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RESEARCH ARTICLE

TROPHIC STATUS OF SOME WATERFALLS IN SUDANO - GUINEAN HIGHLAND ZONES (CAMEROON)

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ABSTRACT

Trophic status of different waterfalls in the highlands of west and northwest regions of Cameroon was assessed by using diatomic index. Ten waterfalls were sampled, in the rainy season (August, September and October 2008) and dry season (January, February and March 2009). Diatomic index and species dominance were calculated. Diatom samples were collected upstream and downstream of each waterfall by scraping the rocks. Samples were treated with oxygenated water to destroy organic matter. Two to three drops of prepared sample were used to mount permanent slides. Identification was made using a light microscope. Diatoms species were observed at 1000x. The state of poor ecological status and moderate ecological status were the most observed respectively during rainy and dry season. The Balatchi waterfall was the most degraded and was characterized by the absence of aquatic plant called *Podostemceae*. Diatomic index varying between 2.27 and 3.76. Dominant species were *Gomphonema parvulum*and *Navicula leptostriata* (upstream), *Cymbella amphicephala* and *Gomphonema parvulum* var. *lagermanii* (downstream). The less degraded non *Podostemaceae* waterfall was Metchie and index values varied between 2.99 and 4.23. The most degraded *Podostemaceae* waterfalls was Anyajua.

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INTRODUCTION

Water ecosystems are very important for their goods and service. They are also a great source of biodiversity (Dudgeon *et al*., 2006).They help in provision of water, disposal of waste, supply of fish, plants and other biota. The extinction rates of freshwater species are up to five times higher than those of terrestrial taxa (Ricciardi and Rasmussen, 1999). These ecosystems are mostly important and benefit through their functions, properly by the fact that they are able to perform a self-cleansing function. They create the restoration of the dynamics of stream water, aquatic habitats (Metcalfe *et al*., 2013). The self cleansing function also helps in increasing the quality of the products and the natural productivity of aquatic ecosystem such as primary producers. These primary producers like the other functions of aquatic ecosystems are mostly affected by the water quality, and the determination of the fresh water status through the primary producers like algae can help in fresh water management, control and conservation systems. Algae are mostly aquatic plants, growing in various environmental conditions and habitat, they can supply useful information about the productivity and health of aquatic ecosystems and are thus used as bio indicators. Diatoms are especially the useful organisms, because of their presence and diversity in many environments. This presence is due to their great tolerance for many environmental variables, and their rapid responses, making them excellent indicators of environmental changes (Dixit *et al*., 1992). Diatoms have been used as indicators of various environmental parameters, including salinity, conductivity, phosphorus, and water level. They can be used in the reconstruction of paleoenvironments and paleoclimates through the study of fossil diatoms (Nguetsop, 1997; Gasse, 2002). In Central Africa, with the exception of a few research done in Mfoundi river algae around Yaoundé (Ebang *et al*., 2012), very few studies have been done on the diatoms including those of the waterfalls. Recently the potential of diatom indices for monitoring water quality in rivers and streams has been explored by authors such

