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Research article

Assessment of surface water quality status of the Aby Lagoon System in the Western Region of Ghana

Michael K. Miyittah [a,b,*], Samuel Kofi Tulashie [b,c], Francis W. Tsyawo [e], Justice K. Sarfo [d], Archibald A. Darko [a]

[a] Department of Environmental Sciences, University of Cape Coast, Cape Coast, Ghana
[b] ACECOR-Centre for Coastal Management, University of Cape Coast, Cape Coast, Ghana
[c] Department of Chemistry, Industrial Chemistry Unit, University of Cape Coast, Cape Coast, Ghana
[d] Department of Biochemistry, University of Cape Coast, Cape Coast, Ghana
[e] Community Water and Sanitation Agency, Ho, Ghana

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ABSTRACT

The pollution status of the Tendo Lagoon, the upstream section of the Aby Lagoon System, was investigated. The water temperature, pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), nitrates (NO_3^-), and phosphate (PO_4^{3-}) levels were evaluated using samples taken during the wet and dry seasons to assess the variabilities in water quality in the area. The water quality data was subjected to paired t-test, One-way ANOVA, Factor Analysis, Cluster analysis (CA) as well as a Water Quality Index (WQI) evaluation using the Canadian Council of Ministers of the Environment (CCME) model. The paired sample t-test confirmed that the surface water quality varies significantly between the wet and dry season samples ($p < 0.05$) except for phosphate loads which may be contributed largely by year-round municipal waste discharges. The results of the ANOVA showed that the variation of the water quality parameters among sampling stations was not statistically significant except for turbidity which was relatively higher in the upstream sections where the Tano River enters the lagoon. The results of FA indicated that three significant factors–relating to the degradation of organic materials, suspended solids (turbidity) and nutrients- accounted for 73.65% of spatio-temporal variations in the water quality. The CA showed that the eight sampling stations can be grouped into four distinct clusters based on their water quality. The source of pollution in the demarcated sections of the Aby Lagoon was concluded to be largely due to the result of localized anthropogenic inputs of domestic waste and sediments carried from the upstream in the Tano River. An evaluation of the CCME WQI for the sampling stations revealed that all the sampling stations showed marginal water quality relative to the target water quality range recommended by the Water Resources Commission (WRC) of Ghana for domestic use and protection of aquatic life. Monitoring programs were recommended with effective management measures instituted and implemented for the sustainability of the lagoon and the Tano River Basin.

1. Introduction

Waste materials and industrial effluent discharges into surface waters in developing countries have gradually depleted the quality of water in recent times (Onojake et al., 2011; Varol and Sen, 2009; Boyacioglu, 2007). Surface waters are vulnerable to pollution because of their role in accommodating industrial, municipal waste and run off from farmlands within their drainage basins (Singh et al., 2004).

The prevention and control of surface water pollution must depend on reliable analysis of water quality and identification of pollutant sources (Shrestha and Kazama, 2007). In order to better understand water quality and its ecological impacts on aquatic systems, monitoring data are usually analyzed using statistical methods (Yidana, 2010). Techniques such as Cluster Analysis (CA), correlation matrix, Factor Analysis (FA) and Discriminant Analysis (DA), Analysis of Variance (ANOVA) and Water Quality Indices (WQI) have proven useful in explaining spatial and temporal trends in water quality data.

Some recent studies that have been successful through the use of multivariate techniques include the work of Onojake et al. (2011), Tanriverdi et al. (2010), Pradhan et al. (2009), Kumar and Riyazuddin (2008), Yilmaz et al. (2010), Shrestha and Kazama (2007). These researchers have shown that multivariate statistical approaches can be used

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* Corresponding author.
E-mail address: m-miyittah@ucc.edu.gh (M.K. Miyittah).

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to reduce data dimensions, bring out the most statistically significant variables underlying variations in water quality, assess the relationship among variables and identify the possible distribution patterns of the observed data.

Onojake et al. (2011) used the Pearson correlation analysis to determine the levels of inter-metal relationship of Warri Rivers. Also, Fan et al. (2010) used PCA and CA to determine the characteristics of water quality and assess the associated patterns in the Pearl River Delta. Pradhan et al. (2009) used PCA to identify latent factors that accounted for variations in the water quality of the Devi estuary. Gridharan et al. (2009) as well as Kamble and Vijay (2011) used CA to categorize the River Cooum and the coastal region of Mumbai respectively into less, moderate and high pollution regions.

Water Quality Index (WQI) is a reliable, useful and efficient tool for evaluating and communicating information about the overall quality of water in a concise manner (Pradhan et al., 2001). The index gives a single value that represents the overall suitability of water quality for a specific intended purpose such as drinking, irrigation or aquatic life protection. Several indices such as the Solway Index and River Ganga Index among several others have been successfully developed and applied for the assessment of water quality (Darko et al., 2013; Gibrilla et al., 2011; Tirkey et al., 2013; Zeid et al., 2017). However, the WQI developed by the Canadian Council for Ministers of the Environment (CCME WQI) has increasingly become the most commonly used because it is not only relatively more robust but also flexible in adapting to various water quality parameters and guidelines (CCME, 2001).

The Aby Lagoon System is situated in the Jomoro District of the Western Region of Ghana. The lagoon system receives freshwater inflows from the Tano and Bia Rivers which drain into areas of urbanizing populations, industrialization and mining. According to the WRC (2012), agricultural and domestic waste disposal as well as land degradation from mining and industrial activities in the catchment of the lagoon have potential adverse impacts on the quality of water resources in the lagoon (WRC, 2012). However, the Tendo and the Aby Lagoon System as a whole supports livelihoods through fisheries and agriculture as well as domestic and recreational uses for the surrounding communities (WRC, 2012; Segbefia et al., 2019; Seu-Anoï et al., 2018). In addition, the Tano River Basin has been earmarked as potential hydro dam site for electricity generation (Volta River Authority, 2006).

As a result of rapid urbanization, industrial and mining activities in the catchment of the Tendo Lagoon, contaminant inputs from both natural and anthropogenic sources may be leading to the deterioration of water quality. Little data is available with respect to water quality in the Aby Lagoon, since the location is far from most research institutions. Moreover, recent invasion of water hyacinth on certain parts of the river calls for an assessment of water quality of the lagoon.

The objectives of this study are to: (1) document the quality of water in the Tendo Lagoon since there is little systematic study on its water quality status by determining these water quality parameters; water temperature, pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), nitrates (NO_3^-), and phosphate (PO_4^{3-}), (2) use statistical tools to assess the seasonal and spatial variations in water quality and (3) determine the extent of impairment and the possible effect of pollution on the water resource.

2. Materials and methods

2.1. Study area

Figure 1 illustrates a map of the study area. The Tendo Lagoon forms part of the larger Aby Lagoon System which comprises the main Aby Lagoon (305 km^2), Tendo Lagoon (74 km^2) and Ehy Lagoon (45 km^2).

