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Application of the Carlson's Trophic State Index for the Assessment of Trophic Status of Lake Simbi Ecosystem, a Deep Alkaline-saline Lake in Kenya

Stephen Balaka Opiyo, Albert Mochache Getabu, Lewis Morara Sitoki, Anakalo Shitandi and George Mokua Ogendi

Abstract
Eutrophication is increasingly becoming the greatest threat to the ecological health of global water resources hence constant screening of the trophic state of these ecosystems is important. This study was aimed at defining the trophic status of Lake Simbi through the Carlson's Trophic State Index (CTSI) which is based on the interactions of three water quality variables viz., Secchi depth (SD), total phosphorus (TP) and the chlorophyll-a (Chl-a). The classification scale for Trophic State Index (TSI) runs from 0 to 100, and the results of this study showed that the mean TSI for SD was 67.60, for TP was 118.56, for Chl-a was 74.86 and finally the overall CTSI was 87.01. These show that Lake Simbi is hypereutrophic which reflects the high concentration of nutrients in the lake. The lake suffers from cultural eutrophication which symptomatically manifests in the prevalent proliferation of algal bloom in the lake. The study therefore recommends adoption of an efficient multi-sectoral plan for monitoring and controlling nutrients loading and other pollutants input into the lake.

Keywords: chlorophyll-a, eutrophication, secchi depth, total phosphorus, aquatic ecosystems

1. Introduction

The whole scientific world currently recognizes eutrophication to be the greatest threat to the quality of water [1], and probably the quality of life in aquatic ecosystems. Eutrophication is the principal source of contamination of fresh water ecosystems [2]. It results from elevated concentration of nutrients in aquatic environments [3]. Eutrophication in lakes is more concerning since it is characterized by heavy pollution of the waters with nutrients which accrue over time due to the complex nature of these ecosystems, which in essence favor limited self-removal mechanisms. The eutrophication menace is caused by the increasing anthropogenic pressure on the catchment areas of water bodies and exacerbated by the changing climatic conditions [4]. The influence of these factors on aquatic ecosystems is revealed by the trophic state, which is an essential attribute of aquatic environments [5]. Evaluation of the trophic state of water bodies has therefore become an integral part of ecological assessments in aquatic ecosystems over the recent past. The assessment of the trophic state is crucial for the formulation of strategies for conservation and management [6]. The Trophic State Index (TSI) scale is valuable in the classification of water bodies which then enables the management authorities to prioritize water bodies for preservation, conservation and/or restoration efforts in order to maintain their ecological health integrity [7]. Eutrophication has deleterious impacts on aquatic animals, especially fish and invertebrates [8]. It is responsible for increased noxious algal bloom proliferation and hypoxic conditions which often causes fish kills [9]. This usually occurs when the algal bloom die off, initiating the decomposition process which consequently diminishes the dissolved oxygen concentration required for fish survival [10].

The trophic state is indicative of the biological productivity in these environments [11]. The nutrient dynamics defines the trophic state of aquatic ecosystems [12]. The changes in nutrient concentrations can lead to changes in the structure of the community in a particular trophic level, therefore numerous trophic state indices have been formulated for assessing these particular variations occurring in the ecosystem [13]. There is no worldwide standard tool for estimating trophic status in aquatic ecosystems because; there exists complex interactions of factors involved in organic productivity in various water bodies [14]. However, the most commonly utilized tool has been the one developed by [15] which was initially tested in the lakes in North America. The trophic state index introduced by [15] has globally been accepted to assess the biological health of aquatic ecosystems, because it is simple and uses only a few parameters as opposed to other complex multi-parameter models [16]. This tool utilizes only three water quality parameters namely, Secchi depth, total phosphorus and chlorophyll-a, since they are the major factors influencing the condition of eutrophication [15]. Total phosphorus is the most suitable and widely used parameter for measuring the trophic status of aquatic ecosystems [17]. This is because; in aquatic ecosystems phosphorus is the most limiting nutrient as compared to nitrogen [18], which therefore explains its significance and inclusion in the Carlson's trophic state index. Despite phosphorus being the most limiting nutrient, anthropogenic activities can elevate its concentration in the water [19]. Chlorophyll-a is a green photosynthetic pigment found in algae, whose concentration can be a useful tool for determining the density (biomass) of the phytoplankton population [20]. The higher the concentration of chlorophyll-a is indicative of a polluted water quality [21], and hence it can be utilized as the major indicator for trophic status of water bodies [22]. The Secchi depth measures transparency, which is basically influenced by the algal density [23], among other factors. The three parameters of Secchi depth, total phosphorus and chlorophyll-a are useful for defining eutrophication since they are correlated [15]. The Carlson's Trophic State Index (CTSI) provides a simple singular scheme for classifying the eutrophication condition of a water body in a way that could be easily understood by the relevant stakeholders.

