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Seasonal macrophyte diversity and water quality in an urban wetland

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The ecosystem services of encroached urban wetlands that receive wastewater and surface run-offs have become more challenging due to climate variability. Our study assessed the seasonal macrophyte diversity and water quality of the streams flowing into and out from Pece wetland in Gulu Municipality. The macrophyte species in the wetland were sampled along five transects. Water samples from the streams were also collected and analyzed in the laboratory. Results indicated forty two macrophyte species that were in twenty four families. Macrophyte diversity and equitability were higher at the wetland edge, but were not significantly different in the entire wetland (p = 0.41, respectively). The recorded faecal coliforms (FC), total suspended solids, electrical conductivity and turbidity in the streams were higher in the wet season than the dry season. The wetland doubled the retention of FC during the dry season and relatively less retention of total suspended solids was recorded in the dry season. The urban expansion and farming might alter the macrophyte abundance and richness in Pece wetland, thus affecting the ecosystem services.

Key words: Diversity indices, faecal coliforms, physico-chemical, surface-run-offs, wastewater.

INTRODUCTION

Wetlands are not only rich in diversity but are also providers of ecosystem services such as ground water recharge, flood control and sediment filtration (Schuyt, 2005). They also provide water purification service when surface run-offs (Schuyt, 2005), raw sewage, and partly treated wastewater containing nutrients (Mugisha et al., 2007) is discharged through them. However, worldwide, the area of wetlands is decreasing, and there is increased pollution and a decline in the ecological functions of such areas (Kyambadde et al., 2004; Bassi et al., 2014). The Millennium Ecosystem Assessment (2005) has estimated that up to half of the world's wetlands are lost due to human activities. This has affected water access to millions around the world and it is becoming more challenging due to climate variability, which also threatens wetlands ecosystem services in the

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drought or flood prone areas. Globally, sanitary conditions and poor water quality have continued to be a great health risks (Horwitz and Finlayson, 2011) and are of widespread concerns (Goshu et al., 2010).

Wastewaters that flow through wetlands have improved quality (Odong et al., 2013; Kyambadde et al., 2004). Their flow in the wetlands also influences the macrophyte growth and development (Kanyiginya et al., 2010; Mugisha et al., 2007; Kansiime and Nalubega, 1999). These result into enriched diversity, and better wetlands' functioning and stability (Lan et al., 2010). Nonetheless, creating new channels and widening of existing ones result into more wastewater entering the wetlands which also affect the distribution of wastewater within the wetlands thus affecting their efficiency in wastewater treatment (Kansiime and Nalubega, 1999). Notwithstanding, Pece wetland that drains run-offs from Gulu Municipality is under pressure of indiscriminate solid wastes and wastewater disposal (Opio et al., 2011). The original macrophytes in some sections of the wetland have also been cleared to give way for urban development and farming (NURP, 1997). The changes might alter the abundance and richness of aquatic biota and there is likelihood of invasive species developing in the wetland (Trombulak and Frissell, 2000). These may also reduce the ability of the wetland to improve on the wastewater quality that flow through it.

A section of Pece wetland also contains stabilization ponds or lagoons that provide tertiary wastewater treatment and the effluent from the lagoons is discharged into the wetland (Sarah, 2014). The lagoons were intended to treat wastewater and sewage for a smaller population. Consequently, the growing human population that is connecting their sewer lines to the lagoons may compromise the efficiency. To improve on the efficiency, such lagoons in the tropical conditions are regularly de-silted to enhance wastewater retention.

In understanding the importance of urban wetlands, an investigation on the wastewater purification of Pece wetland in Gulu Municipality, and also the documentation of macrophyte richness and evenness were made. We hypothesized that there is no seasonal differences in the macrophyte diversity and also in the water quality of the streams flowing into and that flowing out from the wetland.

MATERIALS AND METHODS

Study area

Pece wetland located in Gulu District (Figure 1) has a catchment area consisting of intermediate savannah grasslands characterized by open canopy of trees that are 10 to 12 m high and underlying grasses of 80 cm tall. The area has a bimodal rainfall pattern with a short dry spell in July and one long dry season from late November to early March. The average monthly rainfall ranges between 14 mm in January to 230 mm in August.

