Water Quality Assessment of Densu, Birim and Ayensu Rivers in the Okyeman Area

O. D. Ansa-Asare[1]* and C. Gordon[2]
[1] *CSIR Water Research Institute, P. O. Box AH 38 Achimota, Ghana*
[2] *Volta Basin Research Project (VBRP), P. O. Box LG 2009, University of Ghana*
**Corresponding author; E-mail: osmundansaasare@yahoo.ca*

Abstract

The water quality assessment conducted in the Densu, Birim and Ayensu Basins of Ghana in the Okyeman area between August 2005 and June 2006 identified human and agricultural activities as the main sources of pollution. All the pH values for the rivers ranged from 6.5–8.5. The average turbidity levels in Densu Basin were higher than that of Ayensu and Birim basins. The low turbidity of Ayensu Basin is an indication of higher primary productivity. The conductivity levels in the river basins followed the order: Densu > Ayensu > Birim. The order is depended on the human activities in each basin. Ammonia-Nitrogen (NH_3-N) followed this order in terms of mean levels in the river basins: Densu (0.356 mg/l) > Birim (0.267 mg/l) > Ayensu (0.161 mg/l). The 2005 NH_3-N levels were lower than that of the 2006. This was a reflection of the impact of increased human and agricultural activities in the year 2006. Nitrate-Nitrogen (NO_3-N). The basin had a mean NO_3-N concentration of 1.89 mg/l for Densu, 2.55 mg/l for Birim and 2.63 mg/l for Ayensu with ranges of 0.01–3.96 mg/l, 0.21–6.48 mg/l and 0.001–8.17 mg/l, respectively. All the mean nutrient values for Densu, Birim and Ayensu were not significantly different at 95% from each other (NH_4-N, $p < 0.089$; NO_3-N, $p < 0.385$; NO_2-N $p < 0.203$; PO_4-P $p < 0.188$.) Total hardness and TDS also showed a similar pattern of Densu > Ayensu > Birim. This was as a result of more domestic activities impacting on Densu Basin compared with all other basins. The classification of the water quality index (WQI) system showed in 2005 that all the three basins were in class II, which was fairly good quality. The Ayensu basin was of best quality. The 2006 results indicated that all the stations fell under class III. This showed a deterioration of the state of the rivers in 2006. The WQI also confirmed the fact that Densu Basin was the most polluted compared to that of Birim and Ayensu.

Introduction

Water Resources development are often based on socio-economic and health status of many nations worldwide. However, pollution of waters often negates the benefits obtained from the development of these water bodies. Human settlement and land clearance for food production has been an integral part of history and has shaped rural landscapes in Ghana more than any other factor. The clearance of Forest and intensification of food production have impacted on the quality of soil and of water (Hyams, 1952 and Hillel, 1991).

Agriculture dominates land use throughout Ghana, with intense agro-chemical inputs, which completely lack consideration of environmental quality and protection of living resources. The Okyeman area is a typical example of a degraded forested area from the developing world where agricultural-derived revenue has suddenly quickened the pace of an unplanned development ranging from urbanisation, industrialisation including mining and intense agro-chemical inputs, which completely lacks consideration of the environment.

Due to increased population in the Okyeman area, there is the urgency for proper conservation and efficient utilisation of freshwater bodies for sustainable development. The population pressures in the basins cause an acceleration of the progressive deterioration of water quality because of increased domestic, municipal, agricultural and industrial activities, and effluents being discharged into water bodies resulting in environmental degradation.

The need for raw water quality information in the protection and development of water resources cannot be overemphasized. The assessment of the raw water quality of these river basins is therefore necessary to adequately characterize the rivers for present and future planning purposes.

The aim of this paper is to develop an understanding of the spatial water quality throughout the basins and also identify the main sources of contaminants within the river basin, and to help characterise rivers into various levels of pollution.

Methods

Study area

The Densu basin covers an estimated area of 2,564 km^2 and lies within 0º 10'W, 0º 35'W and 5º 30'N, 6º 15'N and spans nine administrative areas. The Ayensu Basin lies between latitude 5º 20'N to 6º 5'N and longitude 0º 30'W and 0º 50'W and covers an area of 1,709 km^2 and forms part of the Coastal River Basins of Ghana. The Birim basin is located between longitude 0º 20'W, 1º 15'W and latitude 5º 45'N, 6º 35'N, has an estimated area of 3,875 km.^{2}

TABLE 1
Rivers and their Drainage Areas in the Densu, Ayensu and Birim River Basins

River Basin	*Drainage Area (in km^2)*
Birim	3,875 km^2
Densu	2,564 km^2
Ayensu	1,709 km^2

The Densu river shares its catchment boundary with the Odaw and Volta basins to the east and north, respectively, the Birim basin in the northwest and Ayensu and Okrudu in the West.The source of the Densu river is from the Atewa-Atwiredu mountain range near Kibi in the East Akyem District of the Eastern Region of Ghana. The river is about 116 km^2 covering nine administrative districts. The main tributaries include rivers Adeiso, Nsakyi, Dobro, and Kuia (Fig. 1). The Densu reservoir is one of the two main sources of water supply for the western part of Accra.

