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Original research article

Application of CCME Water Quality Index for Drinking Water Quality Assessment along Kalu Ganga, Sri Lanka

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ABSTRACT

Kalu Ganga is considered one of the major rivers in Sri Lanka. The river contributes to drinking water supply, domestic water usage, agriculture, mini-hydropower generation, small-scale industries, and recreation. The present research fills the information gap regarding the water quality status along Kalu Ganga. At the same time, only a few attempts have been made using the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) to interpret water quality conditions in Sri Lankan rivers. Therefore, this study attempted (i) to investigate the temporal and spatial variations in drinking water quality along Kalu Ganga and (ii) to calculate the CCME WQI. Herein, July-October (2020) were considered wet months, while January-February (2021) were considered dry months. Altogether, twenty surface water sampling locations were selected, including six locations in the head zone, seven locations in the transport zone, and another seven locations in the deposition zone. In total, thirteen water quality parameters were measured on a monthly basis using standard methodologies; these included temperature, pH, total dissolved solids, electrical conductivity, salinity, dissolved oxygen, biological dissolved oxygen, nitrate, total phosphate, orthophosphate, total alkalinity, total hardness, and chlorophyll-a. CCME WQI was calculated using the total hardness, total dissolved solids, total alkalinity, electrical conductivity, pH, nitrate, orthophosphate, and total phosphate parameters. All sampling locations were categorised as excellent for drinking according to CCME WQI (95-100), with the exception of sampling locations in the deposition zone with fair-good quality (79-80) during the dry months. Overall, the drinking water in Kalu Ganga was categorized as excellent-fair based on the water quality parameters for this WQI calculation. However, saltwater intrusion was observed up to 14km from the river mouth during the dry months. Further studies, including heavy metals and microbial parameters, can further develop the WQI.

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Keywords: CCME WQI; Kalu Ganga; Water quality

1. Introduction

Rivers are important lotic freshwater ecosystems across the world. Rivers were the center of all the great civilizations of the world [1, 2]. From a human standpoint, rivers are principal water sources for domestic, industrial, agricultural, and recreational purposes [3]. From a hydrological perspective, rivers play a central role in the global cycling of water between ocean, air, and land. Rivers contribute to various ecosystem services, including provisioning, regulating, supporting, and cultural services [4].

Since the 1980s, the global rate of water use has been increasing by 1% annually [5]. As the population grows, water is increasingly threatened by increasing demand [6]. High-quality water is needed for drinking purposes, while other uses can be more flexible to a certain extent [7]. Despite its importance, water is the most poorly dealt resource in most developing countries [8]. With the rapid acceleration of economic activity and urbanization, river pollution has occurred continuously, resulting in severe damage to river ecosystems [9].

Precipitation rate, atmospheric inputs, basin lithology, and weathering processes, including soil erosion, are several significant factors that influence the quality of river water at any point. Besides this, rivers play a significant role in transporting agricultural runoff and industrial and municipal wastewater. Therefore, river water quality assessment is essential because it directly influences public health and aquatic life [10-11]. Water quality can be assessed using various physical, chemical, and biological parameters [12]. Assessing surface water quality involves various parameters, each of which exerts different levels of stress on the overall water quality [13]. Managing water quality is challenging due to the complexity of river dynamics and the impact of both natural and anthropogenic processes. This problem is made more difficult by the lack of systematic information regarding river water quality in developing nations [14].

The suitability of water can be easily described in terms of the Water Quality Index (WQI). WQI has the capability to reduce bulk information into a simplified single value with simple terms (e.g., excellent, good, bad, etc.). Numerous WQIs have been formulated worldwide [13, 15]. To assess surface water quality worldwide, more than 35 WQI models have been introduced by various nations and organizations as of 2019 [16]. One study has reported that although numerous WQI models have been applied in all major types of waterbodies, 82% of applications have been to assess river water quality [16]. Furthermore, the Canadian Council of Ministers of the Environment (CCME) WQI has been used in more than 50% of studies.

The island of Sri Lanka (6º-10º N and 80º-82º E) is an extension of the Indian peninsula, located on the Indo-Australian plate with a total land area of 65,610 km^2 [17]. The island nation has an extensive network of rivers and streams that includes 103 river basins [18, 19]. The island's rivers, 16 of which are more than 100 km long and account for 80% of the island's freshwater discharge, are the main driver of the aquatic biodiversity in the absence of natural lakes [20]. In contrast to lentic water bodies, little information is available on the physicochemical characteristics of the running waters of Sri Lanka [21]. Although most of Sri Lanka's rivers are not contaminated by industrial waste, there is abundant residential and agricultural waste, human and animal sewage, and other waste materials [20]. The Kelani River, which is considered to be one of the most polluted rivers in Sri Lanka, is the most extensively studied in terms of water pollution in various aspects [22-27]. High levels of arsenic and cadmium contamination have been reported in the Malwathu Oya river, which is used for crop watering during the growing season in the catchment area [29]. One study compared pollution trends of the Kirindi Oya, Walawe Ganga, and Menik Ganga and concluded that all three river systems indicate surface water pollution during specific periods of the year [30]. Additionally, high levels of sedimentation are found in the Polwatta River, Galle [31]. Elevated nutrient loads have been observed in different parts of the Gin River basin [32].

Even though there have been several studies on Sri Lankan surface water quality, the CCME WQI has only been used a few times to interpret water quality situations that the general public can understand [33]. Kelani River basin surface water quality [27] and groundwater quality [34] have been evaluated in terms of CCME WQI. CCME WQI has been applied for tank cascade systems [35, 36]. CCME WQI has also been used to monitor groundwater quality in the Colombo catchment of Sri Lanka [33].

Kalu Ganga, one of the major rivers (129 km in length) of Sri Lanka, is the second largest river basin in Sri Lanka, covering 2766 km^2, entirely located in the wet zone of the country [37]. Geographically, the basin lies between 6.32° and 6.90°N and 79.90° and 80.75°E [38]. The river originates from Adam’s peak at an altitude of 2250 m and falls into the Indian Ocean at Kalutara after flowing through Rathnapura and Kalutara districts. According to the Survey Department of Sri Lanka's land use and land cover map from 2016, the Kalu Ganga river basin's land uses included water bodies, wetlands, forests, bare lands, rocky areas, agricultural lands, and built-up areas [37, 39]. Lower Kalu Ganga basin is a site for numerous major artifacts, monuments, and significant archaeological, historical, and cultural sites [40]. The river and its tributaries are associated with medium-scale hydropower generation units and drinking water schemes. The lower floodplains of the Kalu Ganga watershed are densely populated, housing around 2.2 million people [37]. Although several studies regarding the water quality status at different parts of the Kalu Ganga basin have been conducted [41-44], detailed studies are lacking.

Therefore, the current study was carried out with the objective of assessing the spatiotemporal variation of water quality status along Kalu Ganga in terms of CCME WQI.

2. Materials and Methods

2.1 Study area

The present study was carried out from the head region to the river mouth of the Kalu Ganga. The main river was divided into three major zones based on catchment characteristics, river functions, and elevation data collected from Google Earth (Google Earth Pro, 7.3). The upper region (erosional region) was considered as the head zone (HZ, approximately 20 km in length, 36-442 m height from mean sea level (MSL)), the middle region was considered as the transport zone (TZ, approximately 45 km in length, 16-35 m height from MSL) and the lower region was considered as the depositional zone (DZ, approximately 33 km in length, 0-15 m height from MSL).