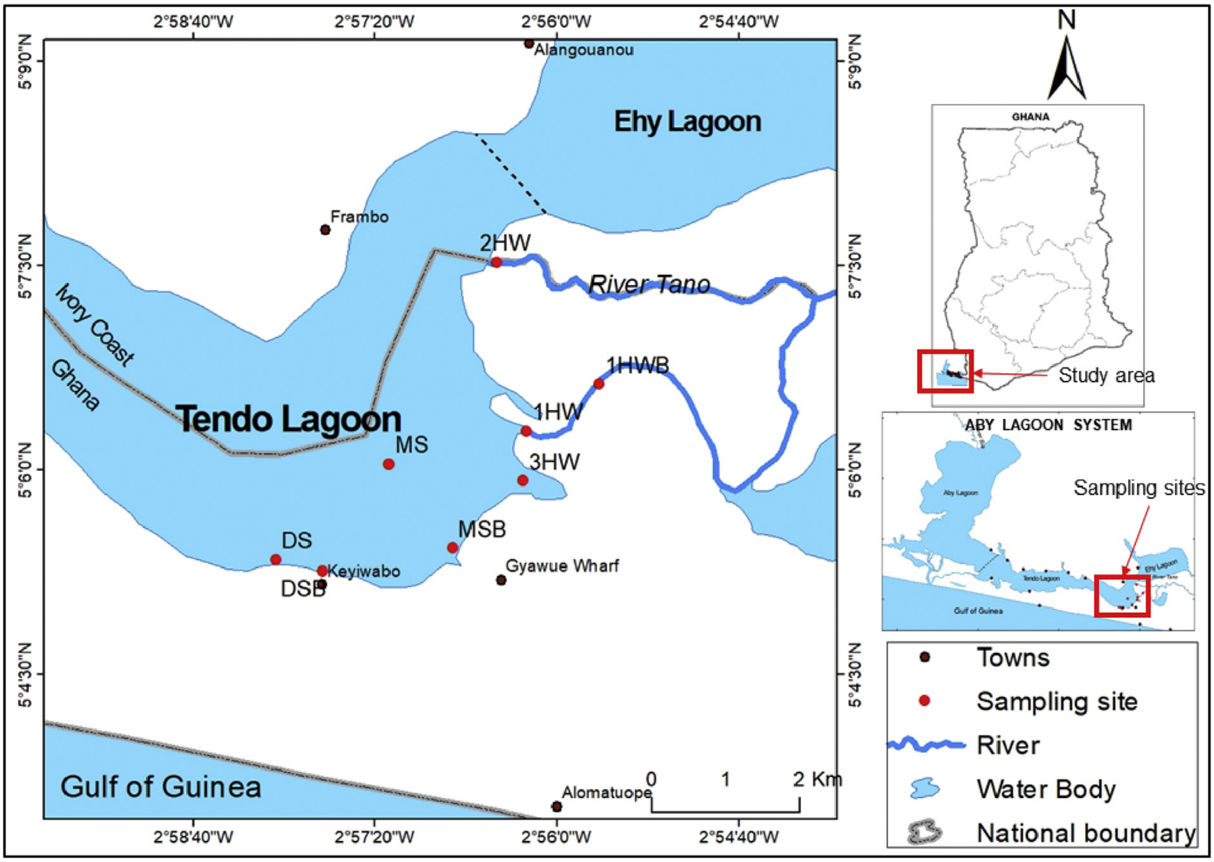

Figure 1. Map of the study area showing sampling stations. 1HW = 1st head water, 1HWB = 1st head water bank, 2HW = 2nd head water, 3HW = 3rd head water, MSB = Midstream banks, MS = Midstream, DSB = Downstream bank, and DS = Downstream.

The study focused on the Tendo Lagoon which receives significant inflows directly from the Tano River. The catchment area is about 15000 km^2 shared between Ghana (93 %) and Ivory Coast (7 %). Most of the Aby Lagoon System is located in Cote d'ivoire but the larger part of the Tano River is in Ghana, which drains into a region of intensive gold mining activities. The district is located within the Western Region in the South-Western Equatorial Climatic zone of Ghana which receives about 2000 mm annual rainfall and a seasonally average temperature of 27.2 °C. Agricultural activities such as coconut, palm, banana, cocoa and coffee cultivation are the main livelihood. In addition, the Aby Lagoon System is surrounded by mangrove forest.

2.2. Field sampling and analytical procedures

A total of eight stations, namely (1HW, 1HWB, 2HW, 3HW, MSB, MS, DSB, and DS) on the Tendo Lagoon and within Ghana's boundaries were selected for water quality monitoring in the wet and dry seasons (Figure 1). The network of sampling stations was designed to cover a wide range of determinants at key sites to reasonably represent the pollution/sewage characteristics of the study area. The water samples were collected between June and October 2012 for the wet season and November 2012 to February 2013 for the dry season. The samples were taken at a depth approximately 10–15 cm below the surface of the water using acid-washed plastic bottles. The water samples from all the stations were taken same day in triplicates between 6am to 10am during each sampling trip per month. The samples were stored in cooling chests and transported to the Department of Fisheries and Aquatic Sciences laboratory of the University of Cape Coast and analyzed within the same day after collection.

Seven physicochemical water quality parameters were monitored: pH, temperature, electrical conductivity (EC), dissolved oxygen (DO), turbidity, phosphate (PO_4^{3-}) and nitrate (NO_3^-). Standard methods were followed in analyzing the water samples for the various quality parameters (APHA, 1999). The pH, Temperature, EC and DO and turbidity were measured on site using the Water Quality Checker (WQC-22A, DKK-TOA, Tokyo). Phosphate concentration in water samples was determined by the ascorbic acid method (Murphy and Riley, 1962) whilst the NO_3^- were analyzed by means of distillation method similar to Olsen and Sommers (1982). Quality assurance and quality control (QA/QC) procedures of analytical and instrument methods were evaluated for all laboratory analyses by including 5% repeats, 5% spikes, standard calibration curves, as well as quality control reference standards. Standard curves were generated every new session to ensure that background signal drifts were consistent and $<1\%$ for all instruments. Spike recoveries were within an acceptable range of 90–110%.

2.3. Data treatment and statistical analysis

Multivariate statistical analyses- Factor Analysis (FA) and Cluster Analysis- were carried out on the data set. Prior to the use of these techniques the data was normalized through the z-scale transformation in order to eliminate the effect of different measurement ranges and dimensions of the variables (Liu et al., 2003). The adequacy of the data set for multivariate analysis was assessed using the Kaiser-Meyer- Olkin (KMO) and Bartlett Tests. The KMO test of sampling adequacy returned a value of 0.662 while the Bartlett's test of Sphericity was significant [$\chi^2 (21) = 122.91, p < 0.01$] indicating that a significant proportion of variance in the data set may be caused by underlying factors thus suitable for structure detection.

