Environ Monit Assess (2010) 161:413–422
DOI 10.1007/s10661-009-0757-4

Chemical and biological characteristics of streams in the Owabi watershed

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Received: 23 June 2008 / Accepted: 27 January 2009 / Published online: 25 February 2009

Abstract In this investigation, concentrations of physico-chemical and bacteriological qualities of water samples from the major streams within the Owabi watershed in Kumasi, Ghana, were measured at five different locations. The streams were moderately soft and neutral, having a mean pH range of 7.08 ± 0.2 to 7.88 ± 0.6. Total dissolved solids, total suspended solids, grease and oil, alkalinity, and the major ion levels varied significantly at each sampling site. Nutrient levels were however low and did not show any clear variation at sample locations. The bacteriological quality of the water was poor, rendering it unsafe for domestic purposes without treatment. The poor bacteriological quality was due to direct contamination by animal and human wastes. The streams have an appreciable self-purification capacity which is stressed by persistent pollution overloads caused by expanding human activities within the catchment. Cluster analysis performed on the data to determine pollution patterns between the streams depicts that River Owabi was less polluted, Rivers Akyeampomene and Sukobri were moderately polluted, while River Pumpunase was highly polluted.

Keywords Bacteriological · Physico-chemical · Pollution · Self-purification · Surface water

Introduction

The increasing vulnerability of natural resources and the environment to pollution is one of the grand challenges to humanity in recent times. Water, which is essential to all forms of life and makes about 50–97% of the weight of all plants and animals, is the most poorly managed resource in the world (Buchholz 1998; Fakayode 2005). About 20% of the world's population lack access to safe drinking water (UNEP 2000). The quality of surface water is constantly changing in response to daily, seasonal, and climatic rhythms. The quality of surface water also depends on the equilibrium between the physical, chemical, and biological characteristics of the surrounding environment (Svobodová et al. 1993; Langmuir 1997; Lester and Birkett 1999). The proportion of available but polluted water is continuously increasing

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as a result of changes in the modes of industrial activities, agricultural production, and increasing urbanization (Pestle 1997).

In Ghana, like in most other African countries, water resources have been under increasing threat of pollution in recent years. This is partly due to the increase in the number of human settlement lacking proper town planning along riverbanks. This applies especially to peri-urban areas, surrounding the larger metropolis of which the Owabi watershed is an example. Many such settlements have developed with no proper water supply and sanitation services and the inhabitants depend on surface water for drinking and domestic purposes (UNEP 2000; Statistical Service 2000). This creates a situation that poses a serious health risk to the people (Verma and Srivastava 1990).

The Owabi watershed is one of the most important water resources in Ghana. Apart from the fact that treated water from the reservoir serves as a source of water supply to some parts of Kumasi, the untreated water from the rivers within the watershed serve as the source of water for the rural and farming communities within the catchment area. Water from the rivers are mainly used for domestic purposes like cooking, drinking, washing, and bathing. Farmers who grow vegetables along the banks of these rivers during the dry season use the water from these rivers to water their crops (McGregor et al. 2000). The rivers also serve as sinks for industrial and domestic wastes. Pollution of the water bodies and the accompanying depletion of their resources can put the lives of humans and aquatic organisms, which depend on these rivers, in danger. Unfortunately, there is no information on the impact of human activities on the quality of water within the catchment. The purpose of this study was to assess chemical and biological pollution of the water in the major rivers within the Owabi catchment whose banks are highly subjected to human activities. Data obtained from this research will be vital for policy makers in the implementation of responsible water quality regulations, for characterizing and remediating contaminations, and for the protection of the health of humans and aquatic organisms.

Materials and methods

Description of the study area

The study was carried out on the Owabi watershed (Fig. 1), which is located within the Kumasi Metropolitan Assembly (KMA) in the Ashanti region of Ghana. Kumasi is the Ashanti regional capital and is the second largest city in Ghana. KMA is approximately 483 km north of the equator and 161 km north of the Gulf of Guinea. With over 2.5 million inhabitants, the city spans a radius of about 29 to 32 km (Statistical Service 2000). On the basis of land use, the study area can be demarcated into four categories: agriculture, human settlement, vegetation cover, and water bodies. The catchment area is densely populated because of rapid urbanization and agricultural growth during the past few decades. The rivers and their tributaries within the catchment run through some communities within the Kumasi Metropolis. The main sources of water pollution include municipal waste from suburbs like Kronum, Bremang, and Abrepo that are situated within the catchment as well as industrial effluents from small-scale industries dotted along the tributaries.

