The Water Quality of Birim River in South-East Ghana

O. D. Ansa-Asare* and K.A. Asante
Water Research Institute, CSIR, P.O. Box 38, Achimota, Accra, Ghana
* *Corresponding author*

Abstract

A limno-chemical characterization and water quality assessment of Birim River Catchment identified mining and domestic activities as the main pollution sources. The concentrations of a range of elements and ions in the river waters were measured over a of 12-month period. The river waters were well oxygenated due to their turbulence with resultant diffusion action, and 72.2% of the waters had dissolved oxygen (DO) above the natural background level range of 5.0 - 7.0 mg L^{-1}. Evidence of high nutrient loads recorded in the basin was as a result of influences from domestic, agricultural and industrial activities, as well as biogeo-chemical reactions in the soil. The seasonal variations of the nutrients were higher in the rainy season than in the dry season. The waters of the Birim basin showed an overall ionic dominance pattern of $Ca > Mg$ and $HCO_3 > Cl > SO_4$, typical of freshwater systems, due to the dominance of Ca and HCO_3. Calcium and magnesium showed a strong linear correlation $r = 0.95$ significant at $P < 0.001$, an indication of strong weathering pattern in the Birim catchment. Variations of chlorides and suspended solids were high in the rainy season. BOD loads were high in the lower reaches, an indication of industrial, domestic and commercial discharges. 84.2% of the measured Mn values exceeded the background level of 0.1 mg L^{-1} as a result of mining activities and other anthropogenic point sources.

Key words: Birim River, Ghana, limno-chemical, nutrient load, seasonality, water quality assessment

Introduction

The development of water resources has often been used as a yardstick for socio-economic and health status of many nations worldwide. However, pollution of waters often negates the benefits obtained from the development of these water resources.

For many people in Ghana, water supply, sanitation and safe disposal of wastes remain the most important of all environmental problems. Control and sustainable management of river catchment are major issues in Ghana because of a variety of pressures placed upon land and water resources. These include nutrient enrichment of surface waters from urban sources and by agricultural chemicals, sediment loading caused by deforestation, eutrophication, improper land management, and abstraction of water for human consumption and irrigation, the requirements for rural and urban development and poverty alleviation (Ansa-Asare, 1995).

In Ghana, not much work has been done on the pollution loads of some freshwater systems and how they affect their inherent resources. Available information on some river quality systems in Ghana are: Ansa-Asare & Asante (1998); Ampofo (1997); Ansa-Asare (1995); Ansa-Asare (1992); Biney (1987); Odei (1975); Amuzu (1975) and Ayibotele (1974). The Birim basin, for example, has not been studied as an entity, although some portions of it relating to mining ativities around Akwatia and Kwabeng have had preliminary documentation on their hydrobiology (Odei, M.A., personal communication).

The Birim, which is an important source of water supply for the people in its catchment area, is being subjected to waste discharges in places like Oda, Akwatia and Kwabeng from mining activities. Deforestation for fuelwood and other domestic uses, excessive use of inorganic fertilizer in agricultural activities and land degradation due to improper agricultural practices have also contributed to the total pollution loads in some portions of the river course (Ampofo, 1997).

The activities of small scale miners have degraded the land littering the basin with unrehabilitated trenches and water-filled excavation and marshy areas.

These generally have turbid waters containing other pollutants from gold extraction and diamond mining (Ansa-Asare, 1995). Furthermore, the demand for adequate water to satisfy the ever increasing needs for domestic, industrial and agricultural uses is increasing. To satisfy such needs through conservation and regulation, it has therefore become imperative to aim at identifying the various sources of contaminants, assess the quality of the river water by quantifying the chemical differences among the waters of Birim River in order to provide the scientific basis for finding appropriate remedies to the contamination problems that confront the basin and their inherent impacts on the populations.