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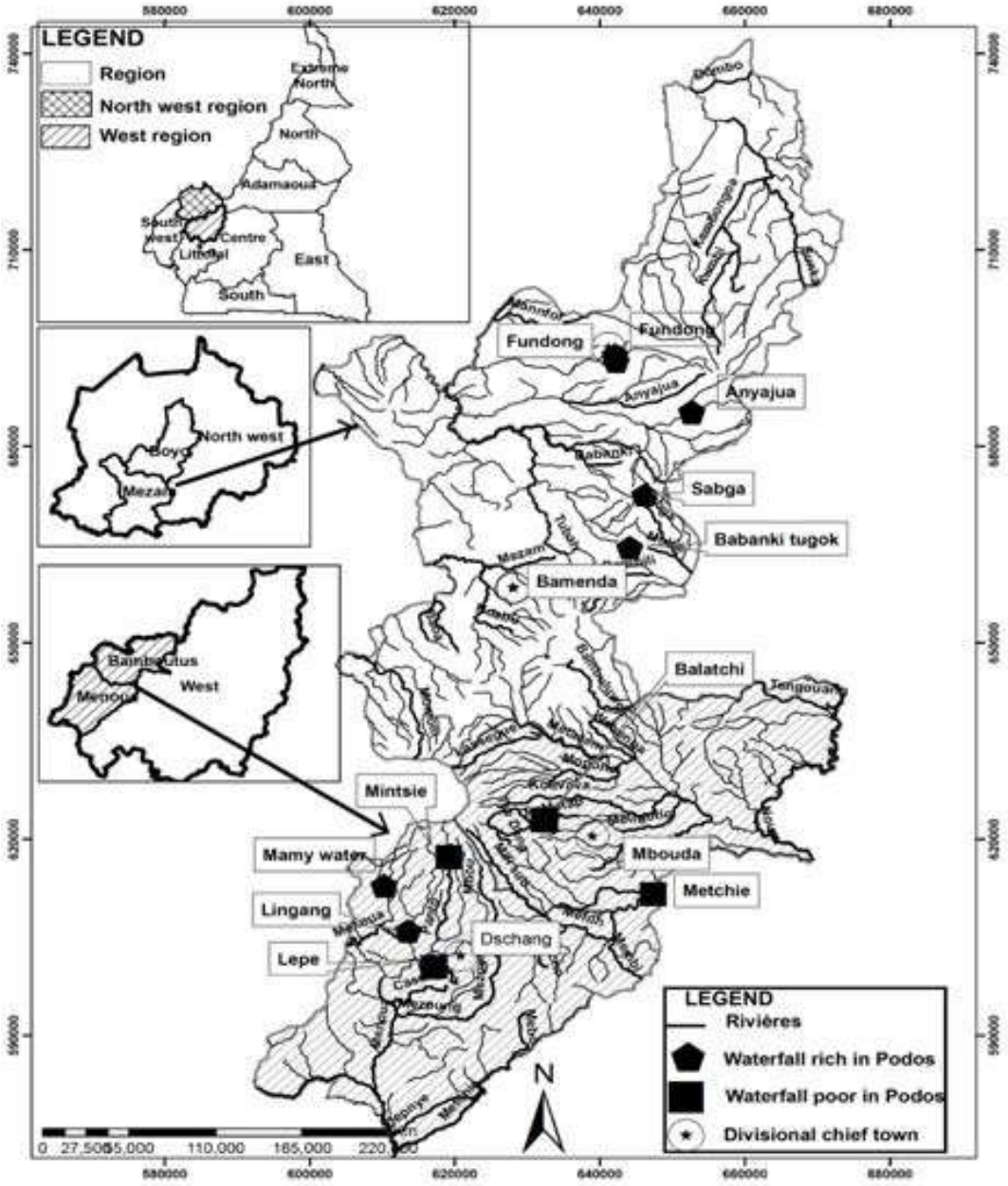

Figure 1. Location of the ten sampling points in the west and northwest region of Cameroon

as de la Rey *et al*. (2004) and Taylor *et al.* (2007). They found that, index scores accurately reflected present conditions as well as being useful to back cast water quality (Taylor *et al*., 2005). It is generally known that , some diatom's species can have the same morphology, but different range of ecological tolerance, and that diatoms are "sub-cosmopolitan" meaning that they may potentially occur anywhere in the world where a certain set of environmental conditions exist which favors the proliferation of a particular species (Padisák, 1998). This concept (sub-cosmopolitan concept) suggests that geographical location is not the determining factor in the distribution of diatom species and the composition of communities, but it is rather the specific environmental variables at each site that determine this distribution. Diatom index can thus represent a useful factor in evaluating water quality accurately and advising clean water for human population. For instance, in this context where the climate change and other anthropogenic activities have damage aquatic ecosystems. Diatom indices were used in this study to provide a numerical reflection of water quality as well as to classify the waterfalls, which are mainly drinking water sources, in a particular water quality class. In other words, it aimed at identifying diatoms and evaluating the trophic status of different waterfalls, based on diatomic index.

MATERIALS AND METHODS

Study site

The study was conducted in the highland of west (5° 30 ' N and 10° 30' E) and the northwest (5° N and 10° 57' E) administrative regions of Cameroon. The landscape of northwestern region is characterized by a contrast offered by panoramic high plateau, surrounded by mountains, deep, valleys, and temporary rivers, which are separated by several waterfalls. Mount Oku, the highest mountain culminates at 2200 m altitude. The west region is also a hilly landscape, with a serie of rounded mountains, ancient volcanoes with the highest altitude in mount Bambouto at 2047 m. In the West and North West, the domestic landscape is predominantly