The layout of the Owabi catchment area and the sample collection points are shown in Fig. 1. The main water bodies that feed the catchment are Rivers Owabi, Sukobri, Akyeampomene, Pumpunase, and Afu. River Owabi flows through agricultural lands close to the village of Maase and then joins other tributaries from the urban area at Atafoa, a rapidly urbanizing agricultural village (McGregor et al. 2000). River Akyeampomene flows through Bremang and Suame townships. Human and developmental activities are sited very closely to the banks of this river. At Bremang, most of the drains and gutters in the entire township are channeled into the stream. River Pumpunase, originating from the Mampong range near Ampabaame, flows northwestwards through Bohyen township. It is joined by other streams before emptying into the Owabi reservoir. It carries municipal wastewater and industrial effluents from the towns and settlements through which it flows.

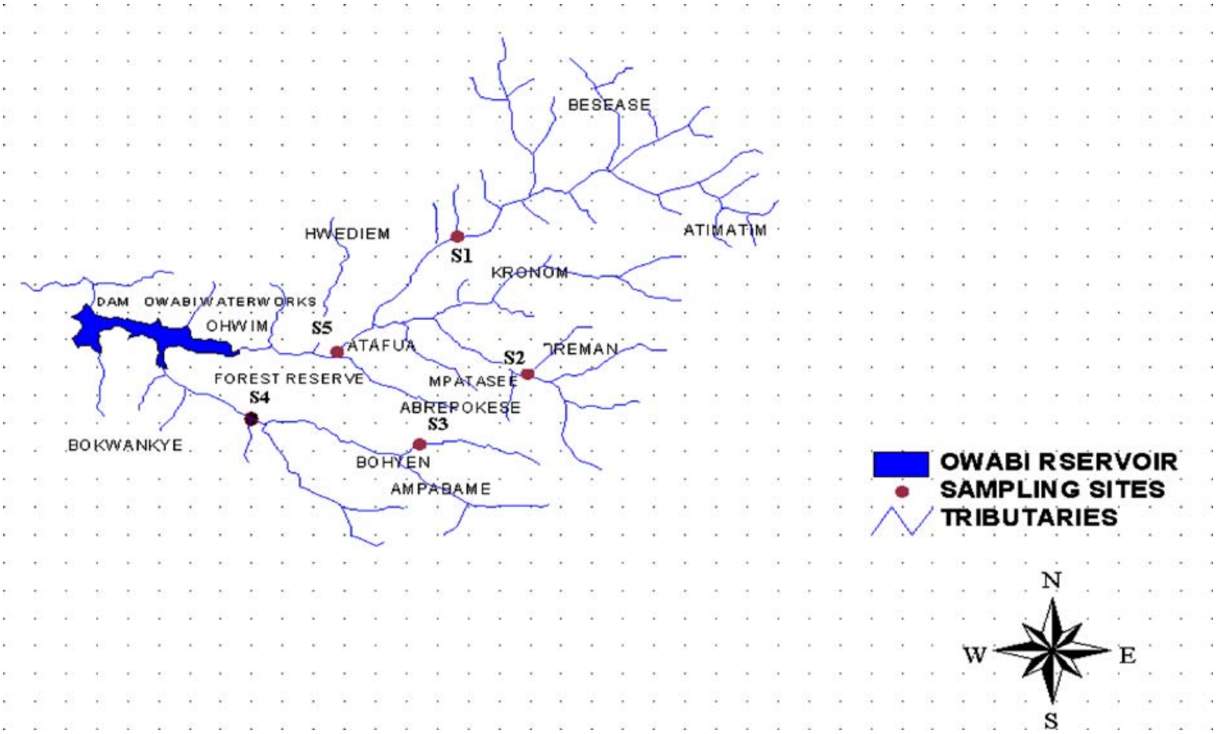

Fig. 1 Map of the study site showing the watershed and the five collection sites

Five sampling sites were chosen. These were from different community locations. Descriptions of the sampling locations are shown in Table 1.

Sample collection and analysis

Surface water samples were collected from five sites (S_1–S_5) within the watershed during the dry seasons from December 2006 to April 2007 where runoffs from hinterland were very scarce. Water samples were collected into plastic bottles previously cleaned by washing with detergent, thoroughly rinsed with tap water, soaked in 10% HNO_3 solution overnight, and finally rinsed with deionized water and dried in an oven. At the sampling sites, sample bottles were rinsed three times with the stream's water before filling. The samples were kept in an ice box and transported to the laboratory immediately and stored in the refrigerator at about 4°C prior to analysis. The pH of the water samples was measured on the field using Fisherbrand Hydrus 100 pH meter.

