

ORIGINAL RESEARCH

Water Quality Assessment in Yan Oya in Sri Lanka using CCME Water Quality Index

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Abstract

Water quality has to be assessed for better management of water resources, hence several water quality indices have been developed and Canadian Council of Ministers of the Environment (CCME) water quality index is one of them. It can be used with multiple water quality parameters in different geographical locations. This study was conducted to assess the water quality in Yan Oya for drinking, fish and aquatic life, irrigation and recreational use by applying CCME water quality index (WQI). Water samples from seven locations along the middle part of the *Yan Oya* were collected once a month representing pre monsoonal, monsoonal and post monsoonal rainy periods during 2014/15 and analyzed for nine physicochemical parameters (electrical conductivity, pH, turbidity, dissolved oxygen, nitrate nitrogen, available phosphorus, calcium, magnesium and sodium) using standard instruments and procedures. Physicochemical parameters were compared with the Sri Lankan Standards drinking water quality guidelines 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 in *Yan Oya* while fair for recreational use fish and aquatic life and irrigation. However, CCME WQI showed high spatial and seasonal variation during the study period. CCME WQI can be successfully used to draw easily expressive and comprehend conclusions from large data matrices of water quality.

Keywords: CCME WQI, Drinking, Fish & Aquatic Life, Irrigation, Recreational use, Yan Oya

Introduction

Characteristics and level of physical, chemical and biological substances in water determines the quality of the water. Water quality standards vary with the type of water use. Good quality water for respective water uses is an essential requirement to prevent the health hazards, improve the life standards and sustainability of the environment. The quality of water can be assessed by analyzing physiochemical and biological parameters of water. Frequent studies on physiochemical parameters of surface water resources is vital in better management of water resources as well as aquatic habitat and the environment^{1, 2}. Further it is vital in decision making of relevant authorities and understanding of general public⁴. With the higher number of physiochemical parameters and sampling points along the river, it will increase the size of data matrix and it leads complex situations for data analysis and interpretation of results⁵. Many authors used different analyzing techniques to simplify the interpretation process of large data sets with different merits and demerits which are unique to each method⁶. They also paid their attention on water quality indices

for decision making when using large data sets⁷. Water quality index (WQI) is a single number index which can express the overall water quality of a location. It is calculated using different observed physiochemical parameters of water. The importance of this index is it can convert complex water quality data matrix into a single number which can provide understandable information to the public⁸.

Although it has demerits which is unique to pollution type and geographical area, 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 quality⁸. Different authors have derived several options especially weight ages in calculation of WQI, but its universal application is limited. Hence, Canadian Council of Ministers of the Environment (CCME) has developed a WQI to overcome the problem of limited applications in different geographical locations and with different measured parameters⁹. 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 calculating the index⁹.

Assessment of water quality based on CCME WQI has been reported from neighboring India, Bangladesh, Africa and Middle East. Studies reported from India have shown that quality of water in Chikkakere, Periyapatna in Mysore district is not suitable for drinking, recreation, irrigation and even for livestock and aquatic lives¹. A similar report from Chakkamkandamlake has also been reported¹¹. Water quality has also been estimated using 8 parameters from 5 different locations along the Aboabo river, Kumasi-Ghana and quality of water was categorized as poor¹². Furthermore spatial variation of CCME WQI was also study and the water quality all along the river was found to be poor. In Bangladesh water quality was analyzed in Surma river and was found to be poor¹⁴. The authors by calculating CCME WQI in three different time periods, showed that water quality in the Surma river is deteriorating at an alarming rate. In Sri Lanka water quality of Kelani river based on CCME WQI has been categorized to be poor for drinking and recreation while categorized as fair irrigation and good for livestock⁸. Based on WQI, water quality of Kesbawa Lake is rated as bad. In this study WHO and CEA standards were used as base values and different rating values were assigned for different water uses as drinking, bathing, irrigation, fish and aquatic lives. Furthermore, weightage factors were assigned using available secondary data¹⁰.