2.2 Sample collection and analysis

Based on a stratified random sampling technique, 20 sampling locations were selected along Kalu Ganga. Six locations in the head zone, 7 locations in the transport zone, and another 7 locations in the deposition zone were selected with 3, 6, and 5 km gaps between locations, respectively. Fig. 1 indicates the 20 sampling locations, while Figs. 2-4 show the sampling locations at different zones. Samples were collected at each location on a monthly basis for six months between July 2020 and February 2021. July, August, September, and October (2020) were considered the wet months, while January and February (2021) were considered the dry months.

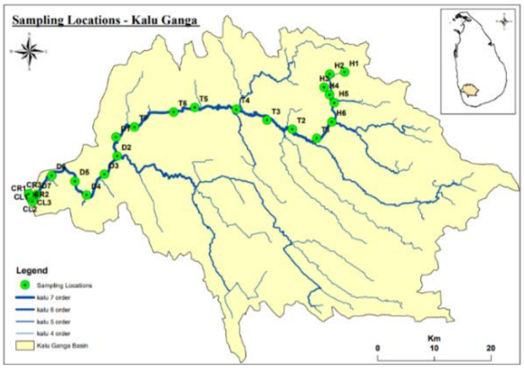

Fig. 1. Sampling locations-Along Kalu Ganga.

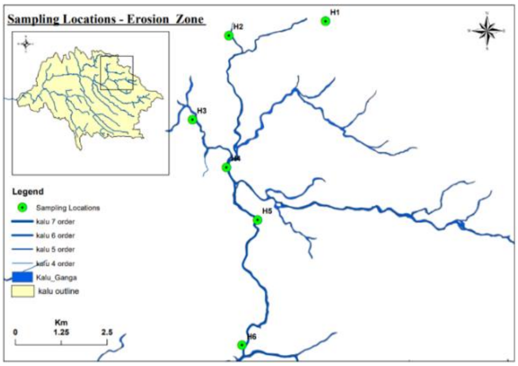

Fig. 2. Sampling locations of Kalu Ganga head zone.

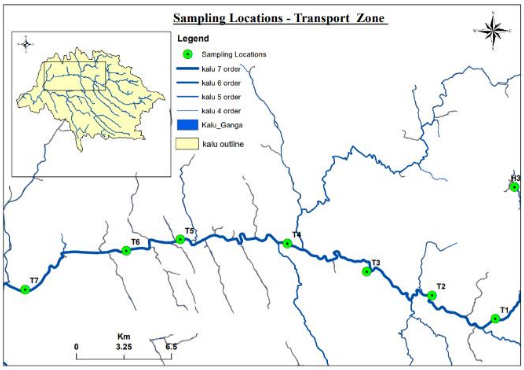

Fig. 3. Sampling locations of Kalu Ganga transport zone.

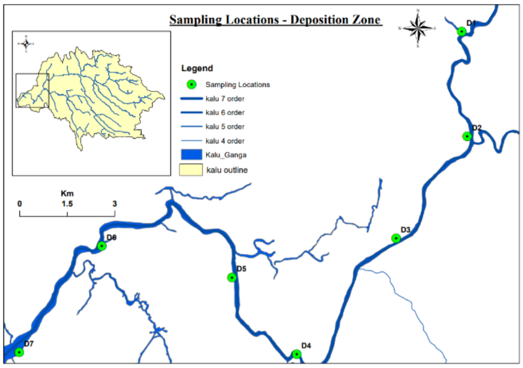

Fig. 4. Sampling locations of Kalu Ganga deposition zone.

Samples were collected into pre-cleaned High-Density Polyethylene (HDPE) screw-capped bottles, transparent glass bottles, and amber colored glass bottles for analysis depending on the purpose. Water pH was measured using a portable pH meter (Consort, C6010), while temperature, electrical conductivity (EC), total dissolved solids (TDS), and salinity were measured by a portable conductivity meter at the site itself (Walk LAB, HC 9021). In the laboratory, dissolved oxygen (DO) and biological oxygen demand (BOD5) were measured using the Winkler method. Nitrate, orthophosphate (OP), and total phosphate (TP) concentrations were measured according to standard spectrophotometric (JENWAY 6305 UV/Vis Spectrophotometer) methods. The EDTA titrimetric method was used to determine total hardness (TH), while the HCl titrimetric method was used to determine the total alkalinity (TA) as $CaCO_3$. Chlorophyll-a (Chl-a) concentrations were measured using the standard spectrophotometric (Thermo Scientific GENESYS 10S Series) method [45].

2.3 Geographical data analysis

The coordinates of localities were determined by GPS (Hand-held Gamin eTrex 30 GPS receiver). The geographical Information System (GIS) package ArcGIS 10.5 was used to generate the sampling location maps.

2.4 Calculation of WQI

The WQI was calculated for each location using the CCME WQI calculator version 1.2 using the drinking water category standard guidance values [46-47] for selected parameters. The water quality categories created by CCME are based on the WQI and are classified as follows: excellent (95-100), good (80-94), fair (65-79), marginal (45-64), and poor (0-44).

2.5 Secondary data collection

Monthly precipitation data was collected from the Meteorological Department, Sri Lanka, for the relevant period [48, 49].

2.6 Statistical analysis

MINITAB 21 statistical software package and Microsoft Excel 2017 were used for statistical analysis. Both parametric and non-parametric tests were performed separately to determine the zone-wise variation of water quality parameters along the river during the wet and dry months. (Significance level 95 %, $\alpha = 0.05$)

3. Results and Discussion

3.1 Monthly average rainfall for Rathnapura meteorological station

The Rathnapura meteorological station is located in the Rathnapura District of the Kalu Ganga catchment area. The monthly total rainfall for the study period and the average monthly rainfall for 30 years are displayed in Fig. 5, while the average number of rainy days per month during the study period and for 30 years is displayed in Fig. 6. The amount of rainfall received during January-February of 2021 (dry months) was lower compared to the amount of rainfall during July-October of 2020 (wet months).

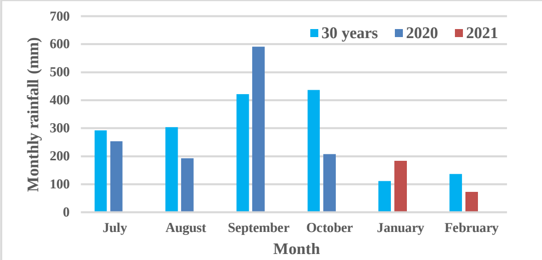

Fig. 5. Monthly total rainfall at Rathnapura meteorological station.

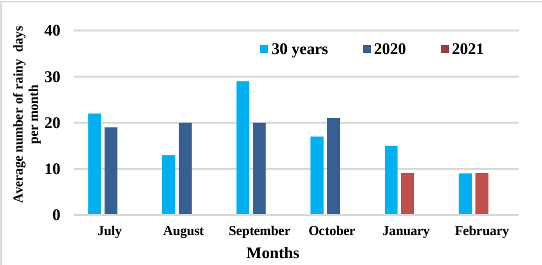

Fig. 6. Monthly average number of rainy days at Rathnapura meteorological station.

3.1 Spatial and temporal variation of selected water quality parameters along Kalu Ganga

For the assessment of water quality in streams, spatial and temporal monitoring has been one of the crucial methods used [50]. The variation of selected water quality parameters during wet and dry months is displayed in Figs. 7-19.

