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ORIGINAL ARTICLE

The effect of heavy metals and physicochemical variables on benthic macroinvertebrate community structure in a tropical urban coastal lagoon

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Abstract
Benthic macroinvertebrates are key bioindicators of pollution and an important component of food chains on wetlands. Here, we investigated the effect of heavy metals and physicochemical variables on the benthic macroinvertebrates community structure in a tropical urban coastal lagoon in Ghana which is known for its importance in the support of migratory waterbirds. Sediment samples were collected from seven different sites in the lagoon and analyzed for heavy metals. The physicochemical characteristics of the overlying water, sediment organic matter and silt/clay content were determined at these sites. The benthic macroinvertebrates abundance, species richness and diversity at each of the sites were further determined. The results indicated low levels of Zn, Cr, Pb, Cu and Cd in the lagoon with chironomids being the dominant benthic macroinvertebrates. Overall, the benthic macroinvertebrates community structure was not affected by the levels of heavy metals as toxic units were less than one. The benthic macroinvertebrates community structure was generally influenced by the dissolved oxygen, temperature levels of the overlying water, silt/clay and organic matter in the sediment. Increased benthic macroinvertebrates abundance was associated with lower water temperatures and elevated levels of silt/clay and organic matter in the sediment.

Keywords Benthic macroinvertebrates · Heavy metals · Physicochemical characteristics · Lagoon

Introduction

Benthic macroinvertebrates are an important component of food chains in many ecosystems. Their species richness and diversity are often affected by multiple environmental factors including anthropogenically induced pollutants, and changes in physicochemical and biological conditions in aquatic environments (Frost et al., 2009; Rumisha et al., 2012). As a result of their different responses to disturbances, sensitive macroinvertebrate species hardly survive in polluted aquatic environments (Connell et al., 2009; Dauvin, 2008). Thus, in polluted and anthropogenically altered aquatic environments, tolerant benthic macroinvertebrates abound compared to sensitive species (Dauvin, 2008). Accordingly, the diversity, species richness and community structure of benthic macroinvertebrates are used as indicators for pollution in aquatic environments.

Heavy metals are common pollutants in aquatic environments especially in developing countries where regulations on their release from anthropogenic sources and control are poor (Islam et al., 2015). Some anthropogenic sources of heavy metals include wastes from industries, mining and informal electronic waste recycling (Birch et al., 1996; Zheng et al., 2008). Heavy metals are also released into the environment from natural processes like weathering (Islam et al., 2015; Labrot et al., 1999). They are non-biodegradable and thus accumulate in the environment over time and become toxic to organisms. In the aquatic environment, heavy metals are adsorbed by suspended solids and sink into sediments (Ciutat et al., 2005; Knutson et al., 1987). Thus, the sediment can serve as a source of heavy metals to aquatic organisms including benthic macroinvertebrates.

A negative effect of heavy metal pollution and deteriorating water quality on benthic macroinvertebrates community structure has been described in many studies (Chen et al., 2010; Rygg, 1985; Somerfield et al., 1994; Warwick, 2001). However, studies on the effect of pollutants and

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physicochemical parameters on benthic macroinvertebrates in lagoons in developing tropical countries such as Ghana are uncommon and are therefore highly valuable in enriching literature. Such studies are also important in guiding decision making in the management of wetlands and their fauna including waterbirds.

The Sakumo II lagoon is a tropical coastal lagoon, and it is in an urban environment with high human population density. The size and physicochemical variables of the overlying water vary during the year (Nixon et al., 2007). This is because there are two wet seasons, namely April–July and September–November, and the dry season is between December and March (Nixon et al., 2007). These variations are also influenced by tidal cycles that result in exchange of materials between the sea and the lagoon (Gbogbo & Otoo, 2015; Tay et al., 2010). The lagoon has a modified hydrology. The lagoon was a closed lagoon (Tay et al., 2010); however, to prevent flooding of a major road along the coast, an artificial connection to the sea was made and the lagoon is now open to the sea. However, occasionally there is no exchange with the sea during the dry season.