Lake Simbi is a Kenyan soda lake that is located in a catchment area characterized by high erosion and heavy anthropogenic perturbations especially agricultural activities which have consequently put it at a higher risk for eutrophication over time. Over the past few years, the waters of this significant natural resource have been experiencing persistent foul-smelling algal blooms that have translated into declining bird populations. Algal bloom is a well-documented symptom of an advanced eutrophication and it can only be defined using trophic state indices. However, studies on the trophic status are scarce in Kenyan waters, and Lake Simbi in particular has none. This study therefore applied Carlson's trophic state index in the determination of the trophic status of Lake Simbi ecosystem for the first time, with the aim of creating a knowledge base that can serve as a reference for future researchers as well as help the relevant stakeholders in the development of appropriate conservatory and management strategies for sustainability of the aquatic biodiversity include the potential fisheries development.

2. Materials and Methods

2.1 Study area

Lake Simbi Nyaima presented in figure 1 is deep soda lake in Kenya that hosts colossal populations of birds, a feature that earned it the status of a national bird sanctuary with international ecotourism recognition. The lake is positioned at an altitude of 1142 m above sea level and lies at 0°22'5"N and 34°37'47"E coordinates on the Nyanzan Gulf approximately 1km from the L. Victoria. The morphometry of Lake Simbi is characterized by a maximum depth of 27.7 m, an average depth of 17 m, a surface area of 0.301 km^2 and a shoreline perimeter of 2.097 km. The lake is situated adjacent to Kendu Bay Town of Homabay County of Kenya, in a semi-arid area receiving an average precipitation of between 500 mm and 1700 mm annually with temperature range between 18 and 31 °C. Being a tecto-volcanic endorheic lake, it doesn't have any recognizable inlet or outlet. However, the water level in the lake is solely maintained by direct precipitation and the inflows from its underground hydrological framework. The lake lacks the capacity to support any fishery activities because of the extreme conditions of salt-tress and hypoxia which are not favorable for the existence of fish populations. Nonetheless, this lake is important for ecotourism, and provides scientific, cultural, religious and educational benefits.