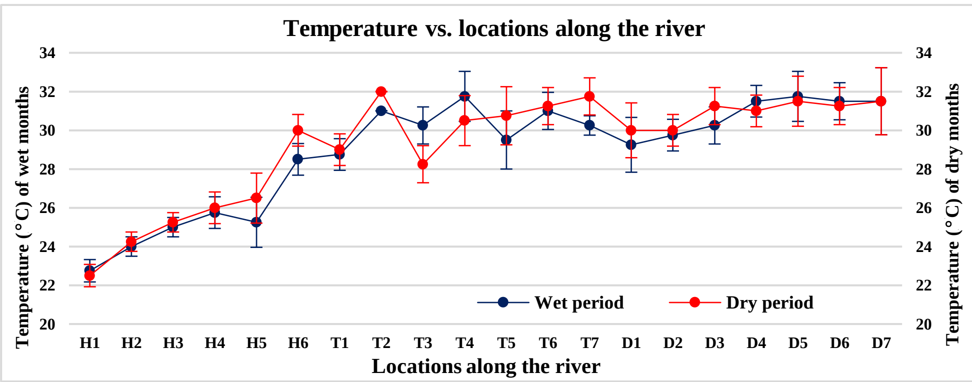

Fig. 7. Temperature vs. locations along the river.

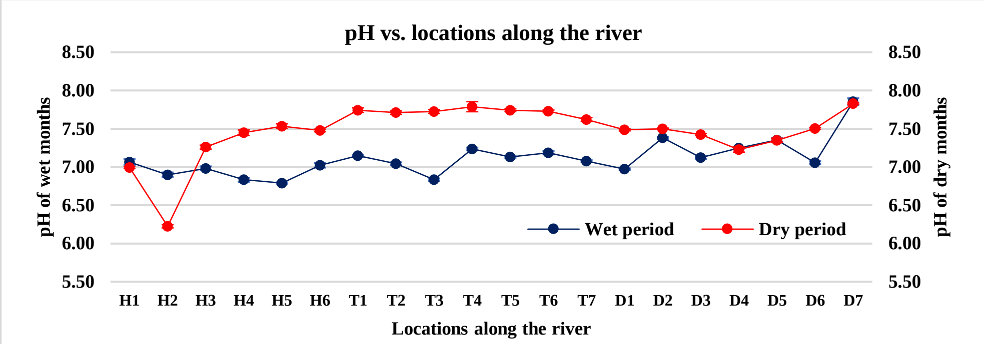

Fig. 8. pH vs. Locations along the river.

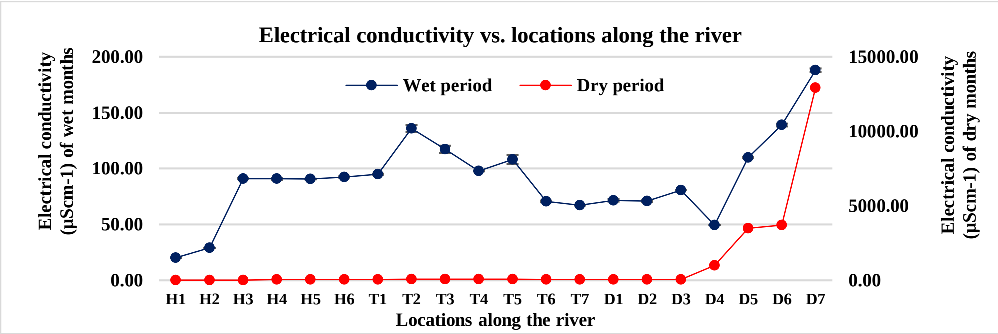

Fig. 9. Electrical conductivity vs. locations along the river.

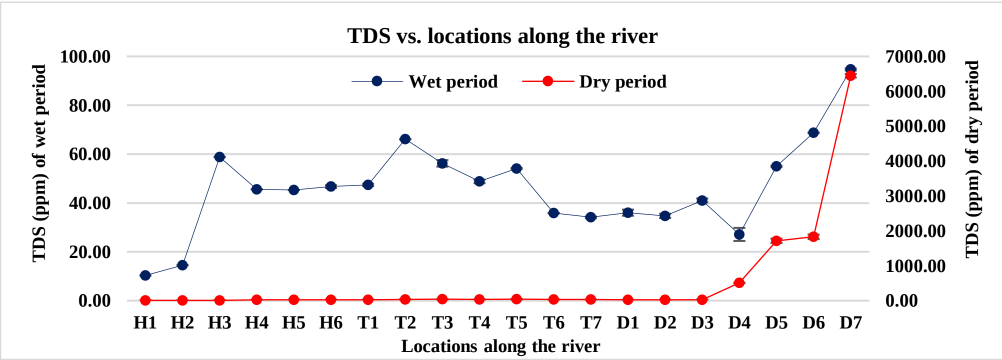

Fig. 10. TDS vs. locations along the river.

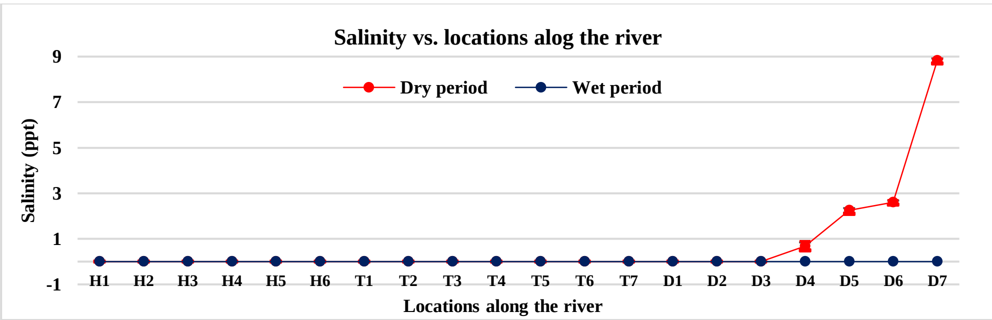

Fig. 11. Salinity vs. locations along the river.

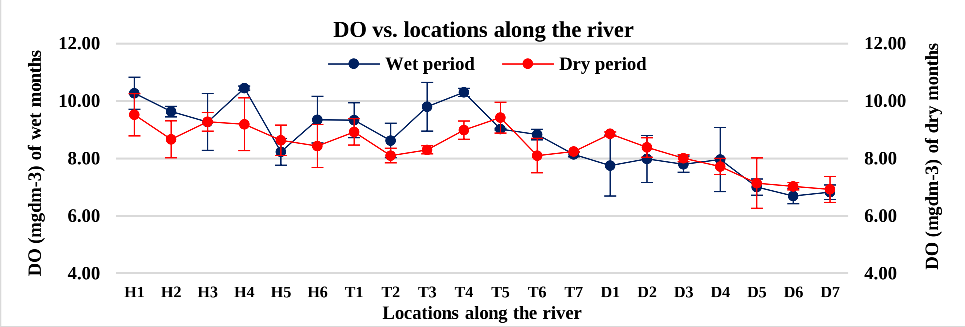

Fig. 12. DO vs. locations along the river.