Table 1 Names of sampling sites, sample-collection streams, and their geographical locations

Location	River/stream	Sample site code	GPS reading
Kronum	Owabi	S_1	N:06.75838 W:001.64526
Bremang	Akyeampomene	S_2	N:06.73532 W:001.63704
Ampabaame	Pumpunase	S_3	N:06.722582 W:001.65160
Abrepo	Sukobri	S_4	N:06.71186 W:001.64004
Atafoa	Owabi	S_5	N:06.73911 W:001.66418

The procedures outlined in the Standard Methods for the Examination of Water and Wastewater (APHA.AWWA, WEF 1998) were followed for the analyses of all the chemical parameters. Samples meant for biochemical oxygen demand (BOD) determination were collected into dark brown bottles and incubated at 20°C for 5 days before analysis. The Winkler's azide modification method was used for measuring dissolved oxygen (DO) in the samples. BOD was determined as the difference between DO of sample for day 1 and day 5 for the same sample after incubation at 20°C for 5 days.

NO_3–N was measured by employing hydrazine reduction followed by spectrophotometric determination at 520 nm; NO_2–N was determined by diazotization and spectrophotometric determination at 540 nm and ammonium by reaction with alkaline salicylate in the presence of chlorine to form a blue-green indophenol complex and measured at 640 nm. Phosphate was determined by reaction with ammonium molybdate and ascorbic acid, and measured at 880 nm. Total dissolved solids (TDS) and suspended solids (TSS) were measured gravimetrically after drying in an oven at 105°C to a constant weight. Fluoride was determined by SPADNS method and total hardness, alkalinity, and chloride were determined by titrimetric methods.

Fecal coliforms were determined by most probable number (MPN) method using Oxoid CM 509 at 44°C and confirmed by MacConkey No. 3 agar (Oxoid CM115). *Escherichia coli* were confirmed by the presence of acid and gas in tryptone broth at 35°C after further incubation for 24 h (Feng et al. 2002). All reagents were analytical grade and instruments were pre-calibrated prior to measurement. Replicate analyses were carried out for each determination to ascertain reproducibility and quality assurance.

Statistical analysis

Statistical analyses of the results at each site were carried out using both Microsoft Excel 2003 Edition and Statistical Package for Social Science (SPSS) 1.30 for windows software. All errors were calculated at the 95% confidence level.

Results and discussion

The range, mean, and standard deviation of hardness and dissolved ion concentration in the streams are presented in Table 2. Calcium hardness (Ca-H) recorded a minimum concentration of 79 ± 20.3 mg/L in River Owabi at Kronum and a maximum concentration of 132 ± 22.8 mg/L in River Pumpunase at Ampabaame. Magnesium hardness (Mg-H) ranged from 20 ± 16.2 to 96 ± 30.8 mg/L. Minimum and maximum Mg-H values were reported in water samples from Kronum and Abrepo townships, respectively. Ca-H and Mg-H were combined to form total hardness (TH). TH varied from a minimum of 99 ± 24.9 mg/L to a maximum of 215 ± 87.8 mg/L in samples from Kronum and Abrepo townships, respectively. World Health Organization (WHO) recommended safe permissible limit for TH is 100–500 mg/L. TH was within permissible limit in all the samples. Ca-H and Mg-H were also within their permissible limits in all the streams. Chloride (Cl^-) varied from a minimum of 37 ± 16.4 mg/L

Table 2 Range, mean, and SD of total hardness and dissolved ion concentrations of the water samples during the sampling period

Parameters/sites	Total hardness (mg/L)	Ca-H (mg/L)	Mg-H (mg/L)	SO_4^{2-}(mg/L)	Cl^-(mg/L)	F^-(mg/L)
S_1; range	60–125	56–101	2–44	12.1–32.0	18–61	0.21–0.40
Mean ± SD	99 ± 24.9	79 ± 20.3	20 ± 16.2	19.43 ± 6.6	37 ± 16.4	0.33 ± 0.06
S_2; range	114–190	68–160	14–112	48.0–92.0	76–96	0.40–0.65
Mean ± SD	148 ± 33.1	105 ± 32.8	44 ± 36	64.4 ± 16.5	83 ± 7	0.51 ± 0.08
S_3; range	164–182	100–164	4.0–80.5	48–91	136–181	0.65–0.85
Mean ± SD	172 ± 8.0	132 ± 22.8	40 ± 25.9	61.6 ± 15.9	157 ± 15.2	0.7 ± 0.07
S_4; range	160–382	80–156	28.0–278.0	31–71	90–121	0.45–0.65
Mean ± SD	215 ± 87.8	121 ± 27.8	96 ± 30.8	39.8 ± 16.2	10 ± 10.7	0.57 ± 0.07
S_5; range	100–182	76–130	19–54	22.6–41.0	40–72	0.03–0.32
Mean ± SD	136 ± 28.4	106 ± 19.1	39 ± 11.8	27.65 ± 6.9	58 ± 11.5	0.13 ± 0.12
Natural Background	–	12	1–99	0.1–10	7.8	–
WHO limit	500	75	30	250	250	1.5

recorded from Kronum township to a maximum of 157 ± 15.2 mg/L observed from Ampabaame township. The chloride content was lower than permissible limit (250 mg/L) in all the samples. High content of chloride gives a salty taste to the water. Sulfates (SO_4^{2-}) recorded a mean minimum of 19.43 ± 6.6 mg/L from Kronum and maximum of 64.4 ± 16.5 mg/L from Bremang. These levels were lower than WHO permissible levels. The streams within the catchment had low fluoride ion concentrations and were below the WHO maximum acceptable limits (1.5 mg/L) for drinking and domestic water. The maximum and minimum concentrations were recorded in R. Pumpunase (0.73 ± 0.02 mg/L) and R. Owabi at Atafoa (0.13 ± 0.04 mg/L), respectively.

