



influence of multiple different water quality parameters from a set of test results (Shweta et al., 2013).

It converts complex water quality data into an easily understandable form for easy interpretation of overall water quality information (Aktek et al., 2016). The ability to understand and predict the seasonality of these changes in water quality is critical for consideration in management and conservation planning to avoid adverse effects on the ecology of the lake and the socioeconomic life of dependent communities (Li et al., 2015). According to a study, scientist evaluating the variation in surface water quality in response to seasonality is therefore critical to assessing the variation in lake pollution on a temporal scale as a result of natural or anthropogenic phenomena (Ling et al., 2017). In this study, the physicochemical characteristics of Lake Bosomtwe water were monitored for a 2-year period from March 2018 to February 2020 using the Canadian Conference of Ministers of Environment (CCME) Water Quality Index (WQI) to communicate important information about seasonality of the lake water quality for easy understanding by the public and all stakeholders for an effective contribution to protection and conservation of the lake.

The extent of natural and anthropogenic influence of the lake follows the dictates of seasonality. These include changes in lake water temperature and volume, rainfall, farming and fishing periods, tourist visits, and holiday events. Therefore, parameters that are considered critical or important in defining the quality of the lake water may not exert influence in another season. Assessment of seasonal variations in quality of the lake water is critical in order to profile the seasonal statuses of the lake water and to direct management effort to the parameters of significant threat in the quest to conserve the lake (Asare-Donkor: Amankwaam et al., 2021).

**2. METHODOLOGY**

In the Bosomtwe Basin of the Ashanti Region of Ghana is located the Lake Bosomtwe Biosphere Reserve. It is a natural lake that lies at latitude 6°30'16"N and longitude 1°24'31"W. With a mean annual rainfall of 1270 mm, the lake basin exhibits the characteristics of tropical rain belts (Nicholson, 2009). The normal seasonal classification as defined by the Ghana Meteorological Agency (GMA) is grouped into four classes, namely: pre-rainy season, which occurs in the period between March and May, the main rainy season which, is characterized by heavy rains between June and September, Pre-dry season from October to December and Dry season or harmattan season between December and February. The Bosomtwe District experiences a mean annual temperature of 24 °C that drops to 21.5 °C and reaches its highest of 27.8 °C (Ghana Statistical Service, 2013). However, with the current phenomenon of climate modification, there is a tendency for some deviations in these classifications to occur. Again, for convenience, some modifications were made in this study.

Analyses of fifteen (15) physicochemical water quality parameters were carried out on the lake water in portions of the lake close to four (4) of the fringe communities, namely Dompaa, Atafraam, Old Brodekwano, and Abono. The choice of these communities was based on the extent to which activities, including crop farming, fishing, illegal mining known in the local parlance as 'galamsey', hospitality, timber harvesting, which are believed to advance seasonal variation of the quality of water occur in the communities. The stations were designated as sampling sites and denoted as S1 to S4. Monthly sampling and analyses were carried out in the four seasons starting in March 2018 to February 2020.

Triplicate samples were taken from three sampling points in each of the four sampling stations for laboratory analysis of physical parameters (total alkalinity, total hardness, total dissolved solids (TDS), total suspended solids (TSS); nutrients (nitrate, phosphate and sulphate), Biochemical oxygen demand; metals (Fe, Pb, and Zn). However, temperature, dissolved oxygen, pH, and turbidity were recorded in situ using the Hannah (HI 9828) Multi-Parameter Probe. The data was subjected to analyses using the CCME WQI modeling. This involved calculation of the values of three factors, namely: Scope (F1), Frequency (F2) and Amplitude (F3), and finding the square root of the sum of their squares which has been divided by 1.732. The result was then subtracted from 100 to obtain the water quality index. This has been summarized and presented in the following steps:

**2.1 Steps for Calculating The Water Quality Index**

Step 1: Calculation of scope value (F1 value): the percentage of variables that do not meet their benchmarks/objectives in relation to the total number of measured variables,

$$i.e. F1 = \frac{\text{failed variables}}{\text{total number of variables}} \times 100\%$$

Step 2: Calculation of frequency value (F2 value): the percentage of individual tests that do not meet their benchmarks/objectives in relation to the total number of measured variables

$$i.e. F2 = \frac{\text{failed tests}}{\text{total number of tests}} \times 100\%$$

Step 3: Three sub-stages are used to calculation of the amplitude value (F3 value): the amount by which the failed test values fell short of their benchmarks/objectives.