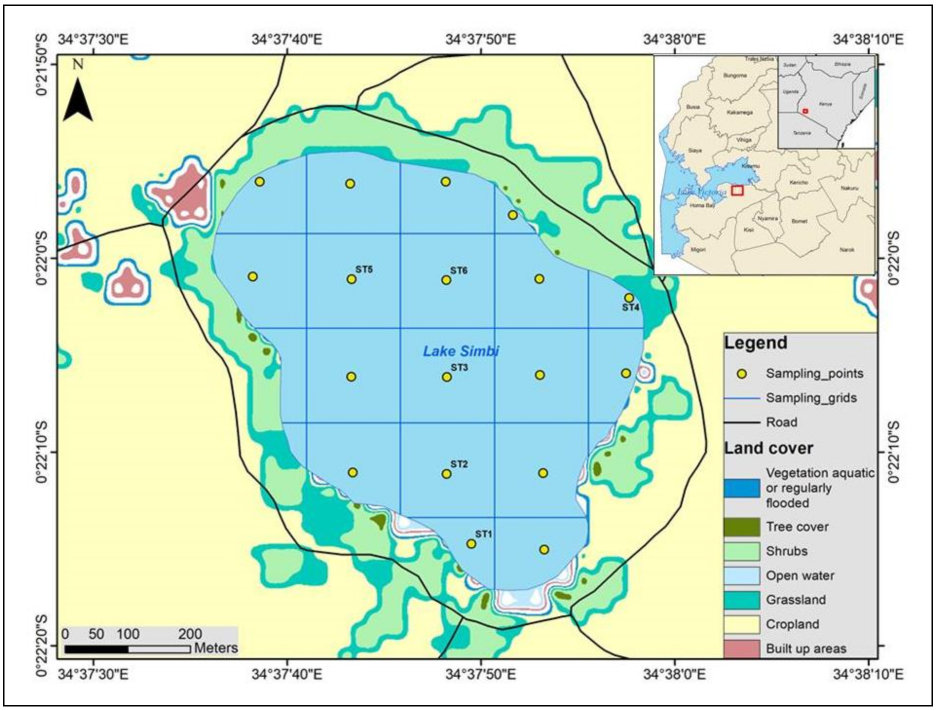

Fig 1: Map of Lake Simbi showing the sampling stations

2.2 Sampling and analyses
Sampling was done on a monthly basis for 6 months from December 2018 to May 2019 at six fixed stations systematically selected as shown in figure 1. The sampling period encompassed both the dry season months (December, January and February) and wet season months (March, April and May) of Kenya. Sampling was always carried out during the morning period. Water transparency (m) at each sampling station was measured at the depth at which the standard black and white Secchi disc disappeared. Chlorophyll-a (μgL^{-1}) concentration at each sampling station was measured using a submersible Conductivity-Temperature-Depth, CTD (Seabird Electronics®) profiling system. Three integrated water samples collected from the depths of 1m, 2m and 3m of the water column with the aid of a Van Dorn water sampler into 500 ml bottles from each of the six sampling stations were taken to the laboratory for nutrients (TP) analyses. The concentration of Total Phosphorus (μgL^{-1}) was analyzed in the laboratory using the standard methods for the examination of water and waste water described in American Public Health Association (1998) [24]. The three trophic state indicators (TSI_{SD}, TSI_{Chla} and TSI_{TP}) were computed mathematically based on the respective equations for the three parameters (Secchi depth, chlorophyll-a and total phosphorus), and the overall Carlson Trophic State Index (CTSI) was calculated by averaging the TSI values obtained from the three trophic state indicators [13]. The equations were as follows:

$TSI_{SD} = 60 - 14.41 LN(SD)$ …………………… Equation 1.
$TSI_{Chla} = 9.81 LN(Chla) + 30.6$ …………………Equation 2.
$TSI_{TP} = 14.42 LN(TP) + 4.15$………......…… Equation 3.
$CTSI = \frac{(TSISD + TSIChla + TSITP)}{3}$ .... Equation 4.

Whereas
Chl-a = Chlorophyll-a concentration (μg/L) SD = Secchi disk depth (meters)
TP = Total phosphorus concentration (μg/L) LN = Natural logarithm
TSI = Trophic State Index

The final value obtained as the CTSI together with other indicators were subsequently used to determine and classify the trophic status of the lake Simbi based on the TSI criteria with an index ranging from 0-100 shown in the Table 1 as oligotrophic aquatic ecosystem (Low ecological productivity), mesotrophic (Moderate ecological productivity), eutrophic (High ecological productivity) and hypereutrophic (highest ecological productivity).

Table 1: Lake trophic state classification scheme based on the Carlson's trophic state index

TSI	Trophic Status	Secchi Depth (SD)	Total Phosphorus (TP)	Chlorophyll-a (Chl-a)
0 – 40	Oligotrophic	>8 – 4	0 – 12	0 – 2.6
40 – 50	Mesotrophic	4 – 2	12 – 24	2.6 – 7.3
50 – 70	Eutrophic	2 – 0.5	24 – 96	7.3 – 56
70 – 100+	Hypereutrophic	0.5 - < 0.25	96 – 384 +	56 – 155 +

Descriptive statistics were done for all study variables using SPSS and results presented in form of tables and graphs. One-way ANOVA and post hoc Tukey test were used to screen for significant spatial and temporal differences among the study variables.

