Water Quality Assessment of a Tank Cascade System using CCME Water Quality Index

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***Abstract*- Canadian Council of Ministers of the Environment (CCME)has developed a water quality index which certainly be used with fairly consistent in different geographical locations and different water quality parameters. This study was conducted to assess the water quality of *Malwathu Oya* cascade-I in tropical Sri Lanka for drinking, fish & aquatic life, irrigation & agriculture and recreational use by applying CCME Water Quality Index (WQI). Water samples from ten tanks were collected once a month representing wet and dryperiods during 2013/14 and analyzed for seven physicochemical parameters (electrical conductivity, dissolved oxygen level, turbidity, pH, nitrate nitrogen, phosphate and sodium) using standard instruments and procedures. Physicochemical parameters were compared with the drinking water quality guidelines[17] and proposed ambient water quality standards for inland waters of Sri Lanka. Average values of CCME WQI showed that water quality is poor for drinking, fish & aquatic life and irrigation & agriculture in tanks of *Malwathu Oy*a cascade- I while, marginal for recreational use. However, it showed high spatial and temporal variation of water quality for all kind of water uses. CCME WQI can be successfully used to draw meaningful and easily understandableconclusions about cascade systems from large data matrix on water quality.**

***Keywords* -CCME WQI, cascade, drinking, fish & aquatic life, irrigation & agriculture, recreational use**

I. INTRODUCTION

Village tanks were the back bone of the hydraulic civilization of ancient dry zone of Sri Lanka and usually located as tank cascades. A cascade is defined as a connected series of small irrigation tanks organized within a meso catchment of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet [1]. Usually tank cascade systems comprise of 4 to 10 small tanks which has its own micro-catchment, however all these tanks located in a single meso-catchment.In tank cascade systems, the excess water of upper level tankscan be captured by lower level tanks, therefore water can be re-use several times. However, there is a risk to accumulate high level of agricultural pollutantssuch as pesticides, fertilizers and sediments, and effluents of industrial and household activities in lower tanks. These pollutants can harm to the crop production, aquaculture, environment and ultimately the human health. Although there is a method developed to evaluate water availability and sustainability of cascade systems, no proper evaluation method or criteria to evaluate cascade water quality yet.

About 180 cascade systems were already identified in *Malwathu Oya* river basin and few of them were evaluated in terms of quality and quantity of water.*Malwathu Oya*cascade-I is a meso catchment of NuwaraWewa catchment which is part of *Malwathu Oya* river basin. It is extended about 25.88 km^2,located in DL_{1b} agro ecological region of Sri Lanka and it belongs to *NuwaragamPalatha - East* and *Mihintale* divisional secretariat areas in Anuradhapura district [2].

Water is one of thebasic needs of human beings andpeople use water for their drinking, sanitation, recreation uses, irrigation and etc. Among the surface water and groundwater resources, surface water is the most popularly used source to fulfil their water requirements. Therefore, almost all the major human settlements are centered on surface water resources.

Physical, chemical and biological substances presence in water determines the quality of the water [3]. However, the water quality is subjective based on thepurpose. Good quality water for respective water uses is an essential requirement of human beings toeliminate the health hazards and to improve the life standards [4]. The water quality should be assessed by analyzing physicochemical and biological parameters of water based on respective water uses. Frequent studies on physicochemical parameters of tank water is required in better management of tank cascades which is the primary water source of many rural communities in dry zone of Sri Lanka. However, these studies should help in the decision making process of relevant authorities and aware the general public [5]. The size of the data matrix is higher in water quality studies due to higher number of physicochemical parameters and sampling points. It cause to complex situations in data analyzing and interpretation of results [6]. Different analyzing techniques to simplify the interpretation process of large data setshas been used with different merits and demerits which are unique to each method [7]. Water quality indices has attained higher attention on decision making using large data sets [8]. Water quality index (WQI) is a single number which can express the overall quality of water in a designated location. It is calculated using different observed physicochemical parameters of water. The importance of this index is the conversion of complex water quality data matrix into a single number which can provide understandable information to the public [9].

Although it has demerits of unique to pollution type and geographical areas, water quality index is a widely used tool in different parts of the world to solve the problems associated with the handling of large data sets on water quality [9]. Different authors derived different options especially weightages in calculation of WQI, therefore universal application is limited. Canadian Council of Ministers of the Environment (CCME) WQI is one of the main WQI which was developed by the CCME It was developed to overcome the problem of limited applications in different geographical locations and with different measured parameters [10]. The application of the CCME WQI requires water quality guidelines and model essentially consists of three measures of variance (scope, frequency and amplitude) from selected guidelines that combine to produce a value between 0 and 100 that represents the overall water quality. The CCME WQI is based on mathematical framework for assessing water quality conditions relative to water quality guidelines. It is flexible as testing of parameters and testing periods are defined by the user. However, defining the water quality parameters, time period and guidelines based on the objectives are vital before the calculation of index [10].