Assessment of macrophyte diversity indices

The diversity indices offer important information about rarity and commonness of species in a community and are important means to understand plants community structure. In this study, 5 transects (T1, T2, T3, T4 and T5) (Figure 1) that were established in Pece wetland were used to assess the seasonal macrophyte abundance and equitability. The distance between transects were approximately 5 km to ensure that the composition of the plant species in both degraded and undegraded areas were captured. The wetland was also demarcated into side A (north and eastern side) and side B (south and western side) using the main water channel. Each of the 5 transects had 6 plots established at an interval of 15 m apart. Each transect had 2 m^2 plots which were used to assess the presence of grasses and herbs and 4 m^2 for shrubs and trees. Plots 1A and 1B represent plot 1 on side A and B, respectively. Therefore, plots 1A, 2A and 3A were alternate to 1B, 2B and 3B. Plant species in the plots were identified and counted after 30 days interval. These covered seasonal variations from the months of February to May, 2015.

Water quality assessment in the inflow and outflow streams of Pece wetland

Water quality assessment was done in the inflow and the outflow streams of the wetland. Water samples were taken biweekly from the inflow and outflow streams (Figure 1). Grab water samples were collected at 10 cm below the water surface of each stream between 8:00 am and 12:00 pm in clean sterilized 500 ml plastic bottles. The bottles were rinsed with the stream water before the samples were collected. The samples were immediately stored in a cool box (4°C) and then transported to Uganda National Water and Sewerage corporation laboratory, Gulu branch on the same day for analysis.

Faecal coliforms analysis

Membrane Filtration Method was used to determine numbers of FC as described by APHA (1992). 100 ml of the water samples were filtered through a membrane of pore space 0.45 nm diameter to retain all the bacteria which was then placed onto a Lauryl membrane sulphate broth pad. This was incubated at 44°C for 12 h and yellow colonies formed were counted as FC. This was expressed in colony forming units (CFU) per 100 ml of water sample.

Physico-chemical water analysis

The total suspended solids (TSS) and turbidity was measured using DR6000 spectrophotometer and 2100Q turbidimeter made by Hach Company, Loveland-Colorado USA, respectively. A blank consisting of 25 ml of deionized water was used to calibrate the spectrophotometer and turbidimeter reading to 0 mg/L. 25 ml of water samples were stirred and put in the spectrophotometer and turbidimeter and readings were taken in mg/L and NTU, respectively. Electrical conductivity (EC) was measured using HQ40D multimeter (Hach Company, Loveland-Colorado USA). The EC probe was rinsed with deionized water and readings taken in µS/cm after inserting the probe into the water samples in a beaker.

Discharge measurement

Floatation method was used to determine water flow at the

Figure 1. Location of Pece wetland in Gulu District, Uganda showing transects and water sampling points.

sampling points of each inflow and outflow streams. Pieces of paper of equal size were made to float on the water surface and their movement downstream was timed within a distance of 1 m. This was replicated three times for each sampling point and the speed of the floating paper was calculated from the distance travelled over the time taken. An average speed for each sampling site was calculated during each visit. The depth and width of the streams channel were also measured using a tape and these were used to calculate the cross-sectional area of the individual streams. The average speed of the pieces of paper multiplied by the cross-sectional area was the water discharge for each sampling site. The load of pollutants into and out of the wetland was calculated by multiplying discharge (m^3/s) with the concentration of the pollutants.

Data analysis

Abundance for each species was calculated as:

$$\frac{\text{Sum of individual species}}{\text{Sum of all the species}} \tag{1}$$

Simpson diversity indices were used to characterize macrophyte species diversity (D) and the equitability (E) in the wetland (Equations 2 and 3, respectively).

$$\mathbf{D} = \frac{1}{\sum_{i=1}^{S} P_i^2} \tag{2}$$

where S is the total number of species in the community (richness) and P_i is the proportion of species (S) made up of the *i*th species.

The equitability (E_D) was expressed as a proportion of the maximum value D could assume, if individual in the community were completely evenly distributed. Equitability took a value between 0 and 1, with 1 being complete evenness.

$$\mathbf{E}_D = \frac{D}{D_{Max}} = \frac{1}{\sum_{i=1}^{S} P_i^2} x \frac{1}{S} \tag{3}$$

The FC concentration, the load and retention were presented in logarithmic scale. The retention of FC and TSS in the wetland were calculated as:

$$\text{Retention} = \left(\frac{\textbf{Total inflow load-Total outflow load}}{\textbf{Total inflow load}} \right) \mathbf{x\ 100} \tag{4}$$

The calculation of the wetland retention was based on the assumption that there was diffused water flow within the wetland, and the processes involved in the retention of FC and TSS were the same during the different seasons. Furthermore, it was assumed that the wetland received inflows from only the nine streams and the run-offs from the catchment at the wetland edge had no influence on the hydrology within the wetland.