Anthropogenic activities have introduced pollutants, organic wastes and nutrients which deplete the water quality of the lagoon. This is due to the proximity of the lagoon to urban centers and activities in the close-by industrial city of Tema which expose the lagoon and its associated wetland to pollutants from domestic and industrial waste. The headwaters of streams running through Tema, for instance, are known to carry pollutants from the city into the lagoon environment, while encroachment of the catchment areas of the lagoon by estate developers and squatters has further been identified as a contributor to the pollution and deteriorating condition of the Sakumo II lagoon in recent times. Several studies (Gbogbo & Otoo, 2015; Laar et al., 2011) have investigated heavy metal concentrations in sediment, water and flora in this lagoon. However, very limited studies have been done to investigate the effect of heavy metals and other physicochemical factors on the benthic macroinvertebrate community structure in tropical urban lagoons.

In the present study, we determined the heavy metal levels, water quality parameters, sediment characteristics and the benthic macroinvertebrate community structure of the lagoon to evaluate the effect of the heavy metals and other physicochemical parameters on benthic macroinvertebrate abundance and community structure in the lagoon. Knowledge of the effect of heavy metals and its interaction with physicochemical variables on the abundance and distribution of benthic macroinvertebrates is particularly important in understanding changes in macroinvertebrate abundance and community structure in tropical urban lagoons and the surrounding coastal wetlands. The importance of such findings in the understanding of waterbird ecology and population trends in the region's flyways cannot be overemphasized.

Materials and methods

Study area

The Sakumo II lagoon (5° 37′ N, 0° 02′ W) is located in Ghana on the west coast of Africa, and it covers an area of about 1–3.5 km^2 (Fig. 1). The lagoon and its wetland cover an area of about 13.4 km^2. It is the third most important Ramsar site in Ghana due to its importance in support

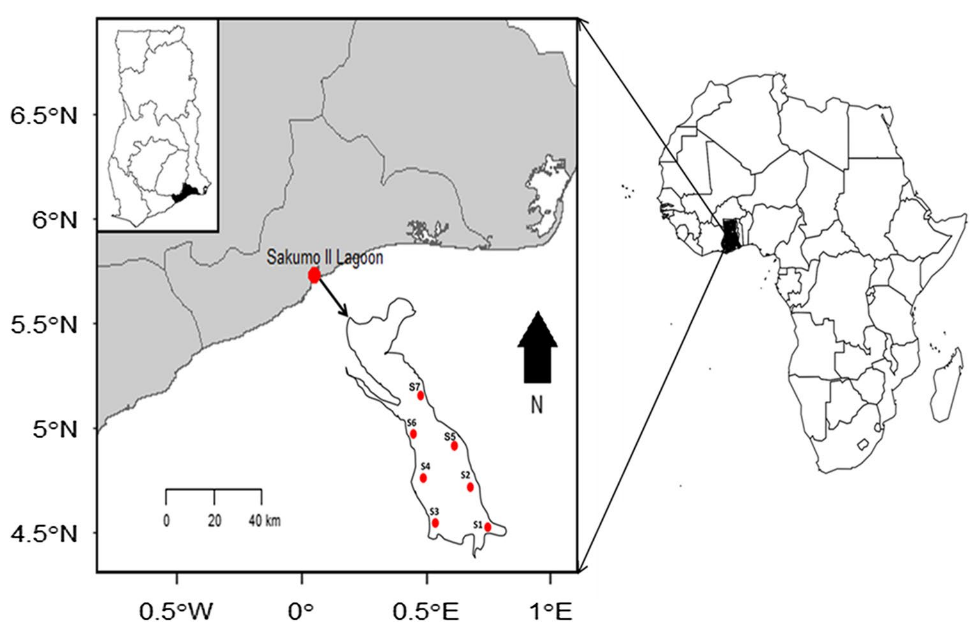

Fig. 1 Map of study area (Sakumo II lagoon) showing the sampling sites

Table 1 Physicochemical parameters of the overlying water at the seven different sites in the Sakumo II lagoon

