An assessment of Environmental Conditions and the Benthic Fauna of the Odaw River Basin

E. D. O. Ansa[1]*, R. L. Sakyi[1], M. H. Asmah[1], M. A. Acheampong[2] and E. Lamptey[3]

[1.] *CSIR Water Research Institute, Env. Biol. and Health Div., P. O. Box AH 38, Achimota, Accra, Ghana*

[2.] *Kumasi Technical University, Faculty of Chemical Engineering and Technology, Department. of Chemical Engineering, P.O. Box 854, Kumasi, Ghana*

[3.] *University of Ghana, Department of Marine Sciences, Legon, Accra, Ghana*

*Corresponding author, E-mail: *edoansa@yahoo.com*

Abstract

The Odaw River is formed from several streams running from the Aburi Mountains in the Eastern Region of Ghana and ending up in the Korle Lagoon in Accra. Human activities have modified the course of this channel resulting in changes in water quality. This study was therefore conducted to investigate the extent of impact on macro-fauna communities by comparing the results with similar studies carried out in previous years. Faunal abundance and the similarity of macro-fauna among sampling stations for each season were respectively investigated by one-way analysis of similarity (ANOSIM) and cluster analysis all based on Bray-Curtis similarity index of species abundance. The Odaw River was found to be highly polluted, showing a pollution gradient from upstream to downstream, the upstream being the least polluted. Shannon-Wiener diversity index upstream was 0.53–2.00, midstream 0.64–1.41 and downstream had the least ranging from 0–0.04. Sensitive taxa of Dytiscidae, Hydropsychidae and Libellulidae were found only upstream from Obommirem to Buade. The mid portion of the Odaw catchment area were dominated by Oligochaeta, Naedidae and Lymnaea while the lower portion was dominated by the Chironomidae. There was no seasonal variation in the physico-chemical parameters analysed except for phosphate which showed significantly higher concentrations in the dry season than in the rainy season. The distribution of invertebrates did not also show seasonal variation in abundance between sampling stations suggesting good adaptation of prevailing species to small changes in water quality. Midstream and lower stream portions of the catchment area showed increased pollution over the years when previous studies were compared. This study shows that prevailing macro-fauna can be used to characterize sites of differing water qualities.

Introduction

Increased population growth puts intense pressure on water resources which tend to impact negatively on the environment (Lücke and Johnson, 2009). Urbanization has been shown to alter the physical and chemical characteristics of streams and cause significant degradation of invertebrate assemblages (Carlson *et al*., 2013).

Macro invertebrate communities are the most commonly used group in biological surveys and monitoring of water quality (Hellawell, 1978). Their direct linkages to the energy pathways in aquatic environments have made them useful as organic pollution indicators (Johnson *et al*., 1993). Some recent studies have shown a graded response of macro-invertebrates to a wide spectrum of

West African Journal of Applied Ecology, vol. **25**(2), 2017: 17–29.

chemical pollutants including heavy metals (De Jonge *et. al.*, 2008).

In Ghana, there has been some effort to document the ecology, composition, spatial and temporal distribution and diversity of fish and macro benthic invertebrate communities of lakes, rivers, and lagoons (Hynes, 1975; Thorne *et al.*, 2000; Aggrey-Fynn *et al.*, 2011; Armah *et al.*, 2012; Kyerematen and Gordon, 2012; Baa-Poku *et al.*, 2013; Aheto *et al.*, 2014). One such river system that has received some attention is the Odaw River system which flows through the capital city Accra, from the Aburi highlands, in the Eastern Region of Ghana. The Odaw River is used mainly as a source of domestic water supply upstream and midstream. Extraction of water from the river for commercial purposes such as car washing and cement block manufacturing is also not uncommon. Downstream in the Greater-Accra Region, particularly in the Airport Residential Area, it is an important source of water and nutrients for vegetable crop production. Previous investigations on this channel focused mainly on the physico-chemical characteristics of the river and particularly on the adjoining lagoon, the Korle Lagoon (Biney and Amuzu, 1995). Some bio-monitoring surveys have also been carried out on the river. Thorne *et. al.* (2000) investigated the macro-invertebrate communities found in some portions of the river. Baa-Poku *et al.* (2013) also focused on the impact of urban effluents on macro-invertebrate communities in one of its polluted tributaries, the Nima Creek. The study seeks to evaluate potential changes in the ecology of macro-fauna, particularly the benthic fauna of the catchment area of the Odaw River over the years, in relation to its present use.

