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Phytoplankton diversity and abundance in water bodies as affected by anthropogenic activities within the Buea municipality, Cameroon

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The importance of phytoplankton in fresh water environment cannot be over emphasized. This study was designed to determine the phytoplankton diversity and abundance in water bodies exposed to different anthropogenic pressures. Water samples were collected from 19 water sources in four categories: Car wash, Municipal wastes, Car wash + Municipal wastes and Drinking water. Phytoplankton species were determined following standard procedures. Palmer's pollution index was used to evaluate the status of organic pollution. A total of 66 phytoplankton were identified belonging to 44 genera, 34 families and six phyla. There were 52, 32, 11 and 38 species recorded for Car Wash, Municipal Waste, Car wash + Municipal wastes and Drinking water sources, respectively. Nine species cut across the four categories while 22, three and two species were unique to car wash, municipal wastes and drinking water sources, respectively. *Nitzschia* and *Chlorella* were the most abundant genera in the different water sources. While phytoplankton abundance correlated positively with nutrients, diversity correlated negatively. The highest and lowest organic pollution indices (24 and 8 respectively), were recorded in the drinking water category. Car wash activity did not only encourage the growth and diversity of algae but also influenced the establishment of unique species, some which are harmful. Human activities in and around water sources in Buea are thus degrading water quality, putting the population at risk. There is therefore need to protect the water resources of Buea.

Key words: Phytoplankton, Water sources, anthropogenic activity, Buea municipality.

INTRODUCTION

Water constitutes part of the dynamic aquatic life-supporting system in which organic and inorganic constituents are dissolved or suspended and in which a wide variety of organisms live and interact with each other (Awah, 2008). In addition, water bodies provide valuable ecosystem services, such as water supply, production, recreation and aesthetics. Having it available in sufficient quantity and quality contributes to the

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maintenance of health. Meanwhile, anthropogenic activities deteriorate surface waters (Chukwu et al., 2008) and impair their basic use through the process of pollution (Wu, 2005; Hur and Jung, 2009; Zhang et al., 2009).

Pollutants in water may come from point or nonpoint sources. Point sources of pollution are those that can be identified to one location such as industrial discharges, spillage and urban sewage treatment plants (Awah, 2008). Nonpoint pollution generally originates from more diffuse sources such as agriculture, urban storm-runoff or other land-uses (Davis and Hirji, 2003). Both pollution types release substances that can alter the inherent physical, biological and chemical properties of water (Gichana et al., 2014).

Algae are widely present in freshwater environments, such as streams, lakes and rivers. Although relatively inconspicuous, they have a major importance in the freshwater environment, in terms of ecology and in relation to human use of natural resources. Phytoplankton is an important primary producer; it is the basis of the whole autotrophic food web in the aquatic ecosystem. Sinha and Srivastava (1991) and Muhammad et al. (2005) reported that the maximum production of phytoplankton is obtained when the physico-chemical factors are at optimum level. The Bacillariophyta (diatoms), Chlorophyta (green algae), and Cyanobacteria make up the three major groups of phytoplankton in fresh water ecosystems.

Species composition of phytoplankton community is an efficient bio-indicator for water quality assessment (Peerapornpisal et al., 2004). Microscopic analyses of water samples provide information on the diversity and density of algal species which could potentially be useful as early warning signs of deteriorating conditions (Jafari and Gunale, 2006). The use of algae as aquatic environmental indicators has long been documented (Battarbee et al., 1986; Michelutti et al., 2001; Simboura and Zenetos, 2002; Muriel et al., 2004; Smol and Stoermer, 2010; Oberholster et al., 2010; Jafari and Alavi, 2010; Bere and Tundsi, 2011). Palmer (1969) published a list of algae tolerant to organic pollution in water environments. Furthermore, Ayodhya (2013) exploited this list to evaluate water quality of River Mulla in India. Fonge et al. (2012) observed the abundance of *Microcystis*, *Anacystis*, *Chloroccocus* and *Peridinum* species in waters from the Ndop wetland plain, Cameroon and concluded that they could be used as bioindicators of water quality. Oben et al. (2006) recorded the presence of the genera: *Microcystis, Lyngbya, Gloeocapsa, Trichodesmium, Chamaesiphon and Aphanocaspa* on the coastal region of Mount Cameroon, following nutrient enrichments.

Some algae in water produce toxins which can affect other biota. *Nuisance* algal levels decrease aesthetic beauty of the water body by reducing water clarity and often create taste and odour problems (Schmidt and Kannenberg, 1998). High levels can generate enough shade that prevents sunlight from reaching rooted aquatic plants, limiting their growth and causing them to die (Addy and Green, 1996). Besides, algal blooms lead to the reduction of oxygen in water column which may cause fish and other animal dieback (Anderson et al., 2002; Sen et al., 2013).

Not only have deaths of dialysis patients from liver injury caused by Cyanobacteria toxins contaminating a water supply been reported (Falconer, 1999), but also livestock death (Smol, 2008). Equally, recreational exposures to water containing toxic algae have caused illnesses ranging from acute pneumonia and hepatoenteritis to mild skin irritation and gastroenteritis (Stewart et al., 2006).

Buea is a municipality on the slope of Mount Cameroon with a rapid population growth. According to the 2005 population census, the population of Buea was 131,325 inhabitants, with an annual growth rate of 5.60% (National Institute of Statistics, Cameroon, 2010), resulting in a derived population of 226,458 inhabitants in 2015. This rise in population leads to a concomitant increase in domestic and municipal wastes, which are not properly disposed. Wastes are deposited along water courses and in drainage paths. The slopy nature of the municipality enhances the transportation of these wastes in runoff into water bodies. The rich volcanic soil in the area encouraged the practice of small scale farming and plantation agriculture characterized by the application of pesticides, some of which end up in water systems. Another perculiar activity in Buea is the fact that cars are driven into streams and washed or washed by their sides, with effluents discharged directly into the water (a non-standard practice).

Studies have pointed out that water resources in the Mount Cameroon area are threatened both in quality and quantity, due to anthropogenic influences (Lambi and Kometa, 2009). Folifac et al. (2009) revealed that anthropogenic activities around the major drinking water sources in Buea presented visible potential threats and pathways for contamination. Despite these efforts, there has been little or no documentation on the characterization of phytoplankton in water sources in Buea under different anthropogenic influences. Baseline information on the pollution status of the different water sources is important in developing a useful management package for the community. This work had as objectives: to identify phytoplankton in water sources in Buea, determine how they vary among water sources across different anthropogenic influences, and to establish the status of organic pollution using bio-indicator species.

