Water Quality Status of Tono and Vea Reservoirs for Aquaculture Development in the Upper East Region of Ghana

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Authors' contributions

This work was carried out in collaboration among all authors. Author EA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors NWA, DAB and TKA managed the analyses of the study. All authors managed the literature searches, read and approved the final manuscript.

Original Research Article	

ABSTRACT

Understanding aquatic ecosystem dynamics is fundamental to sustainable development of aquaculture. This study explores the water quality characteristics over temporal and spatial scale in Tono and Vea Reservoirs in the Upper East Region of Ghana for aquaculture development. Water samples and in-situ measurements were taken for fifteen months, from February 2015 to March 2016. Monthly water quality monitoring were based on stratified sampling from upstream, midstream and downstream zones of these reservoirs. Standard analytical methods for examination of water were employed during sampling and laboratory analysis of reservoir water quality. Phytoplankton analysis was done using light microscopy to obtain phylum abundance. Multivariate statistical methods were used to investigate water quality dataset obtained. Cluster analysis grouped fifteen months of water quality changes into three seasonality regimes (periods)

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based on temporal variation. Principal component analysis (PCA) reduced eighteen water quality variables into five and three factors with total variance of 88.26 % and 79.30% for Tono and Vea reservoirs, respectively. With pH > 7 and alkalinity > 20 but < 100 mg L^{-1} $CaCO_3$, both reservoirs have alkaline water. Dissolved oxygen was > 5 mg L^{-1}. Three phyla of phytoplankton were identified with dominant (in abundance) phylum as Chlorophyta (72%) occurring in Tono reservoir. To understand the spatial relationship using correspondence analysis (CA), the first axis of CA explained 84.2% and 64.3% of total variation in relative abundance of phytoplankton phyla for Tono and Vea reservoirs, respectively. Thus, Cyanophyta showed strong positive association with conductivity, total hardness, nitrate, sulphate, turbidity, water depth and dissolved oxygen which were responsive to the midstream and upstream zones of Tono reservoir. Whiles in Vea reservoir, Chlorophyta under same water quality variable showed responsiveness to the midstream and downstream zones. Reservoir water quality studied were within acceptable limits for fish culture but changes could be linked to anthropogenic activities on reservoir catchment area and seasonality regime. Results from this provide a baseline to enable information to enable assessment of aquaculture impact in Tono and Vea reservoirs. The use of multivariate analysis could be a reliable statistical method for assessing water quality on a spatio-temporal scale.

1. INTRODUCTION

Globally, the demand for fish has increased and fish farming has been proposed as the solution to meet the ever-increasing demand for fish whiles managing capture fisheries [1,2]. Despite having numerous inland fresh water bodies and/or coastal brackish or marine water resources, fish production in Africa had a steady growth, averaging 10.4% over the last one and half decades [3]. However, reservoirs especially in Ghana could be harness to provide some comparative advantage since inland fisheries and aquaculture contribute only 30 percent of the total fish production [4]. Aquaculture production in Ghana is mainly on the lake Volta. Small water bodies such as reservoirs and dugouts are often overlooked due to the quantity and quality of water within such systems. Water quality is one of the most important factors that affect fish health and performance in any aquaculture production system [5] and for that matter cage culture. Poor water quality could lead to stunted fish growth, increase the incidence of diseases, and can cause high fish mortality. Changes in the composition and abundance of phytoplankton may impact the water quality status over the spatial-temporal scale [6]. Deteriorated waters could lead to algal blooms which may produce cyanobacteria toxins that affects fish and other aquatic organisms [7,8]. Cyanobacteria toxins also affects the taste of fish produced due to off-flavour compounds that accumulates in the fish. Water temperature and dissolved oxygen levels helps in determining the feeding rate per the percentage body weight of fish [5,9]. Thus, the first guiding principle for sustainable aquaculture is water quality. The use of physico-chemical properties of water to assess water quality give a good impression of the status, productivity and sustainability of such water bodies.

Currently, reservoirs, dugouts, and other small water bodies in semi-arid zones are being considered and exploited for aquaculture. Formerly, cages were mostly constructed and mounted on large water bodies such as lakes and rivers, but in recent times reservoirs purposely built for irrigation are utilized [3], [10], [11]. Culture-based fisheries in reservoirs is being promoted in countries such as Burkina Faso, Guinea, Madagascar, Malawi, Mali, Niger, Nigeria and Senegal to maximize water use efficiency [3].

Most reservoirs in northern Ghana were seldom used for cage culture. Although few studies recommended exploitation of these reservoirs for aquaculture [10,12], little was being done. Recent tilapia cage culture production in some reservoirs and dugouts (Datoko, Pusu-Namongo, Soe-Yidongo, Bon-Gurigu) yielded 19.5 metric tonnes of fish (Peter Akpaglo, personal communication). Feasibility studies conducted in selected dugouts in the Bongo District of the Upper East Region, indicated that Nile tilapia culture can serve as an alternative livelihood for rural communities as the fish had good growth even in eutrophic waters [11].

The numerous reservoirs and dugouts in the Upper East Region (UER) could have some comparative advantage in tilapia production, thus intensification of tilapia cage culture in Tono and Vea reservoirs in UER is envisaged. This could

be based on successful cage culture production trials in some selected reservoirs and dugs in the UER from 2011-2015 [10,13], coupled with the high demand by the populace for tilapia. Thus, Tono and Vea reservoirs earmarked for cage culture needs extensive water quality studies to understand the water quality dynamics as the first pragmatic step for prudent decision making on its water resources utilization and for sustainable aquaculture. The quality of culture water determines the growth, reproduction, health and quality of fish produced. Water pollution could be exacerbated by aquaculture if the reservoir assimilative capacity is exceeded. Environmental issues such as drought and water pollution from industrial effluent, urban runoff, sewerage and agro-chemicals, which is a threat to water quality cannot be understated. This is because fish are totally reliant on water. Tilapias are more tolerant than most commonly farmed freshwater fish to high salinity, high water temperature, low dissolved oxygen, and high ammonia concentrations [14]. The state, feeding intensity and growth rate of fish is intensely affected by the physical and chemical situations of their environment. Hence, the need to have constant monitoring of the water quality. The aim of this study, was to determine the seasonal characteristics in terms of spatial variability and patterns in reservoir water quality. This could