Using locations as the factor and the measured water quality parameters as response variables, the one-way Analysis of Variance (ANOVA) was applied to examine whether the mean values of the water quality parameters varied significantly among the eight sampling stations. In addition, paired sample t-test was conducted using seasons as factor and water quality parameters as response variables in order to determine whether or not, water quality varied significantly between the dry and wet seasons. All statistical analyses were performed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA) and Statistical Package for Social Sciences (SPSS) Version 21 (SPSS Inc, Chicago, IL, USA). An alpha (α) level ≤ 0.05 was used as a criterion for statistical significance.

2.3.1. Factor Analysis (FA)

Factor Analysis is used to analyze datasets through transformation of a given set of inter-related variables into recognizable new set of variables (Koklu et al., 2010; Mustapha and Aris, 2012). It is designed to transform the original variables into new variables called principal components (PCs), which are a combination of the original variables that are linearly related (Shrestha and Kazama, 2007). FA primarily analyzes the interrelationship among multiple variables in terms of their common underlying dimensions known as factors (Garizi et al., 2011). It provides information on the most significant parameters which describe the overall data set. The technique further suppresses the contribution of less significant variables through orthogonal rotation of the axes obtained and defined by the PCs which gives a new set of uncorrelated PCs called Varifactors (VFs). Factor analysis was performed on the water quality data set by extracting the PCs and applying Varimax rotation to the PCs to obtain the VFs.

2.3.2. Cluster analysis

Cluster analysis is an unsupervised technique that dwells on inherent data structure and underlying patterns to classify cases or objects into groups on the basis of their similarity/nearness (Vega et al., 1998). The most common approach is the hierarchical clustering which forms clusters in sequences by starting with the most similar objects (Mustapha and Aris, 2012). The degree of similarity is usually based on the Euclidean distances which can be explained as the difference between the values of two objects (Otto, 1998). Hierarchical clustering on the observed water quality data was achieved using the Wards method premised on the squared Euclidean distances between the sampling stations as a measure of similarity. This method minimizes the sum of squares of possible pairs of two clusters that can be formed at any step. The method results in a dendrogram which displays stations with similar properties or variables as a group through rescaling.

2.4. Water Quality Index

The computation of the CCME WQI relies on three factors: The Scope (F_1), Frequency (F_2) and Amplitude (F_3) as shown in the Eqs. (1), (2), (4), (5), (6), (7) and (8).

$$WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \tag{1}$$

The denominator 1.732 standardizes the resultant WQI value to the range zero (worst quality) to 100 (best quality). The resultant vector length can reach 173.2. That is:

$$\sqrt{100^2 + 100^2 + 100^2} = 173.2 \tag{2}$$

Thus division by 1.732 gives 100 as the maximum vector length.

F_1 represents the scope or extent of water quality non-compliance with respect to guideline over the period of interest.

$$F_1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \right) \times 100 \tag{3}$$

F_2 is the frequency which represent the proportion in percent of individual tests that are non-compliant (failed) with the respective guidelines

$$F_2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ test}\right) \times 100 \quad (4)$$

F_3 represents the amplitude which is the extent to which the non-compliant (failed) tests did not satisfy the respective guidelines.

$$F_3 = \left(\frac{NSE}{0.01NSE + 0.01}\right) \quad (5)$$

where NSE is the Normalized Sum of Excursions which is the aggregate amount by which the individual failed tests are out of compliance (Eq. (6))

$$NSE = \frac{\sum_{i=1}^{n} excursion_i}{Number\ of\ tests} \quad (6)$$

In the case the test value must not exceed the guideline, the excursion is computed using Eq. (7)

$$excursion_i = \left(\frac{Failed\ test\ value_i - Guideline\ value_j}{Guideline\ value_j}\right) \quad (7)$$

And for cases where the value must not fall below the guideline, the excursion is given by Eq. (8)

$$excursion_i = \left(\frac{Guideline\ value_i - Failed\ test\ value_j}{Failed\ test\ value_j}\right) \quad (8)$$

The CCME WQI value for each of the sampling stations was computed using the WQI Calculator (Version 2.0, CCME). The raw water quality guidelines recommended by the WRC (2003) for domestic use and protection of aquatic life (Table 1) were applied as reference guideline values.

Based on the WQI values, the water quality at each sampling station was categorized and interpreted according to the rating descriptions in Table 2.

3. Results and discussion

3.1. The physicochemical characteristics of the Tendo Lagoon

The descriptive statistical data of water quality in the lagoon are summarized in Table 3. Water temperatures, on the average, varied between 25.49 °C to 26.35 °C in the wet period and 28.89 °C–29.91 °C in the dry period. The mean water temperature variation among the sampling stations in both seasons were within 1 °C range and showed no statistical significance ($F (4.2, 240) = 0.14, p > 0.05$). However, water temperature was significantly lower in the wet season as compared with the dry period ($t (7) = -30.27, p < 0.001$). Water temperature may therefore be influenced by the natural climatic conditions of the area. Water temperature is an important condition in aquatic ecosystems because it influences the reproduction and metabolism of many aquatic organisms and causes variations in most physicochemical variables of the water body (Chapman, 1996).

Table 1. Standard Limits of water quality parameters recommended by the WRC for domestic use and protection of aquatic life.

Parameter (Unit)	WRC Guideline values	
	Lower limit	Upper limit
pH	6	9
Turbidity (NTU)	-	5
Dissolved Oxygen (mg/L)	5	-
Conductivity μS/cm	-	700
Phosphate (mg/L)	-	2
Nitrate (mg/L)	-	6

The observed pH values in the Tendo Lagoon indicate that the water was slightly acidic (Table 3). The minimum and maximum pH for the wet season were 5.96 and 6.90 respectively observed at the upstream (2HW) and downstream (DSB) stations. During the dry season period the minimum pH of 5.08 was recorded at stations 1HWB, MS and DS while the maximum pH (6.38) was recorded at stations 2HW and DS. Based on the one-way ANOVA test, the distribution of pH did not vary significantly among the sampling stations ($F (7, 56) = 0.157, p > 0.05$). However, the paired t-test showed that, the water quality was significantly more acidic in the dry season ($t (7) = 21.79, p < 0.05$) than the wet season. The mean pH values for the dry season were generally below the target water quality range (6–9) for which no significant adverse health effects due to toxic metal dissolution or objectionable taste are expected. On the contrary, the mean values recorded at all stations during the wet season were compliant with the WRC (2003) guidelines.