The patterns of ionic dominance in all the streams were different except that of R. Owabi sampled at Kronum and Atafoa which had the same ionic dominance pattern of calcium > chloride > magnesium > sulfate. Generally, ionic dominance of the Owabi catchment was in contrast with the ionic dominance pattern of calcium > magnesium > sulfate > chloride for freshwater (Burton and Liss 1976; Stumn and Morgan 1981). The dominance of chloride over sulfate could be mainly due to domestic and anthropogenic point sources (Ansa-Asare and Asante 2005; Karikari and Ansa-Asare 2006). The dominance of calcium over the other ions in all five streams except R. Pumpunase reflects a true picture of most tropical freshwaters (Karikari and Bosque-Hamilton 2004).

The stream water samples exhibited an alkaline pH. The mean pH values of water samples from the streams varied between 7.08 ± 0.24 at site S_1 and 7.88 ± 0.61 at site S_3 during the sampling period (Table 3). No significant difference was noticed in the observed pH ranges at each site and the variation due to change in sampling location was also not significant. The WHO range for pH in water for domestic use is 6.5 to 8.5 (WHO 2003). All of the values of pH obtained for the streams fell within this range but were slightly above the natural background level of 7.0. This increase in pH of the water samples above the normal background levels may be due to the presence of dissolved carbonates and bicarbonates which are known to affect pH of almost all surface water (Chapman 1996).

TDS is a common indicator of polluted waters (Tay 2007). The mean levels of TDS measured in the samples varied between 119 ± 57.6 and 572 ± 38.9 mg/L in Owabi River sampled from Kronum and Pumpunase River from Ampabaame, respectively (Table 3). The TDS levels at each sampling site differed significantly and the variation due to change in sampling location was also significant ($p < 0.05$). All the values were below the minimum standard (1,000 mg/L) set by the WHO. The values did not exceed the critical value above which some long-term health problems might be anticipated (Kempster et al. 1997). According to MacCutcheon et al. (1983), the palatability of water with TDS level less than 600 mg/L is generally considered to be good, whereas water with TDS

Table 3 Range, mean, and SD of particulates and oil and grease levels of the water samples during the sampling period

Parameter/sites	pH	TDS (mg/L)	TSS (mg/L)	Alkalinity (mg/L)	Oil and grease (mg/L)
S_1; range	6.75–7.40	28–197	16.0–38.3	156–212	195.2–600.3
Mean ± SD	7.08 ± 0.02	119 ± 57.6	24.76 ± 9.3	173 ± 24	398.3 ± 170.5
S_2; range	7.20–7.92	28–401	450–960	239–474	56–82
Mean ± SD	7.56 ± 0.3	275 ± 146	58.9 ± 19.5	328 ± 83.1	68.2 ± 8.7
S_3; range	7.10–8.81	31–855	28–472	420–841	80.5–121.1
Mean ± SD	7.88 ± 0.6	572 ± 38.9	179 ± 160.5	608 ± 151.3	98.6 ± 16.4
S_4; range	7.35–7.93	28–558	150–77.0	320–681	230.1–302.0
Mean ± SD	7.55 ± 0.2	351 ± 209.1	34.74 ± 23.3	485 ± 141.4	254.7 ± 34.5
S_5; range	7.30–7.67	26–253	10.0–26.9	180–324	14.4–66.0
Mean ± SD	7.57 ± 0.1	169 ± 90.6	17.48 ± 5.4	251 ± 57.7	35.8 ± 22.6
Natural Background	7.0	–	–	–	–
WHO limit	6.60–8.50	1,000	20	400	10

greater than 1,200 mg/L becomes increasingly unpalatable. Hence, the water from the streams could be considered palatable since the average TDS for all the streams were less than 600 mg/L.

The mean TSS values ranged from 17.48 ± 1.7 to 179.3 ± 50.8 mg/L. The highest mean value was recorded for R. Pumpunase while R. Owabi (Atafoa) recorded the least. The values differed significantly from one location to another ($p <$ 0.05). The results showed that the levels of TSS in the samples, except that of River Pumpunase, were above the WHO recommended value of less than 20 mg/L. River Pumpunase recorded the highest mean alkalinity (608 ± 47.9 mg/L) while R. Owabi (Kronum) recorded the lowest (173 ± 7.6 mg/L). These values indicate that the streams have a good buffering capacity.