Materials and methods

The study area

The Odaw catchment area runs from the Aburi Mountains (latitude 5^{o} 52'N) down to Accra (latitude 5^{o} 32'N) where it discharges into the Korle Lagoon. The river is located within longitudes 0^{o} 10'W and 0^{o}15'W and consists of six streams namely; Ntare, Obommirem, Dakobi, Buade, Onyasia and Odaw, as well as two other streams running from East Legon and from behind Shangri-la hotel (Fig. 1). Thirteen sampling stations were selected along the catchment area and these were categorized as upstream, midstream downstream based on categorization adopted by previous studies in the Odaw catchment area (Nana-Amankwah *et al.*, 1995; Thorne *et al.*, 2000; Baa-Poku *et al.*, 2013). Samples were collected from upstream: Obommirem (OB), Agyemadi (AG), Ntare (NT), Dakobi1 (DK1), Buade (BU), and Dakobi 2 (DK2), midstream: Atomic (AT), Okponglo (OKP), Secaps (SEC) and downstream: Alliance Francais (AF), Kawukudi (KKD), Achimota (ACH), and Korle (KO).

The rivers and streams at these locations were all less than 1.0 m deep in both dry and wet seasons and have varied banks ranging from a vegetative cover of shrubs and herbs to bare banks. From Achimota to the Korle Lagoon, the channels consist of concrete drains.

Water quality sampling

Samples for water quality analysis were collected in 1 litre polyethylene bottles.