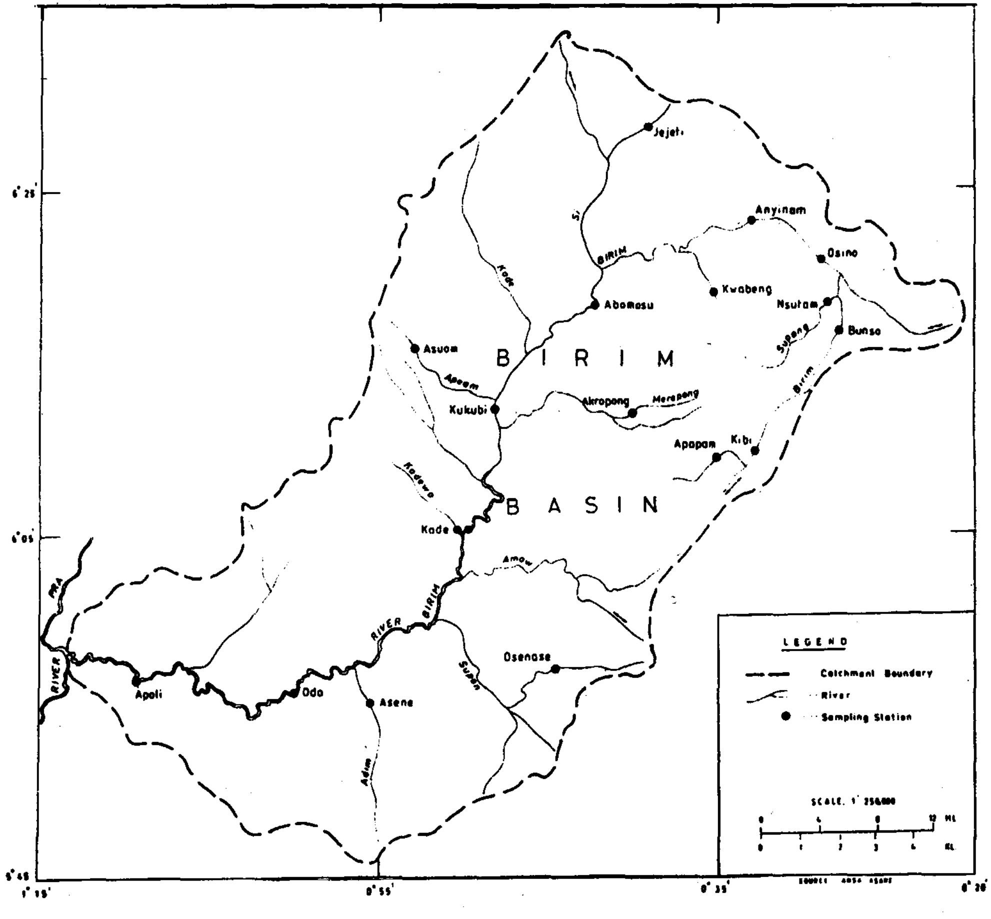

Fig. 1 Birim basin showing sampling stations

Materials and methods

Study area

The Birim takes its source from the Atewa range of hills in the Eastern Region of Ghana and follows a course of 175 km to join the Pra River. The Birim basin located between latitude 0° 20'W, 1° 15'W and longitude 5° 45'N, 6°35'N has an estimated area of 3875 km^2 with seven important tributaries. They are Adim, Apeam, Kadewa, Merempong, Osenase, Si, and Supong rivers (Fig. 1).

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 the peaks in May/June for the 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 32 °C and 21 °C for the cooler periods of June to September/October, respectively (Ankomah, 1986).

The river Birim (from Kade downstream) and some of its tributaries, e.g., Asubone, Supong, Ablasika and Adenkyensu are all diamondiferous. Diamond is the major extracted mineral in the basin however, gold is also won. Mining is both alluvial and terracing.

The bed of the streams consists of sand, gravels, rocks, and are generally muddy with decaying vegetable matter.

