participatory Rural Appraisal (PRA) and Questioner Survey

This research project used Participatory Rural Appraisal (PRA) in order to establish community participation as a tool in assessing the present status of the TCS and changing management practices of the farmer community. This programme was conducted in two stages with an initial meeting and a detailed second meeting. Transect walk was held after the second day meeting to verify the information gathered during two days. Transect walk reviewed the ecology of the catchment of the tanks, current situation of the cascade features, present livelihood patterns, farmer practices, fertilizer application patterns etc. Around 40

participants attended the activity including the extension field officers. In addition to the PRA activity, a pre-tested questioner was administered to get some specific information on the agricultural practices, and the level of awareness of ecosystem components of TCS. For this survey, 60 farmers were selected which was 1/3 of total members of each farmer organizations. Though there were five tanks, only four farmer organizations existed in this TCS (Table 1). Even though, there are separate farmer organizations. These farmers are sociologically connected as they live in the same cascade and thus the farming practices are the same.

Table 1. Farmer organizations and total number of farmers selected for the survey.

Name of the tank	Farmer organization	Total number of farmers	Number of farmers selected for the interview
Alisthana	*Samagi*	20	8
Meegassegama	*Parakum*	58	24
Badugama	*Vendarankulama*	5	2
Vendarankulama		36	15
Bulankulama	*Pubudu*	25	11
Total number of farmers		144	60

The survey data were analysed using descriptive statistics and logistic regression to identify the factors affecting the farmers' willingness to rehabilitate the TCS particularly improve the water quality.

3. Results and Discussion

Safe drinking water is a necessity for humans. Quantity and quality of crops are determined by the availability of water in sufficient quality. Water quality, tested by assessing the properties of water against a set of standards, was used to determine whether water available is suitable for drinking, irrigation or safe for the environment in this TCS.

During the PRA activity, farmers in the area helped in choosing the water quality monitoring sites by identifying drainage canals from one tank to the downstream tanks. Also they briefed the causes for pollution in the area. First, the water quality status of the TCS and then the farmers' perception towards the ecosystem components of the TCS in purifying the water will be discussed.

3.1 Variation of Physical and Physicochemical Water Quality Parameters

Physical and physicochemical parameters such as pH, turbidity, Electrical Conductivity (EC), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were tested over the entire cascade and their average results of three times sampling are discussed.

pH.: Measurement of pH indicates the acidity or alkalinity of the water. Standard pH range given by SLS 614 (18) drinking water quality standard is 6.5 to 8.5 (Table 2). Average pH of water in the entire TCS is within the limits stipulated by SLS 614 [18] drinking water quality standard. Also this water is within the suitability range of pH proposed by FAO irrigation water quality limits (Table 2).

Table 2. Statistical summary of the physical and chemical water quality parameters tested over surface water (average over 34 sites)

Parameter	Max	Min	Mean	SD	SLS	Irrigation-Standard*
Turbidity (NTU)	27.75	1.83	6.54	5.35	2.00	2.00
pH	7.68	6.60	7.16	0.28	6.5-8.5	6.5-8.4
Electrical Conductivity (μS/cm)	1215.50	117.70	403.02	242.93		< 700
Chloride (as Cl^-)	159.85	9.45	51.24	37.83	250.00	< 140
Total Alkalinity (as $CaCO_3$)	451.00	44.33	121.23	90.80	200	
Free Ammonia (as NH_3)	0.30	0.00	0.09	0.07	0.06	
Nitrate (as NO_3^-)	14.23	3.48	5.83	2.13	50.00	< 5
Fluoride (as F^-)	0.85	0.00	0.12	0.19	1.00	
Total Phosphate (as PO_4^{3-})	3.76	0.22	0.69	0.59	2.00	
Sulphate (as SO_4^{2-})	29.54	0.00	4.00	6.82	250.00	
HCO_3^- (as $CaCO_3$)	449.35	41.00	114.81	92.59		
$CO3^{2-}$ (as $CaCO_3$)	26.67	0.00	6.36	7.58		
BOD	7.35	0.20	2.12	1.41		
COD	71.55	5.10	29.58	14.48	10.00	
TSS	41.00	2.00	6.40	6.72		
TDS	745.75	88.00	234.90	145.08	500.00	

Note: All units are mg/L unless otherwise mentioned. SLS: Sri Lanka Standard for potable water quality; *Irrigation water quality standard [19].