In comparison to other studies, the observed pH data generally fall below the range (7.0–9.28) reported by Seu-Anoï et al. (2018) in the lagoon but similar to the mean value (6.7±0.5) recorded by (Adiyah et al., 2013) for an upstream station in the Tano River. Relatively higher pH recorded in the wet season may be due to the inputs of hydroxides, bicarbonates and phosphates associated with natural rock weathering and anthropogenic sources and transported by runoff into the water body (Chapman, 1992). Extreme water pH (<5 or >10) can adversely affect the taste, corrosive impact, toxic metal solubility and mortality of fishes.

3.1.1. Electrical conductivity (EC)

Mean EC levels during the wet season ranged between 122.6 μS/cm at station MS to 195.61 μS/cm at station 1HW while the dry season EC measured between 102.23 μS/cm at station 2HW and 130.5 μS/cm at DSB (Table 3). Generally, EC values were in compliance with the 700 μS/cm target water quality range set by the WRC for raw and domestic water. The values from the present study are consistent with those reported by Kouame et al. (2009) in the Tano River. The variation of EC among the sampling stations was not statistically significant, $F (7, 56) = 0.47, p > 0.05$. However, higher levels were recorded in the wet season relative to the dry season [$t (7) = 3.41, p < 0.05$]. Usually, EC in surface waters is influenced by dissolved ions from natural and anthropogenic origin. Higher EC in the wet season is a probable indication that significant proportions of the dissolved ions were transported into the lagoon by surface runoff from non-point sources such as agricultural farmlands and surface mining activities which are dominant land use within the catchment.

3.1.2. Turbidity

The variation of turbidity in the Tendo Lagoon was statistically significant both seasonally [$t (7) = 3.15, p < 0.05$] and among the sampling stations [$F (7, 56) = 2.87, p < 0.05$]. The maximum turbidity of 30.2 NTU during the wet season and 26.4 NTU during the dry season were observed at the upstream stations, 1HWB and 1HW respectively, where the Tano River enters the lagoon (Table 3). The minimum values of turbidity were 7.25 NTU and 7.0 NTU during the wet and dry seasons respectively both recorded at the downstream station, DSB. The values were all above the WRC target (5 NTU) for no visible turbidity (WRC, 2003). Turbidity in surface waters is an indication of the presence of suspended solids and dissolved organic matter. The variation of turbidity in the lagoon shows that it is associated with seasonal flows in the Tano River. That is, surface runoff in the wet season results in the transport of sediments from exposed land into the lagoon (Jain et al., 2005). As the river enters the lagoon, its velocity reduces from the upstream to downstream thereby allowing the suspended solids to settle to the bottom. Thus, downstream sessions recorded relatively lower turbidity. High turbidity in water affects its suitability for some domestic uses such as washing and drinking and may interfere with the effectiveness of disinfection (Environmental Protection Agency of Ireland, 2001).

Table 2. Rating description of ¶CCME WQI Scores.

Category	WQI Value	Description
Excellent	WQI≥95	All measurements are within the guidelines all the time
Good	80 ≤ WQI<95	Conditions rarely depart from natural or desirable levels
Fair	65 ≤ WQI<80	Conditions sometimes depart from natural or desirable levels
Marginal	45 ≤ WQI<65	Conditions often depart from natural or desirable levels
Poor	WQI<45	Conditions usually depart form natural or desirable levels

¶ Canadian Council of Ministers of the Environment (CCME); Water Quality Index (WQI).

Table 3. Statistical summary of water quality in the Tendo lagoon during the wet (June–October 2012) and dry (November 2012–February 2013) seasons.

Parameter	Season (Descriptive Statistics)	Sampling stations							
		1HW	1HWB	2HW	3HW	MS	MSB	DS	DSB
Water Temperature (°C)	Wet (Mean ± SD)	25.62 ± 0.74	25.49 ± 0.74	25.57 ± 0.58	25.91 ± 0.94	25.57 ± 0.78	26.14 ± 0.84	26.13 ± 0.97	26.35 ± 1.36
	Wet (Min-Max)	25.10–26.66	25.12–26.6	25.08–26.28	25.44–27.32	25.12–26.74	25.5–27.28	25.4–27.56	25.55–28.38
	Dry (Mean ± SD)	28.89 ± 1.0	29.06 ± 1.07	29.27 ± 0.7	29.39 ± 0.91	29.56 ± 1.09	29.91 ± 1.05	29.38 ± 1.06	29.32 ± 1.0
	Dry (Min-Max)	27.98–29.98	27.98–30	28.42–30.1	28.34–30.52	28.36–30.92	28.92–31.38	28.16–30.66	28.13–30.48
pH	Wet (Mean ± SD)	6.65 ± 0.14	6.64 ± 0.14	6.44 ± 0.34	6.42 ± 0.17	6.69 ± 0.11	6.69 ± 0.09	6.67 ± 0.1.0	6.65 ± 0.19
	Wet (Min-Max)	6.48–6.82	6.53–6.84	5.96–6.71	6.28–6.66	6.58–6.83	6.6–6.82	6.58–6.76	6.46–6.9
	Dry (Mean ± SD)	5.82 ± 0.48	5.57 ± 0.46	5.65 ± 0.52	5.53 ± 0.42	5.56 ± 0.45	5.6 ± 0.44	5.74 ± 0.61	5.75 ± 0.56
	Dry (Min-Max)	5.22–6.37	5.08–6.20	5.18–6.38	5.11–6.11	5.08–6.13	5.11–6.14	5.08–6.38	5.10–6.35
Conductivity (μS/cm)	Wet (Mean ± SD)	195.61 ± 79.16	153.3 ± 43.03	163.33 ± 67.0	155.96 ± 51.1	122.6 ± 54.0	151.67 ± 70.71	127.6 ± 26.1	127.7 ± 23.1
	Wet (Min-Max)	94.17–268.26	90.54–188.4	90.37–250.6	88.93–210.26	73.28–194.7	87.04–252	90.53–150.4	96.0–151.08
	Dry (Mean ± SD)	112.76 ± 27.7	107.17 ± 15.67	102.23 ± 21.02	107.8 ± 19.27	112.6 ± 14.2	127.73 ± 34.49	115.54 ± 15.94	130.5 ± 38.4
	Dry (Min-Max)	96.0–154.2	96.9–130.2	84.72–132.78	96.16–136.62	96.34–129.5	97.08–171.06	94.56–132.34	100–185.08
Turbidity (NTU)	Wet (Mean ± SD)	21.35 ± 4.49	20.05 ± 6.78	15.5 ± 6.94	14.95 ± 8.26	15.2 ± 3.64	14.15 ± 6.78	10.65 ± 1.64	9.36 ± 3.89
	Wet (Min-Max)	18.2–27.8	16–30.2	10.8–25.8	9.4–27.2	11.8–20.2	9.75–24.25	9.2–12.6	7.25–15.2
	Dry (Mean ± SD)	16.2 ± 7.39	13.95 ± 7.22	13.3 ± 3.28	13.7 ± 3.7	12.15 ± 3.65	10.56 ± 2.31	9.95 ± 1.36	10.41 ± 3.31
	Dry (Min-Max)	9.6–26.4	8.8–24.6	9.6–17.4	10.8–19	9.8–17.6	9.2–14	8.6–11.4	7.0–14.25
Phosphate (mg/L)	Wet (Mean ± SD)	0.59 ± 0.51	0.42 ± 0.33	0.45 ± 0.48	0.37 ± 0.25	0.27 ± 0.14	0.38 ± 0.41	0.24 ± 0.17	0.46 ± 0.11
	Wet (Min-Max)	0.08–1.26	0.07–0.73	0.09–1.15	0.11–0.69	0.1–0.44	0.08–0.97	0.1–0.48	0.33–0.57
	Dry (Mean ± SD)	0.3 ± 0.19	0.33 ± 0.15	0.33 ± 0.29	0.37 ± 0.33	0.36 ± 0.3	0.29 ± 0.25	0.3 ± 0.19	0.35 ± 0.22
	Dry (Min-Max)	0.13–0.47	0.11–0.42	0.08–0.64	0.07–0.76	0.07–0.72	0.06–0.53	0.1–0.47	0.06–0.57
Nitrate (mg/L)	Wet (Mean ± SD)	3.05 ± 1.64	5.79 ± 5.45	3.34 ± 2.67	3.29 ± 2.38	2.34 ± 1.56	3.04 ± 2.09	3.78 ± 3.55	10.38 ± 13.3
	Wet (Min-Max)	1.3–4.8	1.1–13.67	0.85–6.35	0.80–5.75	1.20–4.55	1.25–5.94	1.00–8.9	0.94–29.94
	Dry (Mean ± SD)	0.66 ± 0.14	0.88 ± 0.33	0.63 ± 0.33	0.67 ± 0.06	0.69 ± 0.14	0.79 ± 0.12	0.65 ± 0.28	0.77 ± 0.18
	Dry (Min-Max)	0.56–0.85	0.6–1.35	0.3–1.05	0.6–0.75	0.5–0.8	0.7–0.95	0.4–1.05	0.6–1.0
DO (mg/L)	Wet (Mean ± SD)	1.45 ± 0.41	1.38 ± 0.43	1.3 ± 0.39	1.18 ± 0.27	1.61 ± 0.45	1.35 ± 0.3	1.2 ± 0.45	0.64 ± 0.15
	Wet (Min-Max)	0.89–1.77	0.8–1.73	0.78–1.65	0.79–1.41	0.95–1.9	0.92–1.61	0.62–1.68	0.43–0.75
	Dry (Mean ± SD)	2.28 ± 1.03	2.03 ± 0.78	1.95 ± 1	2.27 ± 1.13	3.42 ± 1.59	3.08 ± 1.48	2.99 ± 1.75	1.2 ± 0.42
	Dry (Min-Max)	0.90–3.38	1.22–3.10	0.90–3.16	0.88–3.28	1.44–4.82	1.42–4.63	1.44–5.32	0.70–1.58