The Densu basin falls under two distinct climatic zones. Both climatic zones are characterised by two rainfall regimes with different intensities (Dickson & Benneh, 1980). The major rainy season extends from April/May to July. The minor one occurs between September and November. The mean annual rainfall varies from about 800 mm near the coast to about 1600 mm in the river source area. The mean annual temperature is about 27ºC, with March/April being the hottest (32ºC) and August being the coldest month (23ºC). Mainly crystalline rocks, comprising five formations, namely Birimian, Granites, Togo series, Dahomeyan and Accraian, underlie the basin. With the exception of Accraian, the rest are Precambrian. The dominant soils are ochrosols, with patches of gleisols and lithosols.

The economic activities in the catchment include cultivation of crops such as cocoa, maize, cassava, vegetables, pineapples and cocoyam as well as the rising of livestock and fishing. The communities around the river use the water extensively for drinking and other domestic purposes without prior treatment.

The Birim takes its source from the Atewa range of hills in the Eastern Region of Ghana and followed a course of 175 km to join the Pra river. The Birim Basin has seven important tributaries. They are Adim, Apeam, Kadewa, Merempong, Osenase, Si and Supong rivers. The meandering river course is generally sheltered and fringed by gallery forest with trailing vegetation in some portions. The area lies within the tropical rain forest belt of Ghana where rainfall is comparatively high with an annual mean of 1650 mm (Ayibotele and Tuffour-Darko, 1979). There are two main rainy (wet) seasons with peaks in May/June for Major season and October for the minor season, respectively.

Relative humidity is naturally high in the area ranging from 60% to 95% during the year. The hottest months are February to April with the highest mean monthly temperature of 32ºC and 21ºC for the cooler periods of June to September/October, respectively (Ankomah, 1986).

The Inhabitants are mainly farmers, who grow foodstaffs, oil palm, vegetables, fruits and cash crops, for instance, cocoa. Timber and lumber are extracted from the forests in the basin.

The Ayensu River basin drains an area of about 1,709 km^2, covering portions of the Central, Eastern and Western regions of Ghana. It has a length of 98 km. The annual flow volume of the river as recorded at Okyereko pumping station is about 260×10^6 m^3. The minimum annual flows of the Ayensu River are recorded in the months of January and February, and they range between 2.9 and 4.7 million m^3. It takes its source from the Atiwa range of hills in the Akim Abuakwa District. It drains into the Gulf of Guinea at about 16 km east of Winneba. It has rivers Abukyen and Akora as two of its main tributaries.

About 95% of the Ayensu basin is underlain by granite and granodiorites of middle pre-cambrian origin except for the source and towards the mouth regions. The geology of the area consists mainly of the granites of the Cape Coast batholith intrusion which are generally acid rocks often gneissose with aplite and pegmatite. Remnants of the Birrimain rocks in the form of tightly folded pendants in the roof of the batholith exist (Kesse, 1985)

Land uses include cultivation of cocoa and fruit crops like oranges, and oil palm in the forested upper areas. Oil palm and rubber plantations can also be found in some other areas. The remaining non-cocoa growing areas of the basins on the outer margins of the forests outside the coastal savannah and thickets belt are under bush fallow cultivation of food crops including plantains, cocoyam, maize, cassava, vegetables, and fruit crops like pineapples. Coconut plantations occur on the sandy soils on the beachheads along the coast. Large numbers of cattle are known to be kept on the coastal plains.

Sampling stations

The following sampling stations were chosen for the Okyeman rivers based on accessibility and closeness to major population centers. These were:

- Densu River Stations: Koforidua Waterworks-up, Koforidua Waterworks-Down, Akwadum (Cocoa Farm-up), Akwadun (Bridge-down) and Kukurantumi.
- Birim River Stations: Bunso Cocoa College (Bridge), Osino (Bridge-Outskirts), Anyinam (Bridge), Kade

Town-up, Kade Town-Down, Akim Oda (Road Bridge), Apoli (near Etwereso)
- Ayensu River Stations: Anum Apapam, Kofi Pari Village, Asuoko and Nyanoa Mankron.

Sampling was mainly confined to mid-streams of the river courses except on a few occasions where unavailability of a boat limited sampling to the banks. Each station was sampled two times in a year for a period of two years, namely: August and December 2005, May and June 2006. Individual seasons were defined as rainy season (April, May–June and September–October) and the dry season (November, December, January–March).

Methods of physico-chemical analysis of water sample

The study conducted between August 2005 and June 2006 covered the Okyeman area. Water samples for physico-chemical analysis were collected directly into clean 1000 ml plastic bottles. Temperature and *p*H were measured *in situ*, using mercury-in-glass thermometer and portable *p*H meter, respectively.