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

Sampling stations

Eighteen sampling stations were chosen based on accessibility and closeness to major population centers. These were

1.Birim-Apapam,
2.Birim-Kibi,
3.Birim-Bunso,
4.Supong-Nsutam (T)
5.Birim-Osino,
6.Birim-Anyinam
7 Birim-Kwabeng
8.Merepong-Akropong(T)
9.Apeam-Asuom (T)
10.Birim-Kukubi,
11.Birim-Abomosu,
12. Si-Jejeti (T.)
13. Kadewa-Kade (T)
14. Birim-Kade,
15.Supon-Osenase (T)
16.Adim-Asene (T)
17. Birim-Oda
18. Birim-Apoli

(T.= tributary)

There were seven major tributaries (T.) of the Birim river. The 18 sampling stations have been arranged upstream from the headwaters to downstream, at the Pra confluence with the Birim. The river waters are extensively used for drinking purposes with the exception of the Apeam at Asuom where there is a taboo on the exploitation of *Clarias* (catfish) and, as a result, the populations are high there.

Sampling was mainly confined to the midstreams of the river courses except on a few occasions where unavailability of a boat limited sampling to the banks. Each station was sampled seven times in a year, namely: January, March, May, July, September, November 1995 and January 1996. Individual seasons were defined as the rainy season (April, May-July and September-October) and the dry season (November, December, January-March).

Methods of physico-chemical analyses of water samples

The study conducted between January 1995 and January 1996 covered all the 18 sampling stations. Water samples for physico-chemical analyses were collected directly into clean 500 ml plastic bottles. Temperature and pH were measured *in situ,* using mercury-in-glass thermometer and portable pH meter, respectively. For dissolved oxygen (DO) determinations, separate samples were collected into plain glass bottles and the DO fixed using the azide modification of the Winkler's method. Samples for biochemical oxygen demand (BOD) were collected into dark painted glass bottles and were incubated at 20 °C for 5 days before the remaining DO was determined.

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. Dissolved oxygen (DO) and biochemical oxygen demand (BOD) - determined by a modification of the Winkler's method (FAO, 1975).
2. Nutrients:
   - a. Orthophosphate (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 dihydrochloride method;
   - e. Silicates (SiO_2) - silico-molybdate colorimetric method;
   - f. Sulphates (SO_4) - determined by barium chloride method.
3. Calcium (Ca) - EDTA (titrimetric method)
4. Chloride (Cl) - argentometric method
5. Magnesium (Mg) - by calculation as (Total hardness - Calcium hardness) x 0.244
6. Acidity - titration method
7. Alkalinity - titration method
8. Total Hardness: titration with stand. EDTA
9. Conductivity - determined by a conductivity meter (Fisher)
10. Total Dissolved Solids (TDS) - determined by weighing after evaporating a known volume of sample.
11. Hydrogen ion concentration (pH) and temperature (°C) measured using a portable Griffin pH meter and mercury-in-glass thermometer respectively.
12. Heavy metals-determined using Atomic Asorption Spectrophotometry (Varian 1275AAS).
13. Discharge ($m^3 s^{-1}$) - determined using a BFAM00 12A-LCD flow meter by Valeport, Dartmouth U.K.
14. Suspended Solids (SS)-Determined by Membrane Filtration (glass fibre type C) Method (dried at 105 °C).
15. Turbidity (F.T.U) - determined by a DRT 100B Turbidimeter.

The results, in mg L^{-1}, were converted into loads using mean discharges and concentrations measured.

The formula was: Load = concentration (mg L^{-1}) × discharge ($m^3 s^{-1}$), then the units were changed to kg day^{-1} for BOD, nitrate, phosphate, sulphate, SS and TDS.

Dissolved oxygen (DO), biochemical oxygen demand loads, nutrients loads, iron (Fe), manganese (Mn), lead (Pb), and arsenic (As) were chosen as indices of pollution as well as water quality criteria.