The MINITAB software version 17 was used for data analysis. Nonparametric Kruskal-Wallis tests were performed to verify the degree of significance of the variances in the diversity and equitability of macrophytes, and water quality variables so as to compare temporal and spatial variations in the wetland. Parametric analysis was also done for results that indicated significant difference between sites. Data were checked for normality and equal variance and those that did not conform to the conditions were transformed. Tukey multiple comparisons were performed on transformed data to determine similarities and differences between the individual sites. The symbols ≠ and = indicate significant difference and non-significant difference between the sites, respectively. For all p-values ≤ 0.05, H_0 was rejected.

RESULTS

Macrophyte diversity in Pece wetland

A total of 42 species belonging to 24 families were identified (Table 1). The most common family in the wetland was Poaceae. *Digitaria scalarum* Chiov. represented 26.4% of the species abundance while *Cyperus papyrus* L. and *Cyperus rotundus* L. exhibited 17.5 and 12.2%, respectively. The abundance of 39 plant species were below 7% and *Crassocephalum crepidioides* S. Moore., showed the lowest abundance (0.001%). *D. scalarum* was found in all transects (T1-T5), while the rest of the plants were found in particular transects. Four species (*Rottboellia cochinchinesis* (Lour.) Clayton., *Eurphobia heterophylla* L., *Cleome gynandra* L., and *Bidens pilosa* L.) were found only during the wet season, while five others (*Physalis angulata* L., *C. crepidiodes* L., *Amaranthus hybridus* L., *Adenia cissampeloides* (Planch ex Benth.).Harms and *Hibiscus esculenta* L.) were found only during the dry season. *Blechnum cartilaginum* SW., *Dichrostachys cinerea* R.Vig., *Acacia polycantha* Wild., *Hymenocardia acida* Tul. and *Stipa capillata* L., showed seasonal differences in their abundance.

Macrophyte equitability declined at the upstream (T1-T3) and lower diversity was recorded at the downstream section (T4-T5) of the wetland (Figure 2). The downstream section of the wetland exhibited lower and higher variability in the macrophyte equitability, respectively, an indication of uneven distribution of the macrophyte in the downstream wetland section. The upstream section of the wetland was characterized by construction and edge gardening. Overall, macrophyte diversity and equitability in the wetland were not significantly different (p = 0.41 respectively).

Plots 1A and B closest to the water channel had lower diversity while plots 3A and B farthest from the channel showed higher diversity indices (Figure 3). The south and the western side (Plots 2B and 3B) showed higher variability. The seasonal macrophyte diversity indices of all the plots were not significantly different. Analysis of macrophyte equitability in the plots showed higher values during the dry season except for plots 1A and B (Figure 4). These plots are closest to the main water channel in the wetland. There was no significant difference in the seasonal macrophyte equitability in the plots.

FC numbers in the streams and their loads into and out from Pece wetland

FC numbers in the inflow streams and the outflow stream ranged from $3.5\times10^3 \pm 2.8\times10^3$ to $4.4\times10^4 \pm 7.4\times10^3$ and $1.8\times10^1 \pm 0.32\times10^1$ to $5.5\times10^3 \pm 7.7\times10^2$ CFU/100 ml during the wet season and the dry season, respectively.

Table 1. Plant species abundance in the wetland.