agricultural and theoriginal savanna vegetation tends to disappear in favor of crops (possibly fallow), pastures and houses (OMD Report, 2010). Patches of residual forests are encountered however at high altitudes, preserved as sacred forests in the villages around the traditional Chiefs domain. In West region, the climate is Cameroonian altitude type with a rainy season from mid- March to mid- November and dry season from mid -November to mid -March. This climate is characterized by an average temperature of 20.46 ^{0}C (Tekem, 2003). In North West region, the climate of the area is also a Cameroonian altitude type with an average temperature of 22 ^{0}C. (Kemeuze *et al*., 2009; OMD Report, 2010). Ten waterfalls were sampled within six months, including three in the rainy season (August, September and October 2008) and three in the dry season (January, February and March 2009). The studied waterfalls as indicated in figure 1 were chosen based on the presence and absence of *Podostemaceae* plants, which are also bioindicator plants, known to be oligothrophic. Among the waterfalls selected, four are located in the Northwest region (Fundong (FU), Anyanjua (AN), Sabga (SG), Babanki - Tugok (BK), and with the presence of *Podostemaceae* plants (*Podostemaceae* waterfalls) and six located in West Cameroon (Mami -water (MW) and Ligang -Foto (LG) *(Podostemaceae* waterfalls), Balatchi (BT), Lepe (LP), Mintsie (MI) and Metschie (MT) (non *Podostemaceae* waterfall). Thus, we sampled in four non *Podostemaceae* waterfalls and six *Podostemaceae* waterfalls. The collected samples were taken in all cases at the relevant waterfall (downstream), and above the waterfall (upstream). The parameters measured for water samples or *in situ* were: temperature (TEMP), pH (pH), electric conductivity (COND), total dissolved solids (TDS), orthophosphates (PO_4^{3-}), nitrates (NO^{3-}), sulphates (SO_4^{2-}) and total iron (FER).

Biological analysis

Sample for Diatom analysis were collected upstream and downstream of each waterfall by scraping the rocks, dead organic matter in suspension or fixed in the water. These were treated with oxygenated water (H_2O_2) for two hours at 40 to 50^{o}C. Such a treatment destroys the organic matter contained in the samples and deflocculates clays. Samples were further rinsed with distilled water, two to three times to eliminate particle of suspended organic matter or clayed matter. Two to three drops of the remaining preparation were used to mount permanent slides, Naphrax were used as mounted medium. The identification was made using a light microscope, Olympus brand BHT -2. Diatoms encountered were identified to the species level, at 1000X magnification with the identification keys of Bourrelly (1984), Bourrelly and Manguin (1952), Compère (1975, 1976, 1977), Gasse (1986), Krammer & Lange- Bertalot (1991, 1999, 2000), Ludes and Coste (1996). The diatomic index and species dominance were calculated. The diatomic index (EPI- D) was calculated using the formula of Zelinka and Marvan (1961). The formula was also described by Dell'Uomo (2003) in the lotic environments of Italy, by Pa de la Rey (2004) in the Mooi River in South Africa, and by Chahboune *et al.* (2012) in Morocco. The index was applied with precaution in this study, because of the differences in ecological conditions in which the index was established and those that predominate in the studied sites. The formula of this index is given as follows:

$$EPI\text{-}D = \Sigma nj=1\ aj \times sj \times vj / \Sigma nj=1 aj \times vj$$

EPI-D = total index of eutrophication / pollution of the sampled station

aj = relative abundance of species j
vj = flag value (between 1 and 3)
sj = sensitivity index of species j to pollution (between 1 and 5)

The values of the coefficient s and v are those in the taxonomic basis of OMNIDIA software (Lecointe *et al*., 1993). The results obtained are a ranged from 1 to 5. The interpretation according to the environment follows that of Chahboune *et al.* (2012): 5.0 to 4.6 = zero pollution (blue, very good condition), 4.5 to 4.0 = low pollution (green, good condition), 3.9 to 3.0 corresponds to moderate pollution (yellow, medium condition), and 2.9 to 2.0 = high pollution (orange, poor condition), 1.9 to 1.0 = very high pollution (red, very bad condition).