SD: Standard deviation, Min: Minimum value, Max: Maximum value; 1HW-1st headwater, 1HWB-1st head water bank, 2HW-2nd headwater, 3HW-3rd head water, MSB-Midstream banks, MS-Midstream island, DSB-Downstream bank, and DS-Downstream.

3.1.3. Phosphate (PO_4^{3-})

The levels of phosphate did not vary significantly among the sampling stations [F (7, 56) = 0.30, $p > 0.05$] and between the wet and dry seasons [t (7) = 1.61, $p > .05$]. During the wet season, the concentrations of phosphate ranged between 0.07- 1.26 mg/L occurring in the upstream stations 1HWB and 1HW respectively (Table 3). The levels observed in the dry season were relatively lower, ranging between 0.06 at station MSB (midstream) and 0.76 at station 3HW (downstream). It was, however, observed that the mean values did not exceed the guideline value of 2 mg/L recommended by the WRC for the raw water quality and domestic use. Phosphate in water essentially comes from municipal wastes and runoffs from excess fertilizer applications (Tjandraatmadja and Diaper, 2006). Phosphate levels being generally uniform throughout the lagoon and in both seasons may be an indication of various diffused and point source discharges from domestic, industrial and agricultural sources that may be widely distributed and occurring year-round.

3.1.4. Nitrate (NO_3^-)

The measured concentration ranges of NO_3^- were between 0.8- 29.94 mg/L during the wet season and 0.3–1.35 mg/L during the dry season (Table 3). The minimum levels were observed at upstream stations 3HW and 2HW while the maximum loads were recorded at stations DSB and 1HWB respectively for the wet and dry seasons. Whereas the distribution of NO_3^- in the lagoon was significantly higher during the dry wet season [t (7) = 4, $p < 0.05$], the levels of the nutrient did not vary significantly among the sampling stations [F (7, 56) = 0.77, $p > 0.05$]. In the exception of DSB, the remaining sampling stations showed mean values that were compliant with the recommended range of 0–6 mg/L for raw water quality for domestic use and aquatic life protection (WRC, 2003). Nitrate in surface water usually comes from domestic and municipal wastes and agricultural effluents (Tjandraatmadja and Diaper, 2006). Higher NO_3^- in the wet season may be due to runoffs from farmlands. In Ghana, most domestic discharges are not treated before release into the environment, thus, the proximity of station DSB to a human settlement suggests such anthropogenic inputs of NO_3^-. Nitrates is a limiting factor for eutrophication in water bodies and its reduction to nitrite is known to cause Methaemoglobinaemia (blue baby syndrome) in infants (Environmental Protection Agency of Ireland, 2001).

3.1.5. Dissolved oxygen

The variation of DO concentration in the lagoon was not statistically significant among the sampling stations [F (7, 56) = 1.57, p > 0.05]. Seasonal variability was, however, observed with greater values occurring during the dry season [t (7) = -5.82, p < 0.05]. The wet period recorded a DO range between 0.43 mg/L (DSB) and 1.77 mg/L (1HW) while the dry season recorded values within 0.70 mg/L (at 3HW) and 5.32 mg/L (at DS respectively) (Table 3). The values fell outside the recommended range (>6 mg/L) for raw water quality in Ghana (WRC, 2003). Compared with data presented by Seu-Anoï et al. (2018), the current study recorded lower DO values. The relatively low DO concentrations in the samples were probably associated with organic matter and waste decomposition (Environmental Protection Agency of Ireland, 2001). Higher DO during the dry season may be linked to the lower amounts of runoff which usually carry nutrients and wastes into water bodies. Low DO levels may suffocate some fish species and cause imbalances in the aquatic ecosystem.

3.2. Factor analysis of water quality

Factor Analysis was conducted on the data to identify the main factors influencing variations in the water quality. Extraction of the factors gave three PCs with eigenvalues >1 which collectively account for 73.65 % of the total variability in the observed water quality dataset. The data is presented in Table 4.

