Evaluation of Groundwater Quality Index for Drinking Water in Tank Cascade Landscape

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Abstract **: This study investigated the groundwater for drinking purposes in the Malwathu Oya tank cascade landscape using water quality index (WQI). A total number of twenty wells were selected, and two sets of samples were collected from each location in December (to represent the wet season) and August (to represent the dry season) in the study area. Based on the Sri Lankan drinking water quality standards and previous studies, the weights were assigned for each water quality parameter. Thereafter, relative weight was calculated and using the observed concentration and the relative weight of each parameter, the WQI values were computed. The elevated concentration of all the parameters was observed during the dry season compared to the wet season. Hardness and the alkaline nature of the groundwater were the main issues encountered in the collected samples of the study area. An excellent type of water for drinking was found only in the wet season. Eighty percent of the total area was categorized as good type of water during the wet season, and it was decreased up to 37.7% during the dry season. Moreover, the total area under the poor type of water was increased significantly during the dry season than in the wet season. Accordingly, the majority of the groundwater in the study area is not suitable for drinking without proper treatment. Hence, it is essential to install proper water treatment plants with proper management and maintenance practices.**

Keywords **: relative weightage, tank cascade system, total hardness, water quality, water quality index**

I. INTRODUCTION

Fresh, safe drinking water with sufficient quantity is essential in human life, and it is considered as an essential requirement of economic development [1]. Although surface water and groundwater serve as drinking water sources all over the world, it is limited in many regions [2,3]. Moreover, drinking water supplies have become contaminated in many countries of the world. During the last century, due to the rapid population growth, the demand for agricultural land and urbanization has increased the demand for drinking and irrigation water [2,4].

Both the quality and the availability of water resources are considered as the major constraint in the dry zone of Sri Lanka. Due to the excess application of fertilizers and agrochemicals, irrigation water has deteriorated in the dry zone [5–7] whereas, drinking water quality deterioration is mainly taken place due to the industrialization and agricultural activities [8–10]. As the water quality is determined by assessing physical, chemical, and biological parameters, it is difficult to explain the overall condition of the water quality by assessing the quality parameters separately. Hence, a water quality index (WQI) has been developed to summarize the number of water quality parameters into a meaningful single numerical value [11].

Geographic information system (GIS) is an active field of research with the integration of different subjects such as land, ocean, health, water resources, agriculture, defense, forestry, etc. [12–14]. Spatial interpolation methods available in ArcGIS are widely used to interpolate the groundwater quality [15]. Very few attempts were taken to compare the interpolation methods and to select the best interpolation method to estimate water quality parameters [16–18]. The integration of GIS and WQI provides detailed, quick, and reliable information for decision-makers and make them easy to implement the strategies related to water pollution and scarcity [19].

Chronic kidney disease of unknown etiology (CKDu) is identified as the critical health issue in the dry zone of Sri Lanka, especially the North Central, North Western, and Uva provinces [20,21]. Agricultural workers are most affected, and among them, male workers are most vulnerable to this disease.

Tank cascade system (TCS) was developed to overcome the water scarcity problem in the dry and intermediate zone of Sri Lanka [22,23]. TCS is made up of 8-10 number of interconnected small tanks. It has been recognized as a globally important agricultural heritage site by the food and agriculture organization of the United Nations (FAO) [24]. Malwathu Oya cascade-I is a branched type cascade with an area of 26 km^2, located in the DL_{1b} agro-ecological region of Sri Lanka [25]. The mean annual rainfall in this area is less than 1750 mm, while 63% of annual rainfall is received during Maha season [26]. Even though several studies on irrigation water quality were carried out in TCS, no comprehensive study on drinking water quality was reported [27–29]. Hence, this study aimed to assess the groundwater quality for drinking in the Tank cascade landscape using WQI and GIS.

II. MATERIALS AND METHODS

A. Collection of groundwater samples

The total area of Malwathu Oya cascade-I was divided into 1 km^2 grid, and one well from each grid was selected to obtain the uniform distribution of sampling locations through the study area. Accordingly, a total number of twenty groundwater samples were collected for the analysis. Two sets of samples were collected from each location in December (to represent the wet season) and August (to represent the dry season) in the study area. All the samples were collected from shallow (5-10 m depth dug wells) groundwater. Samples were collected in acid cleaned high-density polyethylene bottles rinse with the groundwater to be sampled (Fig.1). All the water samples were brought to the laboratory of soil and water science, Faculty of Agriculture, Rajarata University of Sri Lanka for the chemical analysis, and stored at 4^0C.