Yan Oya (river) that originates from the hilly areas of Dambulla and Sigiriya, flows towards the north-eastern region of Sri Lanka and escape to the sea as a fourth order stream. The catchment of Yan Oya is 1538 square kilometers¹⁶. Yan Oya delivers the water requirement of nearby residents and farming communities. Drainage water of agricultural lands (mainly paddy fields) and residential areas enters Yan Oya in several places and this may badly affect to the quality of water.

Even though a number of studies on water quality of different rivers in Sri Lanka were reported, only very few attempts have been taken to apply WQI to interpret the results⁸. On the contrary no recent studies were reported in water quality status of Yan Oya river basin of Sri Lanka. Hence, this study was aimed to assess the water quality of Yan Oya in Sri Lanka for drinking, fish and aquatic life, irrigation and recreational purposes using CCME water quality index.

Materials and Methods

Sampling points

Water samples from seven locations (Figure1) along the middle part of Yan Oya were collected. Distance along the river from Huruluwewa dam, latitudes and longitudes of sampling locations are listed in Table 1.

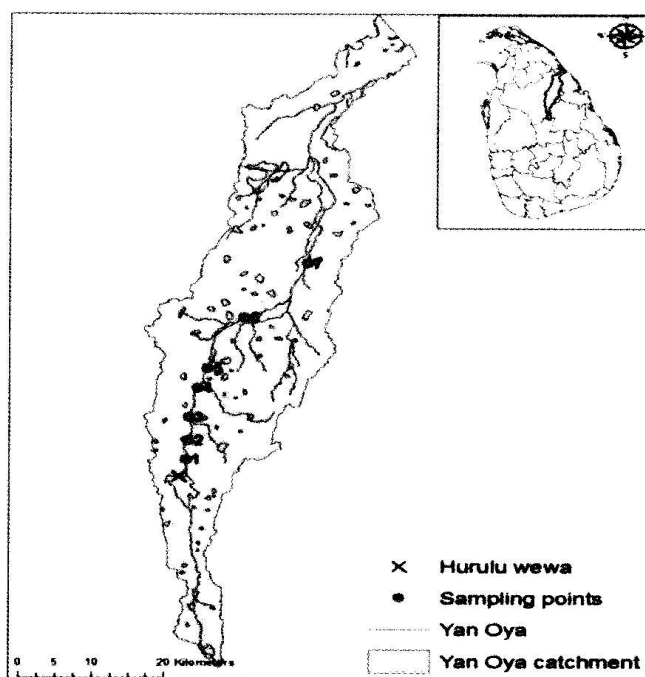


Figure 1. Sampling locations along Yan Oya

Table 1. Locations of sampling points in Yan Oya

Sampling Location	Latitude	Longitude	Distance from Huruluwewa Dam
1	8.287631	80.732361	3 km
2	8.256228	80.72942	6.5 km
3	8.325891	80.733124	11 km
4	8.373595	80.744065	17 km
5	8.406325	80.75675	21.5 km
6	8.577082	80.881223	33 km
7	8.488971	80.802591	47 km

Physiochemical analyses of water

Water was sampled from September 2014 to February 2015 at monthly intervals. Electrical conductivity (EC), dissolved oxygen level (DO), turbidity and pH were measured in-situ using instruments as shown in Table 2. 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 standard procedures¹⁵. Available nitrate nitrogen, available phosphorus,

calcium, magnesium and sodium concentrations were measured using the methods listed in Table 2¹⁵.

Table 2. Instruments and methods used for water quality analysis

Water quality parameter	Instrument / Method
Dissolved Oxygen (DO)	DO meter (EUTECH, CyberScan DO 300)
<i>Gunarathna et al. Rajarata University Journal 2016,4(1):72-81</i>	
pH	Multi parameter analyzer (HATCH, Sension 156)
Electrical Conductivity (EC)	Multi parameter analyzer (HATCH, Sension 156)
Total Dissolved Solids (TDS)	Multi parameter analyzer (HATCH, Sension 156)
Ammoniacal nitrogen (NH ₄ -N)	4500 NH ₃ F Phenate method
Nitrate nitrogen (NO ₃ -N)	Salicylic Acid method
Phosphorus (PO ₄ - P)	Ascorbic acid method
Ca ²⁺ concentration (Ca)	Atomic absorption spectrophotometer (BUCK Scientific)
Mg ²⁺ concentration (Mg)	Atomic absorption spectrophotometer (BUCK Scientific)
Na ⁺ concentration (Na)	Flame photometer (Sherwood Model 360)

CCME WQI Model

The water quality index (WQI) developed by CCME employs the combination of three measures of variance (Scope, Frequency and Amplitude). Detailed calculation procedures and classification are explained in Canadian water quality index 1.0 – technical report as follows⁹.