Physico-chemical parameters measured at the sites and on collected water samples formed the basis of assessing the quality of the river waters. These were: (1) Hydrogen ion concentration (*p*H) and Temperature (ºC) measured using a portable Griffin pH meter and mercury-in-glass thermometer respectively. (2) Suspended Solids (SS) – determined by Membrane filtration (glass fibre type C) Method (dried at 105 ºC). (3) Conductivity – determined by a conductivity meter (Fisher). (4) Total Dissolved Solids (TDS) – determined by weighing after evaporating a known volume of sample. (5) Turbidity (FTU) – determined by a DRT 100B Turbidimeter. (6) Calcium (Ca) – EDTA titrimetric method. (7) Chloride (Cl) – argentometric method. (8) Magnesium (mg) – calculation as (Total hardness – Calcium hardness) x 0.244. (9) Acidity – Titration method. (10) Alkalinity – titration method. (11) Total Hardness – titration with standard. EDTA. (12) Nutrients: (a) Othophosphate (PO_4-P) – determined using ammonium molybdate and ascorbic acid method (Mac-kereth *et al*., 1978), (b) Ammonia-Nitrogen (NH_4-N) – determined by the indophenol blue method (FAO,1975), (c) Nitrate-Nitrogen (NO_3-N) – determined by hydrazine reduction followed by diazotizing to form an azodye which was measured colorimetrically, (d) Nitrite-Nitrogen (NO_2-N) determined by N-(1-naphthyl) ethylene diamine di-hydrochloride method (e) Silicates (SiO_2) – silico-molybdate colorimetric method, (f) Sulphates (SO_4) – determined by barium chloride method. (13) Heavy Metals – determined using Atomic Absorption Spectrophotometry.

Results and discussion

Descriptive Statistics

Based on samples analysed, the descriptive statistics of parameter values for the two-year period have been displayed in Table 2. The data show the extent of temporal variability in the composition of the river waters. Conductivity (Cond.) and Total Dissolved Solids (TDS) in the Densu, Birim and Ayensu rivers were significantly different at 95% with ANOVA ($P < 0.001$) for both conductivity and TDS. There was high variation in the Ayensu waters than that of Densu and Birim (Table 2). Turbidity and Suspended Solids (SS) in the Densu, Birim and Ayensu were not significantly different with ANOVA $P < 0.750$ and $P < 0.560$, respectively, at 95% level.

value should be significant at $P < 0.05$. This implies that in terms of nutrient inputs the river basins are not different from each other they are all influenced by domestic and agricultural activities.

TABLE 2

Descriptive statistics of average element concentration for Densu, Birim and Ayensu basins in Ghana (mg/l unless otherwise indicated

Parameter	*Densu Mean ±SD*	*n*	*Birim Mean ± SD*	*n*	*Ayensu Mean ± SD*	*n*
TDS	107 ± 16.3	20	53.2 ± 5.91	26	92.3 ± 28.4	13
Turbidity	22.6 ± 23.8	20	22.7 ± 24.3	26	16.9 ± 22.2	13
Cond. (µS/cm)	195 ± 29.7	20	95.4 ± 10.8	26	168 ± 51.7	13
SS	18.6 ± 14.2	20	24.1 ± 35.1	26	15.0 ± 14.9	13
Mg	6.37 ± 3.48	20	16.1 ± 14.6	24	27.9 ± 28.7	10
Ca	22.2 ± 6.27	20	4.54 ± 3.58	24	7.58 ± 7.97	10
Cl	17.7 ± 9.1	20	5.8 ± 1.49	12	–	–
NH_4-N	0.356 ± 0.273	20	0.266 ± 0.247	26	0.161 ± 0.178	13
NO_3-N	1.89 ± 1.33	20	2.55 ± 1.83	26	2.67 ± 2.47	13
NO_2-N	0.012 ± 0.014	20	0.006 ± 0.007	26	0.007 ± 0.009	13
PO_4-P	0.256 ± 0.226	20	0.151 ± 0.119	25	0.227 ± 0.257	13
Alkalinity	87.2 ± 25.7	20	43.5 ± 8.89	26	66.6 ± 9.99	13
Tot. Hardness (mg/l $CaCO_3$)	76.0 ± 23.1	20	35.3 ± 8.63	26	58.8 ± 14.1	13
Fe	0.908 ± 0.679	20	1.03 ± 1.76	26	0.579 ± 0.614	13

SD: Standard Deviation; N: number of Samples

Calcium, Magnesium and Chloride had their mean values significantly different from each other in the three river basins. The $P < 0.001$, $p < 0.003$, $P < 0.001$ were ANOVA significant values for Calcium, Magnesium and Chloride, respectively, with Ayensu having the highest variation. All the mean nutrient values for Densu, Birim and Ayensu were not significantly different at 95% from each other (NH_4-N, $P < 0.089$; NO_3-N, $P < 0.385$; NO_2-N $P < 0.203$; PO_4-P $P < 0.188$) p-