Sites	Coordinates	pH	Conductivity (µs/cm)	TDS (mg/L)	Salinity (ppt)	Temperature (°C)	DO (mg/L)
Site 1 (S1)	5° 36′ 53.24″ N, 0° 1′ 59.58″ W	7.10	1857	925	0.93	29.37	1.87
Site 2 (S2)	5° 36′ 55.24″ N, 0° 1′ 57.42″ W	7.19	1808	906	0.91	29.31	1.93
Site 3 (S3)	5° 36′ 57.66″ N, 0° 2′ 4.02″ W	7.27	1813	910	0.92	29.00	2.50
Site 4 (S4)	5° 37′1.09″ N, 0° 2′ 4.96″ W	7.15	1827	914	0.92	29.28	2.44
Site 5 (S5)	5° 37′ 4.89″ N, 0° 2′ 0.91″ W	7.27	1822	913	0.92	29.25	2.03
Site 6 (S6)	5° 37′ 5.11″ N, 0° 2′ 7.91″ W	7.11	1888	948	0.95	29.17	1.90
Site7 (S7)	5° 37′ 10.14″ N, 0° 2′ 2.54″ W	7.30	1804	898	0.91	29.01	1.88

TDS total dissolved solids, *DO* dissolved oxygen

of migratory waterbirds (Tay et al., 2010). The lagoon also serves as a habitat for many aquatic organisms such as fish and crabs that are harvested for food (Gbogbo & Otoo, 2015). The lagoon receives freshwater inputs from two main streams from parts of the Accra and Tema metropolitan areas, and it is open to the sea.

Field sampling

The samples were collected from seven sites (S1–S7) in the Sakumo II lagoon (Fig. 1) in two days in the last week of January 2020 during the dry season in Ghana. The GPS Coordinates of seven sampling sites (S1–S7) located close to the Eastern and Western banks of the lagoon water body are shown in Table 1. The pH, dissolved oxygen (DO), total dissolved solids (TDS), conductivity, salinity and temperature of the overlying water were measured at each of the sampling sites at depths of approximately 0.4–0.5 m. At each of the sites, three replicates of sediment cores were taken at a depth of 10 cm with a corer made of PVC pipe of about 3 mm thick with an area of 0.011 m^2. Three subsamples of each sediment core were taken with a plastic spoon and placed in ziplock bags. The remaining sediment cores were sieved through a 500 µm mesh and the residues that were retained placed in plastic containers and topped with 70% ethanol. The residues were transported to the laboratory where benthic invertebrates were sorted. They were identified under a dissecting microscope using an appropriate aquatic invertebrate identification guide (Birmingham et al., 2005; Biström et al., 2015; Robertson et al., 2012) and counted.

Determination of sediment organic matter and silt/clay content

The sediment organic matter and silt/clay content were determined for samples taken from each site. Sediment organic matter was determined using the loss-on-ignition method (Blankson & Klerks, 2017). One gram of ground sediment dried at 60 °C was heated in the muffle furnace at 550 °C for 4 h. The change in weight after heating is the organic matter content of the sediment. The silt/clay content was determined by sieving a sample of dry sediment through a 63 µm mesh. The sediment samples that were sieved and the fraction that was retained on the mesh were then weighed and used to determine the silt/clay content.

Trace metal analysis in sediment

Each subsample of the sediment core was dried in an oven at 60 °C for 48 h and 5-ml of HNO_3 added to one gram of the ground sediment. The mixture was heated on a hotplate for 3.5 h at 120 °C. The samples were allowed to cool after

Table 2 Comparison of physicochemical variables in the Sakumo II lagoon with other tropical urban lagoons around the world