3. Results
In order to establish the trophic status of Lake Simbi, three water quality parameters of Secchi depth transparency, total phosphorus and chlorophyll-a were analyzed after which their respective TSI indices were calculated. These results are presented in the Tables 1-3 and figure 2.

3.1 Secchi depth (SD) and TSI (SD)
The Secchi disc depth registered a relatively low mean of 0.59 ± 0.01 m in Lake Simbi (Table 2). Significant spatial variations (ANOVA, $P < 0.05$) in SD were realized in the lake (Table 2), with the lowest mean SD (0.55 ± 0.01 m) observed at ST4 and the highest (0.63 ± 0.01 m) observed at both ST1 and ST2 ($F (5, 30) = 5.914$, $p = 0.001$). Significant temporal variations (ANOVA, $P < 0.05$) in SD were also realized in Lake Simbi (Table 3), with the lowest mean SD of 0.56 ± 0.01 m recorded in March 2019 and the highest mean of 0.63 ± 0.01 m recorded in December 2018 ($F (5, 30) = 4.661$, $p = 0.003$). The mean SD of dry season (0.62 ± 0.01 m) was found to be significantly higher (t-test, $P < 0.05$) than the mean SD (0.56 ± 0.01 m) of the wet season (Table 4) ($t (34) = 4.798$, $p = 0.000$). On the other hand, the corresponding Trophic State Index for Secchi depth, TSI (SD), registered an overall mean value of 67.60 ± 0.19, with the lowest (66.62 ± 0.35) and highest (68.50 ± 0.30) means recorded in December 2018 and March 2019 respectively on the spatial scale (figure 2a).

Table 2: Spatial variation of the trophic indicators of lake simbi

Spatial Variation of the Trophic State Indicators of Lake Simbi									
Month		SD (m)	Chl-a (μgL^{-1})	TP (μgL^{-1})	TSI (SD)	TSI (Chl-a)	TSI (TP)	CTSI
ST1	Mean ± SE	$0.63^{a} \pm 0.01$	$81.14^{a} \pm 24.94$	$2795.45^{a} \pm 212.70$	66.68 ± 0.33^{b}	72.00 ± 2.44^{a}	118.37 ± 1.12^{a}	85.68 ± 1.01^{a}
ST2	Mean ± SE	$0.63^{a} \pm 0.02$	$537.35^{a} \pm 266.41$	$2729.14^{a} \pm 229.80$	66.77 ± 0.46^{b}	81.75 ± 7.31^{a}	117.97 ± 1.24^{a}	88.83 ± 2.29^{a}
ST3	Mean ± SE	$0.60^{ab} \pm 0.01$	$181.33^{a} \pm 69.11$	$2817.49^{a} \pm 195.10$	67.50 ± 0.33^{ab}	74.08 ± 6.44^{a}	118.52 ± 1.02^{a}	86.70 ± 2.35^{a}
ST4	Mean ± SE	$0.55^{b} \pm 0.01$	$126.15^{a} \pm 23.32$	$2822.47^{a} \pm 192.89$	68.76 ± 0.31^{a}	77.08 ± 2.03^{a}	118.55 ± 1.01^{a}	88.13 ± 0.67^{a}
ST5	Mean ± SE	$0.56^{b} \pm 0.01$	$164.65^{a} \pm 99.57$	$3013.60^{a} \pm 146.91$	68.45 ± 0.26^{a}	75.20 ± 3.92^{a}	119.58 ± 0.70^{a}	87.74 ± 1.25^{a}
ST6	Mean ± SE	$0.60^{ab} \pm 0.01$	$54.92^{a} \pm 8.86$	$2800.05^{a} \pm 215.63$	67.42 ± 0.35^{ab}	69.04 ± 1.96^{a}	118.39 ± 1.11^{a}	84.95 ± 0.93^{a}
Total	Mean ± SE	0.59 ± 0.01	190.92 ± 53.01	2829.70 ± 77.25	67.60 ± 0.19	74.86 ± 1.85	118.56 ± 0.40	87.01 ± 0.63

Note: Mean values in the same column that do not share a superscript letter are significantly different ($P < 0.05$).