Physical parameters

Densu Basin had *p*H values ranging from of 7.12–8.12 in 2005 and 7.24–8.15 in 2006, the Birim River also had *p*H ranges of 7.40–7.80 in 2005, 7.04–8.08 in 2006. Similarly, the pH of Ayensu River ranged from 7.52–7.97 in 2005 and 7.18–8.06 in 2006. The coefficient of variation in Densu (3.38% RSD) was higher than Ayensu (1.98% RSD) and Birim (1.67% RSD) Basins, implying that Densu was more influenced by leaves and other materials over which the waters run and Densu River was dominated by human activities.

The average turbidity levels in Densu Basin were higher than that of Ayensu and Birim basins. The May and June values were higher in 2006 than the August and December values in 2005. On the average Densu and Birim were higher than that of Ayensu (Fig. 2).

The mean low turbidity levels were recorded in the Ayensu Basin (0.94 FTU). This may imply higher primary productivity in the Ayensu Basin because of deeper light penetration for photosynthesis.

Mean conductivity values in the basins were: Densu 195 µS/cm, Ayensu 169 µS/cm and Birim 96.1 µS/cm. The conductivity levels in the river basins followed the order: Densu > Ayensu > Birim. The order is depended on the human activities in each basin. According to the computed coefficient of variation for conductivity values of the basins, Ayensu showed the highest variation (% RSD of 45 in 2006). This was due in part to human activities and also the soil type in the area.

The conductivity values in Fig. 3 were a reflection of the impact of human activities in the basins.

Total Dissolved Solids (TDS) also followed a similar pattern following the order: Densu (107 mg/l) > Ayensu (92.3 mg/l) > Birim 53.2 mg/l indicating the presence of high human activities impacting on the Densu Basin. These mean values are not significant from each other at 95% level with $p < 0.001$. The mean values of TDS in the basins are 107, 53.2 and 92.3 mg/l for Densu, Birim and Ayensu rivers, respectively. On the average the 2006 values were higher than that of the 2005. There was very hig variation in Ayensu river compared with that of Densu and Birim rivers.

Major ions

Ionic dominance pattern for Densu, Birim and Ayensu river Basins were Na > Ca > Mg > K for cations and HCO_3 > SO_4 > Cl for anions in the year 2005. Different Ionic dominance pattern for Densu, Birim and Ayensu observed in 2006: Ca > Na > K > Mg and HCO_3 > Cl > SO_4. The dominance of Na over Ca was due to domestic activities dominating in the year 2005. The pattern observed in 2006 was as a result of rains and weathering in the catchment. The ionic dominance patterns observed do not conform to the ionic dominance pattern of Ca > Mg > Na > K and HCO_3 > SO_4 > Cl for freshwater (Burton & Liss, 1976). Thus, like most tropical fresh waters there is a dominance of Ca and HCO_3 in the cationic and anionic components, respectively. A similar ionic dominance pattern was observed in the Densu basin by Biney (1987) and Ansa-Asare (1992). It is also apparent that the dominance of chloride over sulphate could be due to large amounts of domestic wastes being discharged into the river waters. Studies conducted by Biney (1990) on characteristics of fresh water and coastal ecosystems in Ghana also confirmed this observation.

Sodium had a mean of 24.7 mg/l for Densu, 12.1 mg/l for Birim and 24.8 mg/l for Ayensu. Sodium values for 2005 were higher compared to the 2006 sodium values as a result of the rains which were heavier in 2005. Ca, SO_4, HCO_3, Mg and Cl also showed similar pattern like Na, with the