Tropical coastal lagoons	pH	Conductivity (µs/cm)	TDS (mg/L)	Salinity (ppt)	Temperature (°C)	DO (mg/L)	References
Ghana							
Present study	7.20 ± 0.08	1831.29 ± 30.55	916.29 ± 16.21	0.92 ± 0.01	29.20 ± 0.15	2.08 ± 0.03	1
Sakumo II lagoon	8.58 ± 0.03	14,838.67 ± 3795.14	–	–	29.70 ± 0.17	–	2
Sakumo II lagoon	9.03 ± 0.26	6026 ± 150	3095 ± 90	3.40 ± 0.11	30.43 ± 0.78	7.87 ± 1.55	3
International							
San Pedrito lagoon (Mexico)	7.12 ± 0.05	–	–	4.5	21–31	–	4
18 coastal lagoons (Rio de Janeiro, Brazil)	7.21 ± 1.20	–	–	15.55 ± 13.35	–	–	5

(1) Present study, (2) (Tay et al., 2010), (3) (Gbogbo & Otoo, 2015), (4) (Mendoza-Carranza et al., 2016), (5) (Caliman et al., 2010)

TDS total dissolved solids, *DO* dissolved oxygen

digestion and centrifuged at 1876.9 g. The extracts were then made up to 25 ml volume with deionized water and analyzed using flame AAS on a PerkinElmer PinAAcle 900T (Blankson & Klerks, 2016).

Toxicity assessment of the heavy metals

The toxicity of the heavy metals in the sediment to the benthic organism was assessed using toxic units (TUs). The toxic unit was calculated by dividing the concentration of each metal by the threshold effect levels (TEL) which are a sediment quality guideline (SQG) (MacDonald et al., 2000). A toxic unit greater than one shows that the heavy metal levels in the sediment are likely to be toxic to the benthic organism in the aquatic environment (Rumisha et al., 2012).

Statistical analysis

Statistical analysis was done with Pearson correlation to determine the association between abundance, trace metals in sediment and other physicochemical parameters measured. Multivariate statistical analysis was also conducted with principal component analysis (PCA). The principal component analysis was used to evaluate how heavy metals and other physicochemical parameters of overlying water and sediment characteristics affect benthic macroinvertebrate community structure. All statistical analyses were conducted with R version 3.5.1 (R Core Team, 2018).

Results

Physicochemical parameters

The physicochemical parameters are shown in Table 1. The results of physicochemical parameters were compared to previous studies (Table 2) in this lagoon (Gbogbo & Otoo, 2015; Tay et al., 2010) and other lagoons around the world (Caliman et al., 2010; Mendoza-Carranza et al., 2016). The pH of the water was neutral and ranged from 7.1 to 7.3. The conductivity ranged from 1808 to 1888 µs/cm, salinity was oligohaline and ranged from 0.91 to 0.95 ppt, and the temperature ranged from 29 to 29.37 °C. The dissolved oxygen was low ranging from 1.88 to 2.50 mg/L, and the total dissolved solids ranged from 898 to 948 mg/L.

Metals in sediment and their toxicity assessment

The metals analyzed in the present studies were Pb, Zn, Cd, Cr and Cu. Cd and Cu were not detected in the sediments from the different sites (Table 3). The average concentration of metals in the sediment in decreasing concentration showed that Zn > Cr > Pb. The concentration of metals

Table 3 Heavy metal concentrations, organic matter and silt/clay contents of sediments collected from the seven sites in the Sakumo II lagoon

Sites	Zn (μg/g)	Cr (μg/g)	Pb (μg/g)	Silt/clay content (%)	Organic matter (%)
Site 1 (S1)	9.73	2.20	0.015	0.292	1.163
Site 2 (S2)	bd	bd	0.017	0.045	0.593
Site 3 (S3)	7.11	3.99	0.016	0.351	1.609
Site 4 (S4)	5.95	2.70	bd	0.091	1.710
Site 5 (S5)	8.71	4.20	0.014	0.259	3.298
Site 6 (S6)	19.16	7.10	0.033	0.966	9.126
Site7 (S7)	10.30	5.15	0.021	0.460	2.078

bd below detection limit

Table 4 Comparison of heavy metal concentration in sediments in the Sakumo II lagoon with other lagoons around the world and sediment threshold values for heavy metals in freshwater, coastal and marine environments