The first Varifactor, VF1 accounts for 33.21% of the overall variance in the water quality data. This factor showed strong positive loadings on DO and temperature but negative loading on pH. VF1 pointed to anthropogenic inputs of contaminants, typically explained by the high concentrations of organic matter which utilize DO and generate organic acids. These acids undergo hydrolysis and consequently lower the water pH. The second factor, VF2, showed a strong positive loading on turbidity and moderate positive loadings on EC and PO_4^{3-}. VF2 explained 23.01 % of the total variance in the water quality data and is mainly contributed by the runoffs carrying erosion sediments and organic materials from fields, resulting in relatively high loads of solids and dissolved organic matter. This factor is also, to a less extent, associated with the dissolved ions perhaps from natural sources and nutrients which may be emanating from anthropogenic origin such as domestic wastes and agricultural activities. VF3 loaded strongly on NO_3^- and explains 17.43% of the total variance in the water quality data. This may probably also indicate inputs of nutrients coming from anthropogenic sources such as municipal waste and nitrogen based fertilizers.

In Figure 2, a two-dimensional scatter plot of the mean scores of VF1 and VF2 for the sampling stations is presented. The data indicates the relative contribution of the factors to the overall water quality conditions and highlights the spatial similarity at each sampling station based on the water quality variables. It was observed that, VF1 variables (pH and DO) were lowest in the DSB and highest in midstream stations (MS and MSB). Also, VF2 was shown to be dominant in the upstream section (1HW, 1HWB, 2HW and 3HW) where the flow had higher velocities and mixing. These phenomena promote the suspension of solids and increase DO levels through atmospheric interaction.

3.3. Spatial variations in water quality

Cluster Analysis of the water quality data set produced a dendrogram (Figure 3) which indicates that the eight sampling stations can be classified into four significant clusters (groups) at a rescaled distance cluster combine value < 15. Cluster 1 comprised of midstream stations MS and MSB as well as DS which was located downstream. This cluster was characterized by their spatial proximity to the center of the lagoon and relative farness from human settlements. The water quality at these stations was probably improved due to settling of solids and reduction in biodegradation activity, thus higher DO and lower turbidity. Cluster 2 was formed by station DSB only, which is located at the bank of the lagoon in the Keyiwabo community. This site was largely influenced by low DO and pH that may result from biodegradable waste and sewage from the nearby human settlements. Cluster 3 consisted of upstream station 1HW only, representing the point where the Tano River flows into the lagoon. This cluster recorded moderate ranges of scores of VF1 (pH and DO) but high in VF2 (turbidity, nutrients and dissolved ions) emanating from both anthropogenic and natural sources. Cluster 4, consisting of upstream stations 1HWB, 2HW and 3HW, were shown to be comparatively moderate to high in both VF1 and VF2.

3.4. Water quality index

Based on the CCME Water quality index evaluation, the water quality in the Tendo Lagoon during the study period can be classified as marginal (WQI score: 58.1) (Table 5). Also, all the eight sampling stations were in the range of marginal water quality ($45 \leq WQI < 65$) with respect to the raw water quality guidelines set by the WRC. The marginal score according to the CCME (2001) indicates that the water quality variables often deviated from the desirable conditions, in this case the WRC (2003) guidelines for domestic use and protection of aquatic life. Thus, the quality of the water may not be suitable for domestic use and sustainably support aquatic organisms. Specifically, more than 80% of the turbidity

Table 4. Factor loadings of Varifactors (VFs) on water quality variables.

Parameter	VF1	VF2	VF3
pH	**-0.804**	0.151	0.183
Dissolved Oxygen	**0.799**	-0.21	0.082
Temperature	**0.793**	-0.161	-0.28
Turbidity	-0.223	**0.819**	-0.063
Electrical Conductivity	-0.383	0.673	0.077
Phosphate	0.274	0.624	0.614
Nitrate	-0.371	-0.07	**0.846**
Eigenvalues	2.33	1.61	1.22
% of Variance	33.21	23.01	17.43
Cumulative %	33.21	56.22	73.65

VF1, VF2, and VF3 = Varifactor 1, 2 and 3 respectively.
Values in **boldface** represent strong loadings.

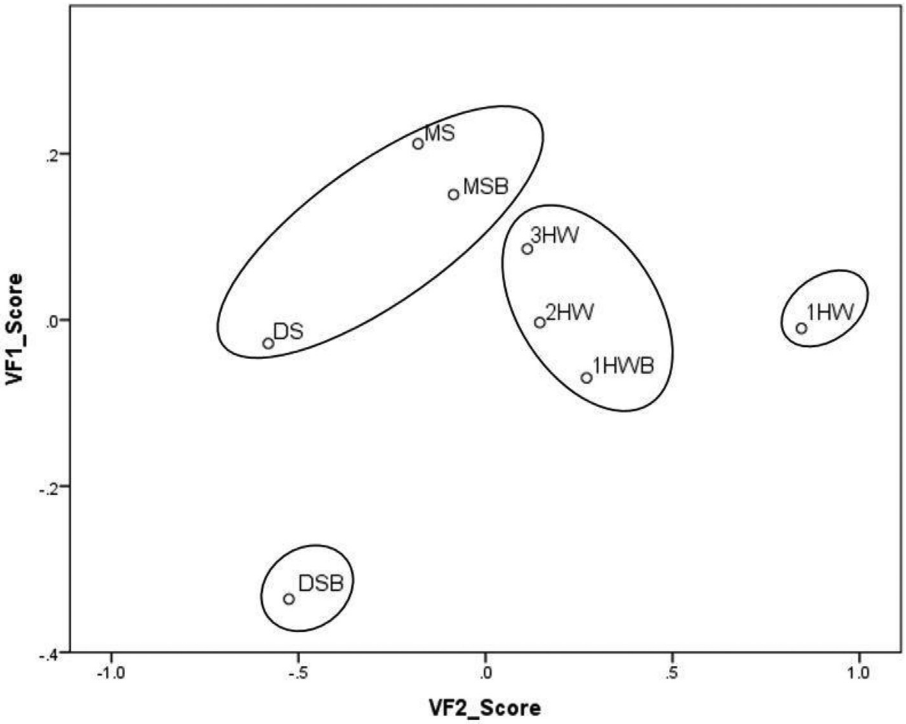

Figure 2. A scatter plot of mean scores of varifactors showing the grouping of sampling stations. 1HW-1st headwater, 1HWB-1st head water bank, 2HW-2nd headwater, 3HW-3rd head water, MSB-Midstream banks, MS-Midstream island, DSB-Downstream bank, and DS-Downstream.