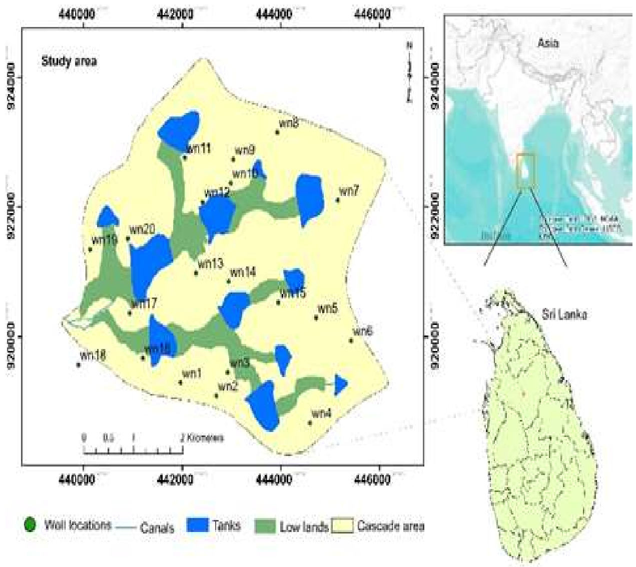

Figure 1. Groundwater sampling locations in Malwathu Oya cascade -I

B. Analysis of groundwater samples

Total dissolved solids (TDS), and pH of the water samples were measured in-situ using a HQ 40d multi-parameter analyzer (Hach, Colorado, USA). Filtered water samples were used for the chemical analysis. Sodium (Na+), magnesium (Mg^{2+}), calcium (Ca^{2+}), total hardness (TH), alkalinity, Cadmium (Cd^{2+}), arsenic (As^{3+}), and nitrate-nitrogen (NO_3^--N) were determined in the laboratory using standard analytical techniques [30]. The samples collected for cation such as sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), Arsenic (As^{3+}), and cadmium (Cd^{2+}) ions were determined by inductively coupled plasma optical emission spectrometry. Alkalinity as $CaCO_3$ was analyzed by acid-base titration. Total hardness was calculated based on the measured Ca and Mg data (Equation 1) [31]. Nitrate nitrogen was measured using the salicylic acid method.

$$\text{TH } (\text{CaCO}_3)\,mg/L = 2.49\,(Ca)\,mg/L + 4.1\,(Mg)\,mg/L \quad (1)$$

C. Water quality index (WQI) calculation

The water quality index (WQI) is successfully used in both irrigation and drinking water quality studies as it reflects the combined influence of different water quality parameters in a single value. Considering the previous studies [11,32], the Sri Lankan standards (SLS) and WHO standards for drinking water quality, weights (w_i) were assigned to pH, TDS, total hardness, total alkalinity, Ca^{2+}, Mg^{2+}, $Na^{+,}$ and NO_3-N to compute the WQI (Table 1).

Table 1: Sri Lankan Standards (SLS) and WHO standards of drinking water quality parameters

Water quality parameter	Sri Lankan Standards	WHO standards
pH	6.5-8.5	6.5-8.5
TDS	500	500
Total hardness	250	-
Total alkalinity	200	120
Calcium	100	75
Magnesium	30	50
Sodium	200	200
Nitrate nitrogen	10	10

Units of all parameters are in mg/l except pH.

Weights were not assigned to Cd^{2+} and As^{3+}, as those trace elements were not found in the groundwater samples. The maximum weight 5 was assigned to TDS and NO_3-N, considering their ability to cause health problems. Meanwhile, other parameters were assigned respective weights depending on the relative significance. The relative weight (W_i) of the chemical parameters were computed using equation 2.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (2)$$

Where Wi is the relative weight, w_i is the weight of each parameter, and n is the number of parameters. After that, a quality scale (q_i) for each parameter was calculated using Equation 3.

$$q_i = {}^{C_i}/_{S_i} * 100 \quad (3)$$

Where q_i is the quality rating, C_i is the concentration of each chemical parameter in the groundwater sample in mg/l, and Si is the Sri Lankan standards for each chemical parameter in mg/l. Finally, WQI was computed for both wet and dry season using q_i and $W_{i,}$ as shown in Equation 4.