All the streams recorded mean concentrations of oil and grease above the WHO maximum permissible levels of 10 mg/L for water for domestic use. R. Owabi sampled at Atafoa recorded the minimum value of 35.8 ± 7.1 mg/L while the maximum value of 398.3 ± 53.9 mg/L was recorded in R. Owabi at Kronum. The high concentrations of grease and oil in the rivers were the result of human activities such as fuel service stations, auto-mechanic workshops, and car washing bays scattered along the stream banks and nearby locations within the catchment area.

Concentrations of nutrients and dissolved oxygen (DO) are shown in Table 4. The DO levels did not differ significantly from one location to another ($p <$ 0.05), being lowest in the samples from S_3 with a mean value of 0.37 ± 0.18 mg/L and highest at S_1 (1.99 ± 1.44 mg/L). The low DO values at the various sampling points might be attributed to the fact that the waste discharge within the watershed contains high concentration of organic matter and nutrients that are highly oxygen demanding (Chapman 1996). DO concentration in unpolluted water is normally about 8–10 mg/L at 25°C (DFID 1999). Concentrations below 5 mg/L adversely affect aquatic life. The low levels of DO in the streams, therefore, make them unsuitable to support aquatic ecosystem.

The levels of biochemical oxygen demand (BOD) varied significantly at each sampling site and the variation due to change in sampling location was also significant ($p <$ 0.05). The mean values recorded (Table 4) for all the water samples were far above the 3 mg/L recommended limit for natural waters (WHO 2004). River Pumpunase sampled at Ampabaame with the lowest mean DO value registered the highest mean BOD value of 423.9 ± 13.3 mg/L and R. Owabi sampled at Kronum had the lowest value of 19.42 ± 4.0 mg/L. The high BOD levels suggest that the pollution of the stream is more of organic origin. Compared to average concentrations in urban streams in Ghana, the mean BOD values obtained for these streams were similar to those reported from samples from the Korle Lagoon (153.02 mg/L) in Accra and the Subin River (161.029 mg/L) in Kumasi (Obiri-Danso et al. 2005).

NO_3–N, NO_2–N, and NH_4–N are considered to be non-cumulative toxins (Dallas and

Table 4 Range, mean, and SD of nutrient BOD and DO levels of the streams during the sampling period

Parameter/site s	NO_2–N (mg/L)	NO_3–N (mg/L)	NH_4–N (mg/L)	PO_4^{3-}(mg/L)	BOD (mg/L	DO (mg/L)
S_1; range	0.0–0.03	0.01–0.17	0.0–0.03	0.12–0.93	5–36	0.4–4.4
Mean ± SD	0.009 ± 0.01	0.098 ± 0.04	0.014 ± 0.007	0.76 ± 0.2	19.42 ± 12.75	1.91 ± 1.44
S_2; range	0.002–0.006	ND–0.25	0.01–0.03	3.8–4.42	53–109	1.3–3.5
Mean ± SD	0.003 ± 0.001	0.14 ± 0.09	0.016 ± 0.007	4.08 ± 0.21	80.8 ± 22.87	2.06 ± 0.81
S_3; range	ND–0.01	ND–0.24	0.0–0.02	2.1–2.7	385–501	0.2–0.7
Mean ± SD	0.004 ± 0.004	0.123 ± 0.09	0.011 ± 0.006	2.43 ± 0.18	423.9 ± 42.10	0.37 ± 0.18
S_4; range	ND–0.06	0.09–0.44	0.01–0.04	2.25–3.17	69–192	0.2–1.5
Mean ± SD	0.002 ± 0.001	0.24 ± 0.12	0.019 ± 0.01	2.632 ± 0.36	102 ± 47.93	0.66 ± 0.58
S_5; range	0.01–0.012	0.07–0.86	0.01–0.04	4.3–11.20	20–42	0.7–2.2
Mean ± SD	0.007 ± 0.047	0.32 ± 0.29	0.031 ± 0.03	7.916 ± 2.41	28 ± 8.33	1.35 ± 0.60
Natural Background	–	0.23	–	0.02	1–3	7
WHO limit	1.0	10.0	1.5	< 0.3	< 3	–

Day 1993). High concentrations of NO_3–N and NO_2–N are potential health risks, particularly in pregnant women and infants under 6 years of age (Kempster et al. 1997). NO_3–N at elevated concentrations can cause cyanosis in infants. Taste and odor problems may arise when the NH_4–H level is greater than 2 mg/L. All the streams in the catchment recorded NO_3–N, NO_2–N, and NH_4–N concentrations lower than the WHO permissible limit for drinking water. The result is presented in Table 4. The patterns of nitrate and nitrite concentrations did not follow any particular order. Apart from S_5, all the sampling sites showed an increase in nitrite concentration from March to April, which could be a result of human activities around these areas.