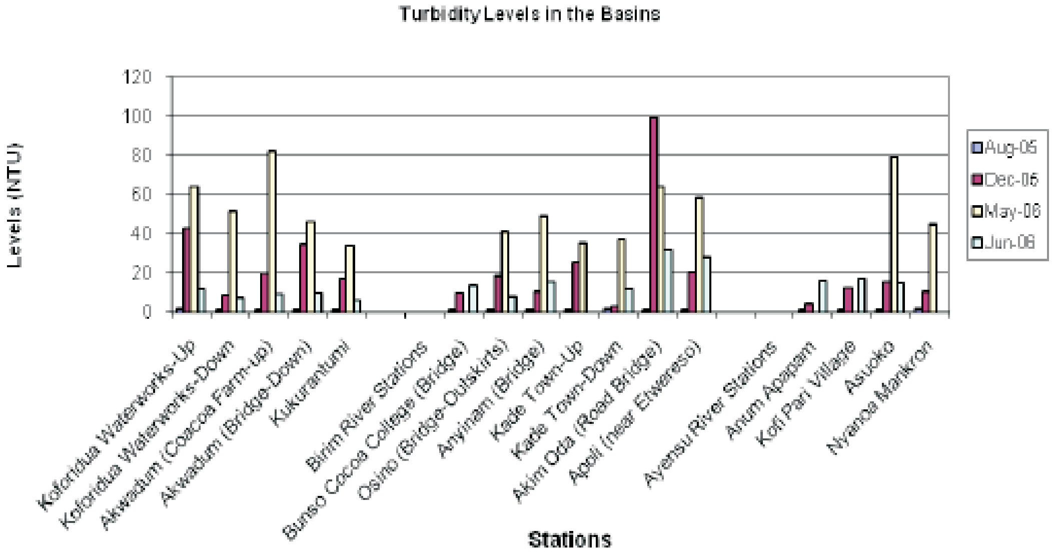

Fig. 1. Turbidity levels for Densu, Birim and Ayensu rivers

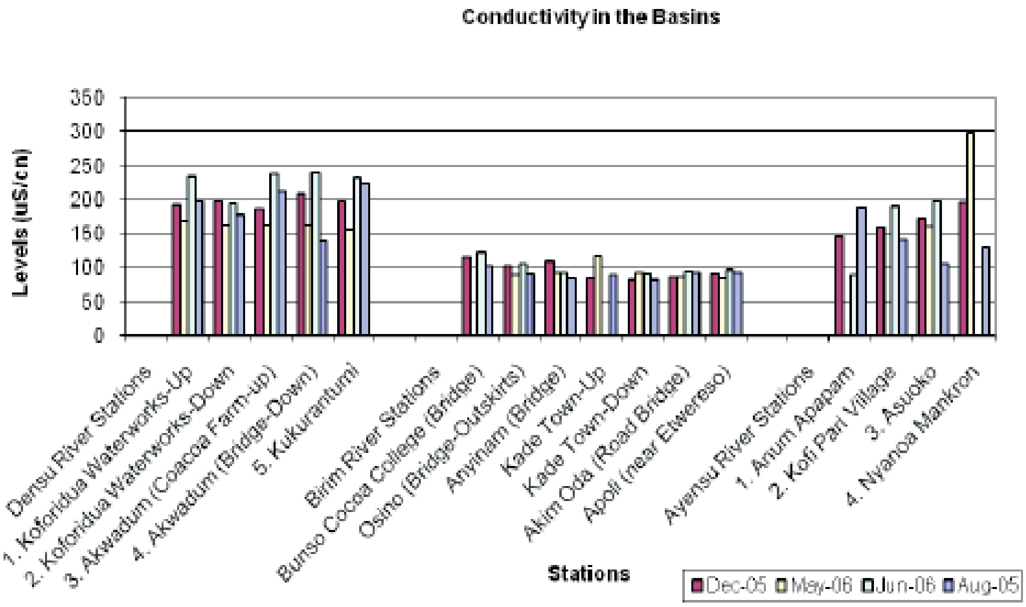

Fig. 2. Conductivity values in Densu Ayensu and Birim

exception of K, which had 2006 levels higher than that of the 2005.

The computed coefficient of variation for the major ions revealed that sulphate had the highest % RSD for all the river basins; Densu (60.6% RSD), Birim (56.9% RSD) and Ayensu (43.7 % RSD) respectively. This implies that sulphate had varied sources from domestic to agricultural origin.

Nutrients

Ammonia-Nitrogen:NH_3-N followed this order in terms of their mean levels in the river basins: Densu (0.356 mg/l) > Birim (0.267 mg/l) > Ayensu (0.161 mg/l). The 2005 NH_3-N levels were lower than that of the 2006.

Nitrate-Nitrogen: The basin had a mean NO_3-N concentration of 1.89 mg/l for Densu, 2.55 mg/l for Birim and 2.63 mg/l for Ayensu with ranges of 0.01–3.96 mg/l, 0.21–6.48 mg/l and 0.001–8.17 mg/l, respectively. The mean nitrate value is high enough to promote eutrophication.

Nitrite Nitrogen: Mean concentrations of 0.012 mg/l for Densu, 0.007 mg/l for Birim and 0.007 mg/l were recorded in the river basins (2005–2006). These concentrations were low, reflecting good nitrification process in the system.

