



Assessment of the quality of the Densu river using multicriterial analysis and water quality index

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Abstract

The natural resources, especially water in the Densu river basin, play significant roles in the socio-economic development of Ghana. The purpose of this study was to analyse the water quality of the Densu river using water quality index (WQI) and multivariate techniques. In this study, physico-chemical and bacteriological parameters were measured from surface water samples taken from eight (8) sampling stations in the study area. water quality index and multivariate techniques such as hierarchical cluster analysis and principal component analysis were utilized in the analysis of surface water quality data. The results indicated that the average WQI of the Densu river for the two sampling periods was sixty-one (61) which is classified as Medium, based on the Solway WQI index. The pH levels of all the samples were within allowable limits of World Health Organization (WHO) guidelines. All the sampling stations for the two seasonal periods had bacteriological parameters higher than WHO guidelines, making the samples unsuitable for most domestic uses. The study revealed that six (6) principal components accounted for about 97% of the total variance of dataset and three (3) spatial clusters were classified. This research has provided the basis for applying both WQI and multivariate techniques in analysing and classifying water quality in a river basin.

Keywords Freshwater · Parameters · Multivariate · Loadings · Variations

Abbreviations

BOD	Biochemical oxygen demand
CA	Cluster analysis
COD	Chemical oxygen demand
DA	Discriminant analysis
DO	Dissolved oxygen
EC	Electrical conductivity
GWCL	Ghana water company limited
HCA	Hierarchical cluster analysis
PCA	Principal component analysis
TDS	Total dissolved solids
TSS	Total suspended solids

WHO	World Health Organization
WQI	Water quality index

Introduction

Freshwater resources have come under the spotlight due to quantity and quality reasons. Surface water resources have been noted to be extremely sensitive to changing natural processes such as rainfall, temperature, forest cover and ultimately climate change (Li et al. 2009; Usman et al. 2014; Wang et al. 2018). These changes in natural environmental processes are greatly influenced by anthropogenic activities that include growth in urban areas and agricultural activities (Khatri and Tyagi 2015; Bouguerne et al. 2017; Verma et al. 2019).

These anthropogenic activities have the potential of causing the degradation of surface water resources. Pollutants from urban areas, industries and agricultural lands make the surface water resources vulnerable (Satterthwaite et al. 2010; Huang et al. 2018; Salerno et al. 2018). High concentrations of toxic materials from pollution sources could lead to diverse environmental challenges such as loss of

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biodiversity, changing the aesthetics of environment around water bodies, algal bloom, loss of flora and fauna (Mishra 2010; Kengnal et al. 2015; Kumar and Ranjan 2017).

Rivers in catchments with extensive agricultural and built-up land-use practises increased pollution inputs (Sickman et al. 2007) in addition to varying the concentrations of nitrogen, phosphorus and other agro-chemical applications (Easton et al. 2007; Khalil and Ouarda 2009).

Freshwater resource availability is the most critical natural resource issue for the whole of humanity (Hinrichsen and Tacio 2002). The freshwater shortage has been mentioned as one of the major emergencies of the twenty-first century (Srinivasan, et al. 2012). In view of the challenges emanating from freshwater scarcity, there has been a conscious effort at ensuring water security for both humans and biodiversity (Vörösmarty, et al. 2010).

Moreover, as a result of the spatial and temporal disparities in water quality, monitoring programmes usually encompass a great number of physico-chemical parameters. Regular water quality sampling periods at various sites are essential for the provision of reliable surface water quality profiles for a given study area (Kengnal et al. 2015; Anteneh et al. 2018; Ustaoglu and Tepe 2018).

As the economies of developing countries advance, there is a resultant extensive land use/land cover changes (Kanianska 2015; Salerno et al. 2018), degradation of water resources and the environment (Zhao et al. 2011). These environmental dilapidations impede sustainable development and compromise livelihoods of human populations (Xu et al. 2009; Huang et al. 2010; Fitch et al. 2016).

Detailed and accurate assessment of the extent of surface water pollution is relatively difficult due to the varied processes and intricate phenomena depicting these environmental conditions (Huang et al. 2010). The physico-chemical and bacteriological analysis is required to effectively assess the different procedures and mechanisms involved in polluting freshwater bodies (Şener et al. 2017; Emami and Koch 2018; Wu et al. 2018).

Physico-chemical parameters such as pH, turbidity, temperature, total dissolved solids, electrical conductivity (EC) and dissolved oxygen (DO) levels are the most frequently used pointers of water quality (Attua et al. 2014).

Numerous studies have recognized some procedures used for assessing water quality (Tian et al. 2019). These methods include an all-inclusive assessment method referred to as the water quality index (WQI). This method is a mathematical tool used to aggregate several physico-chemical and bacteriological parameters of water quality into a single figure (Abbasi and Abbasi 2012; Bouguerne et al. 2017; Şener et al. 2017). Different WQI scales have been adopted for evaluating water quality (Abbasi and Abbasi 2012; Samadi et al. 2015; Ewaid and Abed 2017; Şener et al. 2017). The

WQI values usually range between zero (0) and a hundred (100).

Water quality index (WQI) is a very convenient and effective technique for calculating the suitability of water quality and useful tool for disseminating the evidence on the general quality of water of surface water (Akoteyon et al. 2011). WQI replicates and aggregates the amalgamated influence of diverse water quality parameters. Suitability of both surface and groundwater resources for the human is the viewpoint of WQI (Akoteyon et al. 2011; Abyaneh et al. 2018; Tian et al. 2019).