Table 3: Temporal variation of the trophic indicators of lake simbi

Temporal Variation of the Trophic State Indicators of Lake Simbi								
Month		**SD (m)**	**Chl-a (μgL^{-1})**	**TP (μgL^{-1})**	**TSI (SD)**	**TSI (Chl-a)**	**TSI (TP)**	**CTSI**
Dec 2018	Mean ± SE	$0.63^{a} \pm 0.02$	$49.5^{a} \pm 11.56$	$2212.09^{c} \pm 75.51$	66.62 ± 0.35^{c}	67.80 ± 2.50^{a}	115.36 ± 0.45^{c}	83.26 ± 0.99^{b}
Jan 2019	Mean ± SE	$0.62^{ab} \pm 0.01$	$345.64^{a} \pm 208.67$	$2656.14^{bc} \pm 66.40$	67.00 ± 0.37^{bc}	82.81 ± 5.50^{a}	117.94 ± 1.07^{b}	89.25 ± 1.62^{ab}
Feb 2019	Mean ± SE	$0.61^{ab} \pm 0.02$	$345.24^{a} \pm 207.09$	$2835.19^{b} \pm 114.60$	67.12 ± 0.48^{abc}	81.12 ± 4.79^{a}	118.72 ± 0.63^{b}	88.99 ± 1.55^{a}
Mar 2019	Mean ± SE	$0.56^{b} \pm 0.01$	$167.62^{a} \pm 103.1$	$2718.00^{b} \pm 77.45$	68.50 ± 0.30^{a}	71.34 ± 6.18^{a}	118.15 ± 0.41^{b}	86.00 ± 2.11^{ab}
Apr 2019	Mean ± SE	$0.56^{b} \pm 0.01$	$52.61^{a} \pm 3.07$	$3480.43^{a} \pm 42.18$	68.30 ± 0.39^{ab}	69.39 ± 0.59^{a}	121.74 ± 0.18^{a}	86.47 ± 0.20^{ab}
May 2019	Mean ± SE	$0.57^{ab} \pm 0.01$	$184.94^{a} \pm 57.67$	$3076.33^{ab} \pm 121.11$	68.11 ± 0.27^{abc}	79.20 ± 3.23^{a}	119.91 ± 0.58^{ab}	89.07 ± 0.94^{a}
Total	Mean ± SE	0.59 ± 0.01	190.92 ± 53.01	2829.70 ± 77.25	67.60 ± 0.19	74.86 ± 1.85	118.56 ± 0.40	87.01 ± 0.63

Note: Mean values in the same column that do not share a superscript letter are significantly different ($P < 0.05$).

Table 4: Seasonal Variation of the Trophic Indicators of Lake Simbi

Seasonal Variation of the Trophic State Indicators of Lake Simbi								
Season		**SD (m)**	**Chl-a (μgL^{-1})**	**TP (μgL^{-1})**	**TSI (SD)**	**TSI (Chl-a)**	**TSI (TP)**	**CTSI**
Dry	Mean ± SE	$0.62 \pm (0.01)^{a}$	$246.79 \pm (98.14)^{a}$	$2567.81 \pm (92.72)^{a}$	66.89 ± 0.28^{a}	76.41 ± 4.08^{a}	117.19 ± 1.79^{a}	86.83 ± 2.38^{a}
Wet	Mean ± SE	$0.56 \pm (0.01)^{b}$	$135.05 \pm (39.65)^{a}$	$3091.59 \pm (88.92)^{b}$	68.31 ± 0.03^{a}	73.30 ± 2.89^{a}	119.93 ± 0.15^{a}	87.18 ± 0.11^{a}
Total	Mean ± SE	0.59 ± 0.01	190.92 ± 53.01	2829.70 ± 77.25	67.60 ± 0.19	74.86 ± 1.85	118.56 ± 0.40	87.01 ± 0.63

Note: Mean values in the same column that do not share a superscript letter are significantly different ($P < 0.05$).