RESULTS AND DISCUSSION

Diatomic index and species dominance in non *Podostemaceae* waterfalls

To assess changes in water quality during the study, the diatomic index was calculated in different points in the rainy season and in the dry season, upstream and downstream of each waterfall. These diatomic indices in non *Podostemaceae* waterfall showed that the water of Balatchi have organic pollution status or poor ecological status (PES) and moderate ecological status (MES), both at upstream as well as at downstream (Fig.2 A et B). Upstream, water presented PES from August to January. The lowest values of the indice was 2.54 (September, PES). At that period, the dominant diatoms species were *Gomphonema parvulum* (Kütz) Kütz and *Pinnularia braunii* (Grunow) Cleve. The highest value of the indice was 3.76 (February, MES). The dominant species were *Cymbella amphicephala* Hustedt and *Gomphonema parvulum* var. *lagerman* (Kütz) Kütz At Downstream, there were MES (February) and PES (from August to January; and in March). The lowest value (2.27) was observed in September with MES. The dominant species were *Gomphonema parvulum* and *Navicula leptostriata* Jorgensen. The highest values (3.76) was observed in February, and corresponded to moderate ecological status (MES). The dominant species were *Gomphonema clavatum* var. *bestimte* and *Navicula cryptocephala* Kützing. In waterfall of Lepe, which is non *Podostemaceae* waterfall, the two types of states observed were poor ecological status (PES) and moderate ecological status (MES), both at upstream as well as at downstream (Fig. 2C et D). The high ecological status (HES) was also observed in March. The lowest values of the indices was 2.60 (PES in August) and HES in March at upstream (Fig.2C). At upstream, the water presented PES in August and October. During that period, the dominant diatoms species were *Gomphonema gracile* and *Fragilaria capucina.* The highest value of the indices was 4.61 (March, HES). The dominant species were *Gomphonema pumillum* and *Achnanthes minutissimum* Kützing. At downstream, the PES (August and October) and MES (September; January to March) were observed. The lowest value (2.91) was observed in August with PES. The dominant species were *Gomphonema gracile* Ehr and *Navicula leptostriata*. The highest values were observed in January (3.90), they corresponded thus to moderate ecological status (MES). The dominant species were *Achnanthes minutissimum* and *Navicula leptocephala***.**

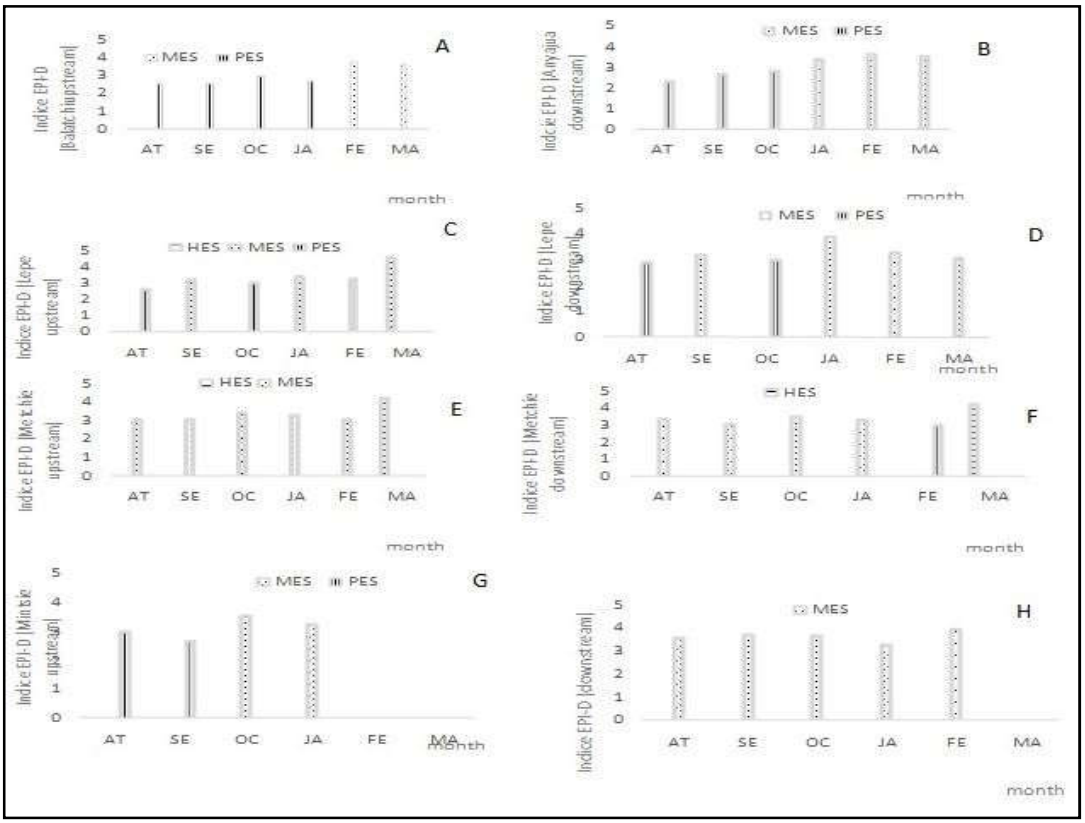

Figure 2. Water quality following the diatom index in Balatchi, Lepe, Metchie and Mintsie waterfalls at upstream (A,C,E,G), and at downstream (B,D,F,H) in the rainy (August , AT; September SE ; OC October) and dry season (January JA; FE February , March MA) : MES: Moderate ecological status, PES: poor ecological status, GES: Good ecological status; HES: High ecological status