$$WQI = \sum_{i=1}^{n} W_i\, q_i (4)$$

Table 2: Relative weights of drinking water quality parameters

Water quality parameter	Weights	Relative weights
pH	4	0.154
TDS	5	0.192
Total hardness	2	0.077
Total alkalinity	3	0.115
Calcium	2	0.077
Magnesium	2	0.077
Sodium	3	0.115
Nitrate nitrogen	5	0.192

Thereby the groundwater samples were categorized into different water types, as mentioned in Table 3. WQI values of all the sampling locations were spatially distributed in ArcGIS software using the Empirical Bayesian Kriging interpolation method [18].

Table 3: Classification of groundwater based on WQI

Class	WQI range	Water type
1	<50	Excellent water
2	50-100	Good water
3	100-200	Poor water
4	200-300	Very poor water
5	>300	Water Unsuitable for drinking

III. RESULTS AND DISCUSSION

A. Chemical characteristics of groundwater

The geochemistry of groundwater is mainly governed by aquifer characteristics, weathering of rocks, residence time, and the presence of other attributes along the flow path [11]. Table 4 shows the average geochemical composition of groundwater in both the wet and dry seasons. The pH of the water is a basic water quality parameter as it determines the solubility and biological availability of chemical constituents in water [33,34]. All the samples were slightly alkaline, and few were more basic (pH 8.4). According to Sri Lankan standards, the optimum pH range for drinking is 6.5 to 8.5. Hence, based on pH, all the samples had good water quality for drinking. The TDS values varied from 102.5 mg/l to 1170 mg/l during the study period. The ions that leached to the groundwater from rock-water interaction and anthropogenic activities may be concentrated due to the high evaporation that prevails in the dry zone. Moreover, the low rainfall and the high evaporation and high ambient temperature accelerate the upward movement of groundwater and tend to accumulate more salts [6]. It led to concentrate more solids in the groundwater [35]. Ca^{2+} is the most prominent cation and the cations vary from Ca^{2+}> Na^{+}> Mg^{2+}. Magnesium concentration in the groundwater is generally less than Ca^{2+} due to the slow dissolution ability of Mg^{2+} bearing minerals and greater abundance of Ca^{2+} in the earth's crust. These two minerals act as the most common minerals that make water hardness. The total hardness expressed as $CaCO_3$ in the study area is much higher than the SLS and WHO standards.

Table 4: Summary of the hydrogeochemistry data of two seasons

Water quality parameter	Wet season			Dry season		
	Min	Max	Avg	Min	Max	Avg
pH	6.9	8.0	7.4	7.2	8.4	7.6
TDS	102.5	1015	377.3	294.8	1170.0	586.9
TH	138.4	503.5	375.9	232.0	1652.0	684.3
Alkalinity	82.5	480.0	232.6	87.5	475.0	247.8
Ca^{2+}	33.0	106.0	67.9	62.0	190.0	121.0
Mg^{2+}	13.0	73.0	50.2	31.2	176.8	69.2
Na^{+}	18.0	253.0	57.9	23.0	504.0	110.3
NO_3-N	0.2	29.9	4.8	0.2	18.8	3.4

B. Water quality variation during the wet and dry season

As shown by Fig. 2 and 3, most of the ionic components are present in higher concentrations in groundwater collected during the dry season when compared to those values in the wet season. The high ambient temperature, high evaporation, and lack of rainfall during the dry season may tend to concentrate the ions in the water. The most probable cause for higher nitrate-nitrogen concentration during the wet season may be due to the leaching of excess fertilizer to the shallow groundwater [5,36].