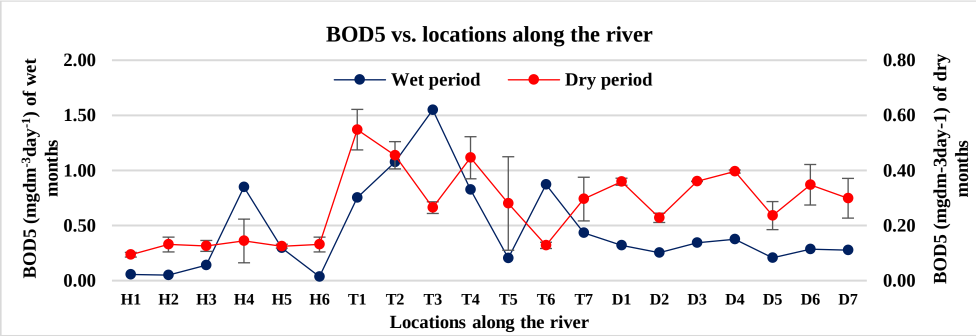

Fig. 13. BOD5 vs. locations along the river.

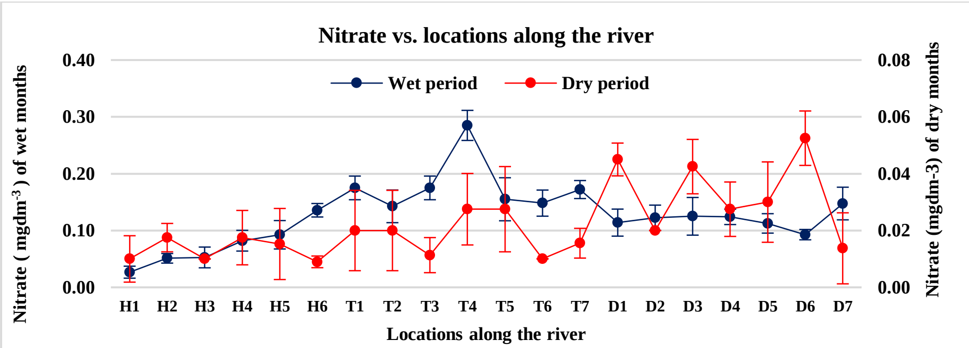

Fig. 14. Nitrate vs. locations along the river.

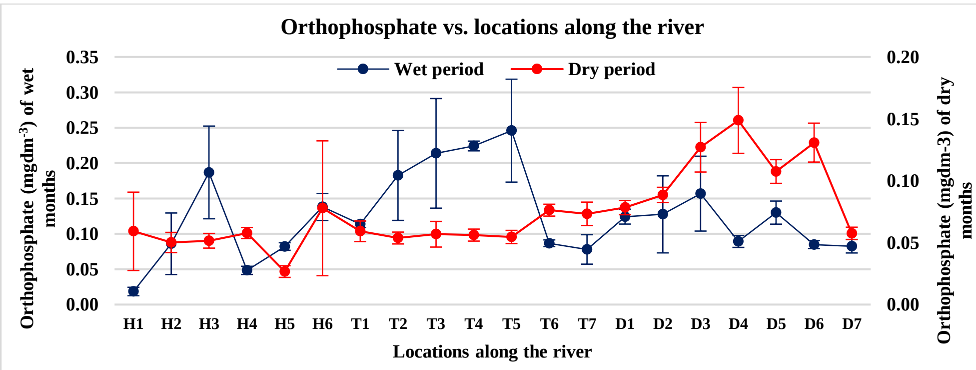

Fig. 15. Orthophosphate vs. locations along the river.

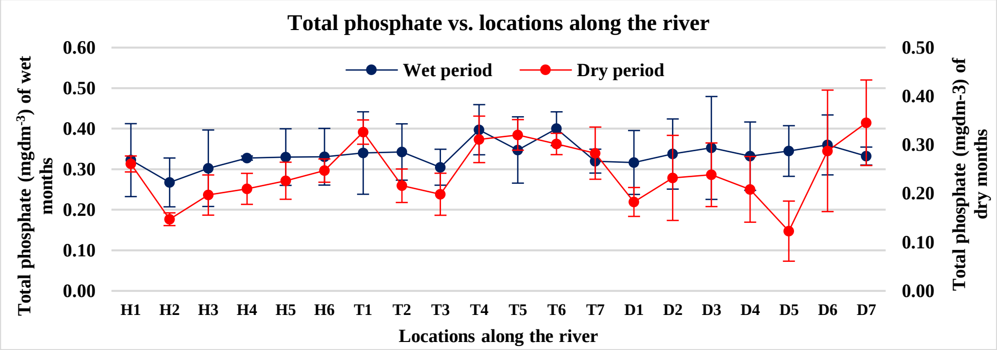

Fig. 16. Total phosphate vs. locations along the river.

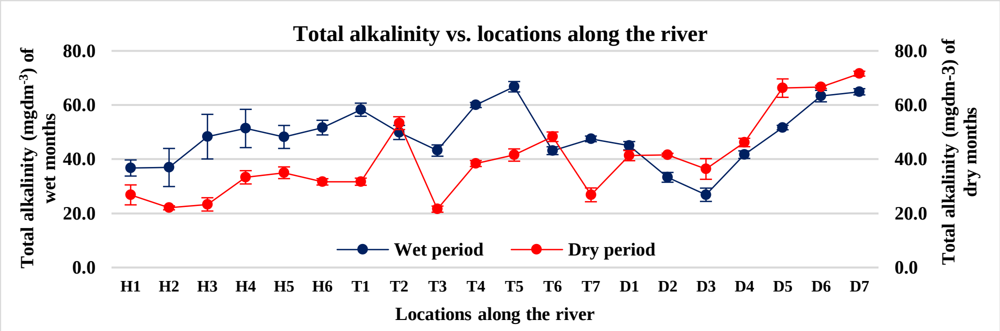

Fig. 17. Total alkalinity vs. Locations along the river.

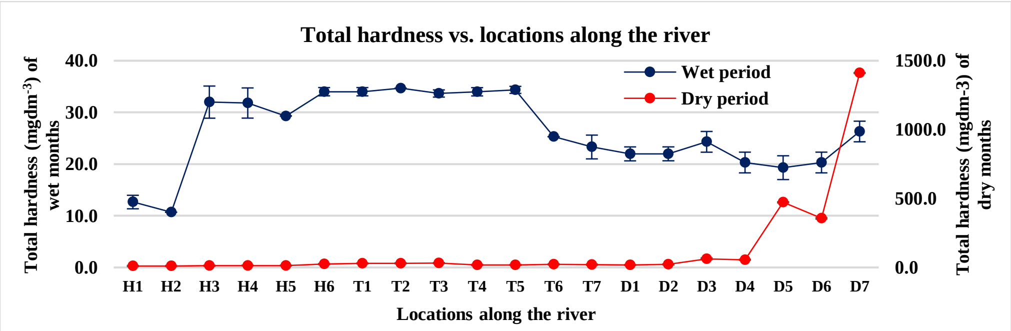

Fig. 18. Total hardness vs. Locations along the river.

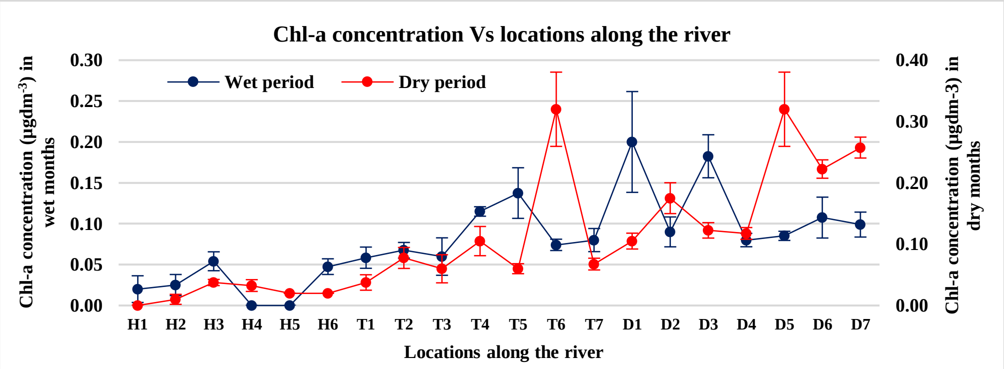

Fig. 19. Chl-a vs. Locations along the river.