Turbidity:

Turbidity of surface water including the water in the command area was in the range of 1.4 to 27.7 NTU with a mean of 6.5 NTU (Table 2). Even the mean turbidity was higher than the value given for drinking water by the SLS 614[18]. According to US EPA, turbidity level lower than 2 NTU is only suitable for directly consumed crops and unrestricted irrigation. However, Spain recommends a level lower than 10 NTU for vegetables especially for

waste water fed irrigation [20]. A high level of turbidity may influence on the performance of the irrigation facility, and can lower the hydraulic conductivity of the soil and pollute the soil surface through surface flow. In addition, through the field survey with farmers, study identified the areas which need to be focused on the turbidity reduction.

Electrical Conductivity (EC):

EC is a measure of dissolved salts in water and the maximum allowable level of conductivity for drinking water is not given by SLS 614[18] or WHO drinking water quality limits. The results show that the measured conductivity of all water samples ranges from 117.7 μS/cm to 1,215.5 μS/cm, and the average conductivity value is 403 μS/cm (Table 2). However for irrigation water, FAO has stipulated EC values less than 700 μS/cm is suitable for any crops. Thus the water even in command area of the TCS is suitable for irrigation water in terms of EC.

Total Suspended Solids (TSS) and Total Dissolved Solids (TDS):

TDS consists of inorganic matters and small amounts of organic matter, which are present as solution in water. TDS in water varied from 88 to 745mg/L with a mean of 234 mg/L (Table 2). The standard or allowable value of the TDS set by SLS 614 [18] is 500 mg/L. TDS during the study period is good for drinking purpose except for few areas. TSS is organic or inorganic matter suspended over the water and it varied from 2 to 41 mg/L in *Thirappane* surface water.

3.2 Variation of Chemical Water Quality Parameters

Alkalinity:

This parameter is an expression of buffering capacity of water and is related to hardness because the main source of alkalinity usually results in from carbonate rocks (limestone) which are mostly $CaCO_3$. Fish and aquatic life is protected by the alkalinity as it buffers against rapid pH changes [20]. Fish naturally breed in these tanks. Therefore required level of alkalinity is important for the aquatic life of these tanks. Alkalinity of TCS varied from 44 to 451 mg/L with a mean of 121 mg/L. The standard values for the alkalinity given by SLS 614 is 200 and the mean value observed is below the critical level.

Chloride and Fluoride:

Chlorides and Fluorides are anions found in natural water. The chloride content normally increases in parallel to the increase in the mineral contents. The distribution of chloride content values, ranges from 9 to 160 mg/L with the mean value of 51 mg/L and are within the permissible limits.

Generally, considerable content of fluoride is observed in the groundwater (sometimes in excess of 5 mg/L) in the Dry Zone, in the North Central Province [21]. However, the surface water doesn't contain high fluoride content and this study also observed a mean value of 0.12 mg/L and which is within the permissible level of SLS 614 for drinking water.

Carbonate and bicarbonate

Carbonate and bicarbonate values were used to analyse the residual sodium carbonate (RSC) values of the TCS. Water containing a high concentration of bicarbonate has a tendency for calcium and magnesium to precipitate which will lead to a reduction in the concentration of calcium and magnesium and a relative increase in sodium. HCO_3^- (as $CaCO_3$) and CO_3^{2-} (as $CaCO_3$) concentrations varied from 41 to 449 mg/L and 0 to 26 mg/L respectively in the TCS.

Nitrate (as NO_3^-) and Total Phosphate (as PO_4^{3-}):

It is recorded that North Central Province where *Thirappane* TCS is located, uses fertilizer in high doses sometimes six to ten times in excess of levels recommended by the department of agriculture, Sri Lanka [22]. The main sources of nitrate and phosphate in water in the area are the excess use of inorganic fertilizer and also rearing of cattle with poor management practices. Mean nitrate and phosphate levels during the studied period of the entire cascade were 5.8 and 0.69 mg/L respectively which are within the recommended level of SLS 614 for drinking water, 50 mg/L and 2 mg/L respectively (Table 2). In addition, the maximum value recorded for phosphate P (3.76 mg/L) exceeded the SLS 614 level for drinking water. These higher concentrated areas of nitrate and phosphate P are located in the drainage canals of command area of *Bulankulama* and *Badugama* tanks respectively. However, these water reach the downstream tanks and total nitrogen and phosphorous in water lead to eutrophication of the tanks. Eutrophication occurs when N content in water reaches 300 μg/L and P concentration exceeds 20 μg/L [23]. Considering these critical values, water of TCS can be categorized as eutrophic. Large number of aquatic weeds could also be observed floating over the water surfaces symbolizing the status of eutrophication of tanks in the TCS.