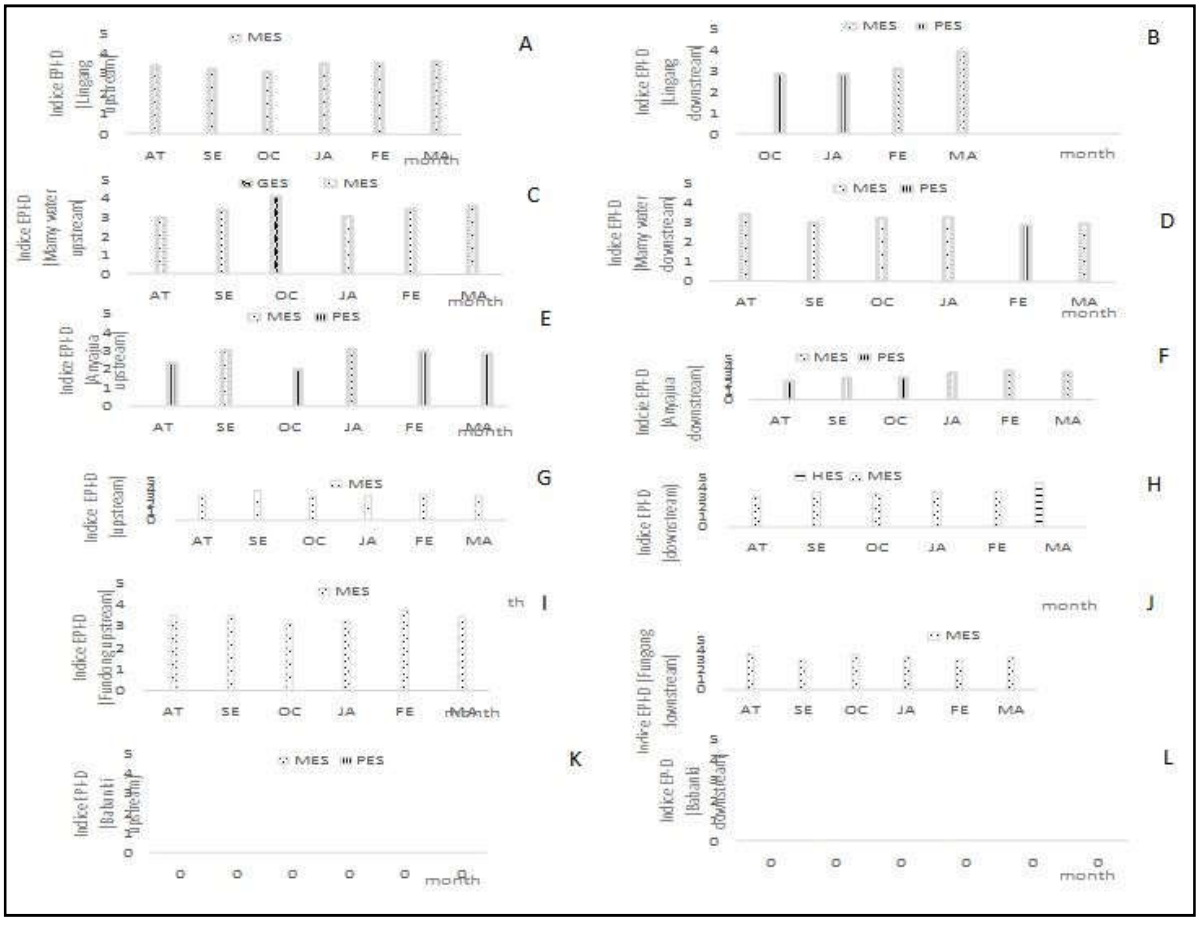

Figure 3. Water quality following the diatom index in Lingang, Mamywater,Anyajua, Sabga,Fungong and Babanki's waterfalls at upstream (A,C,E,G,I,K), and downstream (B,D,F,H,J,L) in the rainy (August , AT; September SE ; OC October) and dry season (January JA; FE February , March MA) :. MES: Moderate ecological status, PES: poor ecological status, GES: Good ecological status; HES: High ecological status