Water temperature is crucial to aquatic ecology because it alters the concentration of the majority of physicochemical factors in water bodies [51]. Surface water temperature presented acceptable values ranging from 23 to 32 °C during the study. It was previously reported that the surface water temperature of the Kelani River was in the range of 24-31 °C [24]. The mean water temperature of the Gin River basin was reported to be 25.8±2.4 °C [32]. During the wet months, the temperature gradually increased from HZ to DZ ($p = 0.002$; Kruskal-Wallis zone-wise comparison = D > T > H). The water temperature will rise along with the air temperature [52]. In Sri Lanka, a regional difference in air temperature is observed mainly due to the changes in altitude. The air temperature increases with decreasing altitude [53]. Kalu Ganga begins at an altitude of 2250 m and flows along a length of 129 km. Therefore, the detected gradual rise of water temperature along the Kalu Ganga is mainly attributed to the decreasing altitude, in agreement with the altitude-based water temperature variations seen in Gin Ganga [32]. The one-way ANOVA showed that the temperature variation among sampling zones was statistically significant during the dry months ($p = 0.000$). The HZ temperature significantly differed from TZ (One-Way ANOVA multiple comparison results, $p = 0.000$) and DZ (One-Way ANOVA multiple comparison results, $p = 0.000$). The water temperature in the middle catchment and lower catchment were similar, while the upper catchment area was different from Gin River [32]. Although Sri Lanka experiences four climatic seasons based on the rainfall, the air temperature does not significantly differ between the seasons. Therefore, there was no significant difference in the water temperature between wet and dry months in each zone, as depicted by this study. The minimum temperature reported in the HZ was due to the microclimate and dense vegetation of the area. The atmospheric temperature fluctuates between 21 °C to 32 °C throughout the year in the Kalu Ganga catchment area [40], and the present study reported the surface water temperature within this range as well.

The pH level determines nutrient solubility and biological availability [36]. Changes in pH can convert some toxic substances in water to even more toxic forms [54]. Although the pH was significantly different between HZ and DZ during the wet months (One-way ANOVA multiple comparisons, $p = 0.011$), during the dry months, it was significantly different between HZ and TZ (One-way ANOVA multiple comparisons, $p = 0.008$). pH levels between 6.5 to 8.5 are ideal for drinking water and aquatic life [55]. Therefore, the measured pH range was within the recommended limit range. In contrast, acidic pH has been reported along Gin Ganga [32]. This demonstrates no substantial negative health implications for aquatic life or humans due to pH along Kalu Ganga. However, no occasional pH fluctuations persisted along the river, as was observed in another study in the Kelani River due to high levels of industrial discharge [24].

The primary source of salts in water is the geochemical weathering of rocks from the earth's upper strata, with atmospheric deposition and human activities serving as secondary sources [56]. Although the salinity level was reported as 0 ppt along the river during the wet months, due to saltwater intrusion impact during the dry months, the salinity level had gradually increased from the D4 location to the D7 location, covering nearly 14 km in length. Ratnayake et al. [44] observed a saltwater intrusion in Kalu Ganga up to 11 km from the river mouth. EC is a unit of measurement for a liquid's ability to conduct electricity. Its capacity is influenced by the temperature of readings, ionic strength, and dissolved ion concentrations [57]. Freshwater streams typically have an EC range of 0-800 μS/cm [58]. Our research along Kalu Ganga in HZ and TZ revealed EC measurements that fell within this range. TDS is typically used to measure the concentration of dissolved ions [59]. These two metrics can be used to examine seawater intrusion because they indicate salinity level [60]. Although no significant difference was reported for TDS between zones during wet months (p = 0.379), during the dry months, TDS significantly gradually increased towards the DZ (p = 0.008; Kruskal-Wallis zone-wise comparison = D > T > H). A similar pattern was observed for EC (wet months: p = 0.316; dry months: p = 0.012; Kruskal-Wallis zone-wise comparison = D > T > H). In agreement with another study, the EC in the present study increased in the lower catchment area of Gin Ganga in February [32]. Sand mining activities, urban activities, and erosion can increase the TDS and EC along Kalu Ganga.

Higher levels of dissolved oxygen encourage an increase in the number of microbes that break down organic matter, increasing oxygen consumption. DO is related to the presence of organic matter. When the water body's capacity for self-purification (through aeration and algal photosynthesis) is insufficient, hypoxia results, directly harming aquatic life [61]. DO was significantly different (wet months: p = 0.000; dry months: p = 0.000) between HZ and DZ (One way ANOVA multiple comparison, wet months: p = 0.000; dry months: p = 0.004), TZ and DZ (One way ANOVA multiple comparison, wet months: p = 0.001; dry months: p = 0.035), as well as TZ and DZ (One way ANOVA multiple comparison, wet months: p = 0.000; dry months: p = 0.004). The HZ had high levels of DO due to the increased dissolving of atmospheric oxygen, in turn due to the high flow rates and steeper slopes. The reduction of mixing water with air could cause a gradual decrease of DO levels along the river from the HZ to the DZ, a similar pattern of DO along the Gin Ganga [32]. The reported DO values exceeded those measured at the Kelani River [24].

The term "Biochemical Oxygen Demand" (BOD) refers to how aerobic biological organisms consume much-dissolved oxygen to break down the organic matter in a body of water at a given temperature over a specific period. It is frequently used to represent the pollutant load and serve as an indicator of the organic quality of water. High numbers of microorganisms require more DO, thus increasing the BOD level [52]. The significantly highest BOD5 was reported in the TZ during wet months (p = 0.017 Kruskal-Wallis zone-wise comparison = T > D > H), similarly in the dry months (p = 0.005 Kruskal-Wallis zone-wise comparison = T > D > H). During the dry months, the highest BOD5 value was recorded in the TZ due to the increased amount of accumulated organic waste in the river, which flows through an urbanized area. Even though the DZ also flows through an urbanized area, the organic matter is deposited in the bottom of the water due to the reduced water velocity along the decreasing slope of the river. Slow-moving water allows organic matter to settle down. Therefore, the amount of organic matter can be reduced in the surface water, reducing the BOD of water. BOD levels remained within the acceptable range for drinking water criteria throughout the study period [53]. When BOD5 concentrations are ≤ 4mg/L, natural rivers are considered polluted with organic matter, yet they are still safe for drinking [60]. Our reported BOD values exceed those from the Kelani River [24].