serve as baseline information for aquaculture development using the physico-chemical and biological attributes of the Tono and Vea reservoirs.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted on the Tono and Vea reservoirs in Upper East Region (UER), Ghana (Fig. 1). Tono and Vea Reservoirs are among the largest man-made water storage systems of ecological and socio-economic importance in the Sudan-savanna ecological zone of Northern Ghana. Tono Reservoir is located in the Kassena Nankana District between Latitude 10°51'40'' and 10°54'30'' North and longitude 1°8'30'' and 1°10'50'' West on River Tono, while Vea Reservoir is located between latitude 10°00'00'' and 11°01'00'' North and longitude 0°45'30''and 0°56'30'' West on River Yarigatanga in the Bongo District, UER. Tono and Vea reservoirs are irrigation schemes under the management of Irrigation Company of Upper Region (ICOUR) with irrigable areas of 2,490 and 468 hectares, respectively. As perennial reservoirs, water volume of 92.6 and 17 million cubic meters for Tono and Vea reservoirs was reported [15], with mean water depth < 10 meters in both reservoirs.
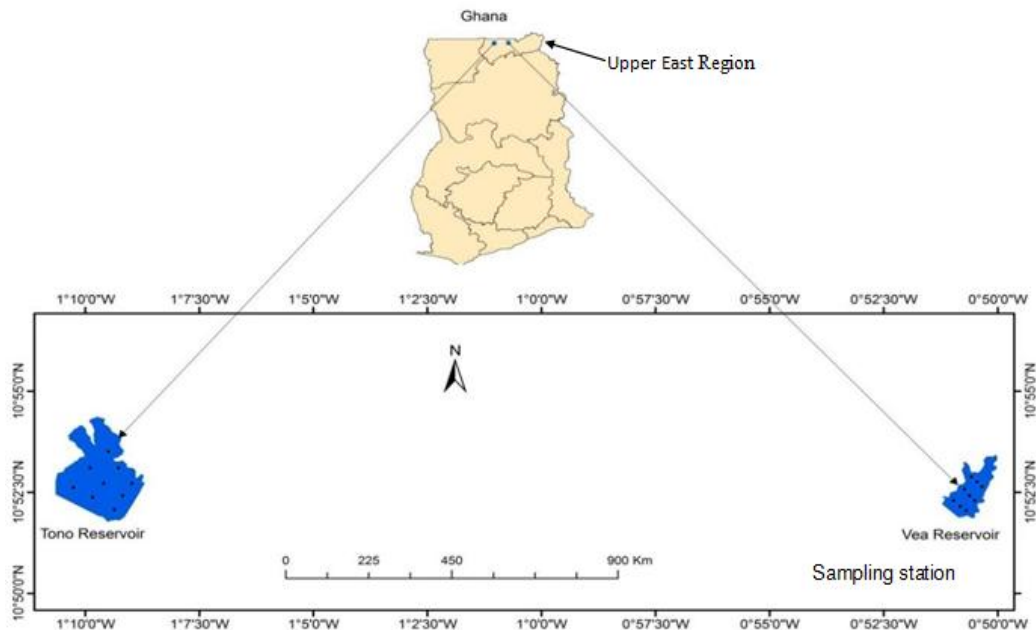

Fig. 1. Tono and Vea reservoirs in the upper east region, Ghana

These reservoirs were built for irrigation and livestock watering with few earthen ponds for rice and fish culture. These earthen ponds are located behind the dam (downstream), most of which have been abounded or under-utilized due to operational difficulties. The fish landing sites in Tono reservoir are known as bay, of which four (4) out of the five (5) of these fish landing sites are in use, whiles Vea reservoir had all three (3) fish landing sites in use. Both reservoirs are not directly exploited for culture fisheries (particularly cage aquaculture) although its capture fishery resources had dwindled over the years, it remains the hub for capture fisheries for Navrongo, Bolgatanga and other communities in the Upper East Region of Ghana. A large number of riparian communities and hundreds of people depend on these two major reservoirs for food, employment, income and livelihood.

2.2 Water Sampling and Quality Assurance

The Tono and Vea Reservoirs were divided into three sections based on the direction of water flow for sampling purposes, namely; Upstream (us), midstream (ms) and down streams (ds). Water samples were collected monthly from February 2015 to April 2016 using linear stratified sampling technique with three replicates from each section. That is, a total of nine sampling stations in each reservoir. In-situ measurement of water temperature (TEM) and pH was done using Hanna HI 83141 portable probe meter, Conductivity (CON) using Hanna HI 8733 portable probe meter; and water depth (WD) and transparency (TRA) in terms of Secchi depth (SDD) were measured using metric tape and Secchi disc, respectively on site.

Water samples were collected into the 1000 ml high density polyethylene (HDPE) bottles, which were pre-washed with dilute hydrochloric acid (10%) and re-washed three times on-site with the reservoir water before sampling. Water samples were collected at mid-depth (0.5-1.5 m). The collected water samples were analyzed for Dissolved Oxygen (DO), Total dissolved solid (TDS), Turbidity (TUR.), Chloride (CL^-.), Alkalinity (ALK.), Total Hardness (T.HAR), Sulphate (SO_4^{2-}), Phosphate-phosphorus (PO_4^{2-}), Silicon dioxide (SiO_2), Nitrate-Nitrogen (NO_3-N), Nitrite-Nitrogen (NO_2-N), Ammonium-Nitrogen (NH_4-N). For hdyro-biological sampling, Chlorophyll-a (CHL-a) samples were collected into 500 ml bottles covered with black plastic sheets and stored in the dark in a cool ice box to prevent deterioration

of green chlorophyll pigment in sunlight. Plankton net was towed within each designated zone or strata to collect phytoplankton samples. Phytoplankton samples were fixed with acid lugol's solution and formalin (3 - 4 drops to 250 ml). All samples were stored in cool box or "ice chest" (insulation boxes) at 4°C to minimize temperature effects on samples during transportation for laboratory analyses. All samples were transported (< 24 hours) to CSIR-Water Research Institute's Laboratory in Tamale for analysis.