In Metchie's waterfall, (non *Podostemaceae* waterfall), the three types of states observed were organic pollution status or poor ecological status PES (February), moderate ecological status MES (August to January) and HES (March) at downstream (Fig.2F). At upstream, water showed HES in March, and MES was observed from August to February (Fig.2E). At upstream, the lowest value of the indices was 3.03 (February, MES). At that period, the dominant diatoms species were *Achnanthes minutissimum* and *Fragilaria ulna* (Nitzsch) Lange-Bertalot. The highest value of the indices was 4.23 (March,HES). The dominant species were *Gomphonema gracile* and *Achnanthes minutissimum*. At downstream, the lowest value (3.02) was observed in September with MES. The dominant species were *Fragilaria sp1*and *Navicula leptostriata*. The highest values (4.23 in March), when the water has high ecological status (HES). The dominant species were *Achnanthes minutissimum* and *Gomphonema pumillum.* In Mintsie's waterfall, (non *Podostemaceae* waterfall) the two types of states observed were organic pollution status or poor ecological status, PES (August to September), moderate ecological status MES (October to January) at upstream (Fig.2G). Downstream, appeared with MES throughout the studied period, from August to March (Fig.2H). Upstream, presents lowest value of the indices was 2.66 (September, PES). During that period, the dominant diatoms species were *Navicula pupula* Kützing and *Fragilaria ulna.* The highest value of the indices was 3.53 (October, MES). The dominant species during that period of the year were *Naviculasp, N. cryptocephala* and *Gomphonema clavatum var. bestimte*. At downstream, the lowest value (3. 24) was observed in January with MES. The dominant species were *Navicula leptostriata* and *Achnanthes minutissimum*. The highest values (3.92 in March) corresponded thus to moderate ecological status (MES). The dominant species were *Fragilaria ulna* and *Gomphonema pumillum*. This result showed that, MES status is the dominance one in all the poor waterfalls and the other status (PES, HES and GES) are punctual. The levels of pollution observed can be explained by the surrounding anthropogenic activities. Indeed, around these rivers, the practice of agriculture increases from year to year, the leaching of nutrient-rich soils and agricultural wastes from the catchment can explained the replacement of the MES by the PES during the rainy season. These modifications of water quality are thus well registered by diatom taxa as *Gomphonema gracile, G. parvulum, G. clavatum var. bestimte*and *Pinnularia subcapitata* in the most degraded waterfall Balatchi. *Gomphonema parvulum* and *G. gracile* have been also observed by Ebang *et al.* (2012), in nutrient-rich environments. Similarly, Kalyoncu and Serbetci (2013) observed *G. parvulum* in polluted waters of the Dari rivers in Turkey. The presence of these eutrophic species in mesotrophic waters indicates probably the variability of water conditions throughout the year. Therefore, the period of eutrophic water can be attributed to high leaching and/or pollution of the basin, but it can also indicate the plasticity of these species. It is known that algal populations respond more quickly to degradation of the site than to an upgrade (Iserentant et Blancke, 1986). The state of the Metchie waterfall (changing of the moderate level of pollution to zero) is quite surprising, because this river drains large areas consisting mostly of farmlands where the input of various fertilizers and organic matter leaching is relatively important. The low pollution in this case could be explained by higher self-purification potential of rivers and particularly the presence of a swamp at about one km upstream of the waterfall, dominated by macrophytes known for their phyto- purifying potential in the western highland (Fonkou *et al*., 2013). The data seem to show a seasonal or spatial variation (upstream / downstream) in the pattern of Diatoms index distribution. The state of organic pollution or poor ecological status (PES) and moderate pollution status or moderate ecological status (MES) are the most observed.