MATERIALS AND METHODS

Study site

Buea is situated between latitude 3°57' and 4°27'N, longitude 8°58'

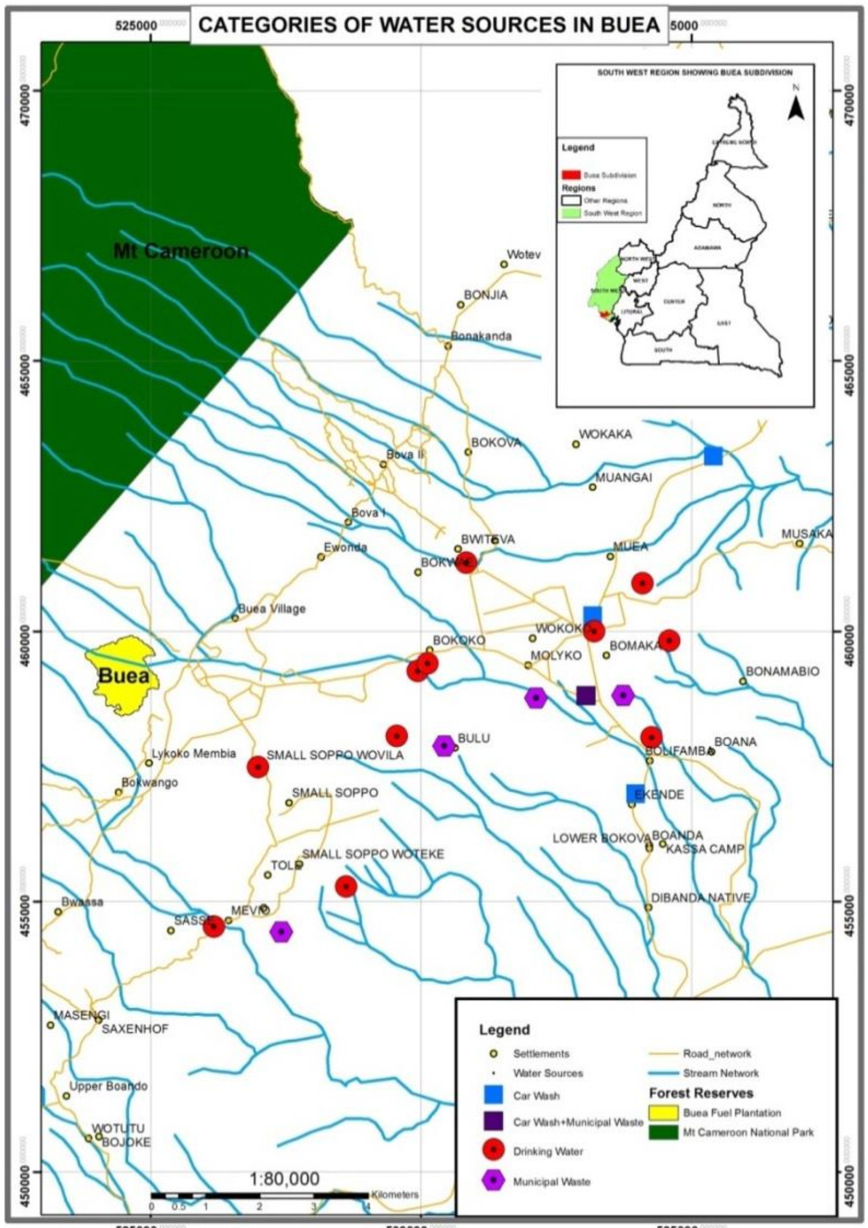

Figure 1. Location of water sampling points within the Buea Municipality.

and 9°25'E, and at an elevation of about 500 to 1000 m above sea level on the east flank of Mount Cameroon. The mean annual precipitation and temperature stand at about 3000 mm and 28°C, respectively. The relative humidity is 86% and sunshine ranges from 900 to 1200 h per annum (Folifac et al., 2009). The climate is equatorial, with two seasons: A dry season from November to February and a rainy season from March to October. Buea is a watershed area, characterized by a number of springs some of which develop into streams at lower elevation. Less than half of the population of this municipality has access to pipe-borne water, which is also erratic particularly in the dry season, increasing pressure on open and risky sources. There is therefore chronic portable water scarcity due to poor management of the available sources, placing the inhabitants at risk (Agbor and Tefeh, 2013) of water related diseases.

Sample collection and analysis

Nineteen points on different springs and streams were sampled (Figure 1 and Table 1) in March (transition between the dry and rainy season) 2013, based on anthropogenic interactions: Points exposed to car wash (CW, 3), those subjected to municipal wastes deposition (MW, 4), that subjected to both car wash and municipal wastes deposition (CM, 1) and those exploited for household usage including drinking (DW, 11). The number of sampling sites per category was determined by availability of such sites within the study area. Farming as an activity cut across all the categories.

All drinking water sources were springs, seven of which had been constructed and water channelled through pipes while the others were open sources. Of these springs, one (Man Ndongo) developed into a stream that runs across a major residential area,

Table 1. Categories of water sources and their sampling points in Buea Municipality.

Category/water source	Code	Coordinates		Collection point
		N	E	
Car wash (CW)				
Nange water	CWNA	04°11'454’’	009°19’38’’	Along the water course
Mile 18 washing point	CW18	04°9’854’’	009°17'934’’	Along the water course
Car wash point Ekande	CWEK	04^{0}8'064’’	009°18'361’’	Along the water course
Municipal wastes (MW)				
Mr Peter Bomaka	MWMP	04°9'051’’	009°18'239’’	Along the water course
Tole Bridge	MWTB	04°6'980’’	009°14'824’’	Along the water course
Bulu bridge	MWBB	04°8'544’’	009°16'453’’	Along the water course
Down Man Ndongo	MWDN	04°9’028’’	009°17’368’’	Along the water course
Car wash + Municipal wastes (CM)				
Mile 17 Hill	CM17	04°9'052’’	009°17'868’’	Along water course
Drinking water (DW)				
Drinking water Wonganjio	DWWO	04°7'134’’	009°15'470’’	From the pipe
Njonji water	DWNJ	04°10'180’	009°18'43’’	At the catchment
Mile 18 drinking	DW18	04°9'699’’	009°17'946’’	From the pipe
Boma Bomaka	DWBB	04°9'603’’	009°18'697’’	At the catchment
Amen Mile 16	DW16	04°8'623’’	009°18'521’’	From the pipe
Sasse water	DWSA	04°6'734’’	009°14'147’’	At the catchment
Drinking water Small Soppo	DWSP	04°8'334’’	009°14'590’’	From the pipe
Boma Sandpit	DWBS	04°8'647’’	009°15'976’’	From the pipe
Woman Ndongo	DWWN	04°9'298’’	009°16'185’’	At the catchment
Man Ndongo	DWMN	04°9’377’’	009°16’283’’	From the pipe
Koke catchment	DWKO	04°10’386’’	009°16’669’’	From the pipe

thus considered DW at the source and MW downstream. The other streams in this study had more remote sources, flow through residential areas and are subjected to different anthropogenic influence. All 19 sources were very shallow with no possibility of stratification (Plate 1). At each sampling site, two sets of water samples (one for chemical analysis and the other for phytoplankton analysis) were collected in triplicates, in 50 mL sterilized plastic bottles following standard procedures (Bellinger and Siegee, 2010). The six DW samples were either collected directly from the pipes or 5 cm below the water surface (in the case of the open sources) at six different points. The CW and CM were sampled at the car wash points because these are point pollution sources while the MW, being non-point pollution sources were sampled along the stream. The CW and CM samples were collected at six equally spaced positions across the stream breadth while MW samples were collected 50 m apart along the stream course. For the six samples per site, three were bulked and subsampled for algal analysis while the other three were similarly bulked and subsampled for nutrient analysis.