2.3 Laboratory Analysis

Standard protocols for water stabilization, storage and water quality analysis were followed according to standard analytical methods for examination of water and waste-water [16,17]. Environmental samples consisting of physico-chemical and nutrient for laboratory analyses were done using 50 ml of the sample with appropriate reagents through titration and colour indicator methods. Except for phytoplankton samples, all other samples were kept in a refrigerator at 4°C until analyses were completed (approximately in 3 days).

Hydro-biological samples analyzed were algal chlorophyll (CHL-a), phytoplankton phyla and phytoplankton biomass. Algal chlorophyll (chlorophyll-a) was determined spectro-photometrically. Filtration of samples was done into a 50 ml centrifuge tube; 10 ml was taken after acetone (90%) extraction in the laboratory. The supernatant was poured into a 1 cm cuvette. The spectrophotometer was zeroed with 90% acetone and readings taken at 663, 645, 630 nm; absorbance. Final chlorophyll-a values were calculated as recommended in [16]. The phytoplankton biomass (PHY.B) was derived through estimation from the equation;

$$PHY.B = CHL\text{-}a \times 67; \text{ based on [16].}$$

Phytoplankton identification was by examination of microscopic material in counting chambers of 25 ml cuvette (1 ml of sample: 24 ml distilled water) with a slide cover under a Carl Zeiss inverted light microscope (BDS 300) as described by [6]. Minimum settling time of 4 hours per every 1 cm height of sample in the chamber [18] was observed. Sedimentation was carried out in counting Chambers, cell counts were made in duplicate and average cell counts per ml computed. Identification of algae taxa (phytoplankton) was aided with a guide to study

of freshwater biology [19] and the manual of algae species drawings for laboratoire D'Ichtyologie Museum National D'Histoire Naturelle, Paris [20].

2.4 Data Analysis

Multivariate statistical methods were employed to explore similarities and identify patterns associated with water quality changes in the reservoirs. Multivariate methods such as cluster analysis (CA), principal component analysis (PCA), correspondence analysis (CoA), discriminant analysis (DA), factor analysis (FA); provides important pattern recognition techniques for reliable management of water resources [21]. Thus, these analyses could elucidate the impact on water quality for aquaculture development in reservoirs.

In this study, cluster analysis (CA) using Ward's method and Bray-Curtis (B-C) similarity measure was run in Community Analysis Package (CAP, Version 1.52) software. During the analysis, transformation of data was performed using log base 10 to reduce the range of the data. Groups clustering at B-C <30% was employed to display similarity of samples across a wide range of scale with clusters to aid understanding of Tono and Vea Reservoirs' system response over temporal scale. Similarity was identified through the linkages between months represented by a tree diagram or dendrogram.

Paleontological statistics (PAST, version 3.11) software was employed to run the physico-chemical parameters (environmental variables) and phytoplankton phylum distribution (biological variables) to detect spatial relationship among the variables. Principal component analysis (PCA) was used to reduce the water quality parameter data set from initial eighteen (18) water quality parameters to obtain the important variables (most significant) that influence spatial variation in Tono and Vea reservoirs. Further PCA and FA statistical analysis were performed in XLSTAT version 2018 software to explain the variance obtained in the original dataset.

Correspondence Analysis (CoA) was performed to compare associations between phytoplankton phylum and most significant environmental variables at various zones (us, ms and ds) of the reservoirs for unimodal spatial response. In these analytical approach, the less significant variables were omitted from the whole data set with a very minimum loss of its original information in the

analysis. The percentages of similarity accounted for by the eigenvectors are provided. Thus, corresponding eigenvector with eigenvalues more than one or close to one are considered significant in obtaining new groups of factors, as recommended [22]. Results were presented in dendrograms, triplot charts, and tables and graphs using Microsoft Excel (2013).

3. RESULTS

3.1 Water Quality Characteristic of Reservoir

Mean values of eighteen (18) water quality variables monitored in the Tono and Vea reservoirs are presented in Table 1. Atmospheric temperature encountered during the study was 27°C - 31.9°C. Dry season produced fluctuating atmospheric temperature of 15°C – 44°C, characterized with hazy winds during the harmattan period (December - Mid March). Both reservoirs had dissolved oxygen levels > 5 mg L^{-1}. The pH of the reservoir water was slightly alkaline ranging between 7.74 - 7.56 and 7.92 - 7.82 for Tono and Vea Reservoirs, respectively. Total alkalinity recorded in both reservoirs were > 45 mg L^{-1}, with conductivity levels > 500 µs cm^{-1}. Tono reservoir had deeper water depth with mean water depth of 5.50 m compared to 3.65 m for Vea reservoir. Transparency in terms of Secchi depth (SDD) were 0.55 m (Tono reservoir) and 0.43 m (Vea reservoir) as velocity of water runoff and land use of reservoir watershed varied (Table 1).

3.2 Temporal Characteristics of Reservoir Water Quality

The results of cluster analysis (CA) for the fifteen (15) months of sampling in Tono and Vea Reservoirs detected temporal similarity in groupings (Fig. 2) in water quality characteristics. Monthly Groups clustering aided identification of seasonal changes in water quality parameters monitored in Tono and Vea Reservoirs. Bray-Curtis (B-C) similarity of clustering at < 30% (Fig. 2), four-clusters were formed with respect to temporal grouping of Tono reservoir: Cluster 1 – December 2015, November 2015, July 2015, June 2015 and May 2015; Cluster 2 – April 2016 and March 2016; Cluster 3 – October 2015, September 2015, and August 2015; Cluster 4 – February 2016, January 2016, April 2015, March 2015 and February 2015.