The application of multidimensional or multivariate data analysis procedures is increasingly becoming very prevalent in environmental studies, encompassing both measurement and monitoring (Oketola et al. 2013). The most common multivariate data analysis procedures used are principal component analysis (PCA), cluster analysis (CA) and discriminant analysis (DA) (Badalians Gholikandi et al. 2011; Oketola et al. 2013; Verma et al. 2019). These multivariate analysis tools identify important components that explain the variations in water quality for a study area (Fathy et al. 2012; Kebede and Kebedee 2012; Garcia et al. 2017).

The adoption of diverse multivariate methods, such as PCA and CA, for the explanation of water quality datasets provides an enhanced understanding and subsequent correlation of water quality and environmental status (Moyel 2014). The multivariate techniques further allow the identification of probable factors that could impact water quality whilst serving as a valuable method for the management of water pollution problems (Shrestha and Kazama 2007; Moyel 2014; Park et al. 2014; Kengnal et al. 2015; Mitra et al. 2018).

PCA and CA have been used extensively to analyse water quality across the globe (Parinet et al. 2004; Mustapha and Abdu 2012; Gomes et al. 2014). According to (Bidhendi et al. 2013), using PCA and CA techniques provided a means for inferring intricate water quality datasets and to help in the design of monitoring networks.

In this study, multivariate statistical techniques were used for analysing the surface water quality of the Densu river at eight sampling stations along the river. The main objective of this study was to use multivariate techniques to classify the water quality of the Densu river basin. This study further seeks to identify the parameters accountable for spatial variations in the quality of the Densu river.

Materials and methods

Study area

The Densu river and its network of streams constitute one of Ghana’s most exploited coastal basins. The basin is located between latitude 5°33’N–5°40’N and longitude 0°20’W–0°24’W. The basin covers an estimated land area of 2600 km².

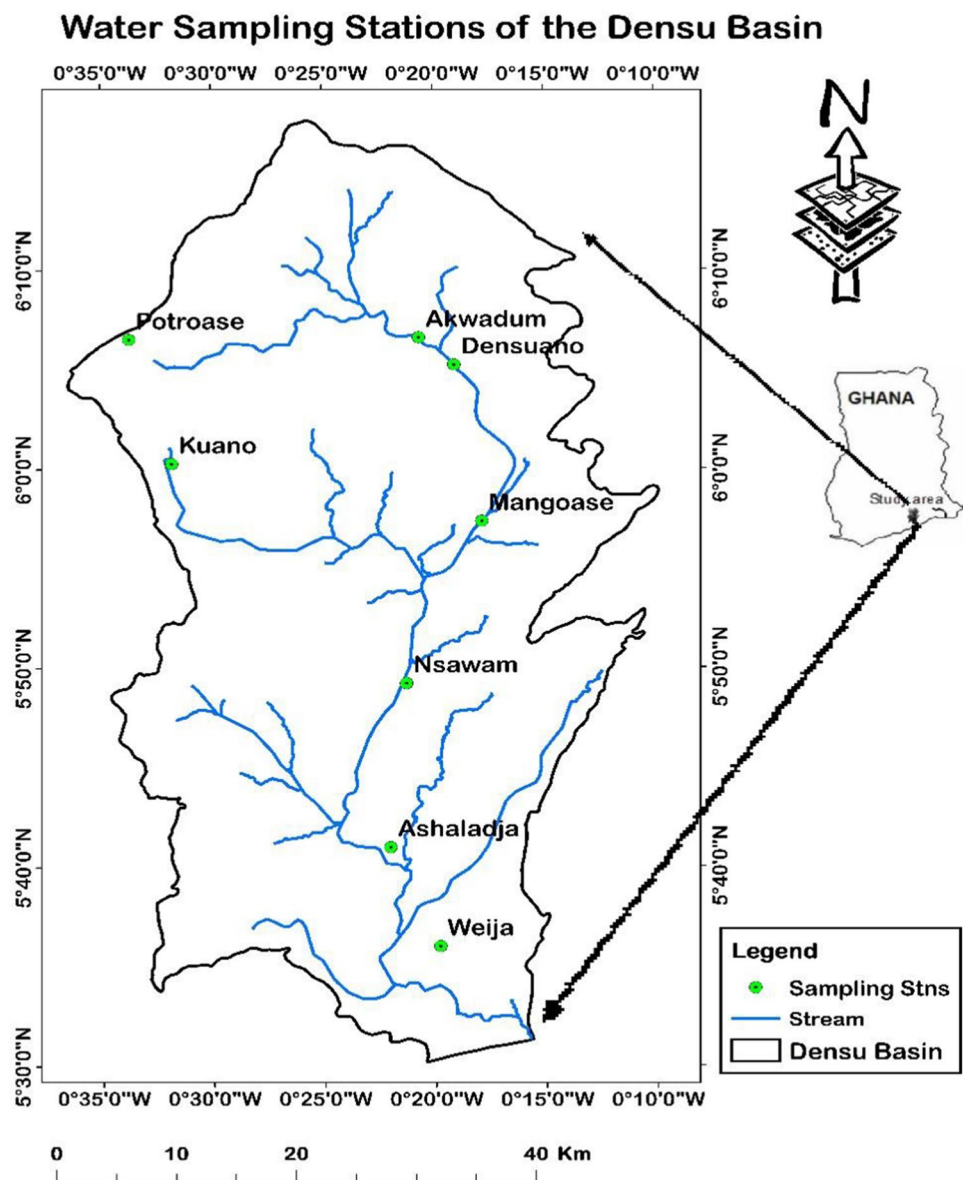
The Densu basin (Fig. 1) is noted for its immense socio-economic importance to Ghana. The Densu river provides water for the Western sectors of Accra through the Weija Treatment plant (Nee-Whang 1999; Obeng 2005; Asamoah

et al. 2008; Owusu 2012; Antwi-Agyakwa 2014; Nyamekye et al. 2016).