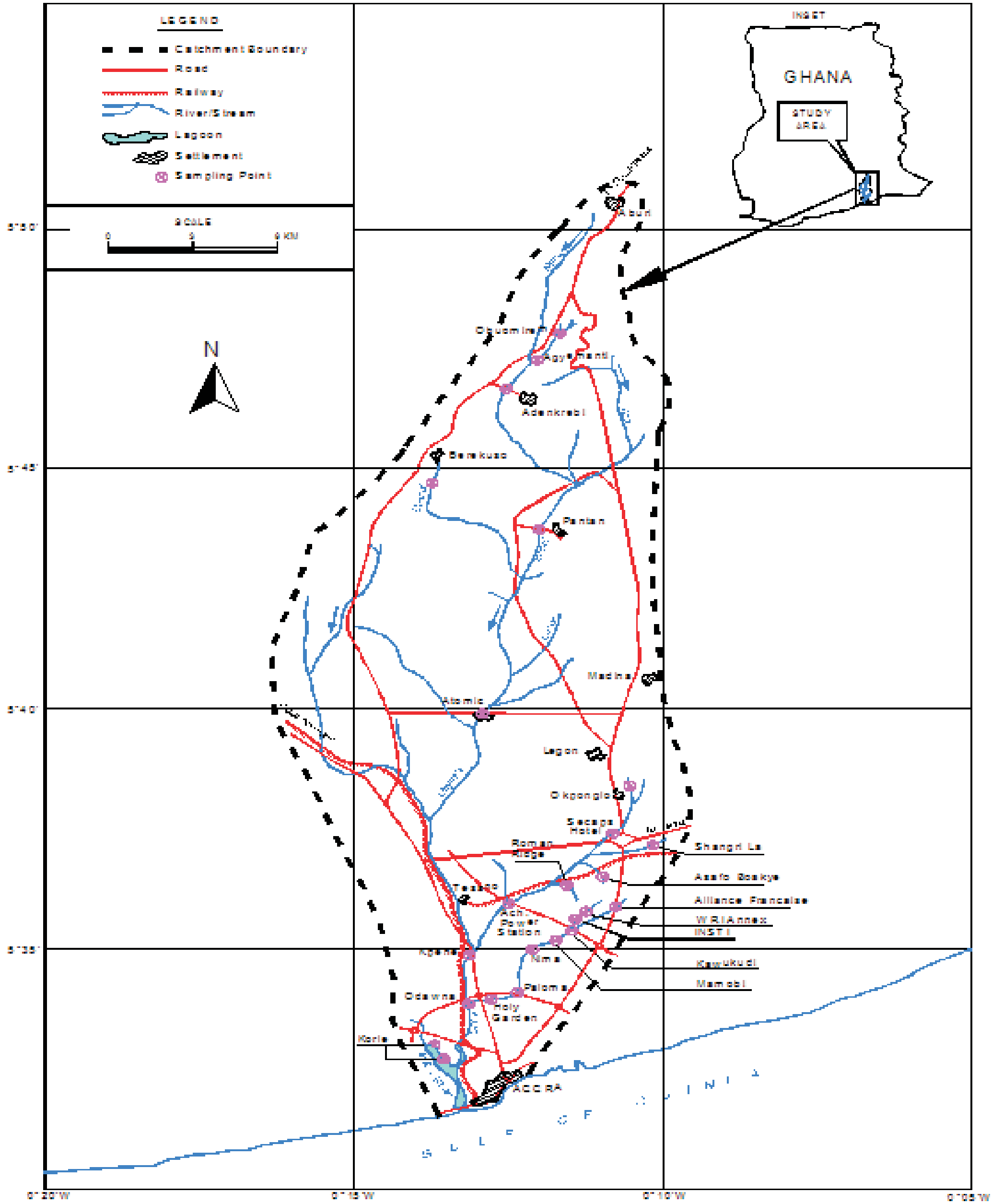

Fig. 1. Map showing the Study Area

Samples were collected both in the dry (November to February) and the rainy (March to August) seasons. Analyses were carried out for the following physico-chemical parameters: temperature, pH, conductivity, turbidity, Biochemical Oxygen Demand (BOD), dissolved oxygen (DO), total suspended solids (TSS), nitrate (NO_3^-), nitrite (NO_2^{2-}), ammonia as nitrogen (NH_4-N), and phosphate (PO_4). BOD, TSS, nitrate, nitrite, ammonia nitrogen and phosphate concentrations were determined by dilution, gravimetric, hydrazine reduction, direct nesslerization and stannous chloride methods respectively as outlined in Standard Methods (APHA, 1998). pH, dissolved oxygen, turbidity and conductivity were measured using WTW 340, WTW Oxi 330, Hach 2100p and WTW LF 340 portable meters respectively.

Sampling of fish and macro-invertebrates

Sampling for fish was done in the rainy and dry seasons using cast nets of 1.2m radius as outlined by Stein *et al.* (2014). Sampling of macro-invertebrates was done by means of a handnet of 500mm mesh size over a defined area. Four replicates per sampling station were used and selection of sampling stations was based on ease of access to the shoreline, and also taking into consideration point sources of pollution. Where rocks existed, they were washed to dislodge attached fauna, which were transferred into containers. Animals retained by net were also washed into containers. Samples were then preserved with 4% formalin in the field. Samples were further processed in the laboratory, and organisms identified up to the family level with the help of taxonomic keys (Thorp and Covich, 2010; Umar *et al.*, 2013).

Statistical analysis

The Shannon-Wiener diversity index (H') (Eq.1), (Clarke &Warwick, 1994), was used to compare the macro-invertebrates of this study with those of studies conducted by other authors over the years, while the Simpson diversity index (Ludwig and Reynolds, 1988) was used to compare the seasonal differences in diversity of macro-invertebrates sampled during this study.

The Shannon Weiner diversity index (H') is given by,

$$H' = \sum_{i=1}^{n} P_i \ln P_i \qquad \text{(Eq.1)}$$

where P_i is the proportion of individuals belonging to the ith species and n is the total number of species

The Simpson diversity index (λ) is given by,

$$\lambda = \Sigma n_i(n_i-1)/N(N-1) \qquad \text{(Eq. 2).}$$

where N = total number of individuals and n_i = total number of individuals in species *i*. Simpson's diversity index λ takes values from 0 to 1 and is inversely proportional to the wealth of species (Hellawell, 1978). Brower and Zar (1977) indicated that in comparing two communities with very small differences in λ, the reciprocal of λ gives a better measure of diversity.

To evaluate the influence of seasonal variations on physico-chemical variables, a Welsh unequal variances t-Test was conducted. The influence of seasonal variation on species abundance at the various sampling stations was assessed using the Analysis of Similarity (ANOSIM) test (Clarke, 1993) of the PRIMER software package (Clarke and Warwick 1994). The spatial relationships between sampling stations was shown by Non-metric Multidimensional Scaling (nMDS) carried out on a Bray-Curtis resemblance matrix following an overall 4th root transformation of abundances.

Results and Discussion

Physico-Chemical Quality of the Odaw River

Results of physico-chemical assessment of the Odaw River showed that there was progressive loading of pollutants from upstream to downstream (Fig. 2). The concentration of Dissolved Oxygen (DO) which is essential to all forms of aquatic