Free Ammonia (as NH_3):

Ammonia is present in variable concentrations in many surface water bodies and water supplies. It is a product of microbial activity and considered also as an indicator of sanitary pollution. In addition higher ammonia concentration is lethal for the fish and reported that lethal ammonia concentration limits for a variety of fish species ranges from 0.2 to 2.0 mg/L (PG, https://water-research.net/in-

dex.php/ammonia-in-groundwater-runoff-and-streams). Sri Lanka Standard (SLS 614) for free ammonia in drinking water is 0.06 mg/L. Average ammonia concentration in TCS is 0.09 mg/L and it varied from 0 to 0.3 mg/L. Higher concentration was only observed closer to *Bulankulama* tank which may probably be due to the digestion of leaves in the area according to the field observation.

BOD and COD:

BOD value approximates the amount of oxidizable organic matter by a mixed population of microorganisms while COD is an index of oxygen required in oxidizing the organic compounds present in water by means of chemical reaction [24]. These two indicators are therefore used as measures of degree of water pollution and the waste water strength. COD level of the TCS varied from 5.1 to 71.5 mg/L with a mean of 29.6 mg/L. SLS 614 recommends 10 mg/L of COD for drinking water and therefore the water in the TCS is not in good status as a source of drinking water. SLS 722 (1985) [25], the raw water tolerance limits for drinking water supply specifies BOD 5 mg/L for raw water to be suitable for drinking after treatment. BOD in the TCS was in the range of 0.2 to 7.3 ppm with an average of 2.1 ppm. Therefore this water, especially in the command area contains a higher amount of oxidizable organic matter. These findings are very useful for implementing a tank cascade management plan.

Table 3. Statistical summary of trace elemental water quality parameters tested over surface water (average over 34 sites)

Element	Max	Min	Mean	SD	SLS
Na	68.32	5.17	30.02	15.57	200.00
Mg	87.05	4.33	18.50	16.74	30.00
K	14.02	3.87	5.80	1.90	
Ca	150.55	15.37	42.11	32.13	100.00
Cu	2.80	0.00	0.64	0.85	1.00
Cd	0.00	0.00	0.00	0.00	0.003
Pb	8.00	0.00	1.93	1.75	0.01
As (µg/L)	0.92	0.00	0.10	0.25	10
Hg (µg/L)	0.06	0.00	0.00	0.01	1
Al	0.12	0.00	0.02	0.03	0.20
Cr	0.34	0.02	0.18	0.07	0.05
Fe	4.89	0.38	1.18	0.95	0.30
Mn	1.75	0.00	0.06	0.30	0.10
Zn	8.95	0.01	1.25	1.89	3.00
Ni	0.00	0.00	0.00	0.00	0.02

Note: All units are mg/L unless otherwise mentioned

3.3 Variation of Trace Elements

This study used inductively coupled plasma optical emission spectroscopy (ICP-OES) as an instrument to test the trace element in water of TCS as ICP-OES was noted as the method with satisfactory trueness and precision, sufficiently large linear range and sensitivity enabling to reach low limits of quantification of the determined metals in the water matrix [26]. Variation of trace elements along with the SLS 614 standard limits are shown in Table 3. This study also tested the concentration of heavy metals (Cd, Pb, Cr, Hg) and metalloid (As), as the people in the area suffer from chronic kidney disease of unknown aetiology. Cd and As are suspected to be causative factors for CKDu [27]. However, out of the heavy metal tested, only Pb and Cr exceeded the SLS 614 level. Fe concentration in water was also recorded higher than the drinking water SLS standard (0.3 mg/L). Moreover, maximum limits of Ca, Zn and Mn recorded in TCS water were above the SLS 614 critical drinking water quality limits (Table 3). Thus the water of TCS is not suitable enough for drinking or storing as a source of drinking water in terms of the concentration of trace elements. When drinking water quality parameters exceeded standard critical limits, water needs treatment to be suitable for drinking. However pollution control at the source is much preferred to treatment. These findings highlight the importance of a proper watershed management plan for the area.