Before collection, *in-situ* measurements were recorded at these points: pH and temperature were measured using a portable Hanna H198127 pH/temperature meter (pH/°C), electrical conductivity was measured using a conductimeter (Hanna H198303) in µS/cm and total dissolved solids were measured in mg/L using a TDS tester. At each pipe, a 10 cm plastic bowl was filled, the probe was inserted 5 cm deep and the insitu-reading noted.

Each sample for phytoplankton analysis was treated with three drops 10% Lugol’s Iodine and transported in ice containers to the Life Sciences Laboratory of the University of Buea for phytoplankton analysis. Nitrate, ammonium, sulphate and phosphates in water samples were analysed at the Soil and Environmental Chemistry Laboratory, University of Dschang, Cameroon.

Phytoplankton identification

Slides of each sample were prepared in triplicate. A drop of sample was placed on a sterilized slide covered with a slip and observed under the microscope. Phytoplankton species were identified and counted by the use of a binocular light microscope (Olympus BH2), at a magnification of 1000 x. Algae were scored for absence (-) and presence (+) in the different water sources for each category. The number of particular alga in the mount was also noted. Identification was through comparative morphology and description using relevant text books, manuals and articles (Trégouboff and Maurice, 1957; Compère, 1977; Nguetsop et al., 2007; Bellinger and Siegee, 2010). Algae were classified according to algaebase.org.

Statistical analysis

The abundance of each alga per milliliter was obtained from the sum of its occurrences in the three slides (drops) as follows:

Plate 1. Different water sampling points. A, Car wash (Nange); B, Municipal wastes disposal in water (Man Ndongo); C, Open drinking water source (Njonji); D, Constructed drinking water source (Man Ndongo).

$$Abundance\ (ml) = \frac{n1+n2+n3}{0.15}$$

Where; $n_1 \ldots n_3$ = algal counts in drops; 0.15 = volume of three drops in ml.

The relative abundance was the percentage of the abundance of the particular alga over the total abundance of algae for the site. Similarities within a category and between categories were determined by computing the Sorensen similarity index thus:

$$S_s = \frac{2a}{(2a+b+c)}$$

Where S_s = Sorenson similarity coefficient; a = number of species common to all sites/category; b = number of species unique to first site/category; c = number of species unique to second site/category

Differences in species composition across sites and categories were evaluated using the Simpson's diversity index.

Simpson's diversity index = 1- D

Where:

$$D = \sum \left(\frac{n_i}{N}\right)^2$$

n_i = number of individuals of species I; N = Total number of individuals of all species.

Pearson's correlation was used to relate physico-chemical parameters and phytoplankton abundance and diversity while the association between them was determined by simple correspondence analysis. Palmer's pollution index based on algal genera was used in rating the water samples for organic pollution. Algae were assigned pollution index values from 1 to 6. Following analysis, the values were totalled and a score of 20 or more was regarded as confirmation of high organic pollution in the water body while scores 0 to 9 indicated no organic pollution.

RESULTS

Phytoplankton occurrence and abundance

Overall, 66 phytoplankton species belonging to 44 genera, 34 families and six phyla were identified from the nineteen sampled points (Table 2.). Of these, nine species were cosmopolitan while 22 (Table 3), three (*Achnanthes* sp, *Cocconeis* sp and *Stauroneis product*) and two species (*Cosmarium moniiforme* and *Prorocentrum*

Table 2. Occurrence of phytoplankton in water sources with different anthropogenic activities in Buea.

S/N	Species	Family	Phylum	Categories*			
				CW	MW	CM	DW
1	*Achnanthes* sp.	Achnanthaceae	Bacillariophyta	-	+	-	-
2	*Amphipleura pellucida*	Amphipleuraceae	Bacillariophyta	-	+	-	+
3	*Anacyctis* sp.	Microcystaceae	Cyanobacteria	+	-	-	-
4	*Anabaena* sp.	Nostaceae	Cyanobacteria	-	+	-	+
5	*Ceratium* sp.	Ceratiaceae	Miozoa	+	-	+	-
6	*Chlamydomonas* sp.	Chlamydomonadaceae	Chlorophyta	+	+	+	+
7	*Chlorella* sp.	Chlorellaceae	Chlorophyta	+	+	+	+
8	*Chlorogonium* sp.	Haematococcaceae	Chlorophyta	+	-	-	-
9	*Chodatella* sp.	Oocystaceae	Chlorophyta	+	+	-	-
10	*Closterium abruptum*	Closteriaceae	Charophyta	+	-	-	+
11	*Closterium arcuarium*	Closteriaceae	Charophyta	+	-	-	-
12	*Closterium gracile*	Closteriaceae	Charophyta	+	-	-	+
13	*Closterium* sp.	Closteriaceae	Charophyta	+	+	-	+
14	*Cocconeis* sp.	Cocconeidaceae	Bacillariophyta	-	+	-	-
15	*Coelastrum-* sp.	Scenedesmaceae	Chlorophyta	+	-	-	-
16	*Cosmarium constrictum*	Desmidiaceae	Charophyta	+	-	-	-
17	*Cosmarium gerdae*	Desmidiaceae	Charophyta	+	-	-	+
18	*Cosmarium minulum*	Desmidiaceae	Charophyta	+	-	-	+
19	*Cosmarium moniliforme*	Desmidiaceae	Charophyta	-	-	-	+
20	*Cosmarium* sp.	Desmidiaceae	Charophyta	+	+	+	+
21	*Cyclotella* sp.	Stephanodiscaceae	Bacillariophyta	+	+	-	+
22	*Cymbella cesatii*	Cymbellaceae	Bacillariophyta	+	-	-	-
23	*Cymbella cuspidata*	Cymbellaceae	Bacillariophyta	+	+	-	+
24	*Diatoma* sp.	Tabellariaceae	Bacillariophyta	-	+	-	+
25	*Diatoma vulgare*	Tabellariaceae	Bacillariophyta	+	+	-	+
26	*Diatomella balfouriana*	Pinnulariaceae	Bacillariophyta	+	-	-	-
27	*Elakatothrix* sp.	Elakatotrichaceae	Charophyta	+	-	-	-
28	*Euglena* sp.	Euglenaceae	Euglenophyta	+	+	+	+
29	*Fragilaria* sp.	Fragilariaceae	Bacillariophyta	+	+	+	+
30	*Gomphonema* sp.	Gomphonemataceae	Bacillariophyta	+	-	-	-
31	*Haematococcus* sp.	Haematococcaceae	Chlorophyta	+	+	-	+
32	*Hantzchia amphioxys*	Bacillariaceae	Bacillariophyta	+	-	-	+
33	*Micrasterias americana*	Desmidiaceae	Charophyta	-	+	-	+
34	*Microcystis* sp.	Microcystaceae	Cyanobacteria	+	+	-	+
35	*Navicula cucpidata*	Naviculaceae	Bacillariophyta	-	+	-	+
36	*Navicula* sp.	Naviculaceae	Bacillariophyta	+	+	+	+
37	*Nitzschia closterium*	Bacillariaceae	Bacillariophyta	+	-	-	-
38	*Nitzschia constricta*	Bacillariaceae	Bacillariophyta	+	-	-	+
39	*Nitzschia foliformis*	Bacillariaceae	Bacillariophyta	+	-	-	-
40	*Nitzschia linearis*	Bacillariaceae	Bacillariophyta	+	-	-	-
41	*Nitzschia palea*	Bacillariaceae	Bacillariophyta	+	-	-	-
42	*Nitzschia scalaris*	Bacillariaceae	Bacillariophyta	+	-	-	-
43	*Nitzschia seriata*	Bacillariaceae	Bacillariophyta	+	-	-	-
44	*Nitzschia sigma*	Bacillariaceae	Bacillariophyta	+	-	-	-
45	*Nitzschia* sp.	Bacillariaceae	Bacillariophyta	+	+	+	+
46	*Oocystis* sp.	Oocystaceae	Chlorophyta	+	+	+	+
47	*Oscillatoria* sp.	Oscillatoriaceae	Cyanobacteria	+	+	+	+
48	*Pediastrum duplex*	Hydrodictyaceae	Chlorophyta	-	+	-	+
49	*Peridinium cinctum*	Peridiniaceae	Miozoa	+	-	-	-
50	*Peridinium crassipes*	Peridiniaceae	Miozoa	+	-	-	-