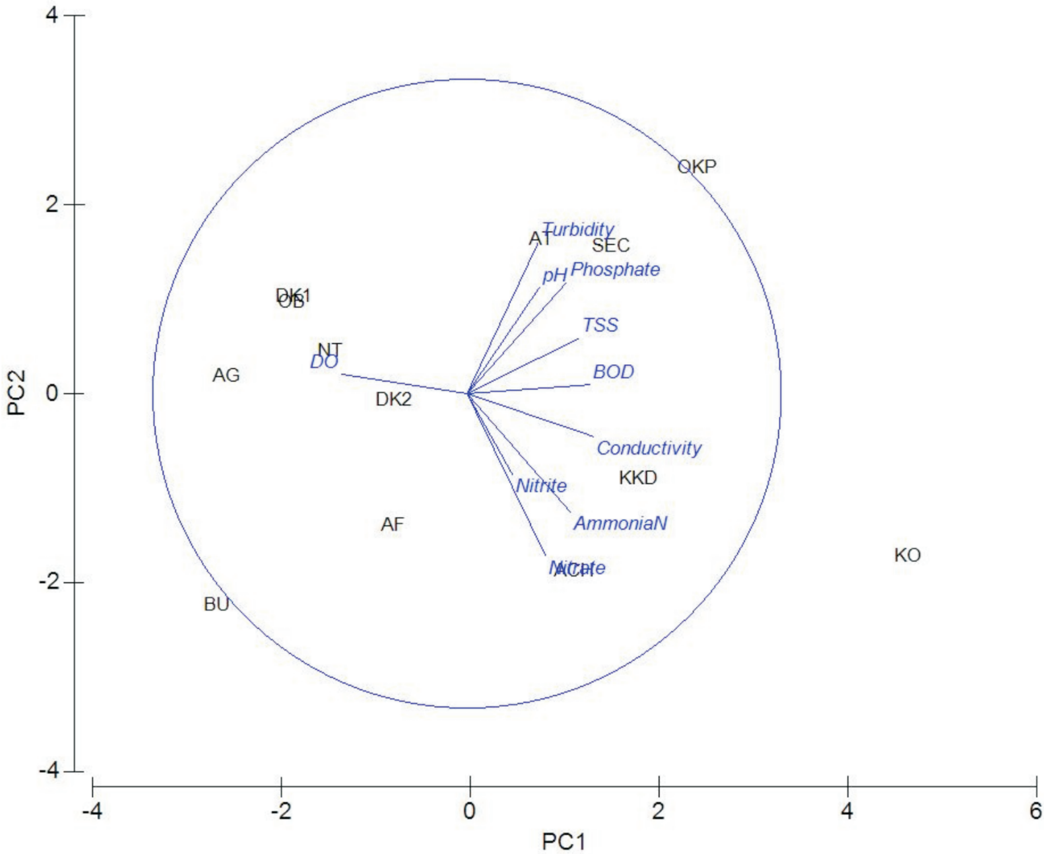

Fig. 2. Principal Component (PC) Analysis showing the spatial variation of various Physico-Chemical Variables. PC1 accounts for 45.2% of the total variation while PC2 accounts for 21.5%. AG: Agyemadi, DK1: Dakobi 1, NT: Ntare, DK2: Dakobi 2, AF: Alliance Francais, KKD: Kawukudi, SEC: Secaps, BU: Buade, KO: Korle, AT: Atomic, OKP: Okponglo.

life decreased from upstream to downstream (Table 1, Fig. 2).

Mean dissolved oxygen concentration values for upstream, midstream and downstream of the Odaw River were 4.54 mg/l, 2.30 mg/l and 1.85 mg/l respectively. Similar studies carried out by Baa-Poku *et al*. (2013), Thorne *et al*. (2000), Dartey (1999), recorded higher concentration values of DO in the midstream and downstream portions of the River. This shows that the impact of organic matter pollution in these portions of the river has increased over the period due to increased anthropogenic activities (Table 1). Indeed, Baa-Poku *et al*. (2013) also recorded lower DO concentrations in the middle to lower portions of the River compared to Thorne *et al*. (2000). The results obtained from this study has shown a clear pollution gradient between the upper, middle and lower portions of the Odaw (Table2). Previous studies conducted on the Odaw channel also identified intensified anthropogenic impacts as one moves from upstream to downstream (Thorne *et al*., 2000; Baa-Poku *et al*., 2013). This is especially reflected in the values of conductivity and TSS as shown in Table 1. BOD, (amount of oxygen required by microorganisms to break down organic matter) increased from upstream to downstream. Studies by Thorne *et al*. (2000) and Baa-Poku *et al*. (2013), however recorded higher BOD concentrations in the middle portions of the River as compared to the lower portions (Table 1).

Nutrients in the Odaw River did not show any temporal trends. The middle and lower portions of the river (Secaps, Atomic, Okponglo, Alliance Francais, Kawukudi, Achimota, Korle) recorded relatively higher concentrations of ammonia, nitrate, nitrite and conductivity. Urban agricultural farms have been established along banks of the river at these locations. Surface run-off from these farms probably contributed to the elevated concentrations of ammonia, nitrate, and nitrite recorded. Streams receiving agricultural run-off have been shown to have elevated concentrations of particulate organic matter, nutrients, suspended solid, increased rates of sedimentation, and lower abundance of Ephemeroptera, Plecoptera and Trichoptera (Lenat, 1984). The absence of these sensitive taxa and the elevated concentrations of TSS, BOD and turbidity in the middle and lower portions of the Odaw River corroborate the findings of Lenat (1984).

Generally, the physico-chemical conditions of this study did not show any seasonal variations, with the exception of phosphate. Phosphate concentration recorded in the dry season (2.37mg/l) was significantly greater than the rainy season value of 0.48mg/l ($t = 2.70$, $P = 0.02$). The higher concentration of phosphate recorded in the dry season could be the result of domestic effluent discharge and the absence of dilution by rainwater as occurs in the rainy season.