The two main elements that affect a water body's production are nitrogen and phosphorus [32]. Usually, surface water contains nitrate in low concentrations, but it can be increased due to agricultural runoff or contamination with human or animal wastes [36]. Orthophosphate, also called “reactive phosphorus”, is an inorganic form of phosphate which organisms can readily use. Total phosphorus measures all forms of phosphorus, dissolved or particulate, found in water [52]. OP was significantly different only during dry months (p = 0.001), between HZ and DZ (One-way ANOVA multiple comparisons, p = 0.001), TZ and DZ (One-way ANOVA multiple comparisons, p = 0.003). However, in the Kelani River, from the river's source to the point of discharge into the sea, pollution indicators (BOD, NO_3^-, etc.) often show a regular increase [61]. NO_3^-, the most oxidized form of nitrogen, is very mobile in soil and abundant in streams. However, nutrient concentrations were reported in low levels. Similar pattern results have been reported for nitrate levels in the Kelani River, which have been considered somewhat unusual compared to the fertilizer load in the catchment. Usually, runoff carries low levels of OP, as they are retained in the soil, and the other portion is settled in the river bottom by readily binding with suspended matter [24]. Since Kalu Ganga is located in the highest rainfall-receiving area of the country, due to the dilution effect of large amounts of water, nutrient concentrations can become low in surface waters. Referring to the land usage in the basin, it is expected that the run-off of nutrients comes from tea estates, paddy fields, and rubber estates in the Kalu Ganga catchment area. All measured nutrient parameters remained within acceptable limits throughout the study period. No significantly different TP values were reported among zones during the research period. The significantly highest nitrate level was reported in the TZ during the wet months (p = 0.001 Kruskal-Wallis zone-wise comparison = T > D > H), similarly in the dry months (p = 0.045 Kruskal-Wallis zone wise comparison = T > D > H).

Although the significantly highest TH was reported in the TZ during the wet months (p = 0.001 Kruskal-Wallis zone-wise comparison = T > D > H), the highest TH was reported in the DZ during the dry months (p = 0.005 Kruskal-Wallis zone wise comparison = D > T > H). The continuous erosion in the HZ can add calcium ions into the river water by dissolving limestone. The decreased pH levels during the wet months can also affect the dissolving of materials. Whenever water moves slowly in the DZ, it allows the deposition of ions into the bottom, reducing the hardness in the DZ to be lower than the TZ. The main reason for the increment of hardness in the deposition zone in the dry months is saltwater intrusion occurring at the latter part of the DZ. The saltwater is rich in calcium and magnesium compounds, which can increase the hardness. Due to the saltwater intrusion in dry months, the hardness only increased at the last sampling points. The recommended raw water limit for domestic use is 250 mg/L [53]. For TA, significantly different levels among zones were reported during dry months (p = 0.001), and TA was significantly different between HZ and DZ (One-way ANOVA multiple comparisons, p = 0.021). Alkalinity in water may originate from various sources, including biological uptake, evaporation and precipitation of minerals, dust deposition from the atmosphere, and weathering of rocks and soil. Sources of alkalinity in the water could be primarily weathering of rocks and soil, biological uptake, evaporation and precipitation of minerals, and atmospheric dust deposition [62].

Chlorophyll-a is a measurement of suspended phytoplankton in a water body. Chlorophyll-a significantly gradually increased towards the DZ from HZ during the wet months (Kruskal-Wallis test, p = 0.001 Kruskal-Wallis zone wise comparison = D > T > H), as well as during the dry months (Kruskal-Wallis test, p = 0.001 Kruskal-Wallis zone wise comparison = D > T > H). Headwater has low phytoplankton densities compared to the transport and deposition zones. The high flow velocities in the upper stream limit the abundance of phytoplankton. Due to the increasing levels of sunlight, reducing water velocity and sufficient nutrients will increase the abundance of phytoplankton towards the DZ. The chlorophyll-a level was in the range of 0-2.6µg/L. Therefore, the river water in every location showed similar levels of an oligotrophic condition lake [63].

In the HZ, except for the other tested parameters, nitrate (p = 0.005), TP (p = 0.005), and TA (p = 0.005) were significantly increased during wet months compared to dry months. Except for the T, DO, BOD, and Chl-a, other tested parameters significantly differed between wet and dry months in the

TZ. Among those significantly different parameters, other parameters had increased during wet months compared to dry months. Although, the pH ($p = 0.002$) had significantly increased during the dry months compared to wet months.

Another study reported no significant variation in water quality status in the Mahaweli River downstream [64]. The river experiences year-round rain as it flows through different climatic regions. Kalu Ganga also experiences high precipitation levels throughout the year. This can help the Kalu Ganga basin to maintain slightly or moderately polluted water quality conditions in different periods.

3.2 CCME WQI

CCME WQI was calculated using the total hardness, TDS, alkalinity, electrical conductivity, pH, nitrate, orthophosphate, and total phosphate parameters. According to the WQI calculation, excellent water quality was observed at all the locations in the HZ and TZ. However, four locations in the DZ indicated good-fair water quality during the dry months resulting from the impact of saltwater intrusion (Table 1). However, this result depends exclusively on the aforementioned parameters. In addition, the provided parameters indicate that the water is suitable for drinking according to the SLS drinking water quality guidelines [47]. The results may vary if heavy metals or biological parameters, such as E. coli, coliform levels, are utilized to calculate the WQI. Therefore, it is unreasonable to conclude that the water in the Kalu Ganga is of outstanding quality without conducting additional tests that include other significant parameters.

Table 1. CCME WQI values along Kalu Ganga.

Location ID	Time	CCME WQI value	CCME category
H1	Wet	100	Excellent
	Dry	100	Excellent
H2	Wet	100	Excellent
	Dry	100	Excellent
H3	Wet	100	Excellent
	Dry	100	Excellent
H4	Wet	100	Excellent
	Dry	100	Excellent
H5	Wet	100	Excellent
	Dry	100	Excellent
H6	Wet	100	Excellent
	Dry	100	Excellent
T1	Wet	100	Excellent
	Dry	100	Excellent
T2	Wet	100	Excellent
	Dry	100	Excellent
T3	Wet	100	Excellent
	Dry	100	Excellent
T4	Wet	100	Excellent
	Dry	100	Excellent
T5	Wet	100	Excellent
	Dry	100	Excellent
T6	Wet	100	Excellent
	Dry	100	Excellent
T7	Wet	100	Excellent
	Dry	100	Excellent
D1	Wet	100	Excellent
	Dry	100	Excellent
D2	Wet	100	Excellent
	Dry	100	Excellent
D3	Wet	100	Excellent
	Dry	100	Excellent
D4	Wet	100	Excellent
	Dry	85	Good
D5	Wet	100	Excellent
	Dry	76	Fair
D6	Wet	100	Excellent
	Dry	76	Fair
D7	Wet	100	Excellent
	Dry	66	Fair

It was reported that Kelani Ganga, which is considered the most polluted river in Sri Lanka, has poor-marginal drinking water along Kelani Ganga based on CCME WQI using eighteen water quality parameters, namely pH, TDS, EC, TP, nitrate, nitrite, hardness, DO, BOD, chemical oxygen demand, Cd, Pb, Al, Zn, Cu, Cr, total coliform, and faecal coliform counts [27]. The current study suggests a low pollution level in Kalu Ganga compared to that. However, the results may vary since the included parameters for WQI calculation are not similar between the two studies. Since the WQI has been developed using the published drinking water guidelines, it can be assumed that such locations are suitable for irrigation, livestock maintenance, and recreational purposes.

However, since the Kalu Ganga catchment area is facing rapid urbanization, there is a possible risk of river contamination with emerging pollutants such as microplastics, pesticides, pharmaceuticals, and personal care products, which could be harmful to the people who consume this water.