Family	Species	T1	T2	T3	T4	T5	Sum	Overall Abundance	Seasonal abundance	
									Dry season	Wet season
Agavaceae	*Agave sisalana* Perrine.	-	-	-	-	36	36	0.00191	0.0026	0.0026
Amaranthac eae	*Alternanthera philoxeroides* (Mart.) Griseb.	-	88	121	83	226	518	0.02742	0.0356	0.0356
	Amaranthus hybridus.	2	-	-	-	-	2	0.00011	0.0003	-
Arecaceae	*Phoenix reclinata* Jacq.	-	-	-	170	-	170	0.009	0.0114	0.0114
	Vernonia amygdalina Delile.	-	171	-	-	-	171	0.00905	0.0029	0.0029
	Bidens pilosa	-	-	2	-	-	2	0.00011	0.0002	-
	Crassocephalum crepidioides	-	1	-	-	-	1	5.29E-05	0.0002	-
Bignoniaceae	*Kigelia africana* (Lam.) Benth.	4	-	-	-	-	4	0.00021	0.0003	0.0003
Blechnaceae	*Blechnum cartilagineum*	-	61	78	229	-	368	0.01948	0.0208	0.0131
Cannaceae	*Canna paniculata* Ruiz & Pav.	-	-	-	20	-	20	0.00106	0.0011	0.0011
Cleomaceae	*Cleome gynandra*	-	4	-	-	-	4	0.00021	-	0.0003
Colchicaceae	*Gloriosa superba* L.	-	-	-	-	229	229	0.01212	0.0037	0.0037
Combretaceae	*Combretum molle* Eng. & Deils.	-	-	20	-	-	20	0.00106	0.0016	0.0016
	Terminalia glaucescens Planch. Ex Benth.	-	-	3	-	-	3	0.00016	0.0002	0.0002
Commelinacea	*Commelina benghalensis* L.	51	309	40	-	-	400	0.02117	0.037	0.037
Cyperaceae	*Cyperus papyrus*	-	1068	572	1657	-	3297	0.17451	0.226	0.226
	Cyperus rotundus.	1142	-	102	548	518	2310	0.12227	0.0976	0.0976
Euphorbiaceae	*Euphorbia heterophylla*	-	-	12	-	-	12	0.00064	-	0.001
Fabaceae	*Vigna unguiculata* (L.) Walp.	-	105	-	-	-	105	0.00556	0.0008	0.0008
	Dichrostachys cinerea	-	33	-	41	-	74	0.00392	0.0039	0.0041
	Albizia glaberrima Benth.	-	-	42	-	-	42	0.00222	0.0029	0.0029
	Acacia polyacantha.	-	-	-	-	8	8	0.00042	0.0006	0.0003
Lamiaceae	*Leucas martinicensis* R.Br.	133	-	-	-	-	133	0.00704	0.0122	0.0122
	Vitex doniana Sweet.	-	-	12	-	-	12	0.00064	0.001	0.001
Malvaceae	*Hibiscus esculentus*.	-	6	-	-	-	6	0.00032	0.001	-
Onagraceae	*Ludwigia octovalvis* (Jacq.) P.H.Raven	62	50	76	215	-	403	0.02133	0.0302	0.0302
Passifloraceae	*Adenia cissampeloides*	6	-	-	-	-	6	0.00032	0.0011	-
Phyllanthaceae	*Hymenocardia acida*.	-	-	16	-	-	16	0.00085	0.0013	0.0007
Poaceae	*Digitaria scalarum*	1667	161	673	318	2160	4979	0.26354	0.2186	0.2186
	Stipa capillata.	-	-	1102	77	-	1179	0.0624	0.0202	0.0422
	Hyparrhenia rufa Stapf.	-	-	-	-	1078	1078	0.05706	0.0765	0.0765
	Paspalum dilatatum Trin.	825	-	-	-	-	825	0.04367	0.1019	0.1019
	Cynodon dactylon (L.) Pers.	593	-	-	-	-	593	0.03139	0.0356	0.0356
	Brachiaria brizantha Stapf.	-	-	368	-	-	368	0.01948	0.0138	0.0138

Table 1. Contd.

	Setaria sphacelata (Schum.). Stapf & C.E.hubb.	-	-	91	276	-	367	0.01943	0.0058	0.0058
	Pennisetum purpureum Schumach.	-	-	8	175	-	183	0.00969	0.0029	0.0029
	Sporobolus pyramidalis P. Beauv.	-	-	69	-	-	69	0.00365	0.005	0.005
	Rottboellia cochichinesis	-	-	-	-	54	54	0.00286	-	0.0044
Rhamnaceae	*Zizyphus abyssinica* Hochst. Ex A. Rich.	-	-	-	-	12	12	0.00064	0.001	0.001
Sapindaceae	*Cardiospermum halicacabum* L.	-	81	2	23	-	106	0.00561	0.0034	0.0034
Solanaceae	*Physalis angulata*	1	19	-	-	-	20	0.00106	0.0003	0.0003
Vitaceae	*Cyphostemma adenocaule* (Steud.) Desc.	-	298	97	66	56	517	0.02737	0.0263	0.0263
	Total						18893			

The highest FC number was at S4 (Figure 5) that received run-offs and leakages from the municipal sewer lines. A recharged stream from underground (S9) showed lowest FC number. The FC numbers were not significantly different between the sampling points during the wet season ($p = 0.304$), but was significantly different during the dry season ($p = 0.000$). Multiple comparison between sites during the dry season indicated S9 = S5 ≠ S10 = S8 = S7 = S1 = S3 = S6 = S2 = S4.