Diatomic index and species dominance in *Podostemaceae* rich waterfalls

In waterfall of Lingang (*Podostemaceae* waterfall) the two type of states observed were organic pollution status or poor ecological status PES from September to January, moderate ecological status MES (August and February to March) at downstream (Fig.3B). At upstream, water was dominant by MES throughout the period of study, from August to March (Fig.3A). At upstream, the dominant diatom species associated to the lowest value of the indices (3.01, MES in October) were *Navicula leptostriata* and *Synedra*sp whereas *Fragilaria sp2* and *Achnanthes minutissimum* were dominant when the indices showed highest value (3.61, MES in March).At downstream, the lowest value was b served in September (2.85) while the highest was registered in March, both corresponding to MES. However, the dominant species where different; *Gomphonema parvulum* and *Navicula leptostriata* where dominant in September whereas *Navicula leptostriata* and *Achnanthes minutissimum* where associated to highest value of March. In waterfall of Mamy water, (*Podostemaceae* waterfall), two types of states were also observed, organic pollution status or poor ecological status PES (February), moderate ecological status MES (August to January and March) at downstream (Fig. 3D). At upstream, water showed MES during August to September and in January, then good ecological status (GES) appeared in October (Fig. 3C). At upstream, the lowest value of the indices was 3.01 (August with MES), it was associated to *Fragilaria ulna* and *Gomphonema gracile* that where dominant. The highest value of the indices was 4.17 in October with GES. The dominant species were *Eunotia minor* (Kuetzing) Grunow and *Navicula radiosafallax* (Kuetzing). At downstream, the lowest value of the indices was 2.95 (February, with PES). The dominant species were *Fragilaria ulna* and *F. tenera* (W. Smith) Lange-Bertalot. The highest value was obtained in August (3.48) and corresponded to moderate ecological status (MES). The dominant species were *Cymbella mesiana* Cholnoky and *Achnanthesminutissimum***.** In the Anyajua's waterfall (*Podostemaceae* waterfall), the two types of states were also observed, organic pollution status or poor ecological status PES from August to October and moderate ecological status MES from January to March at downstream (Fig. 3F). At upstream, water showed MES during September and January, then PES was observed in August, October and from February to March (Fig. 3E). At upstream, the lowest value of the indices was 2.05 (October, MES). At that period, the dominant diatom species were *Navicula leptostriata* and *N. cryptocephala*. The highest value of the indices was 3.13 (January, MES). The dominant species were *Navicula cryptocephala* and *Fragilaria ulna***.** At downstream, the lowest value was registered in August (2.33) corresponded to PES. (PES). The dominant species associated were *Gomphonema parvulum* and *G. gracile*. The highest values (3.67 in February) associated to *Fragilaria ulna* and *Navicula leptostriata* corresponded to moderate ecological status (MES). In the waterfall of Sabga (*Podostemaceae* waterfalls), the two types of states observed were, moderate ecological status MES

(from August to February), and High ecological status (HES) in March at downstream (Fig. 3H). At upstream, water showed MES from August to March (Fig. 3G). At upstream, the lowest value of the indices here was 3.07 observed in October (MES). During that period, the dominant diatoms species were *Navicula leptostriata* and *Gomphonema parvulum* var. *lagermanii* **(**with very low abundances**)**. The highest value of the indices was 3.82 (September, MES). The dominant species were *Navicula leptostriat**a*** and *Achnanthes minutissimum*. At downstream, the lowest value corresponding to MES was observed in August (3.13).

The dominant species were *Gomphonema minutum* (Agardh) Agardh and *Fragilaria capucina*. The highest value of the indices (4.51) was observed in March, when the water had high ecological status (HES). The dominant species were *Gomphonema pumillum* and *Achnanthes minutissimum.* In the waterfall of Fundong, (*Podostemaceae* waterfall), moderate ecological status (MES) was observed throughout the sampling period, either in the rainy or dry seasons at downstream, as well as at upstream (Fig. 3I and 3J). At upstream, the lowest values of the indices was 3.12 (MES) and was observed in October. At that period, the dominant diatoms species were *Navicula cryptocephala* and *Gomphonema parvulum* var. *lagermanii*. The highest value of the indices was 3.76 in February (MES), it was characterized by high abundance of *Navicula cryptocephala.* At downstream, the lowest value was observed in September (3.03) corresponding to MES, the dominant species were *Fragilaria ulna* and *Navicula cryptocephala.* The highest value of indices was observed in August (3.65 corresponding also to MES, but the dominant species were *Navicula cryptocephala* and *Fragilaria ulna.* In the waterfall of Babanki, (*Podostemaceae* waterfalls), moderate ecological status MES was observed from August to October and from February to March at downstream (Fig. 3L). At upstream, MES was observed from September to October, then in March (Fig. 3K). Poor ecological status (PES) was also observed from January to February. At upstream, the lowest value of the indices was 2.76 in January (PES, dominant diatoms specie were *Nitzschia vermicularis* (Kuetzing) Hantzsch and *Fragilaria ulna***.** The highest value of the indices was 3.89, corresponding to MES, the dominant taxa were *Gomphonema parvulum* var. *lagermanii* and *Achnanthes minutissimum.*At downstream, the lowest value was 2.86 (January) corresponding to PES, dominant species associated to these water conditions were *Gomphonema parvulum an*d *Navicula leptostriata.* The highest value (3.70 in March) corresponding to MES of water was dominated by *Eunotia faba* Ehr and *Frustulia rhomboides* (Ehr) De Toni. Different waterfalls and their status are summarized in figure 4. Upstream shows that MES is the most distributed status both in non *Podostemaceae* waterfalls as well as in *Podostemaceae* waterfalls Among the upstreams of waterfalls with *Podostamaceae*, the most degraded one is Fundong (MES was observed throughout the period of study), and the less degraded one is Mamy water (GES was observed at least one mounth). Among the waterfalls without *Podostemaceae,* the most degraded one is the waterfall of Balatchi (It showed the longest period of PES), and the less degraded one is the one of Metchie (Fig. 4A). At downstream (Fig. 4B), MES is also the most spread status in all the waterfalls. The most degraded *Podostemaceae* waterfall is Anyajua (It showed the longest period of PES at up and downstream) and the less degraded one is Sabga (HES was observed at least one mounth).