The river takes its source from the Atwiredu mountains and flows for about 120 km into the Weija lake/reservoir before discharging into the Gulf of Guinea. The Densu Delta Ramsar site is located at the estuary of the river, west of Accra (WRC 2014). The major tributaries of the river are Mame, Kuia, Adeiso, Nsaki and Dobro, which are themselves fed by a network of streams (Adomako et. al. 2011a).

The Ghana Water Company Limited (GWCL) supplies around 190,000 m³ of treated water on daily basis, from the Densu river and its tributaries. Weija treatment plant accounts for about 90% of total water treated along the Densu river. The Weija treatment plant supplies treated water to Kasoa and its environs in the Central Region of

Fig. 1 Densu river basin with water quality sampling stations



Ghana, Industrial and commercial hub in Accra (Alfa 2010; Adank et al. 2011; Alfa et al. 2011; Kasei et al. 2014; Water Resources Commission 2014; Schep et al. 2016).

The main vegetation types identified in the basin can be classified into three. The Northern portion of the basin is generally well-forested land, and the middle section is noted by scattered trees, shrubs and predominantly grassland. The downstream of the basin forms part of the coastal savannah zone (WRC-Ghana 2007; Alfa et al. 2011).

The basin is characterized by relatively high temperatures throughout the year, with a mean annual temperature around 28 °C. March and April are considered the hottest periods, with average temperatures of about 32 °C, whilst August is the coolest month, with a temperature around 24 °C (Water Resources Commission 2014).

The major rainy period in the basin ranges from late February to late July with the peak in June, while the minor rainfall season occurs between August and late October (Water Resources Commission 2014; Nyamekye et al. 2016). The mean annual rainfall ranges between 450 and 1900 mm (Dickson Adomako et al. 2011a, b).

Sampling and analytical procedures

Surface water samples were collected during dry and wet seasons from eight (8) sampling sites using clean and disinfected sampling bottles. The transportation of samples to the laboratory as well as the preservation of the samples was in accordance with standard procedures used by Abbasi and Abbasi (2012), Mahapatra et al. (2012); Ewaid and Abed (2017) and Şener et al. (2017).

Temperature (T), DO, pH and EC were measured in situ by means of thermometer and the Hach 2100AN model workbench turbidimeter (Dharmendra et al. 2018). Volumetric titrimetry was used to measure calcium (Ca^{2+}), magnesium (Mg^{2+}) and chloride (Cl^-) ions (Zeinalzadeh and Rezaei 2017). Spectrophotometer was used to ascertain the sulphate ions (SO_4^{2-}) in the samples (Anteneh et al. 2018). Turbidimetric method was used to analyse the level of turbidity of the samples. Sodium and potassium ions were measured by means of the flame photometry method (Zeinalzadeh and Rezaei 2017). Ammoniac (NH_4^+) and nitrate nitrogen (NO_3^-) were determined using phenate and cadmium reduction methods, respectively (Effendi et al. 2015). All water quality analyses were executed based on standard procedures for the assessment of water (Abbasi and Abbasi 2012).

The water samples for dry season were taken from December 2017 to February 2018. The wet season sampling was done between June 2017 and August 2017. These periods spanned the seasonal variations in the basin. The sampling stations (Fig. 1) were spread across the basin, i.e. from the upstream of the basin to the downstream. This helped to

assess the quality of the Densu river as it traverses the length of the basin to the outfall.

Statistical analysis

Thirty-three (33) physico-chemical and bacteriological parameters were measured from the water samples. The measured water quality parameters were analysed and subjected to statistical scrutiny using water quality index (WQI), cluster analysis (CA) and principal component analysis (PCA).

Water quality parameters such as pH, colour, electrical conductivity (EC), turbidity, total hardness, calcium hardness, magnesium hardness, chloride, biochemical oxygen demand (BOD), dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), total irons, phosphates, copper, calcium, manganese, zinc, magnesium, fluoride, Nitrate–nitrogen, ammonia–nitrogen, nitrate and sulphate were analysed. Heavy metals such as cyanide, mercury, arsenic, chromium and cadmium were tested. Bacteriological parameters such as total coliforms, heterotrophic bacteria counts and *E. coli* were also tested.

Water Quality Index

Water quality index (WQI) has been characterized as the main measure for classification of the quality of surface water based on the usage of standard parameters that are applied during surface water characterization (Kannel et al. 2007; Sánchez et al. 2007).

Across the globe, numerous research institutions have formulated water quality indices as a means for assessing the quality of water samples. Notable amongst the water quality indices include the US National Sanitation Foundation water quality index (NSFWQI), the Canadian Council of Ministers of the Environment water quality index (CCMEWQI), the Oregon water quality index (OWQI), the Solway River Purification Board (RBP) Weighted water quality index and the British-Columbia water quality index

Table 1 Water quality index classification

Class	WQI range	Rating of water quality
I	91–100	Excellent
II	71–90	Good
III	51–70	Medium
IV	26–50	Bad
V	0–25	Very bad

Source (Zeinalzadeh and Rezaei 2017)

(BCWQI) (Abbasi and Abbasi 2012; Şener et al. 2017; Zeinalzadeh and Rezaei 2017).

The NSFQI was formulated to provide a standardized technique for comparing the quality of various water quality samples from different sources in a study (Şener et al. 2017). The classification of the water quality index was based on Table 1.