Fish and macro-invertebrate communities

No fish species were recorded in the study area. Previous studies conducted in the catchment area did not record any fish species either (Nana-Amankwah *et al*., 1995; Thorne *et al*., 2000; Baa-Poku *et al*., 2013). Dissolved oxygen concentration ranging from 0-4.6mg/l can threaten fish survival (Table 1). Twenty-one (21) families of macro-invertebrates were

TABLE 1

Comparison of physico-chemical variables measured in this study with previous studies by other authors in parts of the study area

	Upstream				*Midstream*					*Downstream*			
	S	*B*	*T*	*N-A*	*S*	*B*	*D*	*T*	*N-A*	*S*	*B*	*T*	*N-A*
Temperature (°C)		26.80	25.69	24.5–33.0		28.90	29.80	27.51	22.5–35.0		29.50	25.62	26.7–38.0
pH	6.78	7.40	6.02	6.5–8.3	7.46	7.20	7.50	7.05	7.0–8.5	7.25	7.70	6.21	7.3–8.0
Conductivity(µS/cm)	360.14	527.10	394.67	345–2300	826.88	704.00	966.00	894.00	817–2440	1884.67	1157.50	1111.00	1551–2560
Turbidity (NTU)	17.11	159.20			57.23	50.10	118.00			21.82	14.40		
TSS (mg/L)	8.21	94.20	16.33	225–2100	86.94	141.10	110.00	23.77	900—3900	166.00	216.80	23.80	100–3400
BOD (mg/L)	2.65	15.30	1.44	2.5–24.0	17.18	26.10	39.00	62.61	7.5–420	21.35	13.30	18.39	120–609
DO (mg/L)	4.54	1.20	3.31	2.7–8.3	2.30	2.40	4.60	4.57	0-9.1	1.85	2.20	2.56	0-0.8
NO_3 (mg/L)	0.48	0.90	0.03		0.40	0.70	0.30	0.14		3.46	0.90	2.11	
NO_2 (mg/L)	0.01	0.10			0.12	0.10				0.45	0.30		
NH_3 (mg/L)		6.00				21.60	9.10				17.60		
PO_4 (mg/L)	0.64	3.80	0.05		2.65	3.70	5.30	0.17		1.34	3.00	0.18	
NH_4-N (mg/L)	0.20		0.09		0.62			0.10		6.33		1.04	

S = This study, B = Baa-Poku et al.(2013), T = Thorne et al. (2000), N-A = Nana-Amankwa et al. (1995), D = Dartey (1999).

identified among the samples taken as shown in Table 3. The distribution of macro-fauna shows that the river is greatly impacted upon as the diversity of invertebrates were low even in upstream rivers (Figs. 3 and 4).

A comparison of studies conducted on the Odaw channel from 2000 to 2015 showed that species diversity declined in the middle and lower portions of the River (Table 2). At the upper portions, there was relatively high species abundance, presence of pollution sensitive families like the Dytiscidae, Hydropsychidae and Libellulidae in the streams and rivers (i.e. from Obommirem to Buade) indicating relatively better ecological conditions. However, in the middle to the lower portions in Accra, species abundance reduced along the water course. Macro-fauna in the mid and lower portions of the catchment area were typically those found in polluted waters and included the Psychodidae, Syrphidae, Chironomidae, Oligochaeta and Naedidae (Tables 3 and 4). In the Okponglo-Korle channel, located midstream to downstream (Table 4), Chironomidae was the most dominant family. Chironomids have high tolerance for low oxygen conditions in sediments of freshwater ecosystems (Tudorancea *et al*. 1989) and have therefore been regarded as excellent bioindicators of poor quality waters (Hooper *et al*. 2003). Chironomids in the Odaw River were well represented at all the sampling sites. This observation was also made by Thorne *et al.* (2000), who found that the Psychodidae and Syrphidae were restricted to the lower portions of the river. This study however identified

TABLE 2

Comparison of Shannon Diversity Index (H')

Sites	*Study*	*Baa-Poku et al. (2013)*	*Thorne et al. (2000)*
Obommirem	1.587		1.739
Agyemadi	1.068		
Ntare	1.774		
Dakobi 1	1.997		
Buade	1.24		
Dakobi 2	1.074		
Atomic	0.534		1.554
Okponglo	1.099		1.646
Secaps	0.637	1.3	
Alliance Français	1.41	1.2	
Kawukudi	0.902	1.38	0.288
Achimota	0.037		1.049
Korle	0		0.698

Psychodidae in the middle portions of the river (Table 3). Similar findings were also made by Baa-Poku *et al.* (2013). The Psychodidae are characteristic of anaerobic environments as seen in environments with decaying organic matter. The changes in the number of families and individuals along the pollution gradient corresponded to the broader categorization of the River into upstream, midstream and downstream. Macro-fauna composition and abundance in this study showed that the Odaw River is impacted by human activities, generally showing a trend of high diversity upstream compared to diversity downstream (Figs. 3 and 4).