Step 3.1. Used when the test value must not fall below its benchmark/objective, e. g.

dissolved oxygen.

$$i.e. F2 = \frac{\text{failed tests}}{\text{total number of tests}} \times 100\%$$

$$i.e. Excursion DO = \frac{\text{objective}}{\text{failed test value}} - 1$$

Step 3.2: For other parameters: - the test value must not exceed their objectives;

$$Excursion others = \frac{\text{failed test value}}{\text{objective}} - 1$$

Step 3.3: Calculation of the normalized sum of excursions (nse)

$$i.e. F3 = \frac{nse}{\text{total number of variables}}$$

Calculation of the overall CCME WQI:

$$i.e. Overall CCME WQI = 100 - \left( \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right)$$

The results of the water quality measured (Table 2) were used to characterize the seasonal qualities of the lake water based on the classification and interpretation by the CCME WQI (Table 1).

Table 1: CCME Water Quality Characteristics and Interpretation		
Rating	CCME-WQI	Water Quality Characteristics
Excellent	95.0-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
Good	80.0-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65.0-79	Water quality is usually protected, but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45.0-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0.0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

**3. RESULTS**

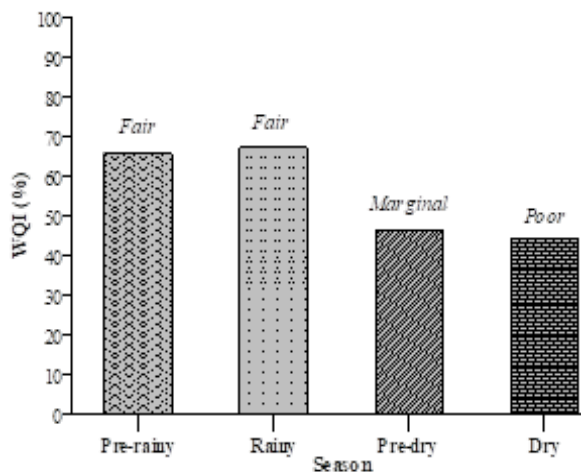
Some important water quality parameters were measured to assess the effect of seasonality on Lake Bosomtwe. The water quality parameters evaluated exhibited variation in pollutant levels in response to seasonality. Results of the levels of water quality parameters (Tables 2) and the calculated Indices determined with the CCME WQI modeling, a unique rating technique used to obtain a single number that reflects a composite influence of the various parameters on the overall water quality during the pre-rainy, rainy, pre-dry and dry seasons are presented.

Table 2: Levels of Water Quality Parameters of Lake Bosomtwe During The Pre-Rainy, Rainy, Pre-Dry and Dry Seasons					
Parameter	Benchmark	Season			
		Pre-rainy	Rainy	Pre-dry	Dry
*pH	8.9	8.6	8.3	8.4	8.8
Temperature (°C)	15	30.1	29.8	30.4	32.3
Dissolved Oxygen	6.0	5.2	5.7	5.4	4.5
Total Hardness	300	120.4	124.3	116.4	116.3
Alkalinity	200	267.9	263.3	301.9	305.9
Turbidity (NTU)	5	6.0	8.6	6.5	5.6
TDS	500	70.2	87.4	79.6	62.4
NO3-	13	1.4	1.4	1.8	2.1
SO42-	500	624.5	596.5	583.1	674.5
PO42-	0.8	0.6	0.7	0.5	0.3
BOD	5	2.35	1.95	2.78	3.10
Fe	0.03	0.03	0.03	0.03	0.03
Pb	0.007	0.006	0.006	0.005	0.005
Zn	0.03	0.02	0.03	0.02	0.02
TSS	25	43.8	50.5	43.7	48.8

Unless otherwise stated, all parameters are measured in mg/L

\* Parameter has no unit of measurement.