Installing saltwater intrusion barriers, such as dams, dykes, weirs, or mangrove-like natural ecosystems, and creating buffer zones along riverbanks to mitigate the impacts of saltwater intrusion on terrestrial ecosystems are some of the mitigation measures available to control the significant environmental and economic impacts that occurred due to saltwater intrusion of Kalu Ganga during the dry months.

4. Conclusion

Based on the resulting CCME WQI values, it can be concluded that there is currently a low level of water pollution in Kalu Ganga in terms of evaluated water quality parameters. Saltwater intrusion was observed up to 14 km from the river mouth during the dry months. Continuous assessments for long periods, including Na^+, Cl^-, TDS, EC, and salinity parameters, will draw a better picture of the saltwater intrusion situation of Kalu Ganga. Developed WQI values can be used in decision-making for locating or relocating water intakes at the deposition zone to avoid the effect of saltwater intrusion into water treatment plants in a better sense. The current study also expresses the capability of WQI to reduce bulk information into simplified singular terms of water suitability. Future studies, especially those that measure heavy metal content and microbial contamination of the study area, are recommended.

References

[1] Balasankar T, Nagarajan S. A correlation study on physicochemical characteristics of groundwater in and around Cuddalore Sipcot, Tamil Nadu. Indian Journal of Environmental Protection 2000; 20(6): 427-9.

[2] Madhuri U, Srinivas T, Sirresha K. A study on groundwater quality in the commercial area of Visakhapatnam. Pollution Research, 2004; 23(3): 565-8.

[3] Ngwenya, F. Water quality trends in the Eerste River, Western Cape-2005. Ph.D. thesis, University of the Western Cape; 2006.

[4] Postel S, Richter B. Rivers for life: managing water for people and nature. London: Island Press, 2003,5-11.

[5] Food and Agriculture Organization. AQUASTAT - FAO's Global Information System on Water and Agriculture. [Online]. 2021 [Cited 2021 March 11].

[6] Tripathi AD, Agrawal M. Assessment of drinking water quality: A case study of Moradabad Area, Uttar Pradesh, India. International Journal of Environmental Sciences 2016; 5(2): 333.

[7] Anseeuw W, Wily LA, Cotula L. and Taylor M. Land rights and the rush for land: Findings of the global commercial pressures on land research project, Italy; 2011.

[8] Fakayode SO. Impact assessment of industrial effluent on water quality of the receiving Alaro River in Ibadan, Nigeria. African Journal of Environmental Assessment and Management 2005; 10: 1-13.

[9] Wang J, Liu XD, Lu J. Urban River pollution control and remediation. Procedia Environmental Sciences, 2012; 13:1856-62.

[10] Mahvi AH, Nouri J, Babaei AA and Nabizadeh R. Agricultural activities impact on groundwater nitrate pollution. International Journal of Environmental Science & Technology, 2005; 2(1):41-7.

[11] Noori R, Sabahi MS, Karbassi AR, Baghvand A, Taati Zadeh, H. Multivariate statistical analysis of surface water quality based on correlations and variations in the data set. Desalination 2010; 260 (1-3): 129-36.

[12] Kazi TG, Arain MB, Jamali MK, Jalbani N, Afridi HI, Sarfraz RA, Baig JA, Shah AQ. Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. Ecotoxicology and environmental safety 2009; 72(2):301-9.

[13] Bharti N, Katyal D. Water quality indices used for surface water vulnerability assessment. International journal of environmental sciences 2011, 2(1):154-73.

[14] Boyd J. Water pollution taxes: a good idea doomed to failure? Public Finance and Management 2003; 1(3): 34-66.

[15] Tyagi S, Sharma B, Singh P, Dobhal R. Water quality assessment in terms of water quality index. American Journal of Water Resources 2013; 1(3): 34-8.

[16] Uddin MG, Nash S, Olbert AI. A review of water quality index models and their use for assessing surface water quality. Ecological Indicators 2021; 122: 107218.

[17] Silva EIL, Rott E, Thumpela I, Athukorala N, Silva ENS. Species composition and relative dominance of reservoir phytoplankton in Sri Lanka: Indicators of environmental quality. The International Journal of Biological Sciences 2013; 4(4):92-104.

[18] De Silva SS. Reservoirs of Sri Lanka and their fisheries. FAO; 1988.

[19] Dharmasena GT 2007. Integrated water resources management and sound information system- Sri Lankan experience. In: Fisher, J. Ed. The 32nd WEDC International Conference, 13-17 November 2006, Colombo, Sri Lanka; 2007.

[20] Dissanayake CB, Weerasooriya SVR. The environmental chemistry of Mahaweli River, Sri Lanka. International journal of environmental studies 1986; 28(2-3): 207-23.

[21] Costa HH. The status of limnology in Sri Lanka. Internationale Vereinigung für Theoretische und Angewandte Limnologie: Mitteilungen 1994; 24(1):73-85.

[22] Abeysinghe NDA, Samarakoon MB. Analysis of variation of water quality in Kelani River, Sri Lanka. International Journal of Environment, Agriculture and Biotechnology 2017; 2 (6): 238965.

[23] Gunawardena A, Wijeratne EMS, White B, Hailu A, Pandit R. Industrial pollution and the management of river water quality: A model of Kelani River, Sri Lanka. Environmental monitoring and assessment 2017; 189(9):1-15.

[24] Herath G, Amaresekera, T. Assessment of urban and industrial pollution on water quality: Kelani River Sri Lanka. Southeast Asian Water Environment 2007; 2(2):91-8.

[25] Kuruppuarachchi HD, Pathiratne A. Toxic hazards of industrial waste receiving canal system in the lower catchment of Kelani River basin, Sri Lanka. Journal of the National Science Foundation of Sri Lanka, 2020; 48(1): 37-47.

[26] Liyanage CP, Yamada K. Impact of population growth on the water quality of natural water bodies. Sustainability, 2017; 9(8):1405.

[27] Mahagamage MGYL and Manage, PM. Water quality index (CCME-WQI) based assessment study of water quality in Kelani River basin, Sri Lanka. International Journal of Environment and Natural Resources 2014; 1:199-204.

[28] Bandara JMRS, Wijewardena HVP, Bandara, YMAY, Jayasooriya RGPT and Rajapaksha H. Pollution of River Mahaweli and farmlands under irrigation by cadmium from agricultural inputs leading to a chronic renal failure epidemic among farmers in NCP, Sri Lanka. Environmental geochemistry and health 2011; 33 (5):439-53.

[29] Perera PCT, Sundarabarathy TV, Sivananthawerl T, Kodithuwakku SP, Edirisinghe U. Arsenic and cadmium contamination in water, sediments and fish is a consequence of paddy cultivation: evidence of river pollution in Sri Lanka. Achievements in the Life Sciences 2016; 10(2):144-60.

[30] Sureshkumar N, Amaratunga AAD, Wickramaarachchi WDN. Comparison of physico-chemical characteristics and

pollution trends of the Menik Ganga, Kirindi Oya, and Walawe Ganga.In: The 25th Anniversary Scientific Conference of NARA on Tropical Aquatic Research towards Sustainable Development, February, Crow Island, Colombo 15. Colombo: Environment science division, NARA, p. 41; 2007.

[31] Amarathunga A, Jinadasa S and Azmy S. 2013. Sedimentary characteristics and water quality status in Polwatta River and Weligama Bay in Sri Lanka. Journal of Environmental Professionals Sri Lanka 2013; 2(1): 38-51.

[32] Amarathunga AAD, Kazama F. Impact of land use on surface water quality: A case study in the Gin River basin, Sri Lanka. Asian Journal of Water, Environment and Pollution 2016; 13(3): 1-13.