Table 2. Contd.

51	*Peridinium* sp.	Peridiniaceae	Miozoa	+	-	-	+
52	*Pinnularia* sp.	Pinnulariaceae	Bacillariophyta	+	+	-	+
53	*Pleurosigma angulatum*	Pleurosigmataceae	Bacillariophyta	-	+	-	+
54	*Pleurosigma* sp.	Pleurosigmataceae	Bacillariophyta	+	-	-	-
55	*Prorocentrum minimum*	Prorocentraceae	Miozoa	-	-	-	+
56	*Sphaerocystis* sp.	Sphaerocystidaceae	Chlorophyta	-	+	-	+
57	*Spirogyra* sp.	Zygnemataceae	Charophyta	+	+	-	+
58	*Spirulina* sp.	Spirulinaceae	Cyanobacteria	-	+	-	+
59	*Stauroneis producta*	Stauroneidaceae	Bacillariophyta	-	+	-	-
60	*Surirella minuta*	Surirellaceae	Bacillariophyta	+	-	-	-
61	*Surirella ovalis*	Surirellaceae	Bacillariophyta	+	-	-	-
62	*Synedra ulna*	Fragilariaceae	Bacillariophyta	+	-	-	+
63	*Tabellaria* sp.	Tabellariaceae	Bacillariophyta	+	-	-	-
64	Tetraëdron sp.	Hydrodictyaceae	Chlorophyta	+	-	+	+
65	*Thalassionema* sp.	Thalassionemataceae	Bacillariophyta	+	+	-	-
66	*Trachelomonas* sp.	Euglenaceae	Euglenophyta	+	+	-	+
	Total			**52**	**32**	**11**	**38**
	Mean			**17**	**8**	**11**	**4**

*CW = Car wash, MW = Municipal wastes, CM = Car wash + Municipal wastes, DW = Drinking water;+ = Present, - = Absent.

Table 3. Abundance (no. of individuals/ml) of phytoplankton in water sources exposed to car wash activities in Buea

Species	Sites*			Total	Rel Abun. %
	CWNA	CW18	CWEK		
Nitzschia sp.	313	207	0	520	22.48
Chlorella sp.	127	0	87	213	9.22
Closterium sp.	93	20	0	113	4.9
Tetraëdron sp.	60	27	0	87	3.75
Cosmarium sp.	53	27	0	80	3.46
Nitzschia palea	**67**	**0**	**0**	**67**	**2.88**
Oocystis sp.	7	47	7	60	2.59
Spirogyra sp.	27	33	0	60	2.59
Navicula sp.	40	13	0	53	2.31
Euglena sp.	27	0	27	53	2.31
Cosmarium constrictum	**0**	**53**	**0**	**53**	**2.31**
Ceratium sp.	0	40	7	47	2.02
Nitzschia sigma	**47**	**0**	**0**	**47**	**2.02**
Fragilaria sp.	13	13	13	40	1.73
Nitzschia constricta	40	0	0	40	1.73
Pinnularia sp.	0	40	0	40	1.73
Diatoma vulgare	20	7	13	40	1.73
Cymbella cuspidata	0	33	0	33	1.44
***Gomphonema* sp.**	**0**	**33**	**0**	**33**	**1.44**
Peridinium sp.	33	0	0	33	1.44
Cosmarium minulum	13	20	0	33	1.44
Cyclotella sp.	13	20	0	33	1.44
Thalassionema sp.	13	20	0	33	1.44
Cymbella cesatii	**0**	**27**	**0**	**27**	**1.15**
Nitzschia scalaris	**27**	**0**	**0**	**27**	**1.15**
Closterium gracile	13	7	7	27	1.15

Table 3. Contd.

Surirella minuta	**27**	**0**	**0**	**27**	**1.15**
Trachelomonas sp.	20	7	0	27	1.15
Oscillatoria sp.	20	0	0	20	0.86
Closterium arcuarium	**0**	**20**	**0**	**20**	**0.86**
***Coelastrum* sp.**	**0**	**20**	**0**	**20**	**0.86**
Hantzchia amphioxys	20	0	0	20	0.86
Nitzschia foliformis	***20***	***0***	***0***	***20***	***0.86***
Nitzschia linearis	***0***	***20***	***0***	***20***	***0.86***
***Pleurosigma* sp.**	**0**	**20**	**0**	**20**	**0.86**
Cosmarium gerdae	7	13	0	20	0.86
Diatomella balfouriana	**7**	**13**	**0**	**20**	**0.86**
Microcystis sp.	7	13	0	20	0.86
Haematococcus sp.	13	7	0	20	0.86
Chlamydomonas sp.	0	0	13	13	0.58
Chodatella sp.	13	0	0	13	0.58
Closterium abruptum	0	13	0	13	0.58
Nitzschia closterium	**13**	**0**	**0**	**13**	**0.58**
Peridinium crassipes	**0**	**13**	**0**	**13**	**0.58**
Surirella ovalis	**13**	**0**	**0**	**13**	**0.58**
Synedra ulna	7	7	0	13	0.58
***Tabellaria* sp.**	**0**	**13**	**0**	**13**	**0.58**
Peridinium cinctum	**7**	**7**	**0**	**13**	**0.58**
***Chlorogonium* sp.**	**7**	**0**	**0**	**7**	**0.29**
***Elakatothrix* sp.**	**0**	**7**	**0**	**7**	**0.29**
Nitzschia seriata	**7**	**0**	**0**	**7**	**0.29**
***Anacystis* sp.**	**7**	**0**	**0**	**7**	**0.29**
Total	**1260**	**880**	**173**	**2313**	**100**

*CWNA = Nange water, CW18 = Mile 18 washing point, CWEK = Car wash point Ekande; Species in bold are those unique to the category.