For Vea reservoir with respect to temporal grouping, groups clustering at B-C < 30% considered to exhibit similar community structure produced three-clusters (Fig. 2). These are: Cluster 1 – November 2015, October 2015, December 2015 and August 2015; Cluster 2 – September 2015, July 2015 and June 2015; Cluster 3 – February 2016, May 2016, March 2016, April 2016, April 2015, January 2016, March 2015 and February 2015.

Table 1. Water quality parameters (Means ±S.E) monitored in Tono and Vea reservoirs in the upper east region of Ghana (Feb.2015-Apr.2016)

	Reservoir	
Parameters (Units)	**Tono**	**Vea**
TURB. (NTU)	147.060 ±24.166	157.729 ±33.523
W.TEMP (°C)	27.635 ±0.627	26.673 ±0.691
DO (mg/L O_2)	8.659 ±0.447	7.643 ±0.263
Cl- (mg/L)	3.192 ±0.232	5.689 ±0.177
SO_4^{2-} (mg/L)	19.640 ±1.707	10.641 ±0.964
PO_4^{2-} (mg/L)	0.092 ±0.012	0.052 ±0.013
SiO_2 (mg/L)	18.356 ±2.546	9.165 ±0.973
NO_3-N (mg/L)	3.048 ±0.982	2.486 ±0.803
NO_2-N (mg/L)	0.256 ±0.083	0.033 ±0.004
NH_4-N (mg/L)	3.174 ±0.644	0.787 ±0.015
COND. (µs/cm)	742.646 ±55.688	1025.145 ±30.218
pH	7.742 - 7.564	7.922 - 7.818
SDD (m)	0.551 ±0.055	0.426 ±0.027
W. DEPTH (m)	5.503 ±0.558	3.656 ±0.245
ALK. (mg/L $CaCO_3$)	48.474 ±1.107	58.387 ±1.504
T.HAR. (mg/L)	66.451 ±0.729	68.067 ±1.938
CHL-a (mg/m3)	1.365 ±0.043	0.061 ±0.003
PHYTO.Biomass	91.477 ±2.907	4.060 ±0.197

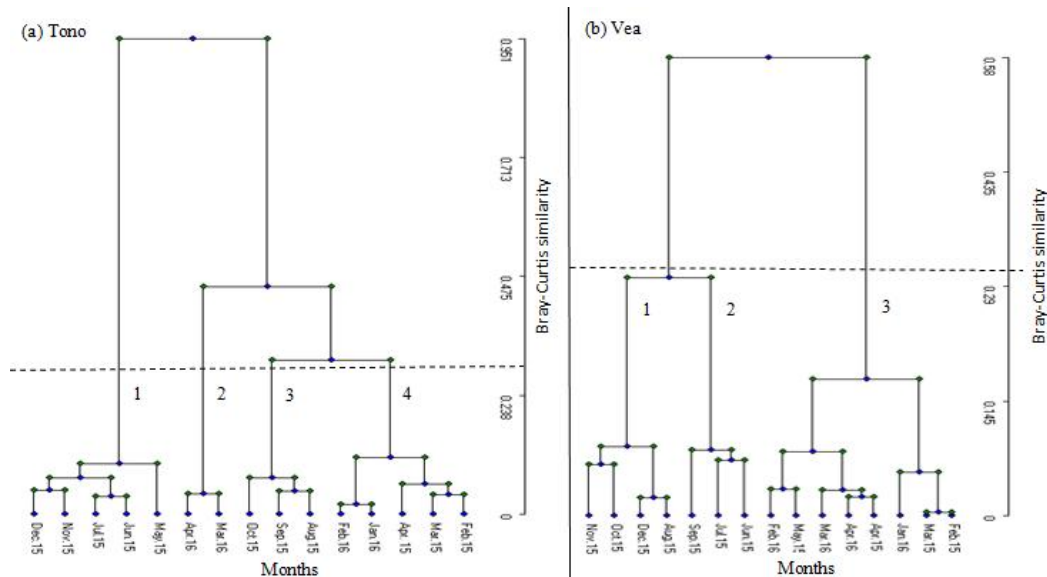*S.E: Standard Error; W: Water; T: Total*

Fig. 2. Hierarchical dendrogram showing temporal variations (cluster analysis) of monitoring periods in (a) Tono reservoir and (b) Vea reservoir in the upper east region. Ward's method, Bray – Curtis (b-c) similarity measure, groups clustering at b-c < 30% were considered to exhibit similar community structure

3.3 Spatial Characteristics of Environmental and Biological Variables at Sampling Zones

Pre-analysis of entire water quality dataset using Principal Component Analysis (PCA) was performed to obtain a correlation matrix of the eigenvalues plotted (Fig. 3). This plot called scree plot are eigenvalues associated with each of the factors extracted, against each other. That is, each eigenvalue corresponds to a factor, and each factor to a one dimension. Thus, at the point that the plot begins to level off, the additional factors explain less variance than a single variable [22].

For Tono reservoir, there were five factors with eigenvalues more than 1; F1: 6.370, F2: 4.397, F3: 2.559, F4: 1.398, F5: 1.163 (Fig. 3). The first five of the eigenvalues correspond to a high number of percentage of the variance, assuring us that the scree plot based on the first five factors are good quality projection of the initial multi-dimensional water quality structure. In the Fig. 3 below, the first five factors allow us to represent 88.26% of the initial variability of the data. This indicates a very good result (>50%). That is, eighteen water quality parameters were reduced to five factors (F1 - F5).

Similarly, for Vea reservoir, from Fig. 4 the first eigenvalue (F1) equals 9.669 which represent 53.72% of the total variability. This means that if data are represented on only one axis, a percentage (%) of the total variability of the data can still be obtained. As such each eigenvalue correspond to a factor, and each factor to a dimension. The second (F2: 2.791) and third (F3:

1.814) of the eigenvalues in addition to F1; correspond to a high number of percentage of the variance assuring us that the scree plot based on the first three factors (F1 - F3) are good quality projection of the initial multi-dimensional water quality structure. In the scree plot, the first three factors allow us to represent 79.30% of the initial variability of the data which also indicates a good result. That is, eighteen water quality parameters were reduced to three factors (F1, F2, F3).