Results and discussion

A summary of the results of physico-chemical analyses and nutrient loads have been presented in Tables 1 to 4. Where

TABLE 1

Mean physical parameters of Birim basin for January 1995 - January, 1996

Units *River/Location*	^{0}C *H20*	*pH*	*mg* L^{-1} *SS*	*F.T.U* *Turbidity*	M^{3} sec^{-1} *Discharge*	*mg*L^{-1} *DO*
1. R. Birim-Apapem	23.2	6.2	11.2	18.6	0.08	8.9
2. R. Birim-Kibi	24.0	6.5	53.0	51.0	0.25	7.5
3. R. Birim-Bunsu	24.0	6.4	11.8	15.6	0.26	8.2
4. R. Supong-Nsutam (T.)	24.4	6.5	16.8	21.4	0.70	7.6
5. R. Birim-Osino	25.8	6.5	23.8	29.0	4.02	6.7
6. R. Birim-Anyinam	26.0	6.4	23.0	19.4	0.20	7.1
7. R. Birim Kwabeng	25.0	6.5	66.4	17.4	0.30	7.9
8. R. Merempong-Akropong (T.)	25.0	6.6	36.3	24.0	0.32	7.8
9. R. Apeam-Asuom (T.)	25.0	6.6	177.9	63.0	0.25	6.4
10. R. Birim-Kukubi	25.5	6.5	61.8	37.6	0.56	7.6
11. R. Birim-Abomosu	25.4	6.6	37.6	38.4	0.32	7.3
12. R. Si-Jejeti (T.)	25.0	6.4	24.4	27.8	0.15	8.1
13. R. Kadewa-Kade (T.)	25.8	6.4	17.4	33.4	0.02	6.8
14. R. Birim-Kade	26.0	6.4	44.0	35.0	0.65	6.6
15. R. Supong-Osenase (T.)	26.2	6.9	7.8	12.4	0.16	7.6
16. R. Adim-Asene (T.)	26.4	6.4	16.5	42.6		6.0
17. R. Birim-Oda	27.0	6.5	64.0	63.8	15.5	7.3
18. R. Birim-Apoli	26.8	6.5	41.4	42.6	14.5	8.5
Mean	24.0	-	37.5	32.9	2.34	7.4
Ranges	23.2-27.0	6.2-6.9	7.8-178	12.4-63.0	0.02-15.5	6.0-8.9
Background levels		6.5-8.5	-	-	-	5.0-7.0

possible, these values have been placed alongside natural background levels for tropical surface waters (Livingstone, 1963; Burton and Liss, 1976; Joergensen, 1979, Stumm Morgan, 1981; WHO, 1984).

Physical parameters

The waters had pHs ranging from 6.2-6.9. Temperatures ranged from 23.2 °C - 27.0 °C which increased gradually from the upper reaches through the midreaches downstream due to volume of water. More than 60% of the pH values fell within the natural background level range of 6.5 - 8.5. Normally, running waters are influenced by the nature of deposits over which they flow (Hynes, 1970).

concentrations coincided with high turbidity levels (Table 1). The high values recorded for some portions of the river basin especially at Asuom (presence of basin especially at Asuom (presence of *Clarias*) implied that most of the suspended solids were small particulates in nature with slow rates of settling. However, that of Oda could mainly be attributed to diamond mining activities within the immediate surroundings of the river basin. The Birim river basin had varied suspended solid values of mean 37.50 ± 39.12 (SD) mg L^{-1} because of different anthropogenic influences as well as different soil types along the banks of the river water course. The flow regime increased after every tributary had joined the main Birim river (Table 1).

TABLE 2

Mean loads of some selected chemical parameters in the Birim Basin (kg day^{-1})

Location	*BOD*	*Nitrate*	*Phosphate*	*Sulphate*	*SS x 10^3*	*TDS x 10^3*
1	22.4	11.6	0.07	53.9	0.077	0.573
2	66.4	18.3	0.56	165.6	1.145	1.327
3	70.1	17.1	0.14	235.4	0.265	1.220
4	121.2	21.2	0.36	330.2	1.016	2.210
5	1.027 x 10^3	288.4	8.93	2.327 x 10^3	8.225	15.70
6	54.1	22.2	0.20	118.4	0.397	0.829
7	74.2	25.4	0.40	68.7	1.721	1.328
8	82.6	34.8	0.53	129	1.004	1.520
9	75.7	30.5	2.93	401.8	1.861	1.524
10	199.1	78.3	1.31	418	2.99	2.157
11	112.8	21.4	0.97	259.8	1.039	1.457
12	52.8	9.3	0.95	83.7	0.316	0.503
13	15.3	0.99	0.21	11.8	0.030	0.101
14	170.7	55.4	2.34	484.8	2.471	2.536
15	40.4	18.7	0.38	42.6	0.108	1.003
17	3.53 x 10^3	22.75 x 10^2	56.16	15.64 x 10^3	82.94	68.48
18	4.38 x 10^3	809	30.30	12.34 x 10^3	48.29	54.00