Phosphate: Mean concentrations of 0.256 mg/l for Densu, 0.143 mg/l for Birim and 0.213 mg/l were recorded in the river basins, resulting in the order Densu > Ayensu > Birim. This reflects the impact of human activities in the basins. Mean phosphate values of the basins were high enough to promote eutrophication. Phosphates in the three river basins were not significantly different from each other at 95% level with $P < 0.188$. This implies that the source of

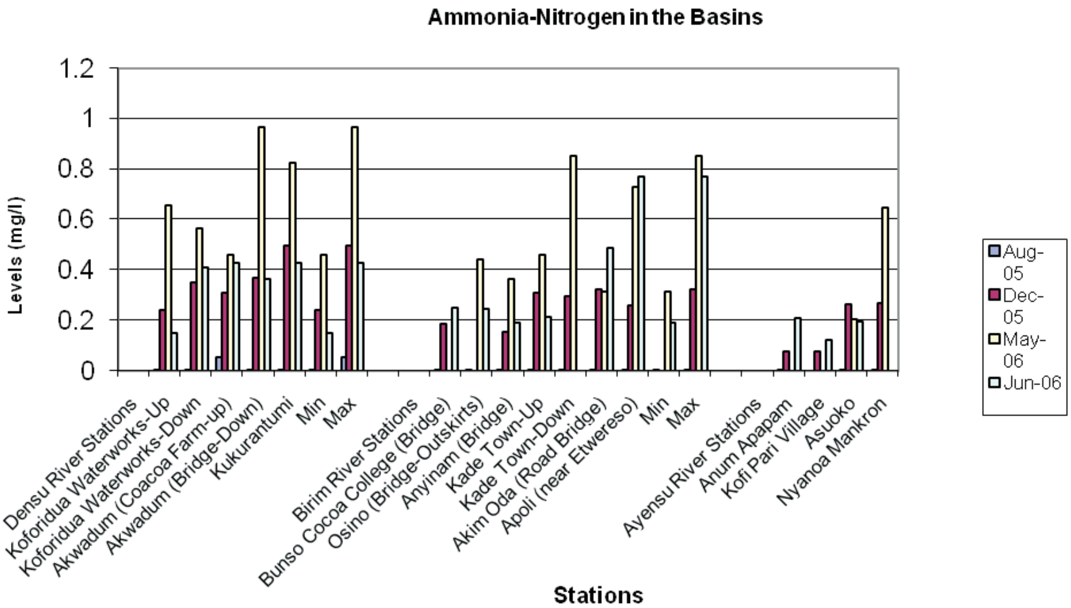

Fig. 4. Ammonia-nitrogen levels in Densu, Birim and Ayensu rivers

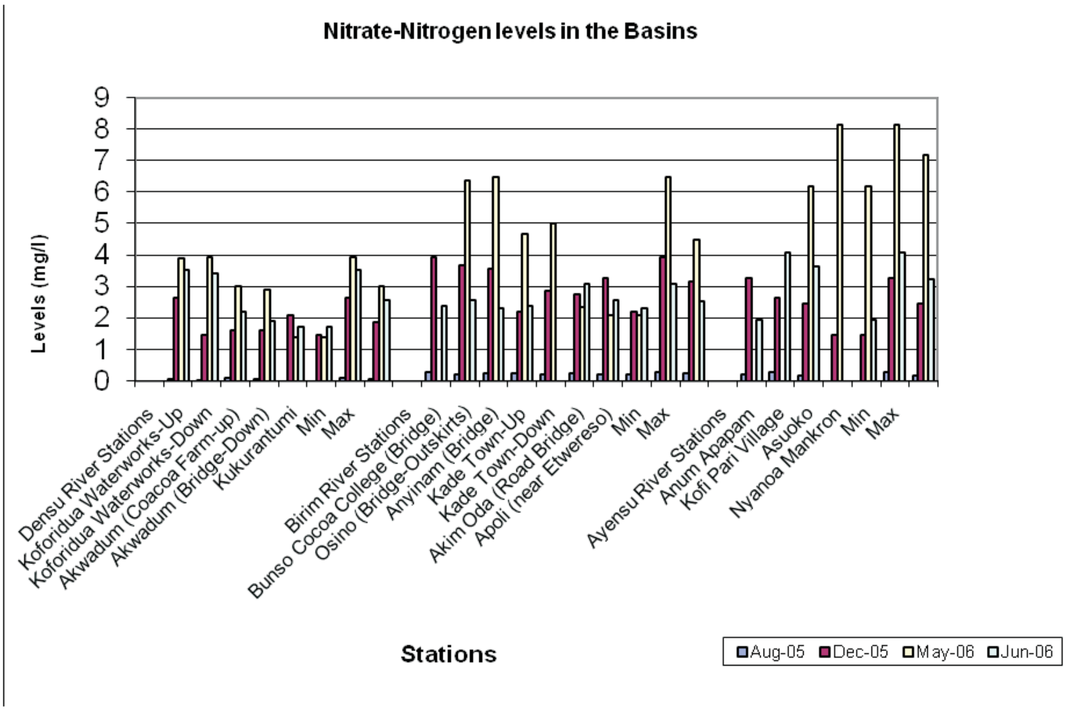

Fig. 5: Nitrate-nitrogen levels in Densu, Ayensu and abirim Basins.