The Sabga waterfall which is a rich *Podostemaceae* waterfall, evolved from a state of moderate pollution to a zero state pollution, it seems to be the less degraded among this category of waterfalls. It is dominated by *Navicula leptostriata* and *Achnanthes minutissimum* at upstream. Downstream, the diatom flora was dominated by *Gomphonema pumillum, G. minutum, Achnanthes minutissimum, Fragilaria ulna, Fragilaria capucina*. This result is similar to that of Kalyoncu and Serbetci (2013) who also identified *Achnanthes minutissimum* and *Fragilaria capucina* in good water quality. The presence of eutrophic species such as *Gomphonema parvulum* in waters of rich *Podostemaceae* waterfalls that are poorly mineralized and favorable to oligotrophic species could be due to the plasticity of the species or more likely to the variability of aquatic conditions through time. The development of eutrophic species can therefore during this period of heavy nutrient contents develop and persist even when the medium becomes again oligotrophic, because of their highly adaptative properties (Indira and Biswajit, 2012). The seasonal variations of water quality linked to climatic and anthropogenic factors, particularly precipitation and associated leaching is also registered in diatoms flora of the Berg River in South Africa, that evolved from poor ecological status (PES) during the rainy season to moderate ecological status (MES) during the dry season. The diatomic index revealed thus a strong temporal and spatial fluctuation of water quality throughout the year from PES to HES, but in the studied sites the moderate ecological status (MES) is the most common either the rich *Podotamaceae* waterfalls or in poor ones (Oliver, 2015). Throughout the study period, MES, PES, GES and HES showed a great fluctuation, even if the moderate ecological status (MES) was the most distributed status (in *Podostemaceae* and non *Podostemaceae* waterfalls). MES was observed from the beginning till the end of the study at many points (Sabga, Fundong and Lingang upstream), but the fluctuation of the dominants diatoms species did not follow the same trend. Different dominant species were observed within the same ecological status. In this study, waterfalls were separated based on the presence or absence of the *Podostemaceae.* This genus is known to grow in highly good oxygenated oligotrophic water and are very sensitive to pollution **(**Ghogue*et al.*, 2013**).** The result of this study revealed through the great fluctuation of species **(**the presence of eutrophic species in waters of *Podostemaceae* rich waterfalls and the distribution of MES and PES in all the two type of waterfalls) that, diatoms are more sensitive to water variation, compared to *Podostemaceae* species, which are also primary producers. This can be due to the fact that, the pollution or modifications are punctual or that, the level of pollution according to the studied parameters was not sufficiently high to alter the development of *Podostemaceae* or that these species are as indicated by Quiroz *et al.* (1997) able to tolerate high concentrations of nutrients. It is in accordance with Dixit *et al*. (1992), who conclude that the rapid response of diatoms to environmental factors, makes them to be an excellent indicators of environmental changes.

Conclusion

The diatomic index showed that the state of organic pollution (PES) and moderate pollution status (MES) are the most observed. Seasonal variations of the state were observed among the waterfalls. It also showed that the less degraded poor waterfall is that of Metchie, while the waterfall of Balatchi proved to be the most degraded one. The most

degraded *Podostemaceae* waterfall is that of Anyajua and the less degraded one is that of Sabga. Changes in diatoms assemblages can be linked to changes in chemical conditions during the year that involve significant variations in rainfall and temperature. In that case, alteration, erosion of the watershed, leaching, evaporation, degree of degradation as well as the nature of human activities around different sites varied throughout the year.

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