A study on designing of water quality index reported that the water quality is bad in Kesbewalakebased on WQI. In this study Qi values were calculated based on WHO and CEA standards and different rating values assigned for different water uses as drinking, bathing, irrigation, fish and aquatic lives. Further, weightage factors were assigned using available secondary data [11]. Physicochemical parameters of Chikkakere andPeriyapatna in Mysore district, India was studied using CCME WQI and reported that the water quality is not suitable for drinking, aquatic lives, recreation, irrigation and livestock [3]. A study on evaluation of pollution status using CCME WQI reported that poor water quality of Chakkamkandamlakein India [12]. Based on 14 physicochemical parameters, Sankey tank was categorized as good water and Mallathahallilakewas categorized as poor water based on WQI [13]. Shivanna and Nagendrappa[14] reported that the successful application of WQI in tank water evaluation in Tumkurdistrict, Karnataka, India.Water quality of the Aboaboriver, Kumasi-Ghana was studied using CCME-WQI model and water samples from five locations along the river were used to estimate eight parameters. Based on the results, overall river water quality was categorized as poor. Further, spatial variation of CCME WQI was also studied and reported that water quality was poor all along the river [15]. Analysis of water samples for eleven parameters drawn from three locations along the Tigris rivershowed that poor water quality according to the CCME WQI for drinking [16]. Water quality of four different places of Surma river in Bangladesh was analyzed based on CCME WQI and concluded that the water quality of the riverwaspoor. By calculating CCME WQI in three different time periods, the study showed that water quality in the Surmariverwasdeteriorating at an alarming rate and it is vital to conduct frequent water quality studies in rivers [17]. In a water quality assessment based on CCME WQI in Kelaniriver basin of Sri Lanka reported that poor water quality for drinking and recreation while fair for irrigation and good for livestock [9].

Although number of water quality studies of different cascade systemsin Sri Lanka were reported, only few attempts were taken on application of WQI to interpret results. Therefore, this study was aimed to assess the water quality of a tank cascade systems in Sri Lanka for drinking, fish & aquatic life, irrigation & agriculture and recreational use by applying CCME water quality index.

II. MATERIALS AND METHODS

A. Sampling points

Water samples from ten small tanks (viz. *Illuppukanniya (IL), Halmillawewa (Ha), Kammalakkulama (KM), MahaKalaththewa (MK), Sattambikulama (SK), Thariyankulama (TK), Palugaswewa (PW), Nelumkanniya (NK), KudaKalaththewa (KK) and Bandialankulama (BK)*) located in*Malwathu Oya* cascade-I were collected (Fig. 1).