Tropical coastal lagoons	Zn (μg/g)	Cr (μg/g)	Pb (μg/g)	Cd (μg/g)	Cu (μg/g)	References
Ghana						
Present study	8.71 ± 5.76	3.62 ± 2.27	0.02 ± 0.01	bd	bd	1
Sakumo II lagoon	30.70 ± 16.50	–	14.92 ± 13.02	0.47 ± 0.35	–	2
Sakumo II lagoon	–	–	bd	43 ± 8	bd	3
International						
Lagos lagoon	18.15 ± 2.59	12.37 ± 2.65	0.15 ± 0.03	5.22 ± 1.39	18.09 ± 2.65 4	
San Pedrito lagoon	36.61 ± 32.99	79.54 ± 31.12	20.87 ± 5.81	3.99 ± 1.67	–	5
Threshold metal levels (TEL)						
Coastal and marine environment						
TEL	124	52.30	30.20	0.68	18.70	6
Freshwater environment						
TEL	123	37.30	35.00	0.60	35.70	7

(1) present study, (2) (Tay et al., 2010), (3) (Gbogbo & Otoo, 2015), (4) (Bawa-Allah et al., 2018), (5) (Mendoza-Carranza et al., 2016), (6) (Macdonald et al., 1996), (7) (MacDonald et al., 2000)

bd below detection limit

Table 5 Species richness, abundance and Shannon–Weaver index at the seven different sites in the Sakumo II lagoon

Site	*S* (species richness)	*N* (abundance)	*H* (Shannon–Weaver index)
Site 1 (S1)	2	363.64	0.6931
Site 2 (S2)	1	0.00	–
Site 3 (S3)	1	1363.64	–
Site 4 (S4)	1	181.81	–
Site 5 (S5)	1	454.55	–
Site 6 (S6)	1	2000.00	–
Site 7 (S7)	1	1272.73	–

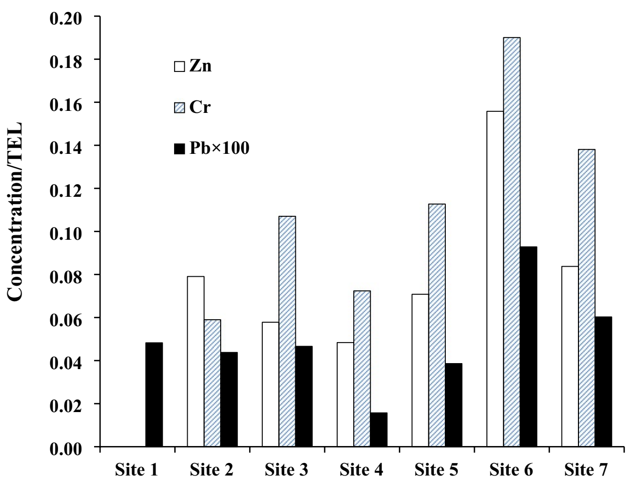

Fig. 2 Toxic units (TUs) of heavy metals (Zn, Cr and Pb) concentration from the sampling sites in the Sakumo II lagoon. The toxic unit was calculated by dividing the concentration of each metal by the threshold effect levels (TEL). The threshold effect levels (TEL) are a sediment quality guideline (SQG)

in sites 6 and 7 was higher compared to the other sites (Table 3). Generally, sediments with high organic matter and silt/clay content tended to have higher concentration of metals than those with low organic matter and silt/clay content (Table 3). The results of the toxic units (Fig. 2) for Zn, Cr and Pb in the sediment were less than one which suggests no toxicity of these metals. A comparison of the levels of the heavy metals in the sediments in the present study with levels reported by previous studies in this lagoon, other lagoons around the world, and threshold level in freshwater, coastal and marine environments is shown in Table 4. The levels of heavy metals in this lagoon were generally lower.

Characteristics of benthic macroinvertebrates

Benthic macroinvertebrates collected from the seven sampling sites from the Sakumo II lagoon were made up of 62 individuals. Except for site two where we did not find any benthic invertebrates, chironomids were found at all the other sites and it was the most abundant invertebrates (Table 5). At site one, in addition to chironomids, we also found *Laccophilus* sp. The benthic macroinvertebrates constituted mainly of chironomids (96.77%) and *Laccophilus* sp. (3.33%).