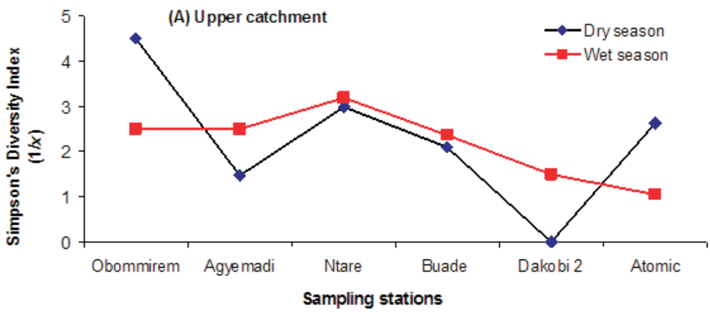

Fig. 3. Macro-invertebrate diversity in the upper catchments of the Odaw basin

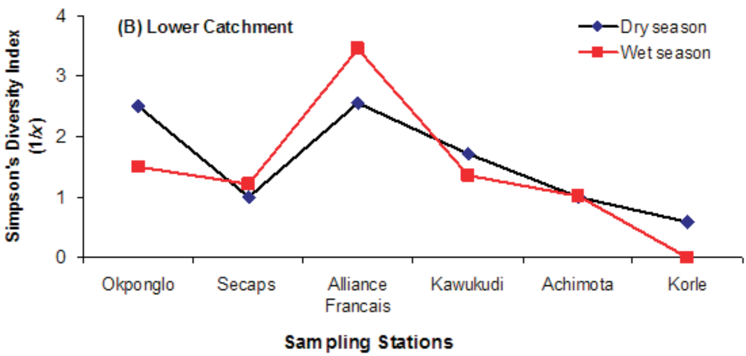

Fig. 4. Macro-invertebrate diversity in the lower catchment of the Odaw basin

TABLE 3

Macro-invertebrate distribution in the rainy (R) and dry (D) seasons in the upper catchments of the Odaw basin

*Stations**	*OB*		*AG*		*NT*		*Dk1*		*BU*		*DK2*		*AT*	
Seasons	*R*	*D*	*R*	*D*	*R*	*D*	*R*	*D*	*R*	*D*	*R*	*D*	*R*	*D*
Diptera														
Chironomidae	8	2			2	1	1	2	9					16
Worms														
Naedidae	2	3												2
Oligochaeta	1	8		2			6	2						2
Mollusca														
Melanoides													104	12
Hemiptera														
Veliidae	4	1	1	14				6						
Gerridae H16	1			1		1			8	2		1		
Odonata														
Gomphidae			1				3			1	1			
Libellullidae		4												
Zygoptera sp					2									
Zygoptera sp					1									
Calopterygidae							4							
Coleoptera														
Dytiscidae		1								1				
Hydrophilidae												1		
Elmidae					1									
Gyrinidae			4		5		4		18		5			
Trichoptera														
Hydropsychidae								1						
Ecnomidae							2							
Philopotamidae							1							
Nematoda														
Hydracarina	2				11									
Hydracarina					1									

*OB: Obomirem, AG: Agyemadi, NT: Ntare, DK1: Dakobi 1, BU: Buade, DK2: Dakobi 2, AT: Atomic

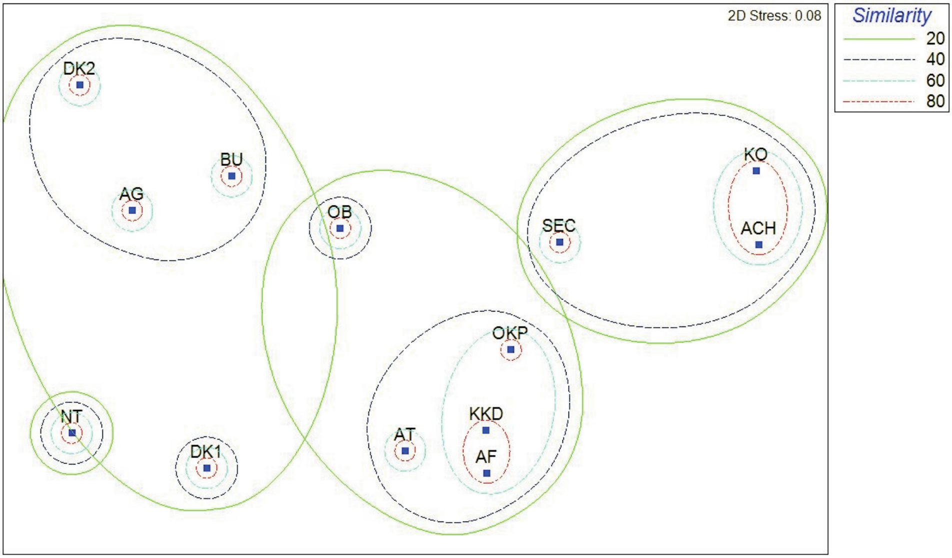

Fig. 5. Two-dimensional nMDS plot of sampling stations with superimposed clusters based on Bray-Curtis similarities after a Wisconsin double standardization and 4th root- transformation of abundances showing three distinct areas of varying degrees of pollution. AG: Agyemadi, DK1: Dakobi 1, NT: Ntare, DK2: Dakobi 2, AF: Alliance Francais, KKD: Kawukudi, SEC: Secaps, BU: Buade, KO: Korle, AT: Atomic, OKP: Okponglo, OB: Obomirem, ACH: Achimota.