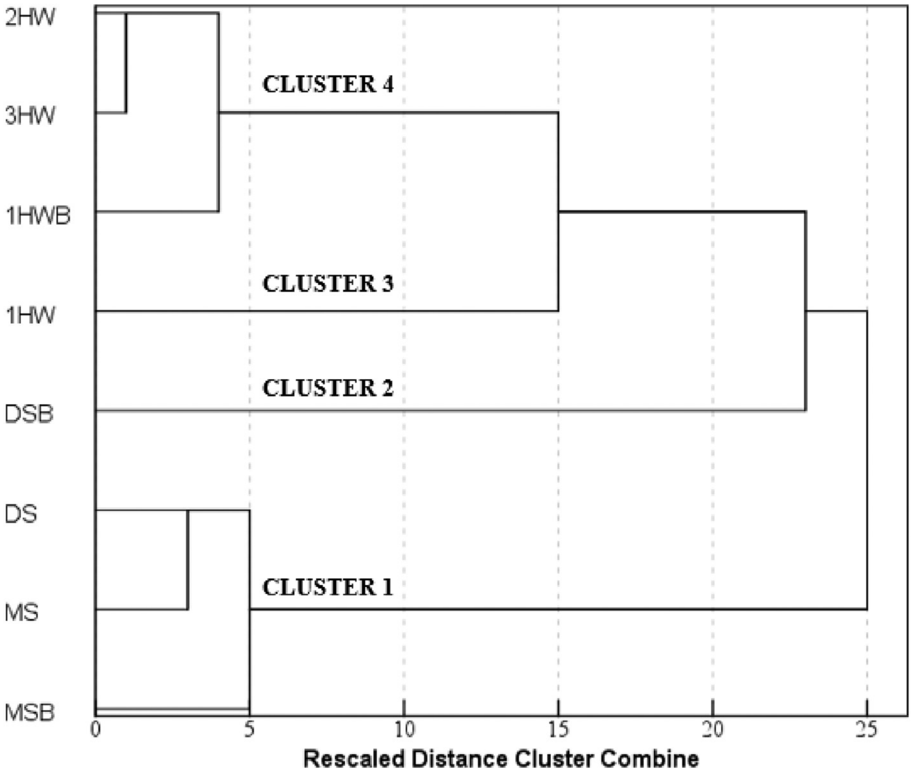

Figure 3. Dendrogram showing the clustering of sampling stations in the Tendo lagoon. 1HW-1st headwater, 1HWB-1st head water bank, 2HW-2nd headwater, 3HW-3rd head water, MSB-Midstream banks, MS-Midstream island, DSB-Downstream bank, and DS-Downstream.

and DO observed from all the sampling stations deviated from the WRC (2003) guidelines. Also, about 40% of pH measurements, mostly in the dry season from all stations except downstream stations (DS and DSB), were below the guideline range of the WRC (2003). The WQI results indicate a relatively homogeneous water quality in the lagoon and shows remarkable consistency with the results of the ANOVA.

Within the marginal category, however, the midstream stations (MS and MSB) showed the highest index values of approximately 63. The

Table 5. CCME WQI quality classification of sampling stations in the Tendo Lagoon.

Station	CCME WQI	WQI Category
1HW	60.2	Marginal
1HWB	54.3	Marginal
2HW	54.3	Marginal
3HW	61.0	Marginal
DS	57.3	Marginal
DSB	51.6	Marginal
MS	63.3	Marginal
MSB	63.1	Marginal
TENDO LAGOON	58.1	Marginal

1HW-1st headwater, 1HWB-1st head water bank, 2HW-2nd headwater, 3HW-3rd head water, MSB-Midstream banks, MS-Midstream island, DSB-Downstream bank, and DS-Downstream.

improvement relative to the upstream sections can be attributed to the natural purification processes such as settling of suspended organic and inorganic solids together with adsorbed pollutants and consumption of algae by fishes when water is impounded. The upstream sections had comparatively moderate WQI scores ranging between 54.3 (at 1HWB and 2HW) to 61 at 3HW. Downstream section (DSB) recorded the lowest WQI score (51.6) compared with the other stations. This can be linked to the anthropogenic activities of nearby communities around the lagoon.

4. Conclusions

This study monitored seven water quality variables in the Tendo Lagoon, the upstream portion of the Aby Lagoon System. With increasing scarcity of freshwater resources, it is imperative that water quality data programs and effective use of data analysis techniques are utilized to generate and interpret underlying information. The paired t-test comparison of water quality between the wet and dry seasons indicated that except for phosphate, all the parameters were associated with seasonal inflow into the lagoon from the Tano River. Wastewater effluents were uniform regardless of the season. Factor analysis revealed three major factors that accounted for approximately 74% of the total variation in the water quality of the lagoon. These factors were related to organic pollution, turbidity and nutrients and influenced by anthropogenic activities. The water quality was generally homogeneous with the Water Quality Index evaluation showing that all the sampling stations were marginal in water quality and showing deviations from the recommended guidelines. The Cluster Analysis classified the sampling stations into four groupings based on similar dominant factors controlling water quality. Therefore, the selection of the dominant water quality parameters in each factor and key sampling stations within each cluster constitute a simple and cost effective monitoring program for the Tendo section of the Aby Lagoon System. This information is relevant to support water quality management efforts in terms of the types and sources of pollutants in the lagoon. The information provided from this study serves as a basis to draw attention to the needed monitoring and management of the lagoon and the Tano River Basin as a whole. These data are provided in order to suggest an efficient water quality monitoring program for the lagoon.

Declarations

Author contribution statement

Michael Miyittah: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Samuel Kofi Tulashie, Francis W. Tsyawo, Justice K. Sarfo: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Archibald A. Darko: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

Adiyah, J., Aboagye-Larbi, H., Acheampong, M., 2013. Comparative assessment of the upstream and downstream water qualities of river Tano in Ghana. J. Environ. Sci. Eng. 2, 283–292.

APHA, 1999. In: Clesceri, L.S., Greenberg, A.E., Eaton, A.D. (Eds.), Standard Methods for the Examination of Water and Wastewater, twentieth ed. American Public Health Association, Washington, D.C.

Boyacioglu, H., 2007. Surface water quality assessment using factor analysis. Water Sa 3, 389–393.

CCME, 2001. Canadian water quality guidelines for the protection of aquatic life: CCME water quality index 1.0. Technical Report. In: Canadian Environmental Quality Guidelines, 1999. Canadian Council of Ministers of the Environment. Winnipeg. Winnipeg.

Chapman, D., 1992. Water Quality Assessment, a Guide to the Use of Biota, Sediments and Water in Environmental Monitoring. University Press, Cambridge, p. 585.

Chapman, D.V., 1996. Water Quality Assessments: a Guide to the Use of Biota, Sediments and Water in Environmental Monitoring/. In: Chapman, Deborah (Ed.), second ed. World Health Organization, UNESCO & United Nations Environment Programme, London. E & FN Spon.