The results of the WQI calculations CCME indicated a water quality that ranges from poor in the dry season to fair in the rainy season (Figure 1).



**Figure 1:** Water quality indices of Lake Bosomtwe in response to seasonality

## 4. DISCUSSIONS

### 4.1 Overall Water Quality Difference

The degradation of water, an indispensable resource for the survival of human life and the socioeconomic development of people, continues to attract attention (Camara et al., 2019). Therefore, the identification of drivers of change in the availability and quality of water remains crucial. In this study, seasonality, which shows significantly effect on tropical aquatic ecosystems was identified as one of these drivers (Anyanwu et al., 2021). The quality of water was generally better in the rainy season and decreased towards the dry season. This is consistent with studies that found rainfall as a very important factor in improving quality water (Costa et al., 2018). A group of researcher also observed higher nutrients in the dry season than in the wet season (Woldeab et al., 2018). The relatively better quality of water during the rainy season could be attributed to the influx of large volumes of water during the season. This causes a dilution of pollutants. In contrast, during the dry season, in addition to the absence of rain and therefore dilution, there is loss of water or reduction in water volume, a situation that represents the concentration of pollutants. These may explain the pollution situations in the pre-rainy and pre-dry seasons (Pokhre et al., 2021).

### 4.2 Seasonal Variation of Temperature

The temperature of the lake water was observed to occur at lower levels during the rainy seasons (29.8°C) than during the pre-rainy season (32.3°C), pre-dry (30.4°C) and dry season (32.3°C) (Table 2), although the difference was not significant ( $p > .05$ ) corroborating the finding of (Anyanwu et al., 2021). Two of the factors that could control the temperature of the receiving lake are the temperatures of the incoming water and that of the lake. If the temperature of the incoming water is higher than that of the lake water, then the net effect is elevation of the temperature of the lake and if it is rather lower, then it decreases. In the rainy season, Lake Bosomtwe receives large amounts of relatively colder water through precipitation. This could explain the lower temperature of the lake in the rainy season than in the dry season. The findings of that water volume increase during the rainy season and the cooling effect associated with precipitation give credence to the results of this study (Sharma and Capoor, 2010; Rooney et al., 2018).

In the dry season, transport of particulate matter by air into water bodies, which in turn causes an increase in temperature through heat retention, may also be promoted (Manisalidis et al., 2020). Life in aquatic environments is to a large extent influenced by the thermal performance of the inhabiting organisms. Water temperature affects the rate of metabolism, reproduction, survival and distribution of aquatic species such as fish and other micro-organisms (Rubalcaba et al., 2020; da Vianna et al., 2020). Studies have shown that an increase in temperatures affects the lake water quality through a decrease in oxygen concentrations, increased thermal stability, and alterations in the mixing pattern (Missaghi et al., 2017; Magee et al., 2018). These suggest that the lake flora and fauna could be affected more negatively during the dry season than during the rainy season.

### 4.3 Seasonal Variation of pH

Acidity increased during the main rainy season (8.3) and decreased during the pre-rainy season (8.8) (Table 1). Depending on the atmospheric concentration of carbon dioxide, the pH of the lake may also be affected. In situations where the atmosphere is laden with a high concentration of carbon dioxide, rainwater may dissolve carbon dioxide to form acid rain and enter the lake and cause a decrease in pH or an increase in acidity (Wondyfraw, 2014). Slash-and-burning is the main activity with the potential to liberate and stock the lake atmosphere with carbon dioxide (Ter-Mikaelian, 2016). However, this activity is promoted during the dry season, which is usually more pronounced and precedes the farming season. Therefore, the expectation would be that once the lake atmosphere is laden with carbon dioxide, there is a tendency for the lake to be more acidic in the dry season.