The FC loads into and from the wetland ranged from $9.9\times10^4 \pm 1.7\times10^4$ to $2.5\times10^6 \pm 3.2\times10^5$ CFU S^{-1} and $3.2\times10^2 \pm 5.6\times10^2$ to $4.2\times10^5 \pm 8.1\times10^3$ CFU S^{-1} during the wet and the dry season, respectively (Figure 6). During the wet season, S10 (Outflow stream) and S5 which was characterized by less settlement, had the highest and lowest FC loads, respectively. FC load at S1, which received wastewater from commercial buildings in the municipality, was the highest during the dry season. Higher FC values were also recorded for S4 and S6 that are characterized with motor vehicle washing. The lowest FC load was at S9 a recharge stream from underground. Except for S7 that exhibited higher variability in the seasonal discharge, seasonal loads at the rest of the sites were not significantly different. The FC loads between the sites were not also significantly different during the wet and the dry season ($p = 0.124$ and 0.4, respectively).

Physico-chemical parameters in the inflows into and outflow from Pece wetland

The effluent from the stabilization ponds (S2) exhibited the highest TSS concentration in both seasons and lowest TSS was at S9 and S5 during the wet and the dry season, respectively (Table 2). Sites S2, S3, S4 and S10 showed seasonal differences in TSS concentration. TSS concentrations between the sites was not significantly different during the wet season ($p = 0.145$) but it showed significant difference during the dry season ($p = 0.007$). Multiple comparison between sites during the dry season indicated S2 ≠ S5 ≠ S7 = S8 = S4 = S1 = S6 = S9 = S3 = S10.

The TSS load ranged between 283.6 ± 44 mg S^{-1} to 26,331 ± 25,046 mg S^{-1} during the wet season and 344 ± 202 to 15,470 ± 805 mg S^{-1} during the dry season (Table 3). Seasonal TSS loads for the sites were not significantly different. There was a significant difference in TSS load between the sites during both the wet and the dry seasons ($p = 0.002$ and $p = 0.001$, respectively). Multiple comparison of TSS load showed, S10 ≠ S3 ≠ S6 ≠ S1 ≠ S9 ≠ S2 = S4 = S7 = S8 = S5 during the wet season, while S10 ≠ S9 ≠ S5 ≠ S6 = S7 = S1 = S4 = S8 = S3 = S2 during the dry season.

The sampling site (S3) that is characterized by fertilized cropping had the highest electrical conductivity during the wet season, while effluent from the stabilization ponds (S2) exhibited the highest EC during the dry season (Table 2). EC was lowest at S9, which is recharge water from the underground. Significant seasonal differences in EC showed up for S1, S3, S5, S6 and S10. Overall, there was significant difference in the EC between sites during the dry and the wet seasons ($p = 0.00$, respectively). Multiple comparison indicated S1 ≠ S9 ≠ S2 = S4 = S6 = S5 = S3 = S10 = S7 = S8 in the wet season, while S4 ≠ S1 ≠ S2 ≠ S9 ≠ S6 = S10 = S8 = S7 = S3 = S5 during the dry season.

Sites S1 that receive run-offs from the municipality and S2 that receive effluent from the lagoons, recorded the highest turbidity during the wet and the dry seasons, respectively (Table 2). Turbidity showed a significant difference between the sites during the wet and the dry seasons ($p = 0.002$ and 0.000 respectively). Multiple comparison indicated, S1 ≠ S9 ≠ S2 = S7 = S4 = S5 = S6 = S3= S8 = S10 during the wet season