[33] Dharmasoma I, Wijayarathna NS, Munaweera K. Application of Water Quality Index to Monitor Ground Water Quality: A Case Study in Colombo Catchment of Sri Lanka. In Proceedings of International Forestry and Environment Symposium, Colombo, Sri Lanka; 2019.

[34] Mahagamage MGYL, Chinthaka SDM, Manage PM. Assessment of water quality index for groundwater in the Kelani River basin, Sri Lanka. International Journal of Agriculture and Environmental Research 2015; 2(5): 1158-71.

[35] Amarasinghe SR, Madushanka PLA. Spatial and Temporal Variation of Irrigation Water Quality of a Small Tank Cascade System in Up-stream of Malala Oya River Basin, Thanamalwila, Sri Lanka. Rajarata University Journal 2021; 6(2): 84-91.

[36] Gunarathna MHJP, Kumari MKN. Water quality assessment of a tank cascade system using CCME water quality index. International Journal of Research and Innovation in Applied Science 2016; 1(3): 1-6.

[37] Panditharathne DLD, Abeysingha NS, Nirmanee KGS, Mallawatantri, A. Application of revised universal soil loss equation (Rusle) model to assess soil erosion in "Kalu Ganga" River Basin in Sri Lanka. Applied and Environmental Soil Science 2019: 1-15

[38] Samarasinghea SMJS, Nandalalb HK, Weliwitiyac DP, Fowzed JSM, Hazarikad MK, Samarakoon, L. Application of remote sensing and GIS for flood risk analysis: a case study at Kalu-Ganga River, Sri Lanka. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science 2010; 38(8): 110-5.

[39] Hapuarachchi HP, Zhijia LI, Wolfgang FA. Application of the SWAT model for river flow forecasting in Sri Lanka. Journal of Lake Sciences 2003; 15: 147-54.

[40] Katupotha J. Cultural and Historical Monuments and Protected Resources of Archaeological Significance in the Lower Kalu Ganga Basin, Sri Lanka. In: The National Archaeological Symposium, 19/20 July 2011, Sri Lanka Foundation Institute (SLFI), Colombo 07;2011.

[41] Batugedara BDIM, Senanayake SAMAIK. Assessment of water quality status in a tropical river mouth: Special reference to Kalu Ganga, Sri Lanka. Proceedings of International Conference on Applied and Pure Sciences; 2022 Oct 14; University of Kelaniya: Sri Lanka; 2022.

[42] Batugedara BDIM, Senanayake SAMAIK. Contamination status of selected heavy metals in Kalu Ganga river mouth and nearby coastal waters, Sri Lanka: A baseline study. 6th International Research Conference, 2022; Uwa Wellassa University of Sri Lanka;2022.

[43] Jayasinghe DLDAR, Hettiarachchi M, 2012. Pollution at a discharge point of treated effluent from a textile mill factory in Kalu Ganga, evaluated by water quality parameters and histological alterations (biomarker of effect) in Rasbora daniconius and Puntius sarana. Proceedings of the eighteen sessions of the Sri Lanka

Association for Fisheries and Aquatic Resources,17th and 18th May 2012, Auditorium of Sri Lanka Foundation Institute Colombo 07;2012.

[44] Ratnayake NP, Silva KBA, Kumara IGIK. Chloride contamination in construction aggregates due to periodic saline water intrusion: a case study in the Kaluganga River Estuary, Sri Lanka. Environmental Earth Sciences 2013; 69(8):2529-40.

[45] APHA. 2017. Standard methods for examination of water and wastewater. 23rd ed. American Public Health Association, Washington.

[46] Central Environmental Authority (CEA), National Environmental, 2019. National Environmental Act, No. 47 of 1980: Ambient Water Quality Regulations, No. 01 of 2019. Sri Lanka.

[47] Sri Lanka Standards Organization (2012), Drinking water Standards- first Revision 614:2013

[48] Department of Meteorology, Sri Lanka (2020). Monthly weather summary, Weather synopsis 2020. [cited 2024 January 13]. Available from: https://www.meteo.gov.lk/index.php?option=com_content&view=article&id=195&Itemid=565&lang=en#2020.

[49] Department of Meteorology, Sri Lanka (2021). Monthly weather summary, Weather synopsis 2021. [cited 2024 January 13] Available from: https://www.meteo.gov.lk/index.php?option=com_content&view=article&id=195&Itemid=565&lang=en#2021.

[50] Shrestha S, Kazama F. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji River basin, Japan. Environmental Modelling & Software, 2007; 22: 464-75.

[51] Chapman D. Water quality assessments: A guide to using biota, sediments and water in environmental monitoring. CRC Press; 1996.

[52] US EPA, Drinking water regulations and contaminants Available at: https://www.epa.gov/sdwa/drinking-water-regulations-and-contaminants (Accessed: 25 April 2022).

[53] Department of Meteorology, Sri Lanka. Meteo.gov.lk 2021. [cited 2021 May 11] Available from: http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=94&Itemid=310&lang=en&lang=en.

[54] Arora, P. Physical, Chemical and Biological Characteristics of Water, 12th December, Central University of Punjab,2017; 4-13.

[55] WHO, Health criteria, and other supporting information. Guidelines for drinking water,1996.

[56] Corwin DL, Yemoto K. Salinity: Electrical conductivity and total dissolved solids. Soil Science Society of America journal 2022; 84(5): 1442-61.

[57] Marandi A, Polikarpus M, Joeleht A. A new approach for describing the relationship between electrical conductivity and significant anion concentration in natural waters Appl. Geochemistry 2013; 38: 103-9.

[58] Moore RD, Richards G, Story A. Electrical conductivity as an indicator of water chemistry and hydrologic process. Streamline Watershed Management Bulletin 2008; 11(2): 25-9.

[59] Rusydi, AF. Correlation between conductivity and total dissolved solids in various types of water: A review. In IOP conference series: earth and environmental science 2018. IOP Publishing, 18, pp.12-9.

[60] Moujabber ME, Samra BB, Darwish T. Atallah T. Comparison of different indicators for groundwater contamination by seawater intrusion on the Lebanese coast. Water Resources Management 2006; 20: 161-80.

[61] Yin K, Lin Z, Ke Z. Temporal and spatial distribution of dissolved oxygen in the Pearl River Estuary and adjacent coastal waters. Continental Shelf Research 2004; 24 (16):1935-48.

[62] Fianko JR, Lowor ST, Donkor A, Yeboah PO. Nutrient chemistry of the Densu River in Ghana. The Environmentalist 2010; 30(2):145-52.

[63] Ileperuma OA, 2000. Environmental pollution in Sri Lanka: a review; 2000.

[64] Floury P, Gaillardet J, Tallec G, Ansart P, Bouchez J, Louvat P, Gorge, C. Chemical weathering and CO2 consumption rate in a multilayered aquifer dominated watershed under intensive farming: The Orgeval critical zone observatory, France. Hydrological Processes 2019; 33(2): 195-213.

[65] Nurnberg G, Shaw M. Productivity of clear and humic lakes: Nutrients, phytoplankton, bacteria. Hydrobiologia 1999; 382(1): 97-112.

[66] Aravinna AG, Priyantha N, Pitawala HM, Yatigammana SK. Seasonal Variations of Water Quality of Downstream Catchment of River Mahaweli. International Journal of Biological Sciences and Engineering 2013; 4(4): 111-20.