The river waters were well oxygenated with a mean DO concentration of 7.4 mg L^{-1}. 72.2% of the streams had DO above the natural background level range of 5.0 - 7.0 mg L^{-1}. The high DO could be attributed to the lotic nature of the stream at the headwaters.

Evidence of low flow and lentic environments favouring the growth of phytoplankton which influence photosynthetic activities corresponding to high DO could not be identified with certainty, because chlorophyll 'a' measurements were not taken.

Nutrient loads

Nitrate-Nitrogen loads increased gradually from the headwaters to the confluence (Table 2) A careful study of the data revealed

TABLE 3

Mean major ions depicting ionic dominance pattern during the period of January, 1995 -January, 1996

Season	*Ca* mgL^{-1}	*CV* (%)	*Mg* mgL^{-1}	*CV* (%)	HCO_3 mgL^{-1}	*CV* (%)	*Cl* mgL^{-1}	*CV* (%)	SO_4 mgL^{-1}	*CV* (%)
January	10.31	27.4	9.73	25.3	7.33	35.0	13.22	17.1	2.39	166.9
March	10.78	32.9	10.39	32.5	61.88	31.4	15.18	29.6	4.18	139.4
May	10.27	22.7	8.23	26.2	49.0	31.7	17.29	39.8	9.72	123.5
July	9.20	21.1	8.56	18.7	46.30	28.7	14.78	22.8	8.11	56.6
September	6.62	30.7	6.46	26.4	42.44	25.4	13.28	18.4	11.10	49.7
November	6.50	28.1	6.20	28.1	43.82	21.2	14.11	14.9	12.03	33.4

CV = Coefficient of variation.

TABLE 4

Mean concentration of trace metals in river Birim (mg L^{-1})

Place	*Zn*	*Pb*	*Cu*	*Cd*	*Mn*	*Fe*
1	0.815	0.014	<0.01	<0.01	0.213	0.111
2	0.892	0.025	<0.01	0.02	0.796	0.438
3	0.703	0.018	<0.01	0.022	0.934	0.170
4	0.010	0.003	<0.01	0.02	0.02	0.111
5	0.771	0.019	<0.01	0.02	0.555	0.111
6	0.054	0.001	<0.01	0.019	0.02	<0.05
7	0.797	0.019	<0.01	<0.01	0.696	0.260
8	0.841	0.022	<0.01	<0.01	0.736	0.379
9	0.878	0.001	<0.01	<0.01	0.354	0.885
10	0.725	0.014	<0.01	0.021	0.414	0.170
11	0.812	0.014	<0.01	0.021	0.676	0.319
12	0.776	0.007	<0.01	0.022	0.494	0.617
13	0.567	0.003	<0.01	<0.01	0.857	2.732
14	0.436	0.014	<0.01	<0.01	0.595	0.438
15	0.824	0.033	<0.01	0.026	0.011	0.289
16	0.883	0.012	<0.01	<0.01	1.158	1.570
17	0.617	0.010	<0.01	<0.01	0.173	0.915
18	0.787	0.019	<0.01	0.021	0.756	0.614
Average	0.686	0.014	<0.01	0.014	0.607	0.614
Background Levels	5.0	0.05	1.0	0.01	0.1	0.3
Ranges	0.01-0.892	0.001-0.033	<0.01	<0.01-0.026	0.02-2.63	0.05-1.57
WHO Limits	0.5	0.05	2.5	0.01	0.5	1.0

an increase in load. The loads of all dissolved species increases with discharge. The loads relating discharge to concentrations are listed in Table 2.

The exceptionally high nitrate load at Oda could be attributed in part to agricultural activities at Asene and Osenase. However, most of the high nutrient loads at Oda could be attributed to domestic and other industrial activities like gold and diamond mining.