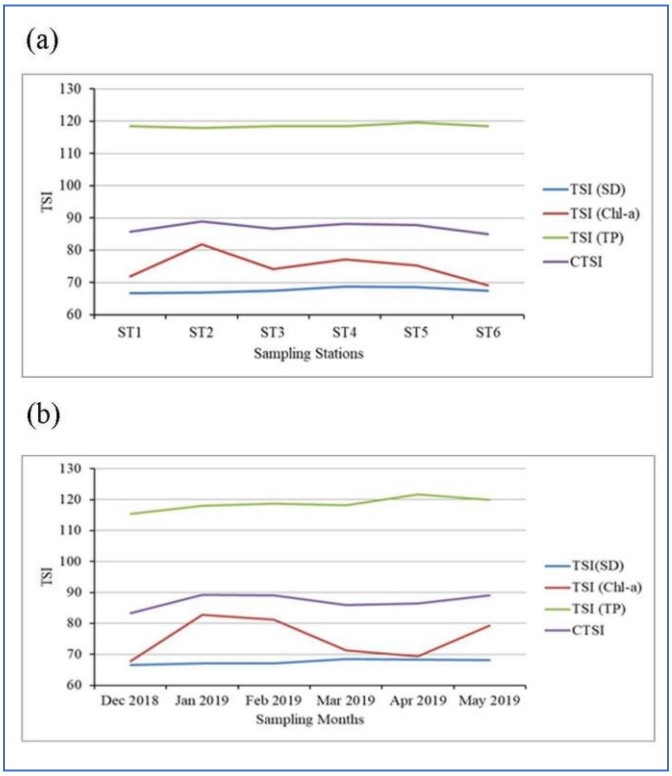

Fig 2: Spatial and temporal trends for the trophic state indicators for Lake Simbi.

On the temporal scale, the TSI (SD) recorded the lowest mean (66.68 ± 0.33) and highest mean (68.76 ± 0.31) in ST1 and ST4 respectively (figure 2b). Based on TSI criteria in Table1, the spatial and temporal ranges of TSI (SD) values classify the lake in the eutrophic category which indicates that it experiences the highest level of ecological productivity.

3.2 Total Phosphorus (TP) and TSI (TP)

The TP recorded relatively high mean of 2829.70 ± 77.25 μgL^{-1} in Lake Simbi (Table 2). Although no significant spatial variations (ANOVA, $P < 0.05$) in TP concentrations were realized in the lake (F (5, 30) = 0.230, $p = 0.947$), the lowest mean TP (2729.14 ± 229.80 μgL^{-1}) was observed at ST2 and the highest (3013.60 ± 146.91 μgL^{-1}) was observed at ST1 (Table 2). Significant temporal variations (ANOVA, $P < 0.05$) in TP were however realized in Lake Simbi (Table 3), with the lowest mean TP of 2212.09 ± 75.51 μgL^{-1} recorded in December 2018 and the highest mean of 3480.43 ± 42.18 μgL^{-1} in April 2019 (F (5, 30) = 15.805, $p = 0.000$). The mean TP of wet season (3091.59 ± 88.92 μgL^{-1}) was significantly higher (t-test, $P < 0.05$) than the mean TP (2567.81 ± 92.72 μgL^{-1}) of the dry season (Table 4) (t (34) = -4.077, p = 0.000). On the other hand, the corresponding Trophic State Index for Total Phosphorus, TSI (TP), registered an overall mean value of 118.56 ± 0.40, with the lowest (117.97 ± 1.24) and highest (119.58 ± 0.70) means recorded in ST2 and ST5 respectively on the spatial scale (figure 2a); On the temporal scale, the TSI (TP) recorded the lowest mean (115.36 ± 0.45) and highest mean (121.74 ± 0.18) in December 2018 and April 2019 respectively (figure 2b). Based on TSI criteria in Table1, the spatial and temporal ranges of TSI (TP) classify the lake in the hyper-eutrophic category which also shows that it experiences the highest level of ecological productivity.