Land use characteristics of the reservoirs shows wide spread post-flood period anthropogenic activities (Dry season; October-December). Dry season farming mostly vegetable cultivation is dominant on the catchment areas for both reservoirs. However, sand-mining and moulding of cement blocks were observed as pre-dominant pre-flood activity within the receded littoral section the Vea reservoir. However, vegetable cultivation were pre-dominant in Tono reservoir than in Vea reservoir. These anthropogenic activities could impact on the water quality especially on nutrient loading in the reservoir and possible cascading effect on phytoplankton abundance in the reservoir.

Biological variables were analyzed to the phytoplankton phylum taxon. Three (3) phyla of phytoplankton identified in Tono and Vea reservoirs were Chlorophyta (Green algae), Bacillariophyta (Diatoms) and Cyanophyta (Blue-Green algae). The dominant phylum was Chlorophyta (72%) and Cyanophyta (52%) for Tono and Vea reservoirs, respectively (Fig. 5). Bacillariophyta had the lowest and same percent abundance in both reservoirs.
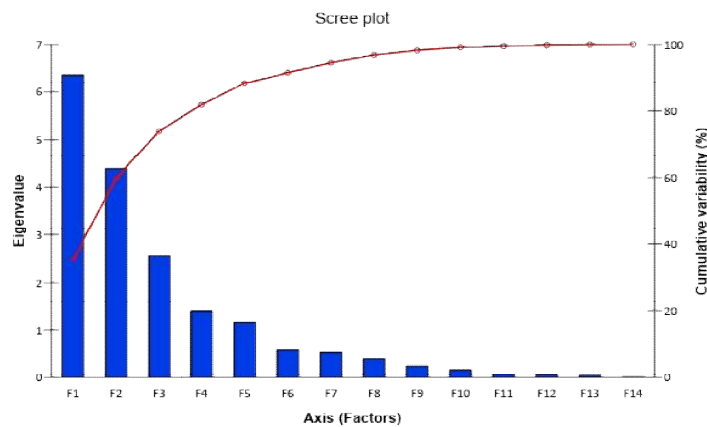

Fig. 3. Scree plot of eigenvalues from principal component analysis (PCA) for Tono reservoir
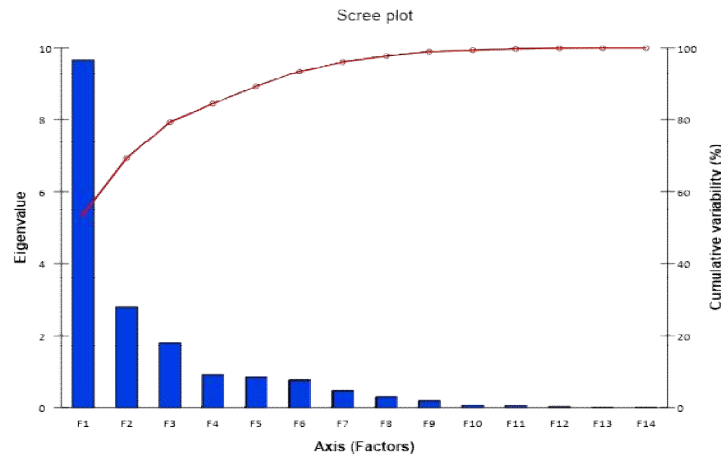
Fig. 4. Scree plot of eigenvalues from principal component analysis (PCA) for Vea reservoir

These phyla from various sampling zones were the biological variable analyzed with the environmental variables. From interrogation of the factors obtained from PCA, further analysis of environmental factors for both reservoirs cumulatively produced six water quality parameters as best variables (from eigenvalues), extracted from the pre-analysed data set. The best variables were; Conductivity, Turbidity, Nitrate, Sulphate, water depth and Total hardness. Although Dissolved Oxygen (DO) was not part of extracted best variables, DO was included into the correspondence analysis (CA) due to its relative importance as an environmental factor to fish survival and growth in aquaculture. The best variables are relevant for water quality monitoring.

Table 2 shows CA results of similarity accounted for by the corresponding eigenvectors and percentages of similarity accounted in each reservoir from the CA performed. The important environmental gradient (spatially varying aspect) indicative as the first CA axis explained 84.2% and 64.3% of the total variance in relative abundance of 3 phyla of phytoplankton for Tono reservoir and Vea reservoirs, respectively (Fig. 6). For Tono reservoir, Bacillariophyta, conductivity, Turbidity, Nitrate, Sulphate, water depth, total hardness and dissolved Oxygen were positively related; showing strong relationship between phytoplankton score and environmental scores (Table 2; Fig. 6,a). Chlorophyta and water depth showed positive relationship of association in Vea reservoir (Fig. 6,b). Comparatively, CA axis 2 in Vea reservoir

showed stronger positive relationship between Bacillariophyta, conductivity, Turbidity, Nitrate, Sulphate, water depth, total hardness and dissolved oxygen, although contributing to (<50%) of the total variance (Table 2).

Results of biological variables at each section of the reservoirs viz. upstream, midstream and downstream assessed in terms of phytoplankton abundance in phyla (cell counts/ml) are presented in Table 3. Spatial variation for site score CA axis 1 indicates strong positive relationship between Phytoplankton phyla and midstream sections (TOMS: 2.98, VEMS: 1.32) in both reservoirs, as shown in Table 3. Thus, midstream sections had relatively more phytoplankton abundance.