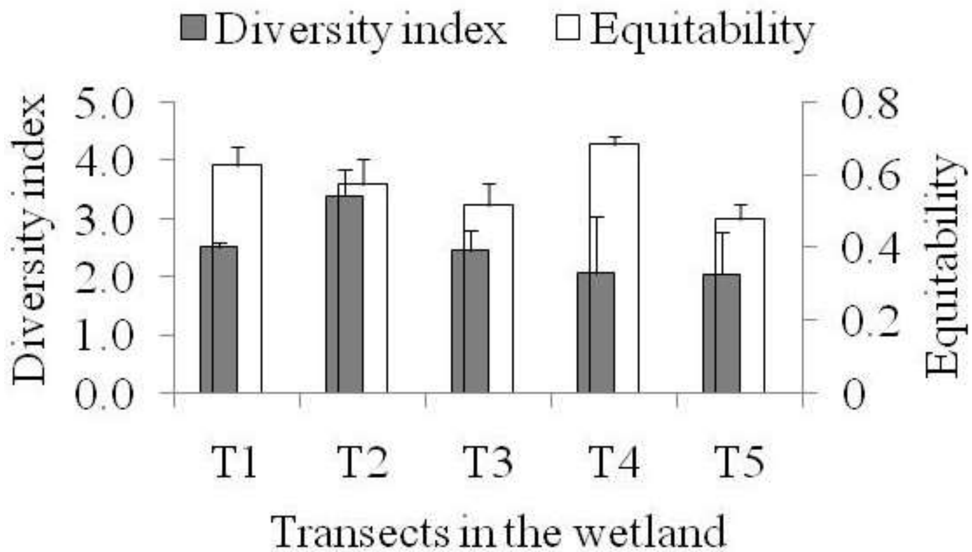

Figure 2. Mean Simpson macrophyte diversity and equitability indices in the wetland. Error bars indicate standard deviation of each transect (n = 4, for both diversity index and equitability).

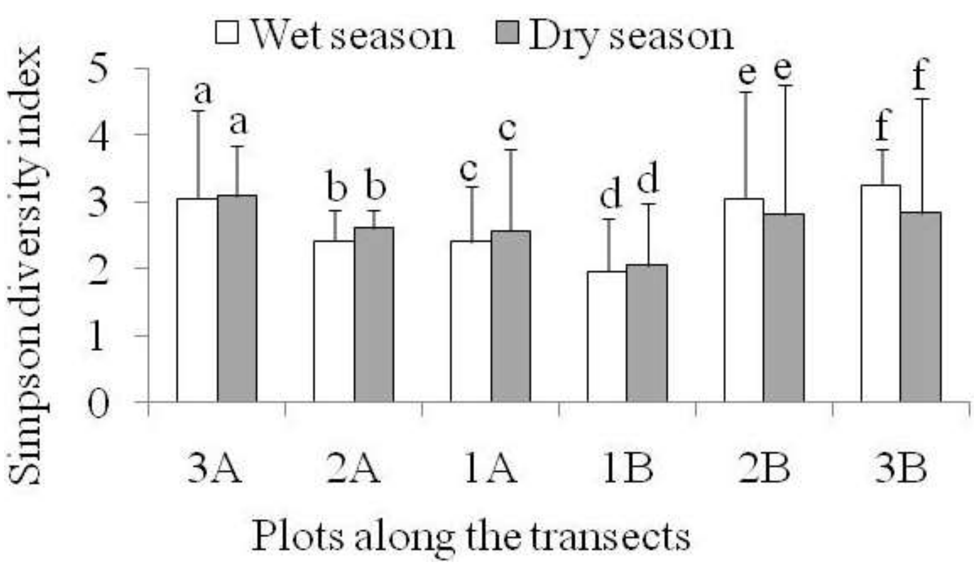

Figure 3. Mean Simpson macrophytes diversity index along plots in transects. 3A-1A and 1B-3B are plots on side A (north and eastern sides) and side B (south and western sides) respectively. Error bars indicate standard deviation (n = 10 for the wet and the dry seasons). Similar letters on the graph for each plot indicate no significant difference.

and S2 ≠ S9 ≠ S5 ≠ S8 = S6 = S1 = S3 = S4 = S7 = S10 during the dry season.

FC and TSS retention in Pece wetland

Overall, FC and TSS inflow into the wetland exhibited higher load than the outflow (Table 4). There was no significant difference in total FC load into and the outflow load from the wetland during the wet season (p = 0.26) but a significant difference occurred in the dry season (p = 0.009). TSS indicated significant difference between the total inflow load into and the outflow load from the wetland for the wet season but there was no significant difference during the dry season (p = 0.500 and 0.100