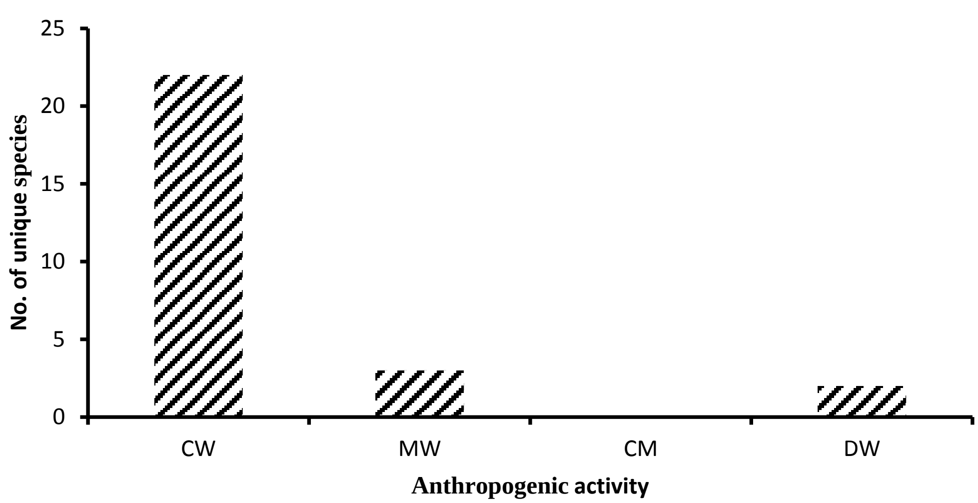

Figure 2. Phytoplankton unique to water of different anthropogenic influence in Buea Municipality. CW = Car wash, MW = Municipal wastes, CM = Car wash + Municipal wastes, DW = Drinking water.

minimum) were unique to CW, MW and DW categories respectively (Figure 2). There was no species unique to CM category. *Nitzschia* was the most abundant genus while the Bacillariaceae was the most abundant family.

Table 4. Abundance (no. of individuals/ml) of phytoplankton in water sources exposed to municipal waste in Buea.

Species	Sites*				Total	Rel Abun.%
	MWMP	MWTB	MWBB	MWDN		
Chlorella sp.	33	200	67	40	340	27.57
Navicula sp.	0	40	20	67	127	10.27
Nitzschia sp.	27	0	20	60	107	8.65
Chodatella sp.	0	73	0	0	73	5.95
Clamydomonas sp.	20	47	0	0	67	5.41
Trachelomonas sp.	13	0	0	53	67	5.41
Closterium sp.	33	7	0	13	53	4.32
Fragilaria sp.	0	13	7	13	33	2.7
Cyclotella sp.	7	0	27	0	33	2.7
Diatoma vulgare	0	7	0	27	33	2.7
Diatoma sp.	0	0	0	27	27	2.16
Sphaerocystis sp.	0	7	0	20	27	2.16
Spirogyra sp.	0	27	0	0	27	2.16
Euglena sp.	0	0	20	0	20	1.62
Amphipleura pellucida	0	0	0	20	20	1.62
Micrasterias americana	0	0	20	0	20	1.62
Pediastrum duplex	7	0	13	0	20	1.62
Spirulina sp.	0	7	7	7	20	1.62
Cymbella cuspidata	13	0	0	0	13	1.08
Haematococcus sp.	7	7	0	0	13	1.08
Pleurosigma angulatum	0	0	0	13	13	1.08
Thalassionema sp.	0	0	0	13	13	1.08
Oocystis sp.	7	0	0	0	7	0.54
Cosmarium sp.	0	7	0	0	7	0.54
Oscillatoria sp.	0	7	0	0	7	0.54
***Achnanthes* sp.**	**0**	**0**	**7**	**0**	**7**	**0.54**
Anabaena sp.	0	0	7	0	7	0.54
***Coconeis* sp.**	**0**	**0**	**7**	**0**	**7**	**0.54**
Microcystis sp.	0	7	0	0	7	0.54
Navicula cucpidata	0	7	0	0	7	0.54
Pinnularia sp.	0	0	0	7	7	0.54
Stauroneis producta	**0**	**0**	**0**	**7**	**7**	**0.54**
Total	167	460	220	387	1233	100

* MWMP = Mr Peter Bomaka, MWTB = Tole Bridge, MWBB = Bulu bridge, MWDN = Down man Ndongo. Species in bold are those unique to the category.

Bacillariophyta was the most abundant phylum. The occurrence of these algae was however not uniform among categories and sites, with mean number of phytoplankton species per category being 17, 8, 11 and 4 respectively for CW, MW, CM and DW (Table 2). *Nitzschia* sp. (22.48 %), was the most abundant in CW category while, *Chlorogonium* sp., *Elakatothrix* sp., *Nitzschia seriata* and *Anacystis* sp. were the least abundant with 0.29% each (Table 3). In the MW category, *Chlorella* sp. scored 27.57% while *Achnanthes* sp., *Anabaena* sp., *Cocconeis* sp., *Microcystis* sp., *Navicula cucpidata*, *Pinnularia* sp. and *Stauroneis producta* were the least abundant with 0.54% each (Table 4). The CM category had *Nitzschia* as the most abundant (34.48%) while *Ceratium*, *Cosmarium*, *Oscillatoria* and *Tetraëdron* were the least abundant with 1.72 % each (Table 5). *Chlorella* was the most abundant (24.27 %) in the drinking water category, while *Amphipleura pellucida*, *Closterium abruptum*, *Hantzchia amphioxys*, *Nitzschia constricta*, *Pediastrum duplex*, *Prorocentrum minimum* and *Synedra ulna* were the least (0.22% each) (Table 6).

Diversity and similarity of phytoplankton within and between categories

The different water sources had very little similarity in

Table 5. Abundance (no. of individuals/ml) of phytoplankton in water source subjected to Car wash and Municipal wastes (CM17) in Buea.

Species	Total	Rel Abun.%
Nitzschia sp.	133	34.48
Navicula sp.	73	18.97
Chlorella sp.	53	13.79
Euglena sp.	40	10.34
Chlamydomonas sp.	20	5.17
Fragilaria sp.	20	5.17
Oocystis sp.	20	5.17
Ceratium sp.	7	1.72
Cosmarium sp.	7	1.72
Oscillatoria sp.	7	1.72
Tetraëdron sp.	7	1.72
Total	387	100

CM17 = Mile 17 Hill.

Table 6. Abundance (no. of individuals/ml) of phytoplankton in water sources exploited for domestic uses including drinking water category in Buea.