An integration of the principal components (from PCA) of environmental and biological factors (Table 2), and site score (Table 3) for spatial relationship using correspondence analysis (CA) are presented in triplot chart (Fig. 6). Based on the first axis of CA for Tono reservoir, axis I alone explained 84.2% of phytoplankton spatially varied distribution in the three zones (Fig. 6). From the triplot chat, Bacillariophyta had positive association with water depth, dissolved oxygen, sulphate, turbidity, nitrate and total hardness at the midstream zone of Tono reservoir (TOMS 2) due to disturbances from anthropogenic activities. Similarly, conductivity and Cyanobacteria seem to have a weak association with the Upstream zone (TOUS 1), whiles Chlorophyta was negatively associated with
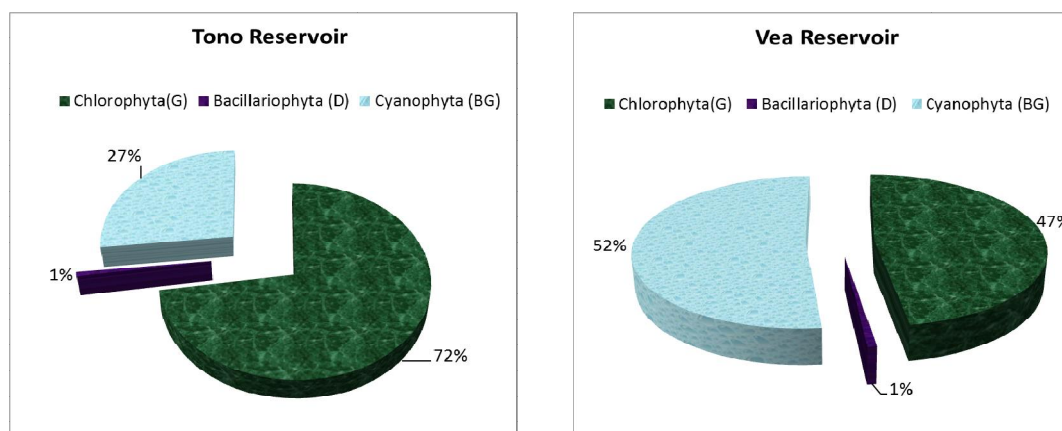
Fig. 5. Percent abundance of phytoplankton (phyla) in tono and vea reservoirs in the upper east region of Ghana. Quarterly monitored (cell counts ml⁻¹) from February 2015 – April 2016. G: Green algae, D: Diatom, BG: Blue Green algae

Table 2. Summary of correspondence analysis (CA) eigenvectors, relating relative abundance of 3 phyla of phytoplankton to environmental variables in Tono and Vea reservoirs, Upper East Region, Ghana, following Chi-squared distances

Parameters	Tono CA axis		Vea CA axis	
	1	2	1	2
Chlorophyta	-0.2115	0.08883	**0.71769**	-0.2252
Bacillariophyta	**2.46079**	**1.07226**	-0.2576	**2.18201**
Cyanophyta	0.12037	-0.1479	-0.7102	-0.1011
Conductivity	**0.65489**	-0.0326	0.3103	**1.54408**
Turbidity	**0.97482**	0.20534	0.27032	**1.56357**
Nitrate	**0.99888**	0.22528	0.30074	**1.47528**
Sulphate	**0.97847**	0.24182	0.30595	**1.55751**
Water depth	**1.0951**	0.42172	**0.53832**	**1.96392**
Total hardness	**0.97659**	0.18858	0.30763	**1.53156**
Dissolved oxygen	**1.09939**	0.31976	0.30163	**1.59256**
Eigenvalue	0.10466	0.01965	0.47131	0.2619
% of total variance	84.196	15.804	64.281	35.719
Cumulative % variance	84.196	100	64.281	100

Bold valves shows strong positive relationship

downstream zone (TODS 3) (Fig. 6, a). Comparatively, a lower percentage variability of 64.3% based on first axis of CA for Vea reservoir (axis I) showed strong positive association with Vea downstream. Phytoplankton spatially varied distribution in the three sites (Fig. 6).

4. DISCUSSION

4.1 Temporal Variation and Seasonality Regime of Reservoir Water Quality

The temporal trends exhibited by the various clusters of temporal grouping were compared with empirical seasonality regimes (dry and rainy seasons) in the Upper East Region of Ghana. Previous studies on the Tono and Vea reservoirs

divided the dry season into two parts; the first part from November to mid-February which is characterized with cold and dry dusty harmattan winds [15]. The second part (Mid-February to March) is characterized by hot, less windy and high atmospheric temperature (> 33 ºC). In this study, based on limnological results obtained over temporal scale; the empirical dry season was divided into two periods; namely pre-flood and post-flood seasons. Whiles the peak periods of the rainy season are called flood season. These assertions were based on the premise that most lentic water bodies like Tono and Vea reservoirs are perennial. That is, these water bodies do not completely dry out. It was inferred that, after impoundment, there had been no period where these reservoirs became literally

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dry (with-out water). Preceding from the premise in this study, similarity of temporal variance (Fig. 2, a) in cluster 1 revealed mixed correspondence in line with post-flood period (December, November) and flood period (May, June, July). This post-flood period accounted for 33.3% of temporal variance in water quality in Tono reservoir. The results of grouping "May, June and July" as part of cluster 1 (post-flood season), instead of it being flood season for Tono reservoir could be due to variation in the amount of rainfall (runoff received) and water quality in those particular months. Recent studies cited May to October as rainy season within the catchment of the Vea and Tono reservoirs [15]. From this current study, the cluster obtained as "May, June and July" was re-classified in line with previous observation as flood season. Thus, anthropogenic activities and seasonal variation could have altered the water quality [23].

Cluster 2 closely corresponding with dry season, was probably an outlier due to few dissimilarity of unexplainable variation in water quality over the period but could be considered. Cluster 3 resonates closely with the flood periods where there is high rainfall (August, September, October), accompanied by water run-off into the reservoir. Thus, the rainy season accounts for 20% of the temporal variation in the reservoir. The study observed that the flood season in the reservoirs usually lasted for 3 months. Cluster 4 denotes the typical dry season periods with virtually no rain fall. Thus, cluster 2 and 4 have

similarity in seasons were considered as one season; post-flood period of the dry season. This season which is also referred to as Harmattan accounted for 46.7% of the temporal variation in water quality in Tono reservoir.