Table 4. Variation of the concentration of salt related water quality parameters over the *Thirappane* TCS.

Parameter	Max	Min	Mean	SD	Irrigation-Standard	Reference
RSC (Meq/l)	0.70	0.00	0.12	0.18	< 2.5	(28)
SAR	1.75	0.00	0.68	0.38	< 10	(12)
SP	37.51	0.00	23.61	8.38	< 60	(29)
EC (dS/m)	1.22	0.11	0.40	0.24	< 0.7	(30)
MH	61.24	23.44	42.75	8.89	< 50	(14)
PI	96.18	33.74	65.52	13.10	< 75	(31)
KR	1.22	0.19	0.50	0.22	>1	(13)

3.4 Salinity Sodicity Related Parameters

Soils may become saline or sodic as a result of excessive use of irrigation water with high levels of salts. EC of water is only one indicator which expresses the salinity status of water which is not sufficient to characterize the

soluble salt content of water. SAR expresses the toxicity effect of irrigation water on crops and degradation effects on soil fertility due to sodium ions. SAR of the surface water of the study area varied from 0 to 1.75 and are within the FAO guidelines limits (Table 4). The Kelly ratio (KR) is also used to determine the hazardous effect of sodium in water for irrigation use. In this study region, it varied from 0.19 to 1.22 in surface water (Table 4). Kelly ratio > 1 is considered to be unsuitable for irrigation. KR of few command areas exceeded the limits while other areas and the mean status of KR is within the safe limit. The RSC indicated the excess of carbonates and bicarbonates over calcium and magnesium in irrigation water. RSC > 2.5 is considered as unsuitable and the water of TCS is within the suitable limits in terms of RSC.

PI is used as a criterion, representing the soil permeability as affected by long term use of irrigation water [31]. In accordance with PI, [31] water is classified as class I (>75%, suitable), class II (25 -75%, good) and class III (<25%, unsuitable). PI of the cascade water varied from 34 to 96 % with a mean value of 65. Thus the water of TCS can be categorized as good for irrigation which may not harm the permeability of soil.

3.5 Drinking and Irrigation Water Quality Index of Tank Water

As several parameters determine the suitability of water for a particular purpose, water quality indices are generally used as a solution by giving different weightage factors for different water quality parameters depending on the suitability limits. In order to assess the suitability of tank water of the cascade, IWQI and DWQI were calculated only considering the results of the water quality parameters measured at tank water quality monitoring sites of five tanks.

Table 5. Average tank water quality in terms of Irrigation and Drinking water quality.

AVG status	Avg DWQI	Avg IWQI
Meegassagama tank	63	22.26
Alisthana tank	36.45	18.22
Bulankulama	53.14	19.97
Vendarankulama	74.41	18.54
Badugama	58.09	15.25

Note: 0-25: Excellent, 26 -50: Good, 51-75 : Poor, 76 - 100: very poor, > 100 : Unsuitable, Adopted from [16]

Irrigation Water Quality Index (IWQI) based on the seven parameters (EC, MH, RSC, SAR, Na %, NO_3 and PI) was calculated from equations 7 to 11, and the classification of water samples was done based on IWQI given as a foot note in Table 5. Average IWQI of water varied between 15.3 and 22.3 in different tanks. According to the classification [16], water of all tanks is excellent for irrigation which is very much suitable for crop growth and also has no detrimental effects on the soil where plants are grown. This water is at present used for irrigation of mainly paddy. As a whole, water during the *Maha* season (high and medium water levels) is suitable for paddy cultivation.

However, this water had been used for drinking purpose since ancient time up to recent past according to the farmers in the area as per the results of the PRA activity. They don't use it now for drinking because of prevailing situation of CKDu incidence in the area and the strongly suspected association of potable water with the CKDu. However, they believe that the surface water is less alkaline and be able to use them for drinking, if they manage the tank cascade system properly. At present, some of them use Reverse Osmosis (RO) water as the drinking water. As such, this study tested the DWQI of all tank water to check the present status of the tanks. As shown in the Table 6, none of the tanks water is excellent for drinking as per the drinking water quality guidelines. The water of *Alisthana* tank is good for drinking in accordance with the parameters tested under high and medium water levels of the tanks. Water of all other tanks is poor according to the classification.