Species	Sites*												
	DWNJ	DW18	DWBB	DW16	DWWO	DWSA	DWSP	DWBS	DWWN	DWMN	DWKO	Total	Rel Abun. %
Chlorella sp.	180	20	13	47	213	113	0	47	47	20	20	720	24.27
Nitzschia sp.	73	27	13	53	0	20	40	0	40	0	20	287	9.66
Navicula sp.	13	0	13	0	7	7	40	20	40	40	7	187	6.29
Euglena sp.	0	0	20	7	67	13	27	7	27	0	13	180	6.07
Clamydomonas sp.	0	33	7	7	53	60	0	7	0	0	0	167	5.62
Spirogyra sp.	67	0	13	33	53	0	0	0	0	0	0	167	5.62
Peridinum sp.	20	0	0	7	20	0	13	40	0	7	20	127	4.27
Closterium sp.	0	13	0	20	27	0	7	0	0	13	27	107	3.6
Cyclotella sp.	20	0	0	13	27	13	7	13	0	7	0	100	3.37
Oscillatoria sp.	0	0	0	13	27	7	0	33	0	0	0	80	2.7
Fragilaria sp.	7	0	7	0	27	0	7	20	0	0	7	73	2.47
Haematococcus sp.	0	0	40	0	13	0	20	0	0	0	0	73	2.47
Tetraëdron sp.	40	0	13	0	13	0	0	0	0	0	0	67	2.25
Diatoma vulgare	0	0	0	7	0	0	0	0	20	33	0	60	2.02
Oocystis sp.	20	7	7	0	13	7	0	0	0	7	0	60	2.02
Cosmarium sp.	0	7	20	0	27	0	0	0	0	0	0	53	1.8
Spirulina sp.	13	0	0	0	13	0	0	20	0	0	0	47	1.57
Cosmarium moniliforme	**40**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**40**	**1.35**
Microcystis sp.	7	0	0	0	0	0	0	0	0	0	33	40	1.35
Trachelomonas sp.	7	0	0	0	0	13	0	13	0	0	7	40	1.35
Pinnularia sp.	0	0	0	0	0	0	0	13	0	7	13	33	1.12
Cosmarium gerdae	27	0	0	0	0	0	0	0	0	0	0	27	0.9
Cosmarium minulum	27	0	0	0	0	0	0	0	0	0	0	27	0.9
Micrasterias americana	0	0	0	0	0	0	0	13	0	13	0	27	0.9
Navicula cucpidata	0	0	0	0	0	7	0	0	0	7	13	27	0.9
Sphaerocystis sp.	7	0	0	0	0	7	0	0	0	0	13	27	0.9
Closterium gracile	0	20	0	0	0	0	0	0	0	0	0	20	0.67
Diatoma sp.	0	0	0	0	0	0	7	0	7	0	7	20	0.67
Anabaena sp.	0	0	0	0	0	0	0	0	13	0	0	13	0.45
Cymbella cusp.idata	0	13	0	0	0	0	0	0	0	0	0	13	0.45
Pleurosigma angulatum	0	0	0	0	0	0	0	0	0	13	0	13	0.45

Table 6. Contd.

Amphipleura pellucida	0	0	0	0	0	0	0	0	0	0	7	7	0.22
Closterium abruptum	0	0	7	0	0	0	0	0	0	0	0	7	0.22
Hantzchia amphioxys	7	0	0	0	0	0	0	0	0	0	0	7	0.22
Nitzschia constricta	0	0	7	0	0	0	0	0	0	0	0	7	0.22
Pediastrum duplex	7	0	0	0	0	0	0	0	0	0	0	7	0.22
Prorocentrum minimum	**7**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**7**	**0.22**
Synedra ulna	7	0	0	0	0	0	0	0	0	0	0	7	0.22
Total	**593**	**140**	**180**	**207**	**600**	**267**	**167**	**247**	**193**	**167**	**207**	**2967**	**100**

*DWNJ = Njonji water, DW18 = Mile 18 drinking, DWBB = Boma Bomaka, DW16= Amen Mile 16, DWWO = Drinking water Wonganjio, DWSA = Sasse water, DWSP = Drinking water Small Soppo, DWBS = Boma Sandpit, DWWN = Woman Ndongo, DWMN = Man Ndongo, DWKO = Koke catchment; Species in bold are those unique to the category.

Table 7. Simpson's Diversity indices for phytoplankton in different water sources in Buea.

Category	Sites	Index	Mean index
	CWNA	0.853	
CW	CW18	0.921	0.85
	CWEK	0.704	
	MWMP	0.861	
MW	MWTB	0.762	0.84
	MWBB	0.852	
	MWDN	0.896	
CM	CM17	0.806	
	DWNJ	0.815	
	DW18	0.844	
	DWBB	0.892	
	DW16	0.835	
	DWWO	0.832	
DW	DWSA	0.753	0.85
	DWSP	0.832	
	DWBS	0.887	
	DWWN	0.821	
	DWMN	0.861	
	DWKO	0.907	

phytoplankton composition with very few species common to all sites within a category. In the drinking water sources for example there was no species that occurred in all the sites. Algal diversity was generally high within water sources in each category with Simpson's diversity indices ranging from 0.704 in CWEK (Car wash) to 0.896 in MWDN (Municipal waste) (Table 7). There were however no significant differences in diversity between the categories of water sources.

Water physico-chemical parameters and their relationship with phytoplankton diversity and abundance

There were variations in physico-chemical parameters among sites and categories. In the car wash category, the highest phosphate (0.73 mg/l), ammonium (3.36 mg/l) and nitrate (1.92 mg/l) were from CWNA. CW18 had the least phosphate (0.61 mg/l) while CWEK had the least ammonium and nitrate (0.56 and 0.89 mg/l, respectively). Temperature and pH were highest in CWEK (23.1 and 7.8 respectively) and lowest in CWNA (22.1) and CW18 (7.3) respectively. The electrical conductivity and total dissolved solids were highest in CW18 (255 µS/cm and 125 mg/l respectively) and lowest in CWEK (205.7 µS/cm and 105 mg/l respectively). In the municipal waste category, phosphates were highest in MWBB (0.80 mg/l) and lowest in MWMP (0.59 mg/l). Ammonium was 0.67 mg/l for all sites except MWTB with the least value of 0.53 mg/l. Nitrates were highest in MWTB (1.32 mg/l) and least in MWMP (0.87 mg/l). Sulphates ranged between 0.16 mg/l (MWBB and MWMP) and 0.13 mg/l (MWTB). Temperature was in the range 21.4 (MWBB) and 24.1 (MWDN). pH ranged between 6.6 (MWBB and MWTB) and 7.7 (MWDN) Electrical conductivity and total dissolved solids were highest in MWBB (226.7 µS/cm and 108.3 mg/l, respectively) and least in MWTB (141 µS/cm and 73.3 mg/l, respectively). In the drinking water category, phosphates were highest in DWWO and DWWN (0.75 mg/l) and lowest in DWBB (0.45 mg/l). Ammonium was highest in DWWO (0.83 mg/l) and lowest in DWSP (0.57 mg/l). Nitrates were highest in DWNJ (1.43 mg/l) and lowest in DW18 (0.62 mg/l). Sulphates were highest in DWWO (0.15 mg/l) and lowest in DW16 (0.11 mg/l). Temperature ranged between 20.5 (DWSP) and 22.9 (DWBB). pH was highest in DWWN (7.5) and lowest in DWSP (6.1). Total dissolved solids ranged between 74.7 mg/l (DW18) and 141.7 mg/l (DWBS) while electrical conductivity was in the range 146.3 µS/cm (DWWN) and 288.3 µS/cm (DW18). Mean values of the different parameters for the different categories ranged between 0.65 mg/l (DW) to 0.71 mg/l (MW and CM) for phosphates, 0.64 mg/l (MW) to 2.24 mg/l (CM) for ammonium, 1.08 mg/l (DW) to 1.53 mg/l (CW) for nitrates, 0.13 mg/l (DW) to 0.14 mg/l (other categories) for sulphate, 21.8 (DW) to 22.9 (CM) for temperature, 6.9 (other categories) to 7.6 (CW) for pH, 197.4 µS/cm (MW)