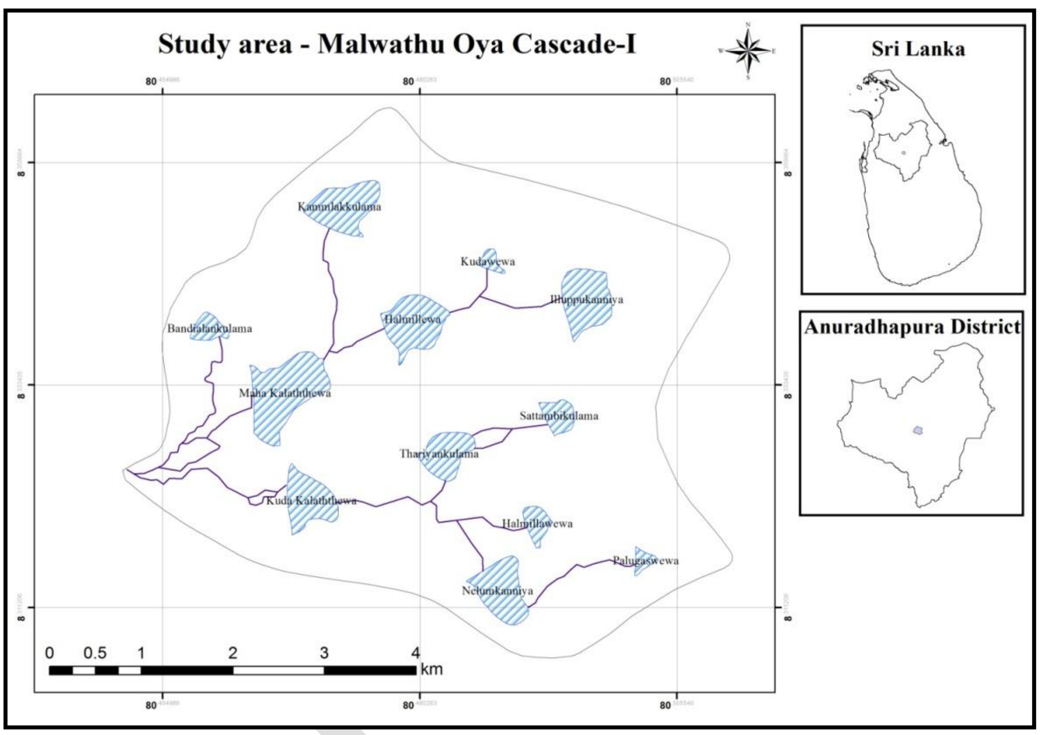

Fig. 1Map of study area - *Malwathu Oya* Cascade-I

B. Physicochemical analysis of water

Sampling was done in 2013/14 in monthly interval basis to estimate seven water quality parameters. At the time of sampling, electrical conductivity (EC),dissolved oxygen level (DO), turbidityand pH were measured using instruments mentioned in Table 01. The water samples were collected, transported and stored for further analysis in soil and water laboratory of Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka following the procedures explained in APHA guidelines for standard methods for examination water and wastewater [18]. Nitrate nitrogen, Phosphate and sodium concentrations were measured using the methods listed in the Table 01 as procedures explained in APHA guidelines.

TABLE I

INSTRUMENTS AND METHODS USED FOR WATER QUALITY ANALYSIS

Water quality parameter	Instrument / Method
Dissolved Oxygen (DO)	DO meter (EUTECH, CyberScan DO 300)
Turbidity (TBD)	Turbidity meter (EUTECH, TN 100)
pH	Multi parameter analyzer (HATCH, Sension 156)
Electrical Conductivity (EC)	Multi parameter analyzer (HATCH, Sension 156)
Nitrate nitrogen (NO_3 –N)	Salicylic Acid method
Phosphorus (PO_4 – P)	Ascorbic acid method
Na^+ concentration (Na)	Flame photometer (Sherwood Model 360)

C. CCME WQI Model

The water quality index (WQI) developed by the CCMEemploys the combination of three essential measures of variance such as scope, frequency and amplitude.Detailed calculation procedures and classification are explained in Canadian Water Quality Index 1.0 – Technical report as follows [10].
Scope (F_1) represents the extent of water quality guideline non-compliance over the time period of interest. F_1 is expressed as indicated in Equation 01.

$$F_1 = \frac{Number\ \ of\ failed\ \ variables}{Total\ number\ \ of\ variables} \times 100 \qquad \text{Equation 01}$$

Frequency (F_2) represents the percentage of individual tests that do not meet the guidelines called "failed tests" as expressed in Equation 02.

$$F_2 = \frac{Number\ \ of\ failed\ \ tests}{Total\ number\ \ of\ tests} \times 100 \qquad \text{Equation 02}$$

Amplitude (F_3) represents the amount by which failed test values do not meet their guidelines. Amplitudeis calculated in three steps.

i. The number of times by which an individual concentration is greater than (or less than, when the guideline is a minimum) the objective is termed an "excursion" and is expressed as follows.

When the test value must not exceed the objective,

$$excursion_i = \frac{Failed\ \ test\ value_{\ i}}{Objective\ \ /guideline\ _{i}} - 1 \qquad \text{Equation 03}$$

For the cases in which the test value must not fall below the objective,

$$excursion_i = \frac{Objective\ \ /guideline\ _{i}}{Failed\ \ test\ value_{\ i}} - 1 \qquad \text{Equation 04}$$

ii. The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions, or *nse*, is calculated as Equation 05.

$$nse = \frac{\sum_{i=1}^{n} excursion\ _i}{Number\ \ of\ tests} \qquad \text{Equation 05}$$

iii. $F_3$is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100. Mathematically, F_1 is expressed as indicated in Equation 06.

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) \qquad \text{Equation 06}$$

The CCME WQI is then calculated as,

$$CCME\ WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \qquad \text{Equation 07}$$

Classification of water quality classes based on water quality index is shown in Table 02 [10].

TABLE II

CLASSIFICATION OF WATER QUALITY CLASSES

Rank	WQI value	Description about water quality
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Seven, four, four and fivevariables used for CCME WQI calculations for drinking, fish & aquatic life, recreational use and irrigation & agriculture respectively. Spatial variation of CCME WQI values were calculated by grouping the tanks in to two groups such as upper level tanks and lower level tanks. Seasonal water quality variation was studiedin rainy period and dry period.