A study conducted on the water quality index of the Densu river (Amoako et al. 2010) adopted the Solway River Purification Board (RBP) Weighted water quality index. This was calculated using Eq. 1:

$$\text{Solway_WQI} = \frac{1}{100} \left(\sum_{i=1}^n q_i w_i \right)^2 \tag{1}$$

where q_i represents the quality of water samples of the n th parameter, and w_i signifies the weighting of the n th parameter.

Cluster analysis

Cluster analysis was used for exploratory analysis of data. These method groups variables and parameters into clusters based on identified levels of similarities (or dissimilarities). Hence, each cluster signifies a definite process (Zhao and Cui 2009). The characteristics of each identified class are not known but may be evaluated from the management of the data used (Shrestha and Kazama 2007). The hierarchical cluster analysis (HCA) was applied for surface water quality parameters using SPSS and Gretl.

Principal Component Analysis (PCA)

PCA is a great multivariate statistical analysis technique which has the capacity to reduce the dimensionality of water quality data comprising of large number of related variables, while maintaining as much as possible, the variability existing in the data (Ouyang 2005; Garcia et al. 2017; Tripathi and Singal 2019).

PCA is basically used to classify patterns in data, bring out their similarities and differences through the reduction of the number of dimensions and related complexity identified in the data matrix of the variables (Arslan 2009; Le et al. 2017).

In PCA, a dataset comprising correlated parameters is transformed into another dataset containing orthogonal and unrelated parameters termed as principal components (Olsen et al. 2012; Le et al. 2017; Mena-Rivera et al. 2017).

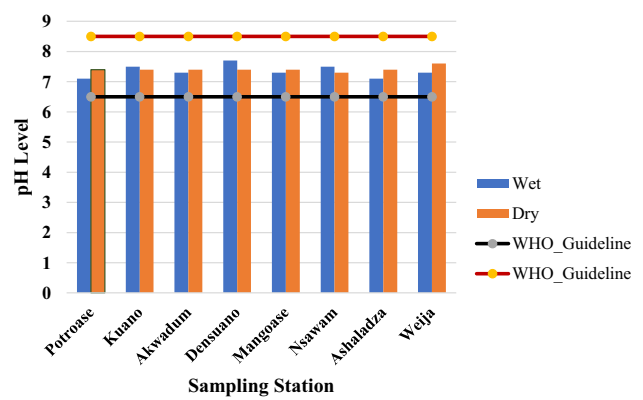


Fig. 2 Average pH for the sampling seasons

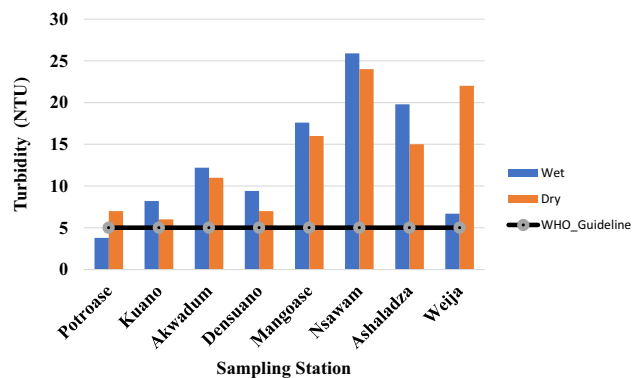


Fig. 3 Turbidity for wet and dry seasons

Algebraically, for n water quality parameters, $x_1, x_2, x_3, \dots, x_n$ and j sample number, principal components are determined using Eq. 2

$$z_{ij} = x_{1jai1} + x_{2jai2} + x_{3jai3} + \dots + x_{njaij} \tag{2}$$

where a represents the loading for each parameter of extracted principal components, z represents the principal component score, and i represents the amount of extracted principal components.

The results from the PCA are linear functions arising from the original variables. This implies that the summation of their variances is equivalent to that of their inventive variables (Olsen et al. 2012; Le et al. 2017).

Results and discussion

Physico-chemical quality analysis

The pH of the water samples during the study period ranged from 7.1 to 7.7. These pH values were with the WHO water guidelines (World Health Organization 2017).

The pH values during the study were all within the recommended levels by the WHO (6.5–8.5). During the wet seasons, the pH for Densuano was the highest (7.7), whilst Weija had the highest pH values (7.6) for the dry season. These results (Fig. 2) are in line with earlier studies in the Densu basin (Asante et al. 2008; Adomako 2010; WRC 2014; Osei et al. 2016).

Higher turbidity results (Fig. 3) were recorded during the rainy seasons apart from Potroase and Weija that recorded relatively lower turbidity levels during the wet season. Potroase sampling point had low runoff points discharging into the stream. Weija sampling station was close to the Weija reservoir, and hence, there is the possibility for some level of settlement of suspended solids and eroded matter that may influence turbidity levels.

Apart from Potroase (wet season), all the other sampling stations had their turbidity levels higher than the WHO guidelines. The low levels of turbidity for Potroase in the wet season were due to less volume of runoff joining the Densu river at the sampling point. The forest cover and shrubs tend to also retard the movement of eroded materials into the stream, especially at the Potroase sampling site.

The Weija sampling station was around the Weija reservoir. There was the likelihood that some level of settlement of suspended solids and eroded materials may have taken place, thereby showing lower levels of turbidity.

The high rate of turbidity may be attributed to the topography of the basin and other anthropogenic activities being

undertaken in various parts of the basin. These activities become high triggers for erosion and runoff into nearby streams.