The high phosphate loads at Osino (8.93 kg day^{-1}), Asuom (2.93 kg day^{-1}), Kade (2.34 kg day^{-1}) Oda (56.16 kg day^{-1}) and Apoli (30.3 kg day^{-1}) respetively, could be mainly attributed to domestic (e.*g*. refuse and detergent) and industrial activities; effluents from the mining company at Akwatia being a major contributor.

At Osino upstream, the high sulphate load (2.327×10^3 kg day^{-1}) could be attributed to the soil type and the underlying rocks. From observations during sampling, the percentage contributions from domestic activities were minimal. After Osino, river water dilution took place at Anyinam as a result of tributary inflows. Then the sulphate level increased again downstream after the effluents of the tailings from the mining activities had been channeled into it at Oda. The high sulphate levels in some portions of the river water were a reflection of the low pH recorded. The high incidence of sulphate in some portions of the river water could be buttressed by the fact that under aerobic conditions pyrite (FeS_2)could be converted by *Thiobacillus* to sulphate.

$$4FeS_2 + 15O_2 + 14H_2O \xrightarrow{Thiobacillus} 4Fe(OH)_3 + 16H^+ + 8\,SO_4^{2-}$$

Ionic dominance

Estimated means of major elements (both cations and anions) for all stations and sampling occasions, were Ca : 8.61 ± 2.45 mg L^{-1} (range 6.72-13.67, CV 28.5), Mg : 8.23 ± 1.59 (range 5.12-11.83, CV 19.3), HCO_3 : 41.57 ± 6.88 (range 33.33-58.01, CV 16.6), SO_4 : 7.72 ± 3.88 (range 2.65-18.6, CV 50.2), Cl :11.08 ± 4.78 (range 12.17-20.66, CV 43.1). The Birim basin showed an overall ionic dominance pattern of Ca > Mg and HCO_3 > Cl > SO_4. This was in contrast to an ionic dominance pattern of Ca > Mg > Na > K and HCO_3 > SO_4 > Cl for freshwater and Na > Mg > Ca > K and Cl > SO_4 > HCO_3 for sea water (Burton & Lissy, 1976). Thus, like most tropical freshwaters, there is a dominance of Ca and HCO_3 in the cationic and anionic components respectively. It is apparent that the dominance of chloride over sulphate could be due to the large amount of domestic wastes being discharged into the river waters. Studies by Biney (1990) on characteristics of freshwater and coastal ecosystems in Ghana also confirmed this observation. On the average, the waters were soft with values within the guideline value of 0-60 mg $CaCO_3$ L^{-1}. There was a strong correlation of 0.95 between calcium and magnesium, significant at $p < 0.001$, indicating strong weathering in the Birim catchment (Fig. 2). Regression of magnesium on calcium indicated a higher possibility of predicting magnesium using calcium data in the catchment by the equation:

$[Mg] = 0.7917 \times [Ca] + 1.1715$, at 95% confidence interval with $R^2 = 0.9246$.

Seasonal variations of chemical parameters

In general, the seasonal variations of nutrients were higher in the rainy season than in the dry season (Table 5). The highest concentration of nitrate occurred in July (2.9 mg L^{-1}), followed by May (1.7 mg L^{-1}), all in the rainy season. Comparing dry and wet seasons using student's *t*-test on nitrate ($n = 54$) at 95% confidence level, dry season recorded the lowest nitrate with mean of 0.410 mg L^{-1}, and that of the rainy was 1.68mg L^{-1}. mg L^{-1}.