The Non-metric Multidimensional Scaling (nMDS) plot reflected the observed pollution gradient among the sampling stations. Three main clusters were identified at 40% similarity. These three clusters coincided with the three divisions of the water course; the upper, middle and lower portions. The station group similarities at 40% coupled with the observed spatial variation indicate that a few dominant macro-fauna species particularly, those that can withstand varying environmental conditions controlled the community structure. The Korle, Secaps, and Achimota cluster, representing the downstream and the channelized sampling stations of the Odaw River, were composed of an entirely different community structure from the mid and upper portions (Fig. 5). The physico-chemical parameters recorded at Korle, Secaps and Achimota were distinctively showing poor environmental conditions of for example low DO and high BOD (Table 1) and this is different from the other two clusters (Fig. 5), hence the species diversity and abundance at these three sampling stations were equally different from each other.

In addition, the channel from Achimota to Korle consisted of concrete drains. These concrete drains may have contributed to the distinct differences in species abundance at these sites as stream substrate constitutes one of the major environmental factors defining the macro-fauna communities. The difference between macro-fauna communities of the natural and the concrete channelized section of the basin observed in this study is similar to those reported in other literature (Horsák *et al*., 2009; Pliûraitë and Kesminas, 2010) where the faunal assemblages of the channelized site had a lower species richness and total abundance of macroinvertebrates. Many environmental factors change seasonally, particularly those which have been shown to have a direct influence on macro-invertebrate life cycles, population dynamics, trophic interactions, etc., such as, temperature, resource abundance, photoperiod, and discharge (Sweeney and Vannote, 1981), and there is the potential for the structure of macro-fauna communities to change with them. In this study, there were some seasonal changes in macro-fauna composition and abundance within sampling stations. Some macro-fauna families showed up in the dry season but not in the rainy season and vice versa. For example, at Agyemadi (AG) and Atomic (AT), Oligochaetes were present in the dry season but not in the rainy season while at Dakobi 1 (DK1) and Agyemadi (AG), Gomphidae were present in the rainy season but not in the dry season. However, these seasonal variations were not significant as one-way ANOSIM of species abundance in both seasons gave an R value of -0.012 at a significance level of $p = 0.534$.

Conclusion

The Odaw River was found to be highly polluted, showing a pollution gradient from upstream to downstream, the upstream being the least polluted. Shannon-Wiener diversity index upstream was 0.53-2.00, midstream 0.64-1.41 and downstream had the least ranging from 0-0.04. The pollution gradient was reflected in the nMDS plot where sampling stations were grouped into three clusters that coincided with the three divisions of the river as upstream, midstream and downstream. Sensitive taxa of Dytiscidae, Hydropsychidae and Libellulidae were found only upstream from Obommirem to Buade. The mid portion of the Odaw catchment area were dominated by Oligochaeta, Naedidae and Lymnaea while the lower portion was dominated by the Chironomidae.

There was no seasonal variation in the physico-chemical parameters analysed except for phosphate which showed significantly higher concentrations in the dry season than in the rainy season. The distribution of invertebrates did not also show seasonal variation in abundance between sampling stations suggesting good adaptation of prevailing species to small changes in water quality. Midstream and lower stream portions of the catchment area showed increased pollution over the years when previous studies were compared. This study shows that prevailing macro-fauna can be used to characterize sites of differing water qualities.

References

Aggrey-Fynn J., Galyuon I., Aheto D. W. and **Okyere I.** (2011). Assessment of the environmental conditions and benthic macroinvertebrate communities in two coastal lagoons in Ghana. *Ann. Biol. Res*. **2**: 413–424.

Aheto D. W., Okyere I., Asare N. K., Dzakpasu M. F. A., Wemegah Y., Tawiah P. , Dotsey-

Brown J. and **Longdon-Sagoe M**. (2014). A Survey of the Benthic Macrofauna and Fish Species Assemblages in a Mangrove Habitat in Ghana. *West African J. Appl. Ecol*. **22**: 1–15.

APHA-AWWA-WEF. (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th Ed. ed. American Water Works Association, USA.

Armah F. A., Ason B., Luginaah I. and **Essandoh P. K.** (2012). Characterization of macro-benthic fauna for ecological health status of the Fosu and Benya lagoons in coastal Ghana. *J. Ecol. F. Biol*. **35**: 279–289.