Scope (F₁) represents the extent of water quality guideline non-compliance at least once over the time period of interest as indicated in Equation 1.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \quad \text{Equation 1}$$

Frequency (F₂) represents the percentage of individual tests that do not meet the guidelines (“failed tests”) as expressed in Equation 2.

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \quad \text{Equation 2}$$

Amplitude (F₃) represents the amount by which failed test values do not meet their guidelines. Amplitude is calculated in three steps.

- 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 (Equation 3 and 4).

If the test value not exceed the objective,

$$\text{excursion}_i = \frac{\text{Failed test value}_i}{\text{Objective/guideline}_i} - 1 \quad \text{Equation 3}$$

If the test value higher than the objective,

$$excursion_i = \frac{Objective/guideline_i}{Failed\ test\ value_i} - 1 \quad \text{Equation 4}$$

- 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*, and is calculated using Equation 5.

$$nse = \frac{\sum_{i=1}^n excursion_i}{Number\ of\ tests} \quad \text{Equation 5}$$

- 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_3 is expressed as indicated in Equation 6.

$$F_3 = \left(\frac{nse}{0.01nse + 0.01} \right) \quad \text{Equation 6}$$

The CCME WQI is then calculated as,

$$CCME\ WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad \text{Equation 7}$$

Classification of water quality classes based on water quality index is shown in Table 3⁹.

Table 3. 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

In order to calculate CCME WQI for drinking, fish and aquatic life, recreational use and irrigation 9, 4, 4 and 5 water quality parameters were used respectively.

Spatial variation of CCME WQI values were calculated as six tests per each variable. Seasonal water quality variation was studied as pre monsoonal period (September and October), monsoonal rainy period (November and December) and post monsoonal period (January and February). Seasonal variation of CCME WQI for drinking, fish and aquatic life, recreational use and irrigation were estimated using 18, 8, 8 and 10 tests respectively.

Water quality guidelines

SLS 614 was used as the guideline for drinking water quality¹⁷. 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 614¹⁸. Proposed ambient water quality standards for inland waters of Sri Lanka were used as the water quality guidelines for fish and aquatic life, irrigation and recreational use¹⁸.

Results and Discussion

Water quality parameters

Water quality parameters measured and there seasonal and special variations are given in Table 4. During the period of study variations were seen in the pH (6.3–8.1), turbidity (11–236 NTU), dissolved oxygen (1.4–13.4mg/l), Electrical conductivity (147– 1727 $\mu S/cm$), Nitrate nitrogen(0.4 – 7.4ppm), Sodium(36 – 110mg/l), Calcium (100 – 253mg/l), magnesium (5.7– 30.5mg/l) and phosphate (0.009– 0.096 mg/l). Of these only sodium and phosphate concentrations levels were found to be within safe limits for drinking. All other parameters measured showed values that exceeded the recommended safe limits for drinking^{17,18}. Under Sri Lankan context for parameters such as turbidity, sodium, calcium and magnesium concentrations no guidelines are available for activities such as recreation, irrigation and fish and aquatic life. Water quality parameters such as pH and phosphate concentrations were within safe limits for irrigation, recreation, and fish and aquatic life. Whilst dissolve oxygen and nitrate nitrogen levels exceeded the safe limits recommended.