Relationship between benthic macroinvertebrates abundance, metals and physicochemical variables

The results of Pearson correlation between the abundance of invertebrates, heavy metals and other physicochemical parameters were determined (Table 6). The abundance of benthic macroinvertebrates had a significant ($p < 0.05$) positive correlation with the concentration of heavy metals (Zn, Cr and Pb) detected in the sediment from the

Table 6 Pearson correlation coefficient between metal concentrations, organic matter, silt/clay content and biological parameters

	Zn	Pb	Cr	N	S	pH	TDS	Conductivity	Temperature	Salinity	DO	OM
Zn	1											
Pb	0.708	1										
Cr	0.903*	0.637	1									
N	0.804*	0.800*	0.888*	1								
S	0.078	− 0.106	− 0.276	− 0.262	1							
pH	0.037	− 0.166	0.295	0.190	− 0.046	1						
TDS	0.415	0.595	0.285	0.359	− 0.279	− 0.752	1					
Conductivity	0.325	0.596	0.208	0.296	− 0.336	− 0.789*	0.981*	1				
Temperature	− 0.375	− 0.335	− 0.649	− 0.755*	0.338	− 0.682	0.267	0.305	1			
Salinity	0.421	0.638	0.356	0.447	− 0.411	− 0.672	0.986*	0.974*	0.135	1		
DO	− 0.232	− 0.564	− 0.043	− 0.037	− 0.239	0.198	− 0.212	− 0.308	− 0.279	− 0.176	1	
OM	0.869*	0.764*	0.807*	0.736	− 0.247	− 0.278	0.775*	0.714	− 0.169	0.793*	− 0.252	1
SC	0.938*	0.889*	0.883*	0.917*	− 0.086	− 0.044	0.548	0.487	− 0.460	0.586	− 0.296	0.900*

N abundance, *S* species richness, *TDS* total dissolved solids, *DO* dissolved oxygen, *OM* organic matter, *SC* silt/clay content

*Significant correlation ($p < 0.05$)

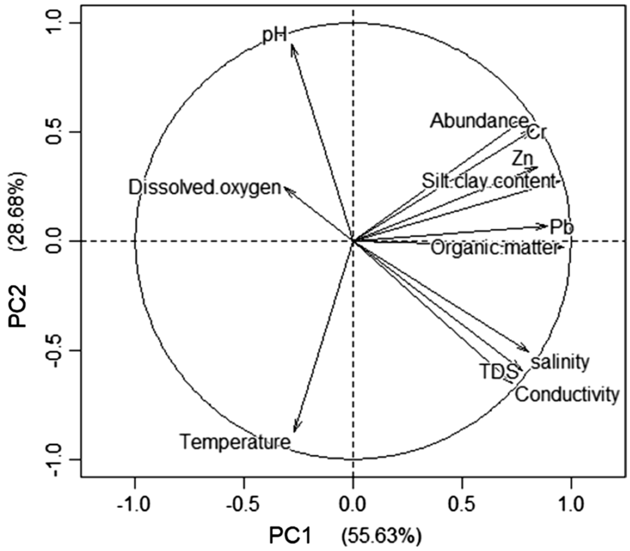

Fig. 3 Principal component analysis for abundance of benthic macroinvertebrates with heavy metals (Zn, Cr and Pb), sediment variables (silt/clay content, organic matter) and water quality variables (pH, total dissolved solids, conductivity, salinity, dissolved oxygen and temperature of the overlying water). The cumulative percentage for PC1 and PC2 was 84.31% (PC1 and accounted for 55.63% and PC2 accounted for 28.68% of variation in data)

different sampling sites. The silt/clay content had a significant ($p < 0.05$) positive correlation with the abundance of benthic macroinvertebrates. While organic matter had a significant ($p < 0.05$) positive correlation with the silt/clay content, its correlation with the abundance of benthic macroinvertebrates was not statistically significant ($p = 0.0594$). The temperatures of the overlying water at the different sites had a significant ($p < 0.05$) negative correlation with the abundance of benthic macroinvertebrates. Generally, the overlying water in the lagoon had low dissolved oxygen of 2.08 ± 0.027 mg/L (mean ± SD, $n = 7$). This level of dissolved oxygen can be described as hypoxic, and it is not suitable for aquatic organisms (Nebeker et al., 1996; Wajsbrot et al., 1990).