Table 8. Correlation matrix of physico-chemical parameters versus phytoplankton abundance and diversity.

Parameter	Temp	pH	EC	TDS	PO_4^{2-}	NH_4^+	NO_3^-	SO_4^{2-}
Abundance	0.324	**0.979**	0.453	0.314	0.414	0.388	0.114	0.539
	0.676	**0.021**	0.547	0.686	0.586	0.612	0.886	0.461
Diversity	-0.771	0.432	-0.255	-0.211	-0.422	-0.733	-0.135	-0.367
	0.229	0.568	0.745	0.789	0.578	0.267	0.865	0.633

Upper value = correlation coefficient, Lower value = significance level at p = 0.05.

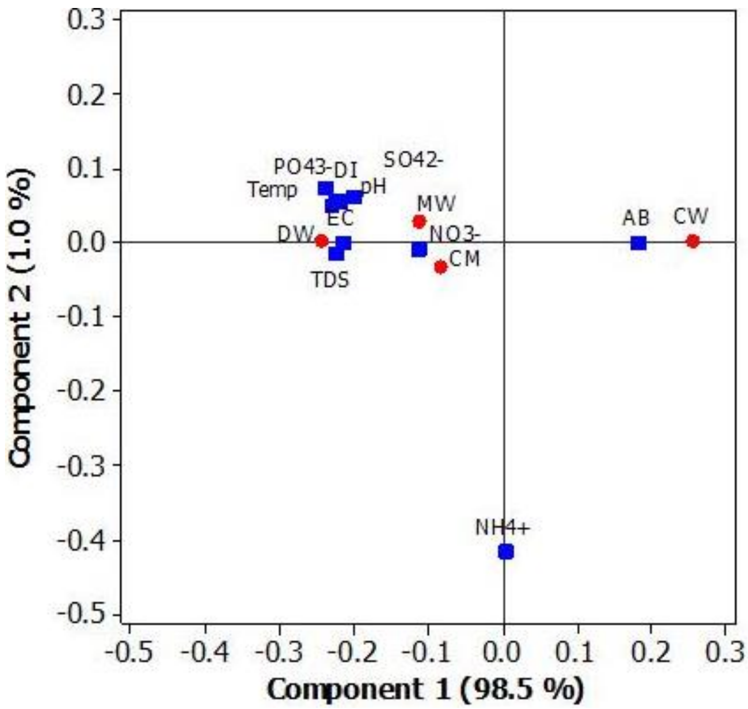

Figure 3. Ordination of physico-chemical parameters with phytoplankton diversity and abundance.

to 233.3 µS/cm (CM) for electrical conductivity and 92.3 mg/l (MW) to 111.8 mg/l (DW) for total dissolved solids.

Phytoplankton abundance had a significant positive correlation with pH. All other correlation coefficients were insignificant (Table 8).

Simple correspondence analysis of physico-chemical parameters, phytoplankton diversity and abundance indicated a strong association between diversity and nutrients while abundance associated more with car wash activity (Figure 3)

Pollution status of the different water sources

The study revealed a total of 11 pollution tolerant genera following Palmer's (1969) (organic pollution) list, in the four categories. The observed pollution tolerant genera belong to four main phyla, with the Bacillariophyceae having the highest number across the different categories and the Euglenophyceae, the least (Table 9). The pollution index values for the different sites ranged from 11 to 22 (CW category), 12 to 16 (MW category), 23 (CM category) and 8 to 24 (DW category). The average index values for the different categories were 15, 13.3 and 16.4 respectively for car wash, municipal waste and drinking sources.

DISCUSSION

In this study the phytoplankton occurrence in the water sources was in the order Bacillariophyta > Charophyta > Chlorophyta > Cyanobacteria > Miozo > Euglenophyta. These findings are similar to those of Sorayya et al. (2011) and Wladyslawa et al. (2007), who reported

Table 9. Pollution Index of algal genera and pollution status of different water sources in Buea Municipality.

Category	Division*	Genus	PP I	Site score										
CW				**CWNA**	**CW18**	**CWEK**								
		Chlorella	3	3	0	3								
	Ch	*Closterium*	1	0	1	0								
		Clamydomonas	4	0	0	4								
	Cy	*Oscillatoria*	5	5	0	0								
		Anacystis	1	1	0	0								
	Eu	*Euglena*	5	5	0	5								
		Cyclotella	1	1	1	0								
		Gomphonema	1	0	1	0								
	Ba	*Navicula*	3	3	3	0								
		Nitzshia	3	3	3	0								
		Synedra	2	2	2	0								
			TIS	**22**	**11**	**12**								
			PS	**V H**	**Mod**	**Mod**								
MW				**MWMP**	**MWTB**	**MWBB**	**MWDN**							
		Chlorella	3	3	3	3	3							
	Ch	*Closterium*	1	1	1	0	1							
		Clamydomonas	4	4	4	0	0							
	Cy	*Oscillatoria*	5	0	5	0	0							
	Eu	*Euglena*	5	0	0	5	0							
		Cyclotella	1	1	0	1	0							
	Ba	*Navicula*	3	0	3	3	3							
		Nitzschia	3	3	0	3	3							
			TIS	**12**	**16**	**15**	**10**							
			PS	**Mod**	**Mod**	**Mod**	**L**							
CM				**CM17**										
	Ch	*Chlorella*	3	3										
		Clamydomonas	4	4										
	Cy	*Oscillatoria*	5	5										
	Eu	*Euglena*	5	5										
		Navicula	3	3										
		Nitzshia	3	3										
			TIS	**23**										
			PS	**VH**										
DW				**DWNJ**	**DW18**	**DWBB**	**DW16**	**DWWO**	**DWSA**	**DWSP**	**DWBS**	**DWWN**	**DWMN**	**DWKO**
	Ch	*Chlorella*	3	3	3	3	3	3	3	0	3	3	3	3

Table 9. Contd.