Table 4. Seasonal and spatial variation of measured water quality parameters

Parameter		SL 01	SL 02	SL 03	SL 04	SL 05	SL 06	SL 07	Pre-M	M	Post- M
Ca ²⁺ (mg/l)	Avg	168.3	202.0	188.2	198.1	190.5	191.5	202.5	179.9	140.4	254.5
	SD	65.2	61.2	53.2	46.7	53.4	63.3	67.0	40.8	20.3	20.9
Mg ²⁺ (mg/l)	Avg	18.0	19.4	16.1	17.2	17.2	15.6	18.8	22.0	10.5	12.0
	SD	7.7	7.5	5.3	6.6	7.5	6.8	9.6	6.21	3.8	4.2
Na ⁺ (mg/l)	Avg	66.4	53.6	60.9	61.2	56.0	59.9	54.2	50.0	69.3	57.2
	SD	17.1	12.3	21.8	19.8	23.9	26.3	11.0	14.3	21.7	14.7
PO ₄ -P (mg/l)	Avg	0.036	0.041	0.039	0.048	0.043	0.031	0.026	0.02	0.03	0.06
	SD	0.037	0.035	0.038	0.033	0.019	0.020	0.015	0.025	0.03	0.02
NO ₃ -N (mg/l)	Avg	4.2	4.6	5.7	2.8	2.5	3.6	3.1	3.1	4.9	3.4
	SD	1.4	1.5	1.5	1.5	0.9	2.1	2.0	2.2	1.3	1.3
Turbidity (NTU)	Avg	42.0	58.3	106.5	63.6	66.8	43.0	83.5	55.2	89.4	54.1
	SD	17.5	26.7	82.5	24.6	18.2	28.8	74.3	49.2	56.3	28.0
DO (mg/l)	Avg	8.9	7.7	9.2	7.5	8.2	9.3	8.8	3.3	10.7	11.5
	SD	5.2	5.0	4.2	3.4	3.5	4.1	4.2	1.1	1.9	1.0
EC ($\mu S cm^{-1}$)	Avg	558.4	514.4	664.0	475.7	582.2	587.1	531.5	836.0	295.1	546.0
	SD	362.8	214.8	541.8	176.9	364.4	336.4	209.6	376.6	103.4	68.0
pH	Avg	7.4	7.2	7.6	7.6	7.6	7.6	7.7	7.3	7.3	7.9
	SD	0.5	0.6	0.3	0.3	0.4	0.4	0.3	0.5	0.3	0.2

CCME WQI

Average values of CCME WQI showed that water quality in Yan Oya is poor for drinking (34), but could be considered as fair for recreational use (70), fish and aquatic life (71) and irrigation (65). CCME WQI for drinking water is affected mainly by high levels of electrical conductivity, nitrate nitrogen, turbidity and calcium concentrations in the water. Furthermore it is also affected by low dissolved oxygen levels and high range of pH values. Recreational use, fish & aquatic life and irrigation were mainly affected by low levels of dissolved oxygen values and high levels of nitrate nitrogen.

Spatial variation of CCME WQI

Variation of CCME WQI for different water uses along the river is shown in Table 5. CCME WQI for drinking water was varied between marginal and poor during the study period. At sampling points 1, 2 and 3 water was categorized as poor, probably attributed to the pollutants load due to agricultural activities of the sub watersheds. Sampling point 4 showed higher WQI and quality of drinking water was categorized as marginal while the WQI was reduced at the sampling point 5 thus resulting poor quality water for drinking. Despite the prominent agricultural land uses, sampling point 04 recorded higher CCME WQI value. It may be due to the uptake and assimilation of nitrogen pollutants by low lying scrub and marshy lands closer to the sampling point 4. Same pattern was also observed in sampling point 6 and 7 also.

During the study period, water of all sampling points were categorized as excellent, good or fair for fish and aquatic life while, it was categorized as good or fair for recreational use. Water in all sampling points was categorized as good, fair or marginal for irrigation (Figure2)