Table 3. Summary of site score for biological variables at various sampling zones in Tono and Vea reservoirs, Upper East Region, Ghana

Zones (site)	CA Axis 1	Axis 2
TOUS 1	0.498311	-1.4337
TOMS 2	**2.97785**	1.73251
TODS 3	-0.616874	0.48309
VEUS 1	-0.790337	-0.132128
VEMS 2	**1.31593**	-0.302956
VEDS 3	0.413316	5.09611

TO: Tono, VE: Vea, US: up-stream, MS: mid-stream, DS: down-stream

Temporal changes in Vea reservoir from cluster analysis results (Figs. 2, b) indicated close correspondence of cluster 1 to pre-Harmattan/Harmattan season (October-December). Cluster 1 could also be referred to as post-flood periods for limnological purposes. During this period, dry dusty winds blow causing early morning turbulence, thereby improving dissolved oxygen levels into the reservoir water. However, the season only accounted for 26.7% of the observed temporal changes in water quality. Cluster 2 produced similarity groupings
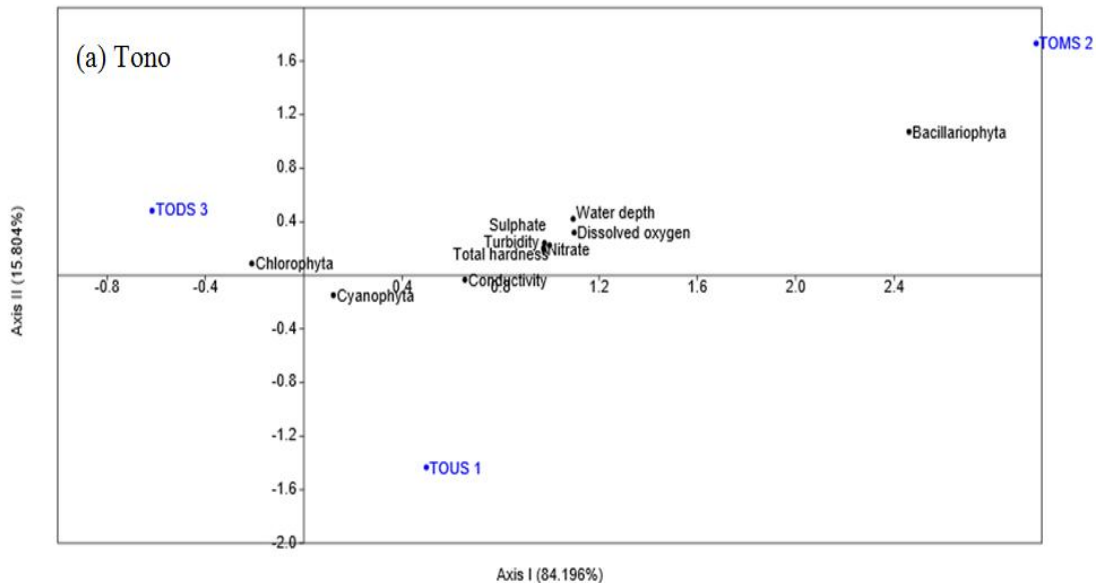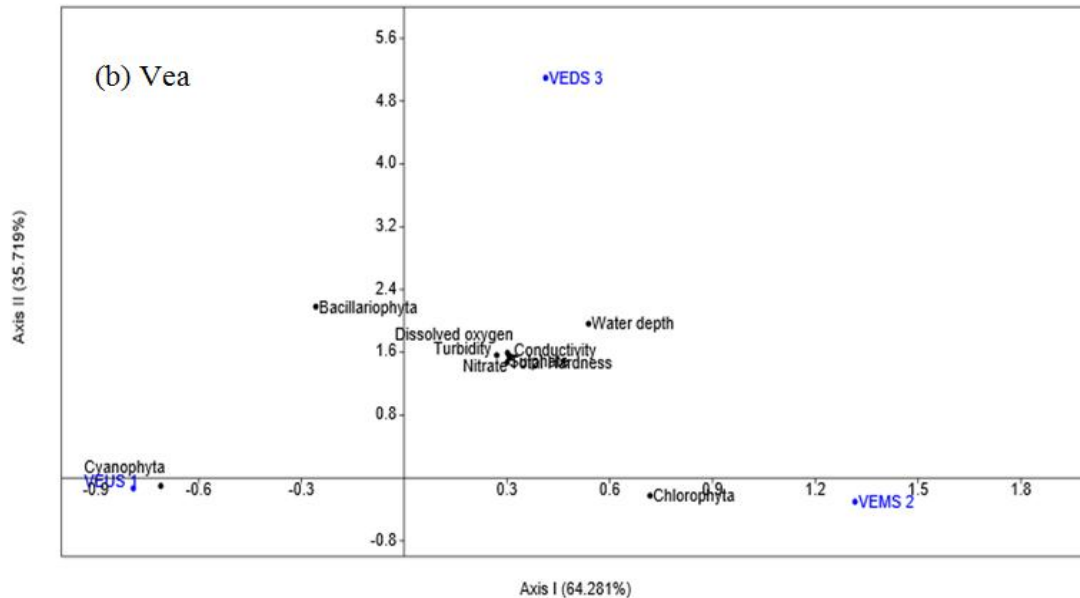
Fig. 6. Triplot chart of correspondence analysis (CA) ordination indicating the relationship among relative abundance of phytoplankton in phyla and environmental variables at various zones/sites in (a) Tono reservoir and (b) Vea reservoir, Upper East Region, Ghana

typical for months with peak rainfall in Upper East Region [13,15], characterized by increased water volume in the reservoir. However, this season accounted for least variance in seasonality dynamics (20%). With cluster 3 accounting for 53.3% of variation in seasonality, it corroborates with the pre-flood season. Thus, pre-flood season (January-April) plays important role in observed changes in water quality over time in these reservoirs. This study observed that temporal changes in Tono and Vea reservoirs could be linked to seasonal regimes. Natural drivers of change in most streams had been reported to be associated with flooding regime, as fish responses vary by season and spatiotemporal scale [24]. For planning purposes, management strategies should be put in place for expected water quality changes during the pre-flood season (dry season) for fish farming in reservoirs.