Multivariate analysis of benthic macroinvertebrate community structure, metals and physicochemical variables

A principal component analysis (Fig. 3) was used to determine how the heavy metals and other physicochemical variables influence benthic macroinvertebrate community structure. We considered the first two principal components (PC1 and PC2) which accounted for 55.63% and 28.68% of the variation in the data (respectively). The first principal component (PC1) had a correlation of 0.97 for the organic matter and 0.94 for the silt/clay content. This suggests that the first principal component is a measure of sediment characteristics and how it influences the distribution of the heavy metals in the sediment, physicochemical characteristics of the overlying water and abundance of benthic macroinvertebrates. An increase in the silt/clay content and organic matter of the sediment resulted in an increase in heavy metals and the abundance of benthic macroinvertebrates. The second principal component (PC2) can be described as a measure of physicochemical characteristics of the overlying water and how it affects the abundance of the benthic macroinvertebrates. Generally, an increase in temperature decreased the abundance of benthic macroinvertebrates in the lagoon.

Discussion

Benthic macroinvertebrates are used as indicators of water quality due to their responses to changes in water quality. In the present study, the benthic macroinvertebrates identified in the lagoon were chironomids and *Laccophilus* sp. The dominant species in the lagoon were chironomids. Previous studies have shown that chironomids and *Laccophilus* sp. are tolerant to pollutants in aquatic environments (Patrick & Palavage, 1994; Xu et al., 2014). However, the *Laccophilus* sp. are less tolerant, while chironomids are more tolerant of pollutants and changes in physicochemical variables in aquatic environments. Thus, chironomids are used as bioindicator species in aquatic environments (Nicacio & Juen, 2015; Xu et al., 2014). The results of the present study show that the current benthic macroinvertebrates community structure is different from what has been reported in previous studies (Gbogbo, 2007; Piersma & Ntiamoa-Baidu, 1995). Polychaetes, oligochaetes and mollusk were recorded in a previous study (Piersma & Ntiamoa-Baidu, 1995). Over a decade, only dragonfly nymphs and oligochaetes were recorded in the lagoon (Gbogbo, 2007). The observation of chironomids and *Laccophilus* sp. in the present study suggests a decline and changes in species composition of benthic macroinvertebrates in the lagoon over time. This has implications for migratory waterbirds that feed in this lagoon and the surrounding wetlands. Due to the importance of this lagoon and the surrounding wetland for migratory waterbirds (Gbogbo, 2007; Tay et al., 2010), a continuous decline in the benthic macroinvertebrates over time may cause a decrease in the waterbird populations or cause these birds to migrate to other environments in search of their food. The potential reasons for the decline and change in the benthic macroinvertebrate community structure in this lagoon may be due to many factors including the presence of pollutants, changes in physicochemical and biological conditions in the lagoon from anthropogenic and natural processes (Frost et al., 2009; Rumisha et al., 2012). In this study, we assessed the heavy metal levels, physicochemical parameters and how they influenced the benthic macroinvertebrate community in this lagoon.