	Closterium	1	0	1	0	1	1	0	1	0	0	1	1
	Clamydomonas	4	0	4	4	4	4	4	0	4	0	0	0
Cy	*Oscillatoria*	5	0	0	0	5	5	5	0	5	0	0	0
Eu	*Euglena*	5	0	0	5	5	5	5	5	5	5	0	5
	Cyclotella	1	1	0	0	1	1	1	1	1	0	1	0
	Navicula	3	3	0	3	0	3	3	3	3	3	3	3
Ba	*Nitzschia*	3	3	3	3	3	0	3	3	0	3	0	3
	Synedra	2	2	0	0	0	0	0	0	0	0	0	0
		TIS	**12**	**11**	**18**	**22**	**22**	**24**	**13**	**21**	**14**	**8**	**15**
		PS	**Mod**	**Mod**	**H**	**VH**	**VH**	**VH**	**Mod**	**VH**	**Mod**	**L**	**Mod**

*Ch = Chlorophyceae, Cy = Cyanophyceae, Eu = Euglenophyceae, Ba = Bacillariophyceae, PPI = Palmer's Pollution Index, TIS = Total Index Score, PS = Pollution Status, Mod = Moderate, H = High, VH = Very High, L = Low.

Chlorophyta, Bacillariophyta, Cyanobacteria and Dinophyta as dominant in the fresh water communities. Similarly, Laskar and Gupta (2009) recorded 34 phytoplankton taxa belonging to Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae, in Chatla floodplain lake (India).

Waste discharge into water and fertilizer applications around water sources increase nitrogen and phosphorus levels in systems (Fonge et al., 2012). Also untreated car wash effluents have been reported to contain phosphates and nitrates above limit (Aisling et al., 2011) and these are nutrients which encourage algal growth. In this study, nutrients correlated positively with phytoplankton abundance while diversity correlated negatively with nutrients in agreement with the fact that increase in nutrients reduce diversity but increase abundance of tolerant species (Chislock et al., 2013; Fonge et al., 2015). Nitrates ranged from 1.08 to1.53 mg/l and were all below the 45 mg/l limit (WHO, 2008) while the phosphates ranged from 0.65 to 0.71 mg/L and were all above the 0.30 mg/l limit (WHO, 2004). The phosphates were more likely implicated in algal abundance. The higher levels of nitrates and phosphates in car wash activity explain the association between phytoplankton abundance and car wash category. The high number of unique species for the car wash category suggests that effluents from this activity promote the growth of particular algae while the lack of unique species in CM17 is probably the consequence of strong interaction between car wash and municipal waste discharge, without ignoring the consequences of single site sampling for the CM category. The dominance of *Chlorella (*Chlorophyta), *Nitzschia* and *Navicula* (Bacillariophyta) in the different sites is attributed to their ability to adapt to a wide range of physicochemical parameters, and anthropogenic influences (Celekli and Kulkoyluoglu, 2006).

In this study the diversity of phytoplankton in all the sites was high, with little differences in mean Simpson's diversity between categories. According to Wan (2010), healthy environments are typified by greater diversity of organisms than degraded ones. However, the observed variability in diversity indices within categories could be explained by categorization based on dominant influence. The age of the catchments (Anderson et al., 2002) and slope through which the water flows are also important factors accounting for such differences in diversity. In the drinking water category for example, the lowest diversity was recorded in Sasse water (DWSA), a colonial catchment that has known little maintenance for close to a century, while Koke water (DWKO), a recently (< 20 years) constructed catchment recorded the highest diversity.

Activity interaction had a tremendous impact on algal diversity, with carwash + municipal waste categories having the lowest number of species (11) and no unique species, as oppose to car wash category with 52 species. It seems evident from this data that the washing of cars directly in streams is dangerous to the aquatic ecosystem, as it resulted in the development of 22 unique species, compared to only three and two respectively for MW and DW categories and 9 cosmopolitan species for all categories. This probably explains the low overall Sorensen similarity index of 0.40. The significant correlation between pH and abundance is justification of the impact of car wash on phytoplankton occurrence. However, the non-significant correlation between pH and diversity and between EC, TDS and diversity possible account for the uniqueness of the species in the different categories.The results confirm the complex relationship between diversity and environmental quality as proposed by Maznah and Mansor (1999). *Chlorella, Chlamydomonas, Oscillatoria, Euglena, Navicula and Nitzschia* were found repeatedly in all the categories and most sites. These genera are amongst those that have been reported in organically polluted waters (Jafari et al., 2006; Jafari and Gunale, 2006; Kshirsagar and Gunale, 2011; Kshirsagar et al., 2012 and Ayodhya, 2013). The presence of these algae in water bodies indicates eutrophic conditions (Fonge et al., 2012). In this study the Bacillariophyta dominated the pollution tolerant group, similar to observations by Arimoro et al. (2008), following studies in the Orogodo river in Nigeria. Their dominance in aquatic environments is a major indicator of water quality and environmental conditions because they are adapted to a wide range of physico-chemical conditions (Ajuonu et al., 2011; Fonge et al., 2012).

The overall mean Palmer's index value for the different categories (15, 13.3, 23 and 16.4 respectively for CW, MW, CM and DW sources) indicate that the water sources generally experienced organic pollution (Palmer, 1969), with CM having the highest degree of the pollution. The catchment of this water source (CM17) was previously the municipal waste dump of the Buea Council before the advent of the waste collection company- HYSACAM in 2010. The same area is currently the terminus of a huge storm drain, increasing organic load to the water way.

There was a complete agreement between diversity indices and Palmer's pollution indices for the various water sources. For example, in the drinking water category, DWSA showed the highest level of organic pollution and the lowest diversity index, while the lowest (8) was in DWMN with a corresponding high diversity index of 0.861.

Although Palmer's pollution tolerant genera list recorded only *Oscillatoria* and *Anacystis* as the only cyanobacteria, the overall study revealed a total of five. The occurrence of this group of algae in water is of great concern. Under suitable conditions, cyanobacteria can increase to excessive levels and form visible 'blooms' which can adversely affect water quality. Poor water quality and the potential for toxicity implies cyanobacteria can cause environmental problems, disrupt drinking water supplies, recreational activities and water-dependent industries, and pose a risk to livestock, wildlife and human health (Falconer, 1999). Microcystins are dangerous hepatotoxins, which can be produced by some strains of *Cyanobacteria* such as *Microcystis, Anabaena* and *Oscillatoria* (Romanowska-Duda et al., 2002).These substances are natural endotoxins, and their high concentration in water can result from cell lysis (Duy et al., 2000).

Conclusion

Phytoplankton occurrence is high and diverse among water sources in Buea. The pollution status of these sources also varies with different anthropogenic activities. Car wash activity had high diversity, mainly due to existence of many unique species and high pollution. However the interaction of car wash and Municipal wastes did not produce any unique species. Human activities in or around water sources in Buea are possibly degrading water quality exposing the population to risk. The study provides baseline data for future evaluation while recommending improved management of water sources in the municipality.

Conflict of Interests

The authors have not declared any conflict of interests.

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