3.6 Social Survey

Stakeholders' involvement is the key to success of watershed management programmes and this study could get the engagement of the main stakeholders even for identifying the drainage paths and selecting water quality sampling sites. First the respondent farming community is queried for a brief description.

Questionnaire survey results revealed that almost all the respondents (100%) were household heads. Of all household heads, 20%, 26% and 54% belonged to age categories of over 61 years, between 36 to 45 years and between 46 to 60 years respectively. Education level of the respondents is an important factor which affects the decision making process. Results explicated that, almost all the respondents (100%) have attained formal education where higher percentage (45%) of respondents did schooling up to General Certificate of Education (GCE) ordinary level (grade 11). Moreover, 25% of respondents did schooling up to grade five and 21% did schooling up

to grade ten while the least number of respondents (9%) completed education up to advanced level. Thus their response is comparatively matured and reliable to be taken into the actions in the watershed management programme particularly in water quality improvement.

3.7 Views of the Farming Community on the Ecosystem Components of the TCS

Study investigated the current situation of different features of *Thirappane* cascade system and the respondents' awareness about the importance of those features. Majority of the respondents reported that the unique ecological features are still visible around the small tank system. Of those features drainage canal (*Kiul Ela*), Earthen embarkment/dam (*Wa kanda*), (upland crops cultivation area, *Chena*), hamlets (*Gan Goda*), downstream wind barrier located in between the sluice and paddy *Katta Kaduwa* (observed in few tanks), Paddy fields (*Keth yaya*), spillway (*Pitawana*), land sluice (*Goda Sorowwa*) and mud sluice (*Mada Soruwwa*) are still observable while (small pond for trapping sediments) *Godawala* and earthen small embankment to prevent entering sediments (*Iswatiya*) are evident up to some extent in the small tank cascade system. But, the land strip around the hamlet for protection (*tisbamme*), trees (specially *Madhuka longifolia*) over the drainage canals, trees over *Katta Kaduwa* are not observable today. Transect work observed that those features are in highly degraded conditions. Further, many of the respondents (81%) highlighted the importance of restoration of these unique features of cascade system.

Table 6. Awareness and willingness to rehabilitate the tank cascade system of *Thirappane*

	Questions related to awareness and willingness to rehabilitate tank ecosystem components	Positive Response of the respondent
1	Awareness that the farmers are living in a tank cascade system and are taking water from the TCS	94%
2	Awareness that each tank has its own ecosystem components and they have specific role in improving the water quality and minimizing the siltation	64%
3	Awareness that present status of the ecosystem components are in degraded status	60%
4	Farmers willingness on the possibility of tank ecosystem components to be rehabilitated as in the past	81%
5	Farmers willingness to supply labour to rehabilitate the tank ecosystem components	54%

According to the views of the respondents major factors that affected the water and soil pollution of the *Thirappane* cascade system were the use of chemical fertilizer and agrochemicals for crop cultivation, soil erosion, movement of buffaloes and cattle, elephants crossing the tank bunds and inadequate repairs and management of the water cannel system. Water quality survey also observed the higher levels of sediments in terms of turbidity and accumulation of *nutrients (NO$_3^-$, PO4^{3-})*, in water. Further, Table 7 displays measures that can be taken to minimize the pollution of the eco-system of the *Thirappane* cascade system.

People in the area believe that proper awareness programme on the importance of ecosystem components of the TCS is one of the main measure to minimize impairment of water in TCS. As an alternative, they wanted to restore the forest in the upper catchment area of each small tank which is now degraded substantially. Respondents in the area accept that minimization of the use of agrochemicals and synthetic fertilizer for crop cultivation will lead to improving the water quality. Around 13 % of the responded farmers also wanted to rehabilitate the ecosystem components of the TCS in order to improve the water quality status of the TCS. Use of appropriate farm soil conservation methods is also believed to be a measure to enhance the water quality status while combating deforestation in the TCS is the least ranked method selected by the respondents.