However, the absence of rain, which dissolves carbon dioxide to form carbonic acid, during the dry season, may also cause a decrease or low input of acidic water into the lake (Langenberg et al., 2008). Again, during the dry season, which usually coincides with the period of frequent and intense sunshine, the rate of photosynthesis, which brings about the consumption of large amounts of carbon dioxide thereby reducing its build-up in the atmosphere, could be promoted. The occurrence of such a situation deprives the system of carbon dioxide, the dissolution of which increases the acidity (or decreases the pH) of the lake. These suggest that the combined influence of photosynthesis and acid rain formation may drive the pH of the lake during the rainy season and could impair the lake productivity.

### 4.4 Seasonal Variation of DO

Dissolution of oxygen in water is limited by the temperature. Therefore, the lake is able to hold only a limited amount of oxygen during periods of high temperature, particularly the dry season, where heat causes extraction of oxygen from the water to the atmosphere (Manisalidis et al., 2020). This could cause unbearable physiological stress on the floral and faunal communities of the lake (Magee et al., 2018). On the other hand, a relatively high concentration of dissolved oxygen occurs in periods of relatively cold weather, usually in the rainy season. In this study, the mean temperatures of the lake water recorded were higher in the dry season and lower in the rainy season. The concentration of dissolved oxygen observed in the study rainy season (5.6 mg/L) was higher than the 4.2 mg/L recorded in the dry season (Table 1). The recorded means for all the study seasons did not differ significantly ( $p > .05$ ) and fell below the CCME Guideline value of 6mg/L. This indicates that the lake remains under-oxygenated all year round, a worrisome situation where this limitation imposes physiological stress aerobic aquatic life.

### 4.5 Seasonal Variation of Biochemical Oxygen Demand (BOD)

The results of the present study show lower levels of BOD in the rainy season and elevated levels in the dry season. The mean values of the BOD recorded were 3.10 mg/L and 1.95 mg/L for the dry season and the rainy season, respectively (Table 2) did not differ significantly ( $p > .05$ ). This is supported by the findings of Kamarudin et al. (2020) who recorded BOD levels of 4.75mg/L for the dry seasons and 1.15mg/L for the rainy season. The higher levels of BOD recorded during the dry season may be due to the relatively stagnant nature of lakes, together with the elevation of temperature in the dry season that facilitates rapid microbial degradation, which is accompanied by the consumption of higher amount of oxygen (Emere and Nasiru, 2008). This is essentially the same as low oxygen concentration in water and may be exacerbated by the presence of high organic matter in the lake.

### 4.6 Seasonal Variation of Alkalinity

In the rainy season, the mean alkalinity, which indicates the ability of the lake water to nullify the effect of alteration of the acidic or alkaline state of a system, was significantly ( $p < .05$ ) lower (263.3 mg/L  $\text{CaCO}_3$ ) than in the dry season (305.9 mg/L  $\text{CaCO}_3$ ) (Table 1). This may be attributed to dilution of salts, including bicarbonates, carbonates and hydroxide (Hoque et al., 2012) in the lake during rainfall. The observed trend of alkalinity in this study agrees with studies that reported lower levels of alkalinity due to higher degrees of dilution during the rainy season (Parik and Mankodi, 2012; Naik, 2012). Although an excessively high level of alkalinity (compared to standard benchmark, for example, 200 mg/L  $\text{CaCO}_3$  by CCME) is undesirable, the results of the present study suggest that the water offers strong resistance to any tendency to offset imbalance in acidity.