The Owabi River (Atafoa) registered the highest mean phosphate concentration of 7.916 ± 0.76 mg/L while samples from Kronum recorded the lowest (0.764 ± 0.08 mg/L). All the values were above the WHO recommended levels of less than 0.3 mg/L. High concentration of phosphate in water bodies is an indication of pollution and is largely responsible for eutrophication (MacCutcheon et al. 1983). The high phosphate levels in all the streams may have come from small-scale farming activities found along the banks of the streams (Sharpley et al. 1987). The levels of phosphate in the streams suggest that the untreated water could not be recommended for drinking and other domestic purposes. Phosphate is an essential component of biological cycles and promotes algal growth in the water bodies. The high phosphate levels recorded for these streams are a threat to the survival of the streams.

Generally, concentrations of nutrients in the streams were low which could probably be as a result of low runoffs since this work was done in the dry season. Ansa-Asare and Asante (1998) reported that there is a general decrease in nutrient concentration in the dry season. Of all the nutrients, phosphorus was exceptionally high in all the streams. The ratio of N:P in the streams ranged from 1:29 in R. Akyeampomene at Bremang to 1:7 in R. Owabi at Kronum. These high phosphorus levels indicate higher algal blooms in the streams, which could lead to eutrophication. The high phosphate levels in the streams may be attributed to phosphate-rich sewage material from the town and the banks that are dumped into the streams (MacCutcheon et al. 1983). It could also come from drains rich in detergents (Akpabli and Drah 2001). The streams are dammed, abstracted, and treated to supply water to parts of Kumasi and its environs. Eutrophication could increase water treatment cost through filter clogging in water treatment works.

The results obtained for microbial analysis are shown in Table 5. Fecal coliform and *E. coli* pollution were widespread, and the entire watershed is not suitable for domestic use without treatment. For agricultural purposes, vegetables watered with these streams may be contaminated. The logarithmic mean fecal coliform count ranged between 10.87 ± 0.36 MPN/100 mL and 13.07 ± 0.29 MPN/100 mL for River Akyeampomene sampled at Bremang and River Pumpunase sampled at Ampabaame, respectively. The high fecal coliform counts in the streams are signs of biological contamination of the streams by pathogens. The high fecal coliform levels observed make the streams unsuitable for swimming, boating, and fishing (WHO 2004; Millipore 1991). It also indicates significant health risks to humans and other aquatic animals. The highest *E. coli* concentration was recorded in R. Owabi (Atafoa) at a logarithmic mean of 11.32 ± 0.27 MPN/100 mL and the least was observed in R. Akyeampomene at a logarithmic mean of 9.61 ± 0.3 MPN/100 mL. High *E. coli* counts detected in the streams

Table 5 Range, mean, and standard deviation of fecal coliform and *E. coli* concentrations of the feeding streams of Owabi reservoir during the sampling period

Parameter/site	Fecal coliform (MPNLog/100 mL)	*E. coli* (MPNLog/100 mL)
S_1; range	10.18–13.96	8.32–11.86
Mean ± SD	11.88 ± 1.38	10.04 ± 1.20
S_2; range	9.32–12.86	8.18–10.86
Mean ± SD	10.87 ± 1.15	9.61 ± 0.96
S_3; range	11.32–14.37	9.96–11.96
Mean ± SD	13.07 ± 0.93	(10.68 ± 0.22)
S_4; range	10.96–12.62	8.86–11.86
Mean ± SD	11.65 ± 0.53	9.83 ± 0.94
S_5; range	12.62–13.96	9.32–12.32
Mean ± SD	13.45 ± 0.47	11.32 ± 0.86
WHO limit	0	Absent

indicated heavy pollution. The results suggest that the general sanitary qualities of the water in the catchment, as indicated by fecal coliform and *E. coli* counts, are unacceptable. For water to be considered as no risk to human health, the fecal coliform and *E. coli* count/100 mL should be zero (WHO 2004). The poor microbial quality might be due to contamination caused by human activities and livestock that graze along the banks of the rivers.

Self-purification is the ability of water bodies (streams) to reduce or eliminate the undesirable contaminants (Mehrdadi et al. 2006). The pollutants in R. Owabi sampled at Kronum (upstream), were compared with R. Owabi sampled at Atafoa (downstream) using the Student's *t* test. Five parameters decreased in concentration from upstream to downstream. Out of the five parameters, DO did not decrease significantly. The remaining parameters (grease and oil, F^-, NO_2^-, and TSS) decreased significantly in their concentrations downstream ($p < 0.01$). The Owabi River exhibited a high self-purification capacity for these parameters. This means that the Owabi River has a high self-purification capacity for these parameters and that it can purify itself when it is polluted upstream. However, 13 parameters showed an increase in concentration downstream. Out of the 13 parameters, only five (TDS, alkalinity, NO_3^-, PO_4^{3-}, and fecal coliform) recorded significant increase ($p > 0.05$). This stream does not have the ability to purify itself completely when polluted upstream.