4.2 Spatial Variation and Responsible Factors for Reservoir Water Quality

Multivariate relationships play important roles in discovering the key factors that influence association and changes in water quality. The Principal Component Analysis (PCA) employed reduced eighteen water quality variables to five and three factors in Tono and Vea reservoirs, respectively. These factors had more variance

(>50%), allowing a good representation of the initial variability of the reservoir water quality. Thus, the first few factors produced better variance [22].

Three phyla of phytoplankton were identified in Tono and Vea reservoirs; Chlorophyta (Green algae), Bacillariophyta (Diatoms) and Cyanophyta (Blue-Green algae). This was consistent with previous study in Vea reservoir where three phyla were observed [12]. Similar findings were reported on Baldi stream in India from thirty-four species of phytoplankton obtained [23]. Percentage abundance of Cyanophyta (Cyanobacteria) was higher in Vea reservoir (> 50%) compared to Tono reservoir, while the Diatoms had equal percentage abundance in both reservoirs (Figure 5). There is little compelling evidence to support reasons for equal percentage abundance of the latter phylum (Diatoms) stated. However, calcareous rocks, calcium carbonates or bicarbonates in the reservoir could have enhance the growth of diatoms [23].

The high levels of Cyanophyta in Vea reservoir compared to Tono reservoir, was contrary to observed land use activities such as vegetable farming. Tono was expected to have higher levels of cyanophyta due to direct dry season vegetable farming activities and other anthropogenic activities on the riparian zone of

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the reservoir catchment area. The high levels of Cyanophyta in Vea reservoir indicated that the reservoir could be receiving higher pollution load, apart from nutrient enrichment as asserted by other studies [23]. Permanent cyanobacterial prevalence is regarded as the ultimate phase of eutrophication [25]. The hydrology and water chemistry of seasonal ponds are governed by the landscape features and changing characteristics, such as landform or soil type; therefore, varying macro invertebrates communities [26], as well as altering its food quantity and quality. This could explain observed changes in phytoplankton abundance (phyla dominance) in Tono reservoir. Based on temporal variation in this study, post-flood periods are characterized by higher water temperature. Higher temperature and adequate nutrition elements leads to increased algae activities [21].

From correspondence analysis performed following principal component analysis, relatively strong positive relationship between the phylum Bacillariophyta and key environmental variable from water quality parameters was detected. Most of the water quality variables obtained during this study were within acceptable limits for aquaculture [27]. Observed monthly mean conductivity level of 742.65 µs cm^{-1} for the Tono reservoir was lower than that for Vea reservoir (1025.15 µs cm^{-1}). Nitrate-nitrogen levels were higher for Tono reservoir (3.05 mg L^{-1}) compared to 2.49 mg L^{-1} for Vea reservoir. High Nitrate levels in Tono reservoir may be due to nutrient loading from the reservoir catchment. Nitrate which is a by-product of ammonia or nitrite but elevated levels are results from agricultural runoff, plant and animal decomposition and excreta (both domestic animals and human). These activities were observed during the study. Higher nitrate–nitrogen levels (> 5 mg L^{-1}) may be linked to eutrophication via nutrient enrichment. Therefore, the positive association between conductivity and cyanobacteria in upstream zone of Tono reservoir in this study, could trigger an imminent phytoplankton bloom. A study suggested conductivity may have no discernible effects on phytoplankton even in the presence of nitrogen and phosphorus [28]. However, the impact of conductivity on phytoplankton could be beneficial for herbivorous fish growth at a given threshold as increased conductivity may decrease zooplankton population whilst increasing phytoplankton population, especially when pH and dissolve oxygen increases above 7.5 and 3 mg L^{-1}, respectively [5,23,27]. Phosphorus considered as

a limiting nutrient in most lakes and reservoirs was not detected as a principal component of the reservoir water quality. The presence of nitrate, sulphate, turbidity and total hardness as key variables of reservoir water quality could be linked to anthropogenic activities such as farming which was observed on the littoral section of the reservoir, are responsible for the changes in reservoir water quality. Agricultural activities had been reported to be linked to similar effects in other lentic water bodies [24,29]. In addition, Chlorophyta as a primary productivity phylum preferred as food for fish showed positive relationship with water depth in Vea reservoir. Water depth is affected by sedimentation of the reservoir bed from loose soils during run-off. Turbid conditions cause light attenuation with water depth with the cascading (negative impact) effect on photosynthesis and Chlorophyta production. As observed from the triplot chart from correspondence analysis (CA), of which the principal environmental factors had good affinity for Bacillariophyta association in the Tono midstream zone and Vea downstream. The dynamics and structure of phytoplankton of an aquatic ecosystem is influenced by the physico-chemical parameters, thus affects distribution and composition [23]. Elucidating on this study result, spatial characteristics in reservoir water quality arguably affect phytoplankton abundance, for that matter the natural productivity within the natural food web could be linked to specific sections or sites within a reservoir.

5. CONCLUSIONS

From this study, limnological evidence from temporal variation and seasonality influences produced three distinct clusters that were characterized as Pre-flood season, flood season and post-flood season. The post-flood period had dominant negative effect on reservoir water quality. This study indicates (from first correspondence analysis axis) that the important environmental variable that influenced reservoir water quality and hence needs regular monitoring for aquaculture in Tono and Vea reservoirs are conductivity, turbidity, total hardness, water depth, sulphate, nitrate and dissolved oxygen. These environmental gradients related spatially with phytoplankton abundance in both reservoirs, thus entire reservoir could be productive for fish farming. Pre-flood to flood seasons are ideal periods for cage culture in Tono and Vea reservoirs as temporal variance in water quality changes are good. Post-flood periods are critical periods and

not recommended as it needs regular monitoring to further understanding of the temporal variation and impact on fish production. However, both Tono and Vea reservoirs can support cage aquaculture. The community and stakeholders should be sensitized and trained to exploit the potentials of these reservoir for sustainable aquaculture. Considerably, multivariate statistical methods could be useful pattern recognition tools for water quality assessment for aquaculture-use. Thus, recommended for managers of reservoirs and dugouts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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