D. Water quality guidelines

SLS 614 was used as the guideline for drinking water quality [19]. Drinking water quality guidelines in proposed ambient water quality standards for inland waters of Sri Lanka was used to get the guidelines for parameters which were not addressed in SLS 614 [20].Proposed ambient water quality standards for inland waters of Sri Lanka were used as the water quality guidelines for fish & aquatic life, irrigation & agriculture and recreational use [20].

E. User perceptions about water quality

Use perceptions about the quality of water and their practical issues related to the water quality were gathered using informal discussions with farmer leaders of each farmer organizations.

II. RESULTS AND DISCUSSION

A. Electrical conductivity

Electriacal conductivity levels were varied between 90 - 3030 µS/cm. During the study period 19% and 23% failure tests were recorded compared to the guidelines of drinking, irrigation & agriculture respectively while no guidelines on recreation and fish & aquatic life in Sri Lankan context [19], [20].

B. Turbidity

Turbidity levels were varied between 0.5 – 153 NTU during the study period as 79% tests showed exceeded levels of turbidity than the guidelines of drinking water quality. No guidelines were found for irrigation & agriculture, recreation and fish & aquatic based on turbidity in Sri Lankan context [19], [20].

C. Dissolved oxygen (DO)

Dissolved oxygen levels were varied between 0.3 – 18.3 mg/l during the study period. 66%, 13%, 43% and 13% failure tests were recorded compared to the guidelines of drinking, fish & aquatic life, recreation and irrigation & agriculture respectively [19], [20].

D. pH

During the study period pH of tank water was varied from 6.3 to 8.5. pH level was within the safe limits only for recreation while, 24%, 1% and 1% failure tests were recorded for drinking,irrigation & agriculture, and fish & aquatic life respectively [19], [20]. .

E. Sodium

During the study period, sodium levels were varied from 0 to 300 mg/l. Based on sodium concentration in Sri Lankan context 3% of failure tests were recorded for drinking and no guidelines were found for irrigation & agriculture, recreation and fish & aquatic life based on [19], [20].

F. Phosphorus

During the study period the phosphate concentration was ranged from 0.0 to 5.0 mg/l. Thirty nine percent (39%), 58%, 39% and 39% failure tests were recorded compared to the guidelines of drinking, fish & aquatic life, recreation and irrigation & agriculture respectively [19], [20].

G. Nitrate nitrogen

Nitrate nitrogen levels were varied between 0.0 – 8.3 mg/l during the study period and 3% of each failure tests were recorded for drinking, irrigation & agriculture, recreation and fish & aquatic life [19], [20].

TABLE III

SPATIAL VARIATION OF MEASURED WATER QUALITY PARAMETERS

Parameter		IL	Ha	KM	MK	SK	TK	PW	NK	KK	BK
EC ($\mu S\ cm^{-1}$)	Av	492.5	824.2	236.7	932.5	416.7	490.8	386.0	393.3	1080.0	395.8
	SD	203.0	560.8	66.8	534.2	100.4	242.0	176.2	139.2	766.2	616.7
Turbidity (NTU)	Av	7.0	18.2	15.9	18.1	10.4	7.5	25.4	7.9	13.3	22.4
	SD	7.9	36.9	25.2	27.3	11.3	7.7	49.1	9.7	21.2	33.1
DO (mg/l)	Av	5.4	5.8	5.6	6.5	4.2	5.2	5.7	4.3	6.8	6.5
	SD	1.2	2.9	1.3	2.1	3.7	1.7	2.3	2.5	5.6	4.1
pH	Av	7.2	7.4	7.1	7.2	7.3	7.7	7.6	7.3	7.6	7.1
	SD	0.5	0.5	0.3	0.5	0.7	0.3	0.3	0.4	0.5	0.5
Na^+ (mg/l)	Av	37.9	29.5	20.8	50.2	7.5	37.6	5.7	27.6	38.2	38.6
	SD	49.3	36.4	27.8	85.6	4.6	65.0	3.4	36.7	60.6	65.1
PO_4–P (mg/l)	Av	0.9	1.4	1.0	1.3	0.5	0.8	0.5	0.5	0.9	0.8
	SD	1.3	1.9	0.9	1.2	0.4	0.6	0.5	0.4	0.9	0.8
NO_3^- - N (mg/l) (mg/l)	Av	1.4	1.4	1.7	1.9	1.7	2.0	1.9	2.6	2.7	2.3
	SD	1.1	1.3	1.2	1.4	1.2	1.5	1.6	2.0	2.1	2.2

H. CCME WQI

Average values of CCME WQI showed that water quality is poor for drinking (32),fish & aquatic life (39) and irrigation & agriculture (41) in tanks of *Malwathu Oya* cascade- I while,marginal for recreational use (53).