### 4.7 Seasonal Variation of Hardness

Hardness is a factor for assessing the quality of water and the level of toxicity in aquatic systems (Wetzel, 1975). It brings about palliation of the toxicity of most elements in water. Hardness appears to be promoted during rainy seasons. For reasons similar to the alkalinity levels, the levels of total hardness recorded in the present study were least in the rainy seasons (Table 1) and support the results of other studies (Kolo and Oladimeji, 2004; Teame and Zebib, 2016). The mean total hardness recorded in this study ranged between (116.4 mg/L CaCO<sub>3</sub> and 124.3 mg/L CaCO<sub>3</sub>) falling below the CCME guideline value of 300 mg/L CaCO<sub>3</sub>, with no significant differences ( $p > .05$ ). Sources of hardness in aquatic systems include both cations (e. g. Ca<sup>2+</sup> and Mg<sup>2+</sup> ions) and anions (including Cl<sup>-</sup>, CO<sub>3</sub><sup>2-</sup> and SO<sub>4</sub><sup>2-</sup> ion) liberated by anthropogenic activities such as agriculture (Zipper et al., 2005; Ganiyu et al., 2018). They may interact in various ways to yield other contaminating compounds. The low levels of hardness in the study seasons suggest that the lake water does not pose hardness problem in any of the seasons. However, the possibility of soap wasting may be significant.

#### 4.8 Seasonal Variation of Nutrients

For sustenance of the aquatic food chain and hence the food web, the availability of nutrients is crucial. Aquatic organisms may demonstrate seasonal abundance, with nutrient availability being a strong defining factor. Aquatic nutrients include nitrogen (as nitrate), phosphorus (in the form of phosphate) and sulphur (in the form of sulphate), although more emphasis has sometimes been placed on nitrate and phosphate with the conviction that they are the nutrients that limit plant growth. Nutrient concentrations in aquatic ecosystems are governed by factors including rainfall, runoff and temperature (Alexander et al., 2009). Higher concentrations of nitrates were recorded in the dry season (2.11 mg/L) and the pre-dry season (1.80 mg/L) than in the pre-rainy and rainy seasons (1.44 mg/L) (Table 2). A similar trend was observed for phosphate; highest in the dry season (0.7 mg/L) and lowest in the rainy season (0.6 mg/L).

Like phosphate and nitrate, sulphate levels were also lower in the rainy season (596.5 mg/L) than in the dry season (674.5 mg/L). Only sulphate showed a significant difference ( $p < .05$ ) in concentration in the two extreme seasons: the rainy and dry seasons. This interactive effect of temperature and available organic matter is also critical in determining nutrient levels in lakes. Although during the dry season availability of the organic materials is limited by the absence of carrier runoff which, in turn is driven by the occurrence of rainfall, temperatures are relatively high to stimulate and facilitate the decomposition of available organic matter to increase nutrient levels in the lake. Nitrate, phosphate and sulphate levels were lower than the respective CCME Guideline values. This suggests that the lake water does not pose a nutrient threat to the human life and aquatic life.

#### 4.9 Seasonal Variation of TDS, TSS and Turbidity

Lakes show highly dynamic temporal variations in quality. This is an important phenomenon that explains the critical factors that regulate the patterns, abundance, composition, and biological mechanisms of aquatic species. The lake studied showed higher levels of TDS, TSS and turbidity in the rainy season than in the dry season (Table 2) although no significant differences ( $p > .05$ ) were observed. The recorded TDS levels for the rainy and dry seasons were 87.4 mg/L and 62.4 mg/L while the TSS were 50.5 mg/l and 48.8 mg/L, respectively. The results are supported by those of other researchers (Lira et al., 2011; Butler et al., 2018). The mean levels of TDS of the lake water fell below the CCME guideline value (500 mg/L) and therefore do not suggest a threat to human and aquatic life. On the other hand, the mean levels of TSS exceeded the CCME guideline value (25 mg/L). This may lower the transparency of lake water and reduce primary production, increase the temperature, and decrease the concentration of dissolved oxygen in the water and also smother fish eggs and other benthic organisms, a situations which are detrimental to aquatic life (Butler et al., 2018; Bilotta and Brazier, 2008).