River Pumpunase (upstream) was also compared with River Sukobri (downstream) to determine the self-purification capacity of the stream. Eight parameters decreased in concentration as the water flowed downstream. Only TSS and NO_2^- showed a significant decrease in concentration ($p < 0.05$). Ten parameters showed increase in concentrations when the stream flowed downstream. TH, DO, Mg-H, PO_4^{3-}, and grease and oil showed significant increase ($p > 0.05$) downstream. The Sukobri River showed self-purification ability when it flows downstream.

Although the streams have an appreciable self-purification capacity, the capacity is strained by persistent pollution overloads. The pollution plight of the streams is because they are flanked by expanding human settlements; institutional and socio-economic activities are also scattered chaotically within the catchment.

In order to detect similarities in terms of pollution between the streams, cluster analysis was performed on the available dataset. As shown in Fig. 2, dendrogram of cluster analysis depicts three distinct clusters, namely, less polluted, moderately polluted, and highly polluted. Cluster 1 consisting of R. Owabi at Kronum and Atafoa sampling points is said to be less polluted. This area is characterized by small-scale farming activities which are scarcely practiced during the dry season. Cluster 2 comprises of R. Akyeampomene and R. Sukobri. R. Akyeampomene passes through Suame light industrial area which is noted for high discharge of domestic waste due to improper sanitation and discharges from automobile workshops. This cluster was moderately polluted. The third cluster represents R. Pumpunase which showed a marked pollution level in this study. River Pumpunase is located at Ampabaame, just adjacent to an Islamic Senior High School. Pollution from drains from the school, human settlements, and miscellaneous

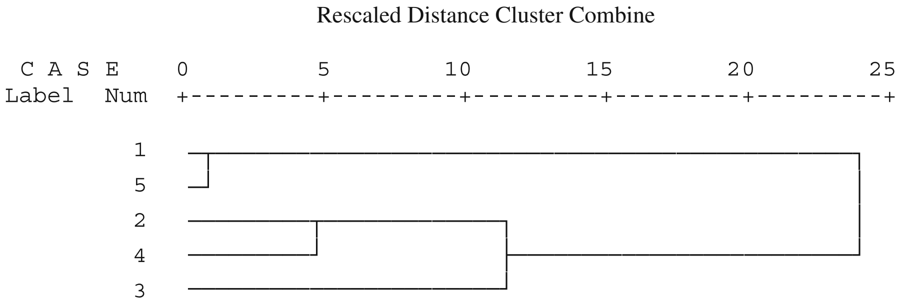

Fig. 2 Dendrogram showing spatial similarity and site groupings according to surface water quality characteristics of the streams within the catchment area

activities along the banks could account for the relatively high pollution levels of the stream.

Conclusion

The results indicated that most of the physicochemical quality parameters of the major rivers sampled were within the WHO limits for drinking water and, therefore, may be suitable for domestic purposes. In contrast, the bacteriological quality of the water points, as suggested by the fecal coliform and *E. coli* counts, far exceeded the WHO standard for potable water. In general, the bacteriological quality of the water was unacceptable, and would pose serious health risks to consumers who use them without treatment. The poor bacteriological quality was due to direct contamination by animal and human wastes.

Self-purification abilities of streams revealed that, although the streams have an appreciable self-purification capacity, the capacity is stressed by persistent pollution overloads along the cause of water flow by expanding human activities. Results of cluster analysis on pollution distribution patterns of the streams suggested that River Pumpunase located at Ampabaame was the most polluted.

Acknowledgements The authors are grateful to the management and staff of Ghana Water Company Limited, Kumasi, for allowing the use of some equipment in their laboratory for this work.

References

Ansa-Asare, O. D., & Asante, K. A. (1998). A comparative study of the nutrient status of two reservoirs in southeast Ghana. *Lakes and Reservoirs, Research and Management, 3*, 205–217. doi:10.1046/j.1440-1770.1998.00074.x.

Ansa-Asare, O. D., & Asante, K. A. (2005). The water quality of Birim Stream in South-East of Ghana. *West African Journal of Applied Ecology, 8*, 23–34.

Akpabli, C. K., & Drah, G. K. (2001). Water quality of the main tributaries of the Densu Stream. *Journal of the Ghana Science Association, 3*(2), 84–94.

APHA.AWWA, WEF (1998). *Standard methods for the examination of water and wastewater* (20th ed.). Washington, DC: APHA.