Baa-Poku J., Asante F. and **Amakye J. S**. (2013). Impact of urban effluents on the macroinvertebrates of a Creek in Accra, Ghana. *West African J. Appl. Ecol*. **21**: 97–109.

Biney C. A. and **Amuzu A. T.** (1995). Review of Korle Lagoon studies. Urban II Development Project, Environmental Protection Agency. Accra.

Brower J. E. and **Zar J. H.** (1977). Field and Laboratory Methods for General Ecology. Wm C. Brown Company Publishers, USA.

Carlson P. E., Johnson R. K. and **Mckie B. G.** (2013). Optimizing stream bioassessment: habitat, season, and the impacts of land use on benthic macroinvertebrates. *Hydrobiologia*. **704**: 363–373.

Clarke K. R. (1993). Non-parametric multivariate analyses of changes in community structure. *Aust. J. Ecol*. **18**: 117–143.

Clarke K. R. and **Warwick R. M..** (1994). Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, UK.

Dartey G. A. (1999). Assessment of microbial population of a stream and a hotel effluent. Institute of Science Technology.

Hellawell J. M. (1978). Biological Surveillance of Rivers: A Biological Monitoring Handbook. Water Research Centre, Medmenham, England.

Hooper H. L., Sibly R. M., Hutchinson T. M. and **Maund S. J.** (2003). The influence of larval density, food availability and habitat longevity on the life history and population growth rate of the midge Chironomus riparius. *Oikos*. **102**: 515–524.

Horsák M., Bojková J., Zahrádková S., Omesová M. and **He-leœic J.** (2009). Impact of reservoirs and channelization on lowland river macroinvertebrates: A case study from Central Europe. *Limnologica*. **39**: 140–151.

Hynes J. D. (1975). Annual cycles of macro-invertebrates in a river in southern Ghana. *Freshw. Biol*. **5**: 71–83.

Johnson R. K., Widerholm T. and **Rosenberg D. M.** (1993). *Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates*, pp. 40–158. In *Freshw. Biomonitoring Benthic Macroinvertebrates.* (D. M. Rosenberg and V. H. Resh, eds.). Chapman and Hall, New York.

De Jonge M.,. Van de Vijver B, Blust R. and **Bervoets L.** (2008). Responses of aquatic organisms to metal pollution in a lowland river in Flanders: A comparison of diatoms and macroinvertebrates. *Sci. Total Environ*. **407**: 615–629.

Kyerematen R. and **Gordon C.** (2012). Aquatic Insect Fauna of Three River Systems in the Akyem Abuakwa Traditional area of The Eastern Region of Ghana. *West African J. Appl. Ecol*. **20**: 73–82.

Lenat D. R. (1984). Agriculture and stream water quality: a biological evaluation of erosion control practices. *Environ. Manage*. **8**: 333–343.

Lücke J. D. and **Johnson R. K.** (2009). Detection of ecological change in stream macroinvertebrate assemblages using single metric: multimetric or multivariate approaches. *Ecol. Indic*. **9**: 659–669.

Ludwig J. A. and **Reynolds J. F.** (1988). *Statistical ecology: a primer on methods and computing*. John Wiley & Sons , New York.

Nana-Amankwaah E., Amuzu A. T. and **Bosque-Hamilton E. K.** (1995). Impact of Development and Urbanization on Urban River Water Quality – The Nima Creek Example.Water Resources Research Institute, Accra.

Pliûraitë V., and **Kesminas V.** (2010). Response of Benthic Macroinvertebrates to Agricultural Pollution and Channelization in the Mûða River, Lithuania. *Fresenius Environ. Bull*. **19**:1327–13334.

Stein III W., Smith P. W. and **Smith G.** (2014). The cast net an overlooked sampling gear. *Marine and Coastal Fisheries* **6**:12-19

Sweeney B. W. and **Vannote R. L.** (1981). Ephemerella Mayflies of White Clay Creek: Bioenergetic and Ecological Relationships Among Six Coexisting Species. *Ecology*. **62**: 1353–1369.

Thorne R. st J., Williams W. P. and **Gordon C.** (2000). The Macroinvertebrates of a Polluted Stream in Ghana. *J. Freshw. Ecol*. **15**: 209–217.

Thorp J. H. and **Covich A. P.** (2010). *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press.

Tudorancea C., Baxter R. M. and Fernando C. H. (1989). A comparative limnological study of zoobenthic associations in the lakes of the Ethiopian Rift Valley. *Arch. Fur Hydrobiol. Suppl*. **83**: 121–147.

Umar D. M., Harding J. S. and **Winterbourn M. J.** (2013). *Freshwater Invertebrates of the Mambilla Plateau, Nigeria*. University of Canterbury, New Zealand.