The calculated value of 5.157, exceeded the tabulated *t* value of 1.960, hence, there is a significant difference between wet and dry seasons, significant at $p < 0.001$. There was a gradual reduction in concentrations of magnesium and calcium, with the change from rainy season to dry season (Table 3), as a result of reduced erosion and runoff. From Table 3 the seasonal variations for Ca, Mg and Cl were low with variance of 4.5, 3.4 and 2.0, respectively. However, sulphate coefficient of variation was very high due to

TABLE 5

Seasonal variation of nutrients in Birim Basin (mg L^{-1})

Season	*PO_4-P mg L^{-1}*	*CV (%)*	*NO_3-N mg L^{-1}*	*CV (%)*	*NO_2-N mg L^{-1}*	*CV (%)*	*SiO_2 mg L^{-1}*	*CV (%)*
January	0.028	100	0.406	64.3	0.096	252	14.1	28.1
March	0.026	200	0.535	79.1	0.063	368	16.0	40.7
May	0.082	104	1.716	110	0.204	335	10.1	110
July	0.148	403	2.936	58.6	0.074	184	19.4	17.4
September	0.025	132	0.401	60.8	0.242	69.4	18.9	17.8
November	0.019	90	0.410	59.5	0.271	47.2	16.9	26.4

CV = Coefficient of variation.

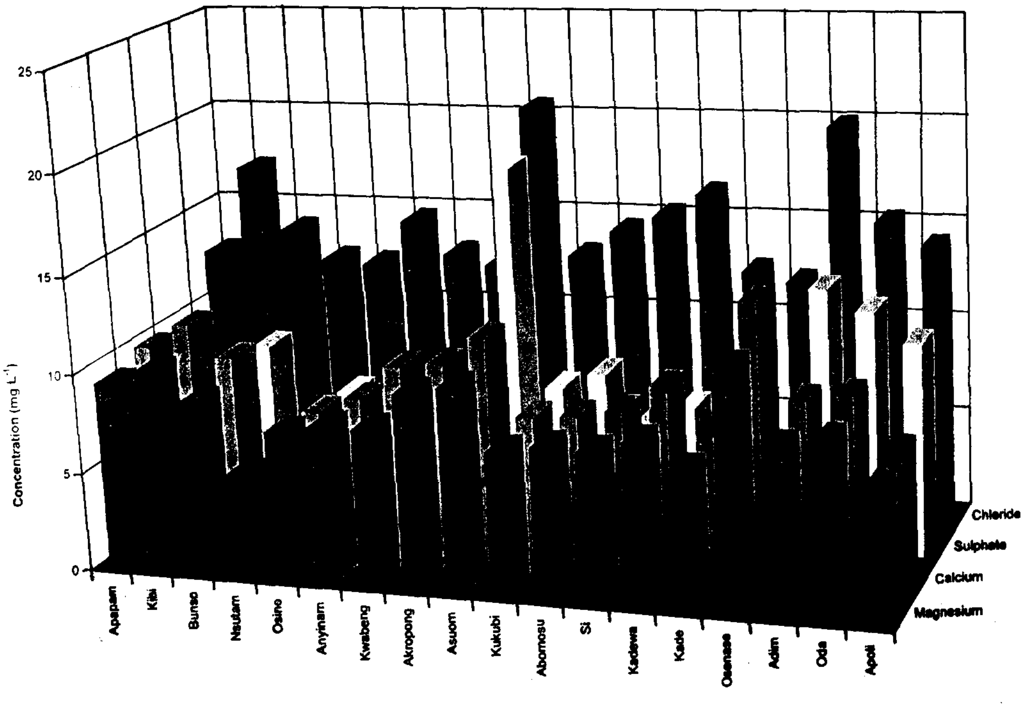

Fig. 2 Spatial distribution of Magnesium, Calcium, Sulphate and Chloride in Birim

evapotranspiration and several other factors.

The seasonal pattern of July > May > March > September > January > November for nitrates with more variations in the rainy season than the dry season were observed in the Birim catchment. Similarly, seasonal pattern of May > July > March > September > January > November, for phosphate with more variations in the rainy season than the dry season were also observed. The nutrient seasonal variations were higher in the rainy season than in the dry season as confirmed by the student's *t*-test results.

Conductivity, chloride and suspended solids

Seasonal variation for chlorides followed this pattern: May > March > July > September > January > November with standard deviation of 4.0, indicating low seasonal variation of chlorides which is an indication that there is little variations in domestic activities with changes in the seasons. From statistical analyses of the data, conductivity followed a pattern of Jan. > July > May > Nov. > Sep., with a standard deviation of 36.6. This showed the varied sources of ions with the resultant effect of evapotranspiration in the dry season.