3.3 Chlorophyll-a and the TSI (Chl-a)

The chlophyll-a registered an overall mean of 190.92 ± 53.01 μgL^{-1} in Lake Simbi (Table 2). Although no significant spatial variations (ANOVA, $P < 0.05$) in Chl-a concentration were realized in the lake (F (5, 30) = 2.148, $p = 0.087$), the lowest mean Chl-a (54.92 ± 8.86 μgL^{-1}) was observed at ST6 and the highest (537.35 ± 266.41 μgL^{-1}) observed at ST2 (Table 2). Also, with no significant temporal variations (ANOVA, $P < 0.05$) in Chl-a concentration realized in the lake (F (5, 30) = 1.044, $p = 0.410$), the lowest mean Chl-a of 49.50 ± 11.56 μgL^{-1} was recorded in December 2018 and the highest mean value of 345.64 ± 208.67 μgL^{-1} in January 2019 (Table 3). Although, the mean Chl-a of dry season (246.79 ± 98.14 μgL^{-1}) was found to be higher than the mean Chl-a of the wet season (135.05 ± 39.65 μgL^{-1}), the t-test revealed no significant difference ($P < 0.05$) between the dry season and the wet season (t (34) = 1.056, p = 0.299) (Table 4). On the other hand, the corresponding Trophic State Index for Chlorophyll-a, TSI (Chl-a), registered an overall mean value of 74.86 ± 1.85, with the lowest (72.00 ± 2.44) and highest (81.75 ± 7.31) means recorded in ST1 and ST2 respectively on the spatial scale (figure 2a); On the temporal scale, the TSI (Chl-a) recorded the lowest mean (67.80 ± 2.50) and highest mean (82.81 ± 5.50) in December 2018 and January respectively (figure 2b). Based on TSI criteria in table1, the spatial and temporal ranges of TSI (Chl-a) values classify the lake in the hyper-eutrophic category which reveals that it experiences the highest level of ecological productivity.

3.4 Carlson's trophic state index (CTSI) for Lake Simbi

The CTSI registered an overall mean of 87.01 ± 0.63 in Lake Simbi (Table 2). Although no significant spatial variations (ANOVA, $P < 0.05$) in CTSI were realized in the lake ($F (5, 30) = 0.916$, $p = 0.484$), the lowest mean CTSI (84.95 ± 0.93) was recorded at ST6 and the highest (88.83 ± 2.29) was recorded at ST2 (Table 2, figure 2a). Significant temporal variations (ANOVA, $P < 0.05$) in the CTSI were however realized in the lake ($F (5, 30) = 2.97$, $p = 0.027$), with the lowest mean CTSI of 82.98 ± 1.12 recorded in December 2018 and the highest mean of 89.07 ± 0.94 recorded in May 2019 (Table 3, figure 2b). Although, the mean CTSI of the wet season (87.18 ± 0.11) was found to be higher than the mean CTSI of the dry season (86.83 ± 0.38), the t-test revealed no significant difference ($P < 0.05$) between the dry season and the wet season ($t (34) = -0.270$, $p = 0.789$) (Table 4). Based on TSI criteria in Table1, the spatial and temporal ranges of CTSI values effectively classify the entire lake in the hyper-eutrophic category which indicates the highest level of ecological productivity in the lake.

4. Discussion

The low Secchi depth could be attributed to the suspension (and re-suspension) of high phytoplankton density and other solid substances in the water column [23], due to the wind action. The spatial variations in SD could be attributed to variations in depth among stations whereby shallow stations would record low Secchi depths compared to deeper stations because the shallow ones experience perturbations of their bottom settled sediments due to wind action which are then suspended in the water column as opposed to the deeper ones which have their sediments away from any wind action. The temporal variations in SD could mainly be attributed to the seasonal variations in the amounts of precipitation received within that region whereby the rainy season is characterized by high run off from the surface and increased flooding brought by the high discharge. These inflows are characterized by enormous quantities of suspended particles which when deposited in the water decreases the transparency [25]. The study found the Secchi depth to be relatively lower than TP and chlorophyll-a, both of which were relatively higher. These findings agree with the earlier observation that, as Secchi depth decreases, the concentration of both phosphorus and chlorophyll-a increases [30].