1) Spatial variation of CCME WQI

Spatial variation of CCME WQI for different water uses of tanks in *Malwathu Oya* cascade –I is shown in Table 04. CCME WQI for drinking water was varied from marginal to poor during the study period. CCME WQI for fish & aquatic life and recreational water were varied between marginal and fair respectively. CCME WQI for irrigation and agriculture were varied between marginal to good.

Based on CCME WQI, the water quality is poor for drinking (32), in tanks located at the upper part of *Malwathu Oya* cascade- I while, marginal for fish & aquatic life (53) and irrigation & agriculture (53) recreational use (54).

Furthermore, CCME WQI showed that water quality is poor for drinking (32), fish & aquatic life (38) and irrigation & agriculture (40) in tanks located at the lower part of *Malwathu Oya* cascade- I while, marginal for recreational use (52).

2) Temporal variation of CCME WQI

Temporal variation of CCME WQI for different water uses of tanks in *Malwathu Oya* cascade –I is shown in Table 05. CCME WQI for drinking water, fish & aquatic life, recreational use and irrigation & agriculture were varied between fair to poor, excellent to poor, good to marginal and excellent to marginal during the study period respectively.

Based on CCME WQI water quality is poor for drinking (31) in tanks of *Malwathu Oya* cascade- I while, marginal for fish & aquatic life (50), irrigation & agriculture (52) and recreational use (50) during dry periods.

Furthermore, water quality is marginal for drinking (47), fish & aquatic life (55) and irrigation & agriculture (53) in tanks of *Malwathu Oya* cascade- I while, fair for recreational use (67) during wet periods.

TABLE IV

SPATIAL VARIATION OF CCME WQI AND WATER CATEGORIES

Location	Drinking		Fish &aquatic life		Recreational use		Irrigation &agriculture	
	CWQI	Category	CWQI	Category	CWQI	Category	CWQI	Category
IL	52	Marginal	65	Fair	68	Fair	64	Marginal
Ha	42	Poor	48	Marginal	63	Marginal	49	Marginal
KM	51	Marginal	76	Fair	68	Fair	86	Good
SK	53	Marginal	67	Fair	66	Fair	75	Fair
TK	51	Marginal	78	Fair	66	Fair	75	Fair
PW	50	Marginal	69	Fair	69	Fair	65	Fair
NK	50	Marginal	53	Marginal	53	Marginal	64	Fair
KK	37	Poor	49	Marginal	49	Marginal	47	Marginal
BK	29	Poor	66	Fair	54	Marginal	64	Marginal
MK	36	Poor	72	Fair	66	Fair	70	Fair

TABLE V

TEMPORAL VARIATION OF CCME WQI AND WATER CATEGORIES

Location	Drinking		Fish &aquatic life		Recreational use		Irrigation &agriculture	
	CWQI	Category	CWQI	Category	CWQI	Category	CWQI	Category
Feb	26	Poor	72	Fair	66	Fair	65	Fair
Mar	60	Marginal	63	Marginal	67	Fair	63	Marginal
Apr	64	Marginal	70	Fair	81	Good	76	Fair
May	39	Poor	45	Marginal	47	Marginal	49	Marginal
Jun	38	Poor	43	Poor	46	Marginal	47	Marginal
Jul	51	Marginal	76	Fair	69	Fair	73	Fair
Aug	43	Poor	65	Fair	54	Marginal	59	Marginal
Sep	26	Poor	72	Fair	66	Fair	65	Fair
Oct	38	Poor	69	Fair	66	Fair	64	Marginal
Nov	40	Poor	48	Marginal	60	Marginal	50	Marginal
Dec	67	Fair	100	Excellent	82	Good	100	Excellent
Jan	62	Marginal	69	Fair	85	Good	77	Fair

IV. CONCLUSIONS

Average values of CCME WQI showed that water quality is poor for drinking, fish & aquatic life and irrigation & agriculture in tanks of *Malwathu Oya* cascade- I while, marginal for recreational use. However, it showed high spatial and temporal variation of water quality for all kind of water uses. Since results of CCME WQI akin with the farmer perceptions and their practical problems related to the water quality,CCME WQI can be successfully used to draw meaningful and comprehensible conclusions from large data matrix on water quality of a cascade systems.

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