The pattern for suspended solids on the other hand was May > Nov. > Sep. > July > Jan., attributable to the influences of alluvial flow from the mining areas, and also the nature of the terrain as well as the soil type in the basin.

Other parameters

BOD loads ranged from 15.3 at Kadewa to 4.38×10^3 kg day^{-1} in Apoli with a mean of 5.933×10^2 kg day^{-1}. The high BOD loads at Osino (1.027×10^3 kg day^{-1}), Oda (3.53×10^3 kg day^{-1}) and Apoli (4.38×10^3 kg day^{-1}) were due to excessive discharges of raw domestic and agro-industrial effluents into them. Such discharges suggest that the SS are of organic origin and possess high oxygen demand. However, the high oxygen levels at those portions of the river were due to high flow rates and the turbulent nature of the river water. The SS loads were on the average high, with a mean value of 5.068×10^3 kg day^{-1}. These high values correlated well with the high TDS values.

Heavy metals

From Table 4, copper was undetectable at all stations and 42.0% of cadmium were below the limit of detection. Pb and Zn values also fell within the background level.

Of all the river waters, 57.9% of them had excess iron (Table 4) because of the ferrigineous nature of the sediments. The high iron concentration of Kadewa, 2.73 mg L^{-1}, must have been as a result of low pH and soft nature of the river water in that area, because Fe, Cu and Pb are precipitated at high pH (Solomons and Forstner, 1984).

Analyses of rocks in Ghana (Kerbyson & Schandorf, 1966) has shown that Fe_2O_3 composition in granite is about 2.8%. This is primarily the source of Fe in surface waters. It has been shown by Langanegger (1987) and Pelig-Ba (1989) that corrosive materials contribute significantly to the amount of Fe in our waters. Of measured Mn value 84.2% exceeded the background level of 0.1 mg L^{-1} as a result of mining activities and other anthropogenic point sources.

Conclusion and recommendations

The waters were slightly acidic with pH range of 6.2-6.9. 61.1% of the pH values fell within the natural background level range of 6.5-8.5. The river waters were well oxygenated (Mean DO 7.4 mg L^{-1}) with 72.2% of the streams having DO above the natural background level range of 5.0-7.0 mg L^{-1}.

The high nutrient loads were influenced

by domestic, agricultural and industrial activities, as well as biogeo-chemical reactions in the soil. The seasonal variations of nutrients were higher in the rainy season than in the dry season.

The Birim basin showed an overall ionic dominance pattern of Ca > Mg and HCO_3 > Cl > SO_4, which was characteristic of a freshwater system because of the dominance of Ca and HCO_3.

Seasonal variations of chlorides and suspended solids were high in the rainy season and low in dry season. However, conductivity followed a different pattern with high levels at the peak of the dry season. The BOD loads indicated that the river waters were polluted downstream. Of all the river waters, 57.9% of them had excess Fe (Table 4). 84.2% of measured Mn values exceeded the background level of 0.1 mg L^{-1} as a result of mining activities and other anthropogenic point sources.

Changes in the physical and chemical properties of soil and pollution of surface and ground waters result in impacts which decrease the sustainability of the agricultural ecosystem as well as the quality of water resources and these have negative feedback on the environment. For example excessive use of chemical fertilizers has direct impact on the nitrogen-load of water supply systems. The Birim which is mainly a source of water supply to the inhabitants along its stretch should be utilised and managed on a sustainable basis. Since farmers in the basin use considerable volumes of pesticides, nematicides, fungicides and herbicides to control a variety of pests and diseases, pesticide residue analysis must be carried out to enhance better management of these agro-chemicals. Farmers should be assisted in fertilizer application by agricultural extension officers to avoid the incidence of high nutrient loads in surface waters. Environmental education should also be given to the inhabitants along the river stretch to avoid any outbreak of diseases due to continuous insanitary practices. All mining companies should have, at least, primary treatment of their effluents before discharging into any nearby surface water. Deforestation as a result of farming and fuelwood collection should be controlled to achieve sustainable use of these resources of the river basin.

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