The concentration of heavy metals observed in this lagoon was lower than that reported in previous studies in this lagoon (Doamekpor et al., 2018; Laar et al., 2011; Tay et al., 2010). The results for Cu and Pb were similar to other studies conducted in this lagoon (Gbogbo & Otoo, 2015). Moreover, the heavy metal levels in sediment were lower compared to levels reported in other lagoons around the world (Bawa-Allah et al., 2018; Desmond et al., 2013; Mendoza-Carranza et al., 2016). The levels of heavy metals in the lagoon were all below the threshold levels in freshwater, coastal and marine environments. Although this lagoon receives many pollutants from anthropogenic activities of the surrounding environments, the results show that the heavy metal concentrations were low. This may be due to the low anthropogenic input of heavy metals compared to what has been reported for aquatic environments near mining areas in the country (Armah et al., 2010; Duncan et al., 2018). In this study, due to the low concentrations of the heavy metals in the sediment and toxic units of less than one for the metals, we did not observe any toxic effect of these metals on the benthic macroinvertebrates. This observation agrees with other studies that have shown that heavy metals at these concentrations in the environment have no toxic effect on aquatic organisms (MacDonald et al., 2000; Rumisha et al., 2012).

In the present study, organic matter and silt/clay content of the sediment influenced the benthic macroinvertebrate community structure. The study showed that the chironomids were more abundant in sediment with high organic matter and silt/clay content. This suggests that sediments rich in organic matter and silt/clay content had more nutrients for the chironomids. The sediments with high organic matter and silt/clay content also had higher heavy metal levels. It is known that organic matter in sediment reduces the bioavailability of metals by binding to the metals and in the process decreases their distribution in the sediments. These processes lead to high concentrations of metals in sediments but low bioavailability to benthic invertebrates (Charriau et al., 2011; Lin & Chen, 1998).

The results of the physicochemical parameters indicate similarity of some variables to previous studies in this lagoon and other lagoons around the world (Caliman et al., 2010; Gbogbo & Otoo, 2015; Nixon et al., 2007). The physicochemical variables are influenced by both anthropogenic and natural processes. The results suggest a strong freshwater influence on water quality with little or no influence of seawater. The overlying water of the lagoon was oligohaline, and the pH was neutral which is typical of a freshwater ecosystem. This observation may be due to natural processes such as precipitation, evaporation, groundwater inputs, surface runoffs, freshwater inputs and reduced or no intrusion of seawater from the ocean (Kjerfve, 1994). These processes also influence the benthic macroinvertebrate community structure in the lagoon.

In the present study, the results indicate that the dissolved oxygen and temperature of the overlying water influenced the benthic macroinvertebrate community structure. The lagoon can be described as hypoxic during the time of study as dissolved oxygen was generally low, and this may be the reason why chironomids were the dominant species found in the sediment of the lagoon. Generally, aquatic environments with low levels of dissolved oxygen can support only a few aquatic organisms that are tolerant of low oxygen levels like chironomids and oligochaetes (Morais et al., 2010). The low levels of dissolved oxygen observed in this lagoon may be due to urban runoff, industrial and domestic waste discharges into the lagoon. These discharges lead to increased organic waste which reduces the dissolved oxygen in aquatic environments. Another factor that results in low levels of dissolved oxygen levels is increasing temperatures which decrease the solubility of oxygen in aquatic environments (Bianchi, 2007). In the present study, the Pearson correlation showed a negative correlation between temperature and abundance of benthic invertebrates. The PC2 had a negative correlation with temperature and a positive correlation with abundance. These results suggest that an increased temperature of the overlying water of the Sakumo II lagoon decreased the abundance of chironomids. These results agree with other studies (Larocque et al., 2006; Lencioni et al., 2012) which have demonstrated that the temperature of the overlying water is an important factor that influences the distribution of chironomids in aquatic environments.

Conclusion

In conclusion, this study demonstrated a decline and changes in the benthic macroinvertebrate community in Sakumo II lagoon. The changes were not due to heavy metal levels in the sediment of the lagoon, and this is because the metal levels were low with toxic units less than one. However, the benthic community (mainly chironomids) assemblage was related to the increasing temperature of the overlying water, low levels of dissolved oxygen, organic matter and silt/clay content of the sediment. The decline and changes in the benthic macroinvertebrates have implications for organisms at higher trophic levels in the food web. This includes important migratory waterbirds that feed in this lagoon and the surrounding wetlands.

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Data availability Data associated with metadata and calculation tools are available on request from the authors (erblankson@gmail.com).

Declarations

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

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