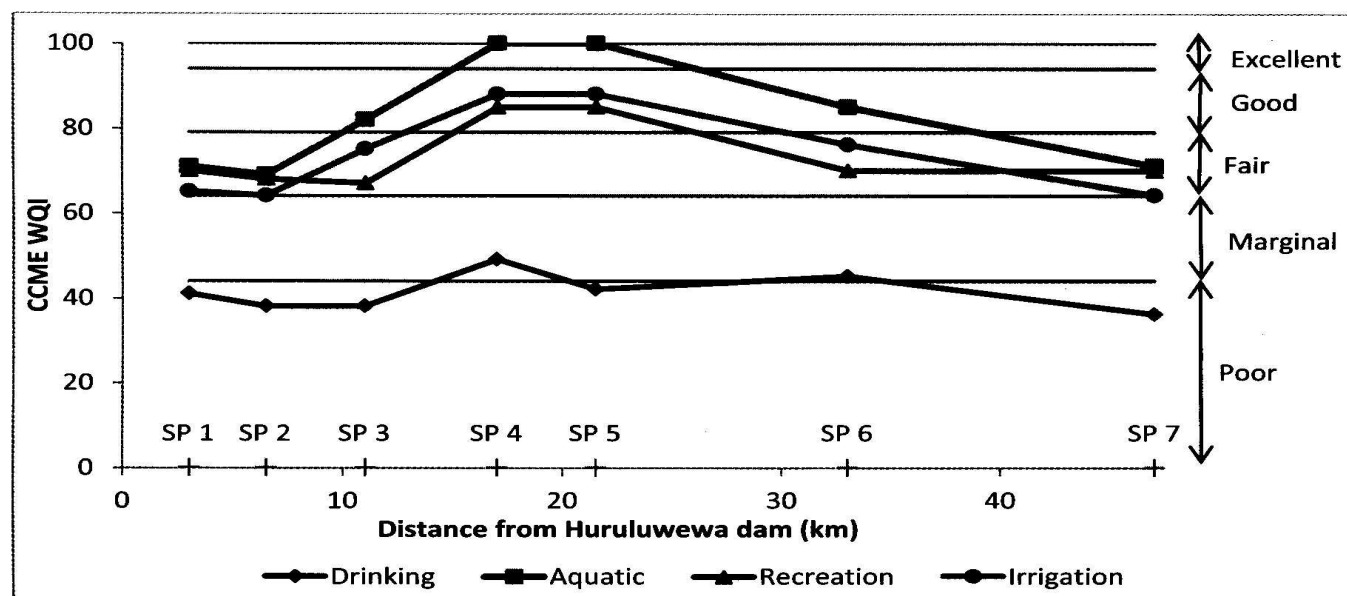


Figure 2. Spatial variation of CCME WQI and water categories

Seasonal variation of CCME WQI

Seasonal variation of CCME WQI for different water uses is shown in Table 5. CCME WQI for all water uses recorded low values during the pre-monsoonal period compared to monsoonal rainy period and post monsoonal period. It is due to concentration of pollutants excessive evaporation and low rainfall. Despite the addition of washout materials to the water, dilution of elements present in water with high rainfall and runoff during the monsoonal rainy period added remarkable value to the CCME WQI of all water uses. Even with the high rainfall and runoff, water quality of Yan Oya was categorized as poor for drinking during the monsoonal rainy period and it was categorized as marginal during the post monsoonal period. Marginal water quality for irrigation during the pre-monsoonal period changed into the good category during the monsoonal period due to dilution effect. However, it reaches fair category during the post monsoonal period due to the lower concentrations of pollutants. The CCME WQI of all other water uses continuously increases from pre monsoonal period through monsoonal rainy period and post monsoonal period. The higher WQI values in post monsoonal period is mainly due to by the decrease in turbidity levels compared to monsoonal rainy period.

Table 5. Seasonal variation of CCME WQI and water categories

Location	Drinking		Fish & Aquatic life		Recreational use		Irrigation	
	CWQI	Category	CWQI	Category	CWQI	Category	CWQI	Category
Pre-M	37	Poor	70	Fair	65	Fair	63	Marginal
M	43	Poor	84	Good	84	Good	87	Good
Post-M	48	Marginal	86	Good	86	Good	77	Fair

Pre-M – Pre monsoonal period; M – Monsoonal rainy period; Post-M – Post monsoonal period

Conclusion

Average values of CCME WQI showed that water quality is poor for drinking (34) in Yan Oya while fair for recreational use (70), fish & aquatic life (71) and irrigation (65). However, it showed high spatial and seasonal variation of water quality for all kind of water uses. CCME WQI can be successfully used to draw meaningful and easily understandable conclusions from large data matrix on water quality.

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