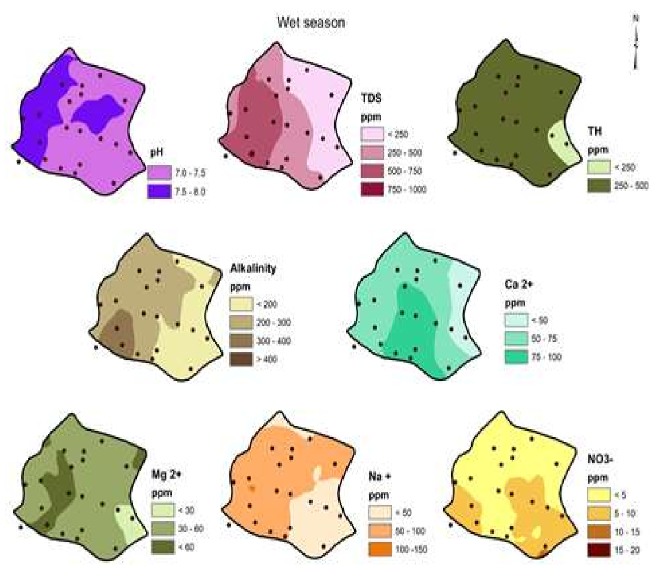

Figure 2. Water quality variation in Malwathu Oya cascade –I during wet season

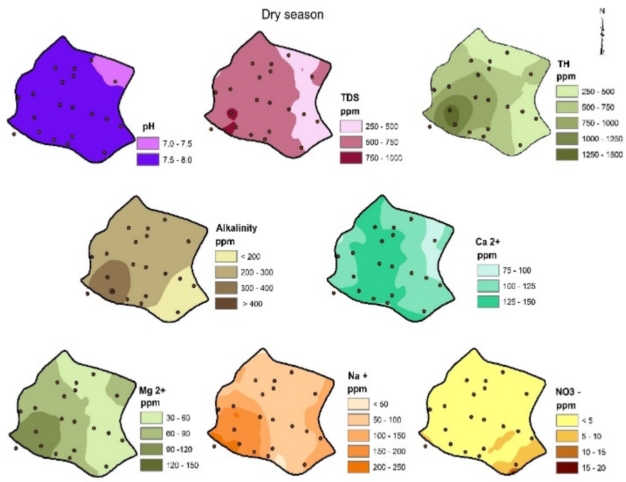

Figure 3. Water quality variation in Malwathu Oya cascade –I during dry season

Hardness is much higher in the dry season compared to the wet season in the study area. Several researchers suggested that the hardness below the threshold level correlated with good health, and the increase of iconicity above the threshold would correlate with CKDu [37].

C. Drinking water quality zoning in Malwathu Oya cascade-I

The WQI values never exceeded the 200 limit. Hence only three categories (excellent, good, and poor) of water were found in the study area. In the dry season, the WQI values were generally higher than those in the wet season. Overall, water quality is deteriorated during the dry season compared to the wet season. The excellent water is present only in the wet season. The good type of water is decreased, and the poor type of water is increased in the dry season. Accordingly, 37.7% and 62.3% of water is categorized as good water and poor water for drinking during the dry season, respectivel(Fig. 4). On the other hand, 1.3%, 80%, and 18.7% of the study area is categorized as excellent water, good water, and poor water for drinking during the wet season, respectively.

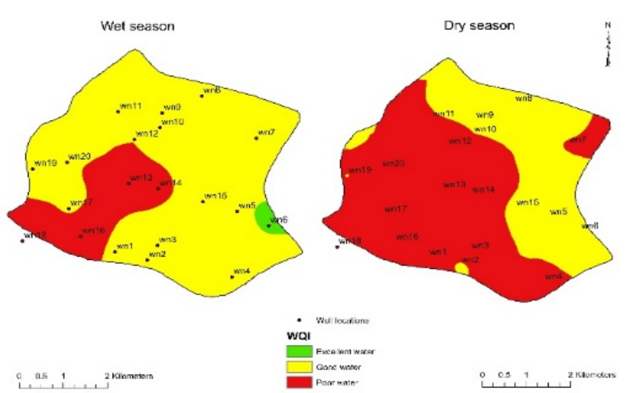

Figure 4. Drinking water quality zoning based on WQI in Malwathu Oya cascade –I

IV. CONCLUSION

The suitability of groundwater for drinking was assessed using WQI in the Malwathu Oya cascade-I. An elevated concentration of almost all the parameters was observed in the dry season compared to the wet season. Hardness and the alkaline nature of the groundwater were the main issues encountered in the collected samples of the study area. Based on WQI values, excellent type water (WQI <50) was found only in the wet season. Moreover, the good water category was 80% during the wet season, and it was reduced up to 37.7% during the dry season. Poor type of water was increased during the dry season compared to the wet season. However, the majority of the groundwater in the study area is not suitable for drinking without proper treatment. Hence installation of proper treatment plants with proper management and maintenance is suggested.

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