The high TP comes from several years of nutrients inflows and pollution of the lake from the catchment areas experiencing intense agricultural activities among other unsustainable land uses. Aquatic ecosystems are majorly influenced by anthropogenic activities that cause nutrient enrichment of the water, essentially with phosphorus [26]. The location of Lake Simbi in a depression surrounded by high areas coupled with its closed nature would also favor nutrient enrichment, because of the high velocity of the run-off draining into it and the subsequent prolonged stay in the lake due to lack of an outlet. The spatial variations in TP could be attributed to the closeness of some sampling stations to the shores, the intensity of agricultural practices nearby and the vegetation cover of the shoreline. The temporal variations in TP could be attributed to the seasonal variations in rainfall amounts which in turn influences nutrient deposition intensity whereby the wet season experiences high nutrient enrichment from the high surface runoff and flooding that sweeps the various nutrients from the heavily cultivated farms with loosened soil and no vegetation cover into the lake, as opposed to the dry season which experiences little to no rain.

Chlorophyll-a is reflective of high phytoplankton abundance in the water [27]. The high chlorophyll-a observed in Lake Simbi could be as a result of high photosynthetic activity occurring in the water due to high solar radiation and high temperatures characteristic of semi-arid region in which the lake exists. The high nutrient loads carried by the surface runoff and flood inflows from the fertilizer used in the heavily cultivated catchment together with high temperatures of the region might have caused high propagation of the algal communities which translated to heavy photosynthetic activity. The spatial variations in Chl-a can be attributed to the variations in sampling time between stations and the cloud cover. The ones sampled in the morning when there's low solar intensity would record lower concentrations due to the decreased photosynthetic rates as opposed to those sampled closer to noon when there is intense solar radiation causing high rates of photosynthesis [28]. The temporal variations in Chl-a observed in lake Simbi can be attributed to the variations in the precipitation patterns, temperature, light intensity conditions during sampling. The increased solar intensity and reduced turbidity has been documented to be responsible for high phytoplankton abundance during the dry season [29]. The TSI for Chl-a was greater than the TSI for SD which implies that the turbidity and consequently light attenuation in the water of Lake Simbi was emanating from the substantial amounts of suspended algal biomass and not the mineral or solid substances. Whenever TSI (Chl-a) is greater than the TSI (SD), it is an indication that algae in the water dominates the light attenuation [15].

Generally, all the TSI indicators definitively classified the trophic status of Lake Simbi as hyper-eutrophic which reflects the magnitude of nutrients concentration in the lake. This status reflects the cultural eutrophication of Lake Simbi emanating from the pressure caused by anthropogenic disruptions, erosion and siltation, domestic organic wastes dumping, heavy agricultural fertilizer use in the catchment area and direct detergent use in domestic washing, all of which have altered the water quality. It could also be attributed to the natural environmental processes. These assumptions concurs with Guldin (1989) [31] who opined that apart from the sources emanating from human activities such as mining, industrial operations and poor agricultural practices, nutrients ending up in water masses can occur from the natural processes of the atmosphere and fixation by micro-organisms and lightning. The hyper-eutrophic status of Lake Simbi justifies the occurrence of the cyanobacterial bloom (in form of algal scum) observed in the lake throughout the study period. This assessment is based on Ramesh and Krishnaiah (2013) [32] that had found eutrophication to be the cause of blooms. The occurrence of cyanobacterial bloom in aquatic ecosystem is the greatest symptom for rapid eutrophication [33]. This algal bloom proliferation may further exacerbate the anoxic conditions of the lake, because when they algae die off, the ensuing decomposition process may reduce the concentration of dissolved oxygen in the lake [34].

5. Conclusion

The Carlson's Trophic State Index indicated that Lake Simbi is hypereutrophic which reflects the high magnitude of nutrients concentration in the lake. The hyper-eutrophic condition is responsible for the proliferation of cyanobacterial bloom in the lake. This shows that the waters of Lake Simbi are heavily polluted and hence are of poor quality which can compromise the health of the biodiversity present in it such as the lesser flamingos. Lake Simbi is evidently suffering from advanced eutrophication due to the long-term synergistic effects of unsustainable anthropogenic interventions especially farming and livestock rearing, and natural environmental processes. The hypereutrophic status of Lake Simbi should be a clarion call for initiating restoration programs that can conserve its ecological health. The CTSI index can be valuable during future assessments for evaluating the effectiveness of these programs in remedying the degraded ecological health of the lake.

6. Acknowledgement

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