Buchholz, R. A. (1998). *Principles of environmental management. The greening of business* (2nd ed.). London: Prentice-Hall.

Burton, J. D., & Liss, P. S. (1976). *Estuarine chemistry*. New York: Academic. 7:229.

Chapman, D. (1996). *Water quality assessment. A guide to the used of biota, sediments and water in environmental monitoring* (2nd ed.). London: E. and F. N. Spon.

Dallas, H. F., & Day, J. A. (1993). *The effect of water quality variables on rivers and ecosystems.* Water Research Monitoring Commission report No. TT 61/93. South Africa.

DFID (1999). A Simple Methodology for Water Quality Monitoring. Report OD 142 (KAR Project R6662). In G. R. Pearce, M. R. Chandhry, & S. Ghulum (Eds.), *A simple methodology for water quality monitoring* (p. 16). HR Wallingford: UK.

Feng, P., Weagant, S. D., & Grant, M. A. (2002). *Enumeration of Escherichia coli and the Coliform Bacteria.* US FDA/CFSAN.

Fakayode, S. O. (2005). Impact of industrial effluents on water quality of the receiving Alaro River in Ibadan, Nigeria. *AJEAM-RAGEE, 10*, 1–13.

Karikari, A. Y., & Ansa-Asare, O. D. (2006). Physico-chemical and microbial water quality assessment of Densu Stream of Ghana. *West African Journal of Applied Ecology, 10*(10), 158.

Karikari, A. Y., & Bosque-Hamilton, E. K. (2004). The water quality of Lake Bosomtwi and its feeder streams. *Journal of the Ghana Science Association, 6*, 117–127.

Kempster, P. L., Van Vliet, H. R., & Kuhn, A. (1997). The need for guide to bridge the gap between ideal drinking water quality and quality which is practicable, available and acceptable. *Water South Africa, 23*(20), 163–167.

Langmuir, D. (1997). *Aqueous environmental geochemistry.* Upper Saddle River: Prentice-Hall.

Lester, J. N., & Birkett, J. W. (1999). *Microbiology and chemistry for environmental scientists and engineers* (2nd ed.) New York: E and FN Spon. Management, Office of Water Quality, Assessment Branch, Surveys Section, Indianapolis.

MacCutcheon, S. C., Martin, J. L., & Barnwell, T. O., Jr. (1983). Water quality. In *Handbook of hydrology.* New York: McGraw-Hill.

McGregor, D. F. M., Thompson, D. A., & Simon, D. (2000). *Water quality and management in peri-urban Kumasi, Ghana.* Case Study 16 inland-water linkages in rural watersheds. Rome: FAO. Electronic workshop.

Mehrdadi, N., Ghobadi, M., Nasrabadi, T., & Hoveidi, H. (2006). Evaluation of the quality and self purification potential of Tajan Stream using QUAL2E Model. *Iranian Journal of Environmental Health Science and Engineering, 3*(3), 199–204.

Millipore. (1991). *Water microbiology. Laboratories and field procedures* (p. 32). Bedford: Millipore.

Obiri-Danso, K., Weobong, C. A. A., & Jones, K. (2005). Aspects of health-related microbiology of the Subin, an urban stream in Kumasi, Ghana. *Journal of Water and Health, 3*, 69–76.

Pestle, S. (1997). Fairing water scarcities. *World Watch Environmental Alert Series, 38,* 239.

Sharpley, A. N., Smith, S. J., & Naney, J. W. (1987). The environmental impact of agricultural nitrogen and phosphorus use. *Journal of Agricultural and Food Chemistry, 35,* 812–817. doi:10.1021/jf00077a043.

Statistical Service (2000). *Ghana population and housing census, statistical service.* Accra: Ghana Publishing.

Stumn, W., & Morgan, J. J. (1981). *Aquatic chemistry* (p. 780). New York: Willey.

Svobodová, Z., Lloyd, R., Máchová, J., & Vykusová, B. (1993). *Water quality and fish health.* EIFAC Technical paper No. 54. FAO.

Tay, C. K. (2007). Chemical characteristics of groundwater in the Akatsi and Ketu Districts of the Volta Region, Ghana. *West African Journal of Applied Ecology, 11*, 3–25.

UNEP (2000). *Global Environmental Outlook*, United Nations Environment Programme Global State of the Environment Report, 2000.

Verma, B. L., & Srivastava, R. N. (1990). Measurement of the personal cost of illness due to some major water-related issues in an Indian rural population. *International Journal of Epidemiology, 19*, 169–176. doi:10.1093/ije/19.1.169.

WHO (2003). *Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization. WHO/SDE/WSH/03.04

WHO (2004). *Guidelines for drinking water quality (Addendum).* Geneva. www.who.int/water_sanitation-health/publications/facts2004/en/index.html