The turbidity of a stream may be attributed to the clay particles within the eroded soil of the catchment area (Rubio-Arias et al. 2012). The dissolution of soil material especially during rainy seasons and ensuing runoff end in streams thereby affecting the turbidity of the receiving streams.

Research has confirmed that high turbidity levels influence negatively, the aesthetics of streams and waterbodies. Thus, recreation, tourism and cost of water treatment may be affected negatively (Memon et al. 2011; World Health Organization (WHO) 2017; Bouckaert et al. 2018).

Total dissolved solids (TDS) were higher in the dry season for the sampling points, relative to the wet season (Fig. 4). This result could be linked to the dilution resulting from increased runoff (Pullanikkatil et al. 2015).

The total dissolved solids of the Densu river varied from upstream towards downstream (Fig. 4) due to river bank cultivation, sand mining, soil disturbance and construction activities close to the river (Pullanikkatil et al. 2015). The TDS for wet season ranged between 99 to 192.8 mg/l, while the dry season values ranged between 136.5 and 508 mg/l.

The EC results for wet seasons were greater than the dry season readings (Fig. 5). The results ranged between 216 to 417 microS/cm for wet season and 27.3–101.6 microS/cm for dry seasons. These results were corroborated by an earlier studies (Hoque et al. 2013; Makwe and Chup 2013; Nienie et al. 2017) which stated that EC values are higher in the wet seasons compared to the dry seasons.

According to the WHO guidelines for safe and healthy water (World Health Organization 2011, 2017), there should be no identifiable bacteriological parameter in water, especially for domestic usage. All sampling stations (Figs. 6 and 7) had their bacteriological quality parameters (Heterotrophic bacteria counts, E. coli and total coliforms) above the WHO guidelines.