Intestinal disorders attributable to a high level of TSS could also be associated with the lake water consumption. The lake water studied was also more turbid in the rainy season and less turbid in the dry. The respective mean values were 8.6 NTU and 5.6 NTU. These agree with the results of other studies (Ojok et al., 2017; Mena-Rivera et al., 2017; Dey et al., 2021). The causes of turbidity include suspended sediment such as clay, silt, matter of organic origin (eg, algae, plankton, and decaying substances) and inorganic matter (Kishor and Joshi, 2005). Again, the proliferation of algae can cause an increase in turbidity. The generation of these materials and organisms is facilitated by intense rainfall and impedes light penetration to reduce water transparency and hence reduction in productivity (Oso and Fagbuaro, 2008).

#### 4.10 Seasonal Variation of Metals (Pb, Fe and Zn)

The occurrence of heavy metals and particularly toxic metals in global lakes, with their characteristic environmental persistence, is of great concern. Metals studies conducted on for Pb, Fe and Zn. Lead and zinc levels remained relatively stable, showing no significant temporal variation ( $p > .05$ ) defined by seasons. Lead is among the abundant heavy metals and shows stability characteristics and biological toxicity through complex processes. The mean concentration of Pb recorded was higher in the rainy and pre-rainy seasons (0.011 mg/L) than in the dry and pre-dry seasons (0.005 mg/L). These concentrations were lower than the CCME guideline value (0.007 mg/L). The recorded Pb levels did not differ significantly at ( $p > .05$ ), indicating that the Pb concentration did not respond to seasonal variation despite the high sensitivity of the lake ecosystem. It may not show a potential risk of metal pollution (Jiao et al., 2010).

The probable sources of Pb loadings include the geology of the lake and the anthropogenic factor, runoff from agricultural soils, poor agricultural practices, and waste management systems (Ewuzie et al., 2019; Yi et al., 2011). Zinc, an essential element in natural waters for biological processes that include growth, undergoes complex interactions with the environment to define its bioavailability. Its extensive daily use is one of the underlying factors that explain the proneness of lakes to zinc contamination. Iron, an essential growth nutrient, is a natural agent that limits the availability of phosphorus to algal and serves as a precursor for macrophytes to the domination of lake plant community (Dokpayi et al., 2017). The concentration of Zn (0.03 mg/L) was higher for the wet season than for the dry season when 0.02 mg/L, although not significant ( $p > .05$ ).

This agrees with the results of a study that reported the accumulation of higher mean levels of Zn in the three species of fish during the wet season compared to the dry season and attributed the observation to the impact of washoff into the lake during rainy periods (Bakker et al., 2016). However, the Fe concentration remained fairly constant throughout the seasons. Both Fe and Zn levels were within the CCME (0.03 mg/l) and WHO guideline values (3.0 mg/L) that of Fe were the same as the CCME guideline value of 0.03 mg/L. The observed results suggest that the extent of anthropogenic input of Zn and Fe could be less important and therefore may rule out toxicity problems for aquatic life and humans who depend on the lake for consumption and other domestic uses.

#### 5. CONCLUSION

The quality of water in a lake is a function of input-output dynamics of solids, liquids and gas particles, most of which are usually attributed to anthropogenic sources. The effect of these particles on the quality status of the water is affected by temporal and, specifically, seasonal variations. In the present study, the water quality of Lake Bosomtwe, which serves as a source of livelihood for communities in the Lake Bosomtwe basin, in response to seasonal variation has been assessed using the water quality indices of the water quality parameters. The results indicated normal levels defined by the CCME guideline values throughout the seasons except dissolved oxygen, which was lower; temperature, total suspended solids and turbidity, which were higher, and alkalinity sulphate and iron was significantly higher. The CCME WQI model indicated that Lake Bosomtwe water is influenced by typical seasonality trends, declining from descriptive indicators of fair status in the pre-rainy season (65.7%), fair status in the rainy season (67.2%), through marginal in the pre-dry seasons (46.5%) to poor in the dry seasons (44%), which is a period of general low volume of water resources and hence high dependence on the lake and, therefore, points to compromised ecology and health risk to communities that depend on the lake for domestic consumption.

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