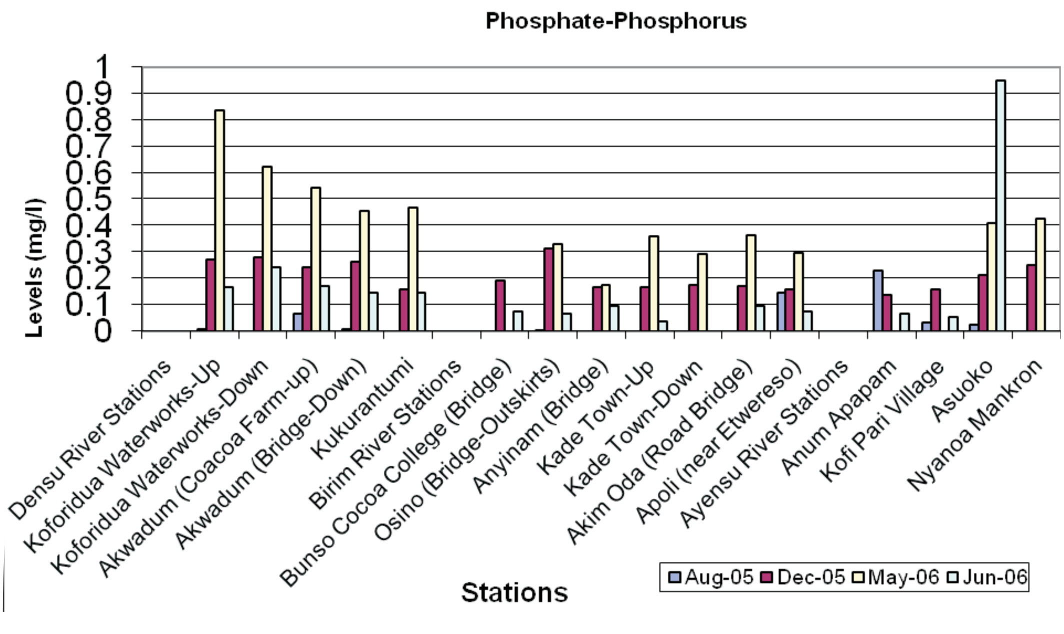

Fig. 6. Phosphorus in the Densu, Birim and the Ayensu basins

phosphates in the Densu, Birim and Ayensu were not of varied origin, they are mainly from agricultural and domestic sources.

Other Chemical Parameters

Alkalinity:Mean alkalinity values were: Densu, 82.7 mg/l $CaCO_3$; Birim, 44.2 mg L^{-1} $CaCO_3$; Ayensu, 66.6 mg L^{-1} $CaCO_3$. These were a reflection of the domestic activities in the basins. Total Hardness: Total hardness also showed a similar pattern of Densu > Ayensu > Birim. This was as a result of more domestic activities impacting on Densu Basin compared with all other basins. Total Dissolved Solids: Total Dissolved Solids (TDS) also showed a similar pattern with Densu River dominating because of high domestic and agricultural activities in the basin.

On the average, the waters were soft with values within the guideline value of 0-60 mg $CaCO_3$ L^{-1}, with the exception of few Densu and Birim values within the range of 60-100 mg $CaCO_3$ L^{-1}.

Water Quality Index (WQI)

The Water Quality Index (WQI) is a classification system that uses an index calculated from selected water quality parameters. The index classifies water quality into one of the four categories: good, fairly good, poor, and grossly polluted. Each category describes the state of water quality compared to objectives that usually represent the natural state. The index thus indicates the degree to which the natural water quality is affected by human activity. The index can be used to describe the state of water quality as a whole in a body of water. It also indicates the suitability of water for various uses such as domestic, recreation and agriculture (i.e. irrigation and livestock watering), where such uses are naturally sustainable.

The adapted WQI used in assessing the state of the Okyeman rivers in Ghana is based on the Solway River Purification Board (RPB) Weighted Water Quality Index developed by Bolton *et al.* (1978), and adopted by WRC (2003). This is the general water quality indices type in which various physical, chemical and microbiological variables are aggregated to produce an overall index of water quality. The parameters that were used to calculate the Water Quality Index for the river basins are: Dissolved Oxygen (% Saturation), Biochemical Oxygen Demand (BOD), Ammonium Nitrogen (NH_4-N), Faecal Coliform, pH, Nitrate as Nitrogen (NO_3-N), Phosphate as Phosphorus (PO_4-P), Total Suspended Solids (TSS), Conductivity and Temperature.

Table 3 below shows the description of the state of water quality based on the adapted classification system that uses a class system and a scale of zero to 100 in various ranges for the corresponding classes.

TABLE 3
*Criteria for Classification of Surface Waters**

Class	*Range*	*Description*
I	> 80	Good – Unpolluted and/or recovering from pollution
II	> 50–80	Fairly good
III	25–50	Poor quality
IV	< 25	Grossly polluted

*(Source: WRC, 2003)

In 2005 all the three basins were in class II which was fairly good quality. The Ayensu basin was of best quality (Fig 7). The 2006 results indicated that all the stations fell under class III. This showed a deterioration of the state of the rivers in 2006 and would have been interesting to have looked at the 2007 trend if that would have improved or deteriorated further.