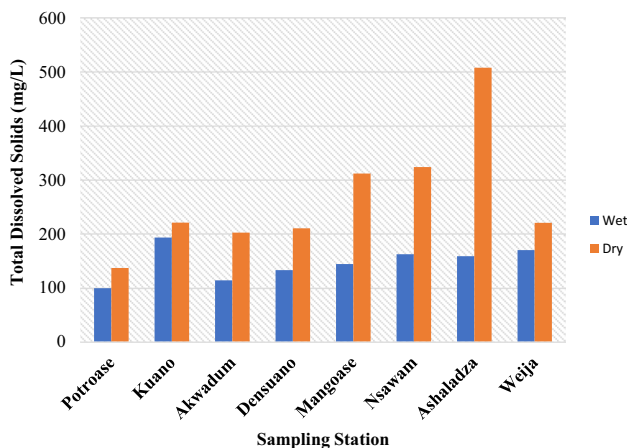


Fig. 4 Total dissolved solids for wet and dry seasons

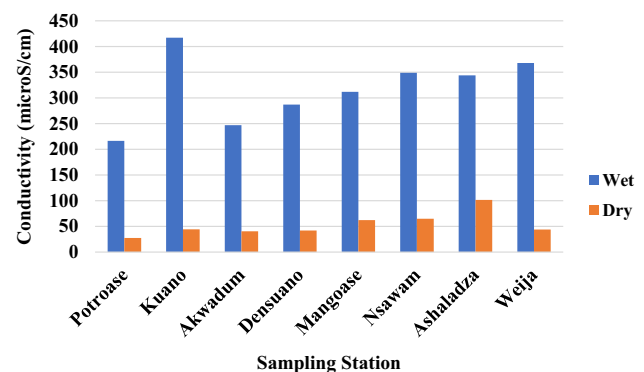


Fig. 5 Electrical conductivity for wet and dry Seasons

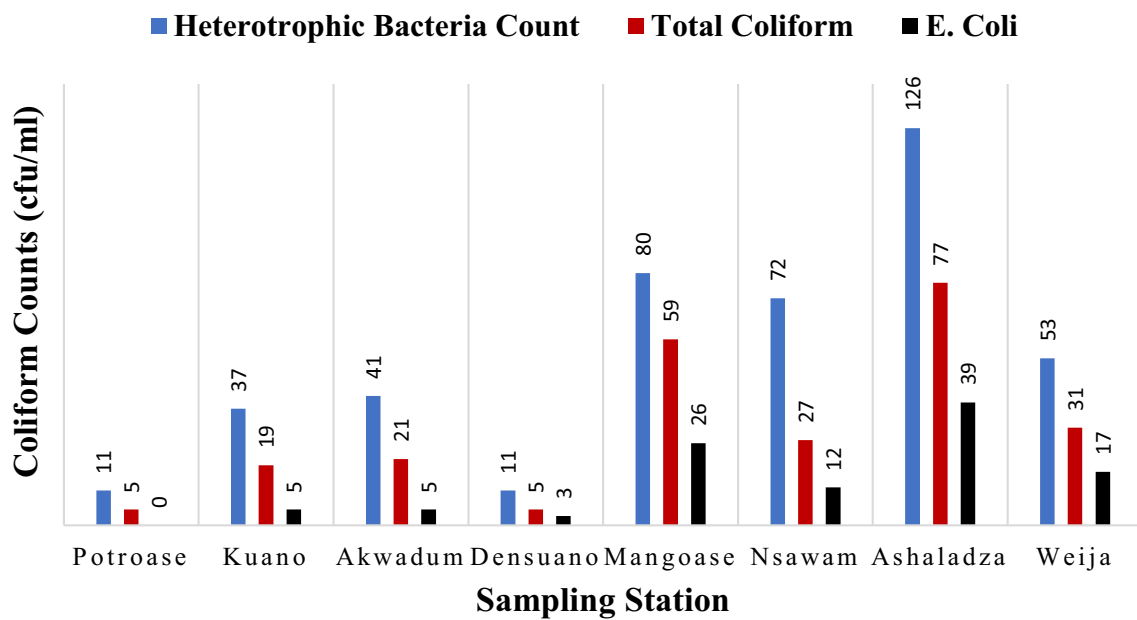


Fig. 6 Bacteriological quality for dry season

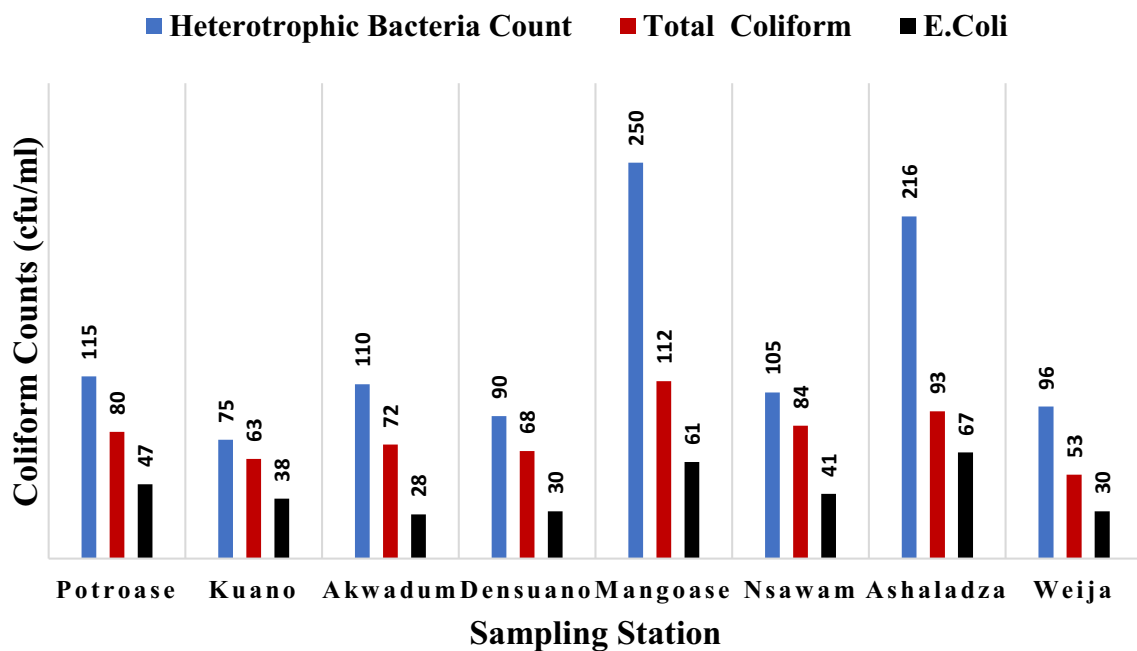


Fig. 7 Bacteriological quality for wet season

Exception can be made for Potroase whose dry season E. coli level was suitable by the WHO guidelines. It can be deduced from Fig. 6 that Ashaladza reported higher levels of bacteriological parameters. Meanwhile, Mangoase (mid-stream sampling station) reported high levels of bacteriological parameters (Fig. 7) during the wet season.

The water quality index for the Densu river was calculated using parameters displayed in Table 2. Based on the

sample calculation shown in Table 2, the WQI for both dry and wet seasons is calculated and plotted (Fig. 8).

Based on the WQI values (Fig. 8), the average water quality for dry season sampling period was 61.87 representing Medium quality. The wet season sampling period had an average of 60.72 denoting Medium quality. These results attest to the fact that the average water quality of Densu river is Medium based on the WQI indices.

Table 2 Wet season water quality index for Potroase

Parameters	Raw results	Q-values	Weighing	Total value
Dissolved oxygen	5	50	0.17	8.5
Faecal coliform	47	53	0.16	8.48
pH	7.1	90	0.11	9.9
Temperature	26.9	13	0.11	1.43
Total phosphate	5	13	0.1	1.3
Nitrate	0.5	97	0.1	9.7
Turbidity	3.8	88	0.08	7.04
Biochemical oxygen demand	0.5	98	0.11	10.78
Total solids	109.23	83	0.07	5.81
Water quality index				62.94

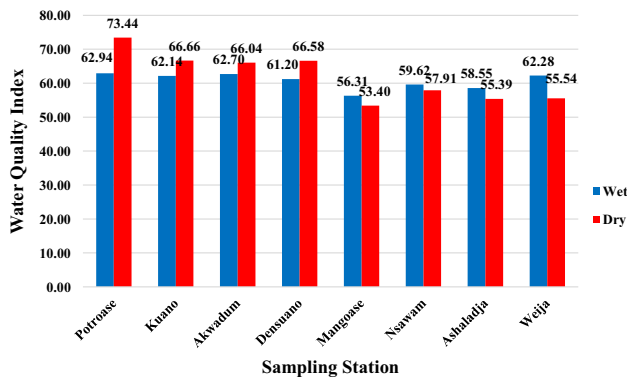


Fig. 8 Water quality index for the Densu river

Table 3 Initial PCA for dry season

Component	Initial eigenvalues for dry season		
	Total	% of variance	Cumulative %
1	11.805	35.774	35.774
2	6.252	18.946	54.720
3	4.360	13.212	67.932
4	4.182	12.673	80.605
5	3.435	10.409	91.014
6	2.059	6.238	97.252
7	0.907	2.748	100

Table 4 Initial PCA for wet season

Component	Initial eigenvalues		
	Total	% of variance	Cumulative %
1	11.093	33.614	33.614
2	8.381	25.398	59.012
3	4.191	12.701	71.713
4	4.175	12.651	84.364
5	2.798	8.480	92.844
6	1.619	4.905	97.749
7	0.743	2.251	100

The WQI for Potroase, Kuano, Akwadum and Densuano had their wet season values being lower than the dry season results. These results attest to the fact that the main occupation of the upstream communities was farming. The farmers mainly engage in rainfed agricultural practices; hence, the use of agro-chemicals and farming inputs tend to lead to the decline in water quality.