Darko, H.F., Ansa-Asare, O., Paintsil, A., 2013. A number description of Ghanaian water quality—a case study of the southwestern and coastal rivers systems of Ghana. J. Environ. Protect. 4 (11), 1318–1327.

Environmental Protection Agency of Ireland, 2001. Parameters of Water Quality: Interpretation and Standards. Environmental Protection Agency, Wexford. (Accessed 12 December 2019).

Fan, X., Cui, B., Zhao, H., Zhang, Z., Zhang, H., 2010. Assessment of river water quality in Pearl River Delta using multivariate statistical techniques. Proc. Environ. Sci. 2, 1220–1234.

Garizi, A.Z., Sheikh, V., Sadoddin, A., 2011. Assessment of seasonal variations of chemical characteristics in surface water using multivariate statistical methods. Int. J. Environ. Sci. Tech. 8, 581–592.

Gibrilla, A., Bam, E.K.P., Adomako, D., Ganyaglo, S., Dampare, S.B., Ahialey, E.K., Tetteh, E., 2011. Seasonal evaluation of raw, treated and distributed water quality from the Barekese dam (river Offin) in the Ashanti region of Ghana. Water Qual. Expo. Health 3, 157–174.

Gridharan, L., Venugopal, T., Jayaprakash, M., 2009. Assessment of water quality using chemometric tools. A case study of river Cooum, south India. Arch. Environ. Contam. Toxicol. 56, 654–669.

Jain, P., Sharma, J.D., Sohu, D., Sharma, P., 2005. Chemical analysis of drinking water of vil- lages of Sanganer Tehsil, Juipur district. Int. J. Environ. Sci. Technol. 2 (4), 373–379.

Kamble, R.S., Vijay, R., 2011. Assessment of water quality using cluster analysis in coastal region of Mumbai, India. Environ. Monit. Assess. 178, 321–332.

Koklu, R., Sengorur, B., Topal, B., 2010. Water quality assessment using multivariate statistical methods- A case study: Melen River system, Turkey. Water Resour. Manag. 24, 959–978.

Kouame, K.V., Yapo, O.B., Mambo, V., Seka, A., Tidou, A.S., Houenou, P., 2009. Physicochemical characteristics of the waters of the coastal rivers and lagoonal system of Cote d'Ivoire. J. Appl. Sci. 9 (8), 1517–1523.

Kumar, R.A., Riyazuddin, P., 2008. Application of chemometric techniques in the assessment of groundwater pollution in a suburban area of Chennai city, India. Curr. Sci. 94, 1012–1022.

Liu, C.W., Lin, K.H., Kuo, Y.M., 2003. Application of factor analysis in the assessment of groundwater quality in the Blackfoot disease area in Taiwan. Sci. Total Environ. 313, 77–89.

Murphy, J., Riley, J.P., 1962. A modified simple solution method for the determination of phosphates in natural waters. Anal. Chim. Acta 27, 31–36.

Mustapha, A., Aris, A.Z., 2012. Spatial aspects of surface water quality in the Jakara Basin using chemometric analysis. J. Environ. Sci. Health Pt. A 47, 1455–1465.

Olsen, S.R., Sommers, L.E., 1982. Phosphorus and nitrates determination. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. Am. Soc. Agron., Madison, Wisconsin, pp. 403–439.

Onojake, M.C., Ukerun, S.O., Iwuoha, G., 2011. A statistical approach for evaluation of the effects of industrial and municipal wastes on Warri Rivers, Niger Delta, Nigeria. Water Qual. Expo. Health 3 (2), 91.

Otto, M., 1998. Multivariate methods. In: Kellner, R., Mermet, J.M., Otto, M., Widmer, H.M. (Eds.), Analytical Chemistry. WileyeVCH, Weinheim, Germany, p. 916.

Pradhan, S.K., Patnaik, D., Rout, S.P., 2001. Water quality index for the ground water in and around a phosphatic fertilizer plant. Indian J. Environ. Protect. 21, 355–358.

Pradhan, U.K., Shirodkar, P.V., Sahu, B.K., 2009. Physico-chemical characteristics of the coastal water of Devi estuary, Orissa and evaluation of its seasonal changes using chemometric techniques. Curr. Sci. 96, 1203–1209.

Segbefia, A.Y., Honlah, E., Appiah, D.O., 2019. Effects of water hyacinth invasion on sustainability of fishing livelihoods along the River Tano and Abby-Tano Lagoon, Ghana. Cogent Food Agric. 5 (1), 1–17.

Seu-Anoï, N.M., Kouadio, N.K., Koné, Y.J., Ouattara, A., Gourène, G., 2018. Spatial and temporal distribution of cyanobacteria and their relationship with environmental parameters in the Aby Lagoon System (south-eastern Ivory Coast, West Africa). Aust. J. Basic Appl. Sci. 12 (1), 37–44.

Shrestha, S., Kazama, F., 2007. Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. Environ. Model. Softw. 22, 464–475.

Singh, K.P., Malik, A., Mohan, D., Sinha, S., 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)- a case study. Water Res. 18, 3980–3992.

Tanriverdi, C., Alp, A., Demirkiran, A.R., Fatih, U., 2010. Assessment of surface water quality of the Ceyhan River basin, Turkey. Environ. Monit. Assess. 167, 175–184.

Tirkey, P., Bhattacharya, T., Chakraborty, S., 2013. Water quality indices- important tools for water quality assessment: a review. Int. J. Adv. Chem. 1 (1), 15–28.

Tjandraatmadja, G., Diaper, C., 2006. Sources of Critical Contaminants in Domestic Wastewater- A Literature Review. CSIRO: Water for a Healthy Country National Research Flagship.

Varol, M., Sen, B., 2009. Assessment of surface water quality using multivariate statistical techniques. A case study of Behrimaz stream, Turkey. Environ. Monit. Assess. 159, 543–553.

Vega, M., Pardo, R., Barrado, E., Deban, L., 1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Water Res. 32, 3581–3592.

Volta River Authority, 2006. Identification of potential hydro sites among rivers of Ghana. Volta River Authority Newsletter.

WRC, 2003. Ghana Raw Water Criteria and Guidelines, Vol. 1. Water Resource Commission, Accra, Ghana.

WRC, 2012. Tano River Basin - Integrated Water Resources Management Plan. Water Resources Commission, Accra, Ghana.

Yidana, S.M., 2010. Groundwater classification using multivariate statistical methods: southern Ghana. J. Afr. Earth Sci. 57, 455–469.

Yilmaz, V., Buyukyildiz, M., Marti, A.I., 2010. Classification of surface water quality of Kizilirmak Basin in Turkey by using factor and cluster analysis. Balwois 25, 1–11.

Zeid, S.A.M., Seleem, E.M., Salman, S.A., Hafiz, M.A.A., 2017. Water quality index of shallow groundwater and assessment for different usages in El-Obour city, Egypt. J. Mater. Environ. Sci. 9 (7), 1957–1968.