Table 7. Measures to minimize the pollution of *Thirappane* cascade system

Rank	Measure to minimize the pollution	Response of the respondent
1	Awareness programme for farmers about the importance of conservation of *Thirappane* tank cascade system	29%
2	Reforestation of upper catchment area of small tanks of the cascade system	25%
3	Minimize the use of agrochemicals and synthetic fertilizer for crop cultivation	20%
4	Rehabilitation of features of tank cascade system according to the standards	13%
5	Use of proper conservation methods (ridges, drainages etc.)	9%
6	Minimize the deforestation of tank area	5%

Table 8. Factors affecting on community participation decision to conserve *Thirappane* tank cascade system

Variable	Measurements	Pr>Chisq	Estimate	Odd ratio
Educational level of the respondent	Up to grade 5	0.95	5.865	<0.001
	Up to grade 10	0.95	-5.2781	<0.001
	Up to grade O/L	0.96	-4.2565	<0.001
	Up to grade A/L	0.97	6.895	1.000
Drinking water source	Tap water	0.94	-8.794	<0.001
	Filtered water	0.98	2.931	1.000

Variable	Measurements	Pr>Chisq	Estimate	Odd ratio
Satisfaction about the quality of drinking water source	Well water	0.99	2.931	1.000
	Satisfied Vs. not satisfied	0.006*	-2.40	<0.001
Number of years living in the area	< 5 years	0.99	-5.595	<0.001
	< 10 years	0.87	-5.910	<0.001
	< 20 years	0.95	5.75	1.000
Land extent	Acres	0.98	0.0058	1.000
Annual income	Rupees	0.08**	6.47	1.000
Presence of features of cascade system	Yes	0.01*	0.947	6.563
Awareness about cascade system	Yes	0.07**	1.14	9.778

*significant at 5% significant level and **significant at 10% significant level

Table 8 shows the results of logistic regression estimates of the factors affecting the participation decision for the conservation of *Thirappane* tank cascade system. According to the results, satisfaction about the quality of drinking water ($p<0.05$), presence of ecosystem features of tank cascade system ($p<0.05$), annual income of respondents ($p<0.1$) and awareness about the tank cascade system ($p<0.1$) significantly influenced the participation decision of the community for the rehabilitation of TCS.

Results revealed that, when the community people lost their satisfaction about the quality of drinking water (OR=<0.001) many of the respondents tend to change their decision to participate in tank cascade system conservation. Presence of features of ancient tank cascade system (OR=6.563) affected positively to change the respondents' decision to participate in conservation programmes. Further, increase in annual income of respondents (OR=1.00) results in many of the non-participants to participate in cascade conservation. Meanwhile, more awareness about the importance of cascade system (OR= l.00) leads to change non-participants decision.

The social survey highlighted the positive attitudes of the people towards conservation of *Thrappane* TCS and their willingness to participate in watershed management programme in order to make the water safe for drinking as their forefathers used. The information collected under this study is very vital to the scientific community, government officers and farmers themselves in protecting the TCS in Sri Lanka. Similar studies shall be continued as a routine procedure in other TCS too to understand the reality and harness the water at a lesser cost as practiced by the early Sri Lankans.

This study could not consider the microbiological properties of water and could not test the water quality parameters for the 2020 *Maha* as planned due to Corona pandemic situation. However, this study became the ground for the formulating of a cascade management plan with the support of the community. This study shall be an example and an eye opener to the country to formulate sustainable watershed management plan.

4. Conclusions

Health of the *Thirappane* TCS in terms of water quality of *Maha* cropping season was tested and the mean status of some drinking water quality parameters such as turbidity, free NH_3, COD, Pb and Cr exceeded the SLS 614 (2013). Other than that, maximum values recorded for EC, total alkalinity, total phosphate, COD, TDS, Mg, Cu, Cr, Fe, Mn and Zn of the *Thirappane* TCS were higher than the stipulated standard values for potable water. Moreover, calculated DWQI of tanks water of TCS was not up to the suitable level to use the water as potable water. However, most of the irrigation water quality parameters tested and IWQI guarantee that the TCS water is suitable for irrigation of any crops which would not deteriorate the yield and the soil properties. This study further concluded that awareness programme on the importance of ecosystem components of the TCS would help to conserve the TCS and clearly showed the willingness to participate for the rehabilitation work of the ecosystem components by the stakeholders in improving the water quality status. However, the presence of ecosystem features of tank cascade system, annual income of the respondents, satisfaction of the quality of drinking water, and the awareness about the tank cascade system significantly influenced the participatory decisions of the community on the rehabilitation of TCS.

Data Availability

Whenever needed, the data can be shared.

Conflicts of Interest

No conflicts of interest among authors.

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