Principal component analysis

The PCA was treated to reconnoitre the origins of pollutants by manipulating the dataset to obtain the most critical influencing factors. The varimax rotation method was used to further determine the factor variables with slight significance. The dataset was tested using the Kaiser–Meyer–Olkin (KMO) sphericity test.

The initial results of PCA, comprising the eigenvalues, variance, and cumulative values for both dry (Table 3) and wet (Table 4) seasons showed six (6) main components. The six (6) PCs with their cumulative eigenvalues were accounting for more than 97% in the dry season, whilst the six PCs accounted for about 98% in the wet season.

PC1-PC4 explains a cumulatively, 80.61% of the total variance in water quality during the dry season. PC1-PC4 explains 84.36% of the total variance in water quality during the wet season.

PC analysis for dry season

PC1 for dry season had strong positive loadings of conductivity (0.991), TDS (0.991), total hardness (0.760), calcium hardness (0.600), chloride (0.816), calcium (0.700), magnesium (0.647), total coliforms (0.857), *E. coli* (0.873) and heterotrophic bacteria (0.923). These results show that electrical conductivity, TDS and the bacteriological parameters greatly influenced the quality of the river.

Some moderate loadings such as dissolved oxygen (0.592), BOD (0.426), turbidity (0.446) and total suspended

solids (TSS) (0.546) were recorded. There were some negative loadings such as Nitrate–nitrogen (−0.384), nitrite (−0.574) and ammonia–nitrogen (−0.532).

PC2 has negative loadings for colour (−0.571), turbidity (−0.635), BOD (−0.720), DO (−0.347), TSS (−0.676), copper (−0.555), manganese (−0.659) and chromium (0.747). There were positive loadings for total iron (0.596), cadmium (0.625), arsenic (0.625) and mercury (0.625). PC2 highlighted the heavy metals that were dominant in the samples.

PC3 has positive loadings for calcium hardness (0.537), cadmium (0.611), arsenic (0.611) and mercury (0.611). There were negative loadings for phosphate (−0.744), Nitrate–nitrogen (−0.633) and ammonia–nitrogen (−0.677). PC3 characterises the organic irons generated mainly from agricultural activities.

PC4 has positive loadings for magnesium hardness (0.563), copper (0.501), manganese (0.536) and negative loadings for DO (−0.567), zinc (−0.504) and nitrite (−0.503). PC4 depicted the hardness parameters of the Densu river.

PC5 has significant loading for total alkalinity (−0.808) and cyanide (0.904). For PC5, traces of cyanide ions leached from the geological formations were prominent in this component. PC6 has loadings for turbidity (0.522), total iron (0.513) and nitrite (0.547). PC6 shows the parameters that influence the colour of the Densu river.

The varimax rotation results indicated that for PC1, the conductivity (0.888), TDS (0.888), chloride (0.916), sulphate (0.919), total coliform (0.928), *E. coli* (0.936) and heterotrophic bacteria count (0.919) were the strong positive loadings identified.

PC2 indicated that colour (0.930), turbidity (0.807), TSS (0.826) and copper (0.934) were the strong positive loadings. PC3 had the following loadings identified pH (−0.895), magnesium hardness (0.841) and magnesium (0.841). PC4 was predominantly heavy metals being the parameters with the strong loadings—cadmium (0.949), arsenic (0.949) and mercury (0.949).

PC5 designated ammonia–nitrogen (−0.944) as a strong loading even though it is negative. PC6 reported that total alkalinity showed a strong positive loading (0.952).

PC analysis for wet season

PC1 for dry season had strong positive loadings of colour (0.842), turbidity (0.846), total hardness (0.802), calcium hardness (0.915), calcium (0.915), Nitrate–nitrogen (0.845), nitrite (0.976), total coliforms (0.736), *E. coli* (0.544) and heterotrophic bacteria (0.597). These results show that the hardness of the Densu river during the wet season was influenced mainly by the presence of calcium ions.

PC2 has negative loadings for pH (−0.832), conductivity (−0.630), TDS (−0.635), magnesium (−0.856), chloride

(−0.596). Some positive loadings of PC2 were phosphate (−0.802), total iron (0.773), total coliform (0.553), *E. coli* (0.595) and heterotrophic bacteria count (0.505).

PC3 exhibited positive loadings for sulphate (0.952), TDS (0.506), conductivity (0.505), DO (0.706) and cadmium (0.771). PC4 showed positive loadings for temperature (0.897), total alkalinity (0.611), chloride (0.606) and *E. coli* (0.515).

PC5 has significant loading for zinc (0.525) and negative loading for arsenic (−0.637). PC6 did not show any loading above 0.500.

The varimax rotation results indicated that for PC1, colour (0.923), turbidity (0.922), copper (0.939), total hardness (0.760), calcium hardness (0.848), calcium ions (0.848) and nitrite (0.848) were the strong positive loadings identified.