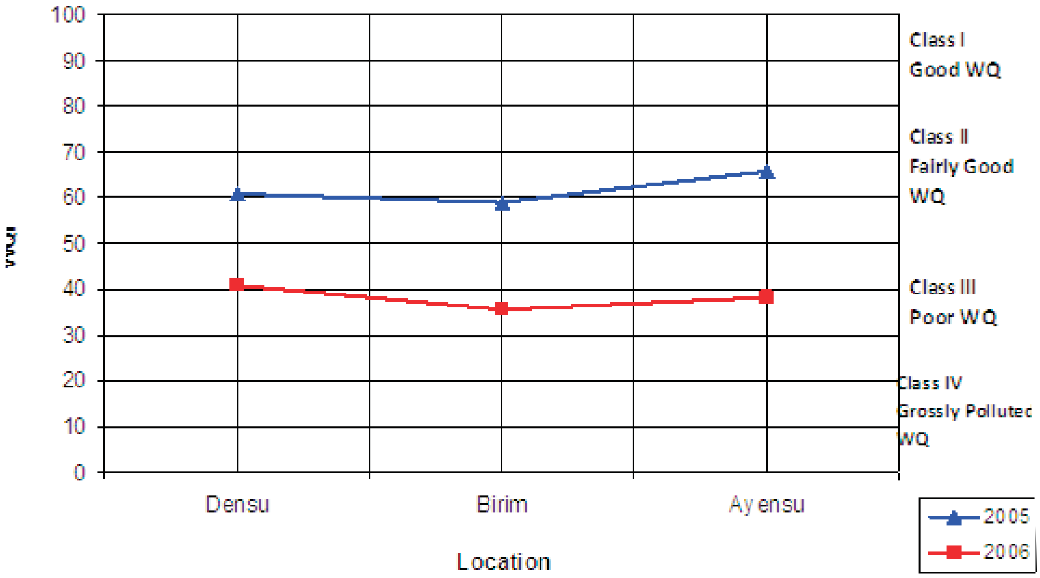

Fig. 7. Annual mean Water Quality Indices from 2005 to 2006 in the Densu, Birim and Ayensu Basins.

This is an indication of the polluted nature of the rivers due to human activities. In both cases Birim had the lowest index due to mining and other human activities in that basin.

Conclusions

The % RSD in Ayensu was higher than Densu and Birim Basins, showing that Ayensu is more influenced by leaves and other materials over which the waters run. The average turbidity levels in Densu Basin were higher than that of Ayensu and Birim basins. The low turbidity of Ayensu Basin is an indication of higher primary productivity. The conductivity levels in the river basins followed the order: Densu > Ayensu > Birim. The order is depended on the human activities in each basin. According to the % RSD of the conductivity in the basins, Ayensu showed the highest variation in the conductivity levels in between the stations.

Ammonia-Nitrogen (NH_3-N) followed this order in terms of mean levels in the river basins: Densu (0.356 mg/l) > Birim (0.267 mg/l) > Ayensu (0.161 mg/l). The 2005 NH_3-N levels were lower than that of the 2006. This was a reflection of the impact of increased human and agricultural activities in the year 2006.

Nitrate-Nitrogen (NO_3-N) The basin had a mean NO_3-N concentration of 1.89 mg/l for Densu, 2.55 mg/l for Birim and 2.63 mg/l for Ayensu with ranges of 0.01 – 3.96 mg/l, 0.21 – 6.48 mg/l and 0.001 – 8.17 mg/l respectively. The mean nitrate value is high enough to promote eutrophication. The mean values are high enough compared to the guidelines WRC, 2003, to cause the waters to be eutrophic. Phosphate also showed mean concentrations of 0.256 mg/l for Densu, 0.143 mg/l for Birim and 0.213 mg/l were recorded in the river basins, resulting in the order Densu > Ayensu > Birim. This reflects the impact of human activities in the basins. Mean phosphate values of the basins were high enough to promote eutrophication.

The mean alkalinity values for Densu (82.7 mg L^{-1} $CaCO_3$), Birim (44.2 mg L^{-1} $CaCO_3$) and Ayensu (66.6 mg L^{-1} $CaCO_3$) were a reflection of the domestic activities in the basins.

Total hardness and TDS also showed a similar pattern of Densu > Ayensu > Birim. This was as a result of more domestic activities impacting on Densu Basin compared with all other basins.

The classification system showed in 2005 that all the three basins were in class II which was fairly good quality. The Ayensu basin was of best quality. The 2006 results indicated that all the stations fell under class III. This showed a deterioration of the state of the rivers in 2006.

Recommendations

There should be comprehensive studies on the river basins for a longer period (at least 4 years) in order to identify trends in the water quality of the river basins. The ecosystem approach model can be well validated if the data available can show trends.

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