PC2 indicated that pH (0.931), magnesium hardness (0.898) and magnesium ions (0.900) were the strong positive loadings. Meanwhile, *E. coli* showed a negative moderate loading (−0.503). PC3 had the following loadings identified pH (−0.895), magnesium hardness (0.841) and magnesium (0.841). PC4 reported strong loadings for conductivity (0.916), TDS (0.911), total alkalinity (0.945) and chloride ions (0.619).

PC5 designated dissolved oxygen (0.981), sulphate ions (0.760), cadmium ions (0.762) and mercury (0.679) as a strong positive loading. PC6 reported zinc ions (0.951) and ammonia nitrogen ions (0.561) the main strong positive loading.

Cluster analysis

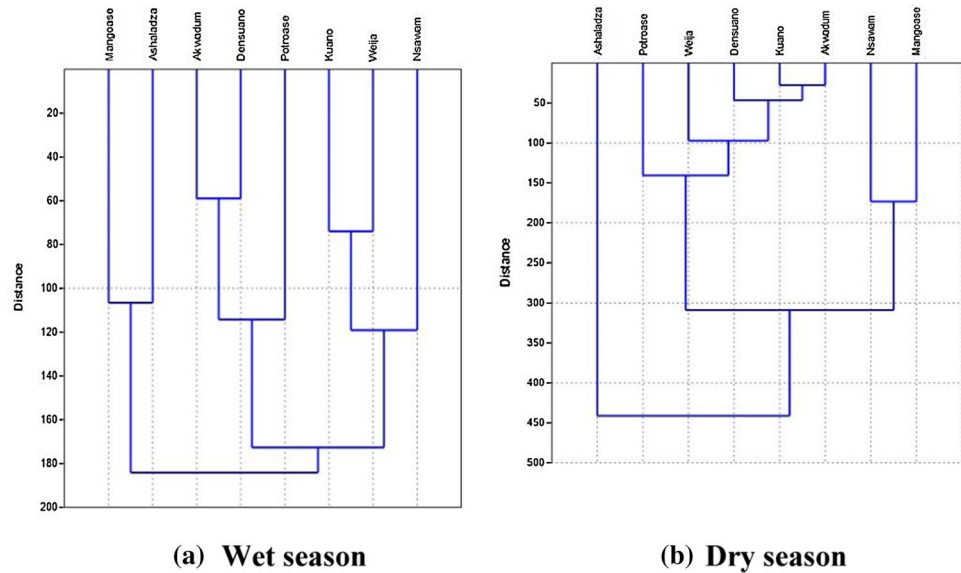
Spatial cluster analysis (CA) was applied to assemblage the sampling stations with comparable water quality physiognomies. A dendrogram (Fig. 9) produced by CA grouped the eight (8) sampling stations into three (3) clusters.

The grouping of the monitoring stations was based on statistically significant clusters in a distant connection (D_{link}/D_{max}) $\times 100$. Hierarchical clustering was achieved consistent with Ward's method as well as a squared Euclidian distance (Varol et al. 2011; Hamil et al. 2013; Fathi et al. 2018).

The CA results were very substantial, because the created clusters shared similar characteristic features in addition to land use patterns.

During the wet season, the clusters identified comprise Cluster 1 that includes two locations (Ashaladza and Mangoase). These two stations have agricultural activities being dominant occupation. Cluster 2 entails three locations (Densuano, Akwadum and Potroase). These locations are part of the upstream sampling stations. There is some forest cover around these areas which serve as canopies for

Fig. 9 Dendrogram showing clustering of sampling stations Densu river water quality features



the streams (Ofosu et al. 2020). Cluster 3 comprises three locations (Kuano, Nsawam and Weija). Nsawam and Weija represent heavily urbanized communities along the Densu river. Kuano is one of the built-up rural communities in the basin quite close to the Densu river.

During the dry season, the clusters noticed encompass Cluster 1 that includes one location (Ashaladza). This station has agricultural activities being dominant occupation around it. Cluster 2 involves five locations (Petroase, Densuano, Akwadum, Kuano and Weija). These locations are part of upstream sampling stations and the southernmost station (Weija).

There are some forests around the upstream areas which serve as canopies for the streams (Ofosu et al. 2020). Cluster 3 comprises two locations (Nsawam and Mangoase). Nsawam and Mangoase represent mid-stream sampling stations. Vegetable farming activities are predominant in the Nsawam and Mangoase during the dry seasons (Ayivor and Gordon 2012; Darko et al. 2013).

Conclusion

By means of WQI, the quality level of surface water in the Densu river basin was ranked. The upstream sampling stations had better quality compared to the downstream stations. This could be ascribed to seasonal variations, agricultural practices and other human-induced activities. The results of PCA revealed that six (6) factors accounted for about 97% of the dataset variances for both wet and dry sampling seasons. The PCA resulted in significant reduction of variables and also helped to extract the reasons

accountable for variations in the quality of the Densu river at different sampling stations. The results of the PCA demonstrated that the level of pollution surges towards the downstream. CA clustered the sampling stations into three main clusters for both wet and dry seasons based on comparison of the Densu river quality characteristics. These results infer that domestic, agricultural and other anthropogenic pollutions caused variances in terms of water quality of the Densu river. Finally, this study has confirmed the practicality of water quality index (WQI) and multivariate statistical methods for analysis and explanation of data from surface water quality analysis.

Densu river quality monitoring schemes could be developed and applied taking into cognisance, the identified principal components, clusters of sampling stations and seasonal variations of water quality parameters.

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Data availability The data are presented in the manuscript. The authors declare that datasets used in the manuscript are readily available upon request from the corresponding author.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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