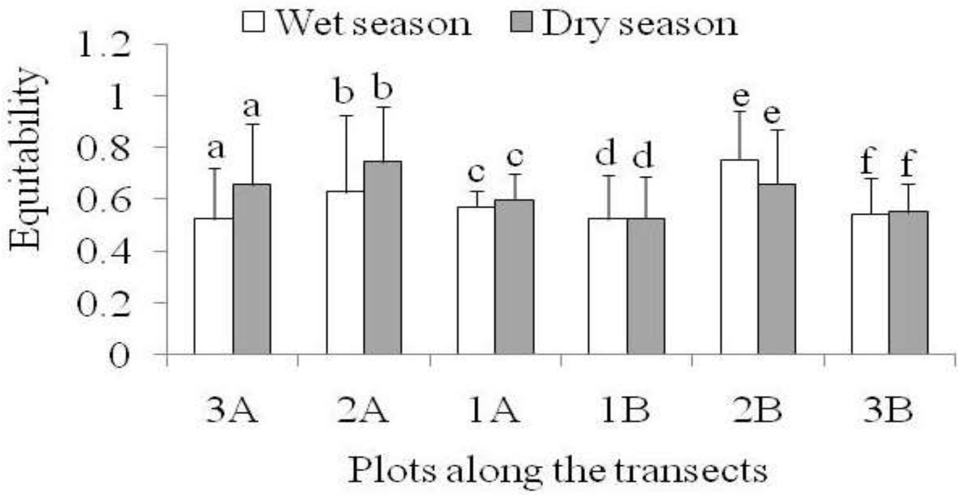

Figure 4. Mean macrophyte equitability in the plots. 3A-1A and 1B-3B are plots on the side A (north and eastern side) and side B (south and western side), respectively. Error bars indicate standard deviation (n = 10, for the wet and the dry seasons). Similar letters on the graph for each plot indicate no significant difference.

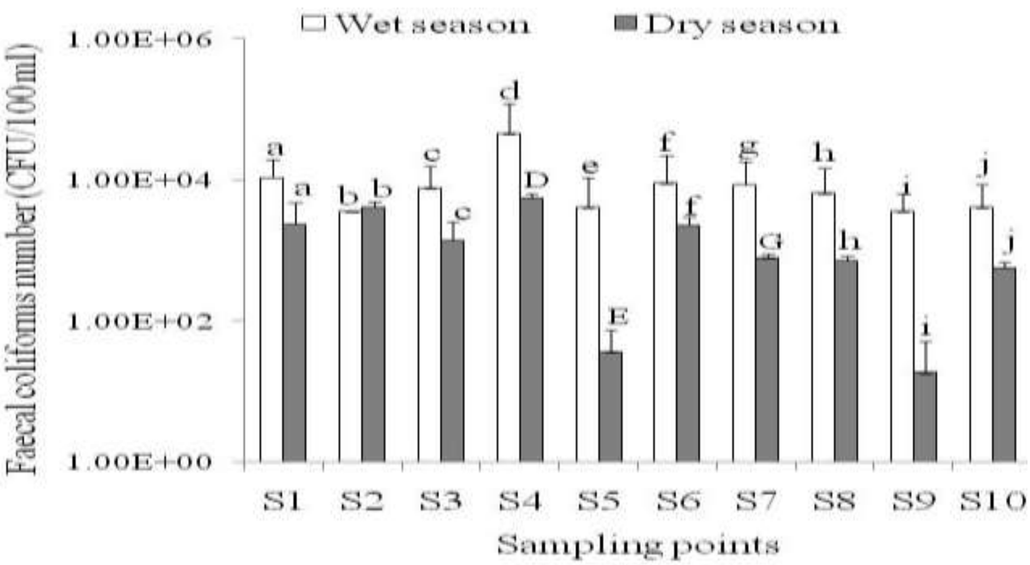

Figure 5. Faecal coliforms numbers in the inflow streams (S1-S9) and outflow stream (S10). Error bars indicate standard deviation (n = 6 for the wet season, n = 5 for the dry season) and logarithmic scale has been used. Similar letters in lower case for each site indicate no significant difference. Similar letters but in different cases for each site indicate significant difference.

respectively). There were higher retention of FC and TSS in the wetland during the dry season (Table 4).

DISCUSSION

The majority of the macrophytes that were identified in Pece wetland were grasses and herbs. Jogo and Hassan (2010) reported that in most wetlands, shrubs and trees are always harvested as fuel biomass when alternative sources are scarce. The wetland showed lower macrophyte diversity and equitability indices downstream. Lower macrophyte diversity and equitability indices were associated with lesser ionic content (Chappuis et al.,

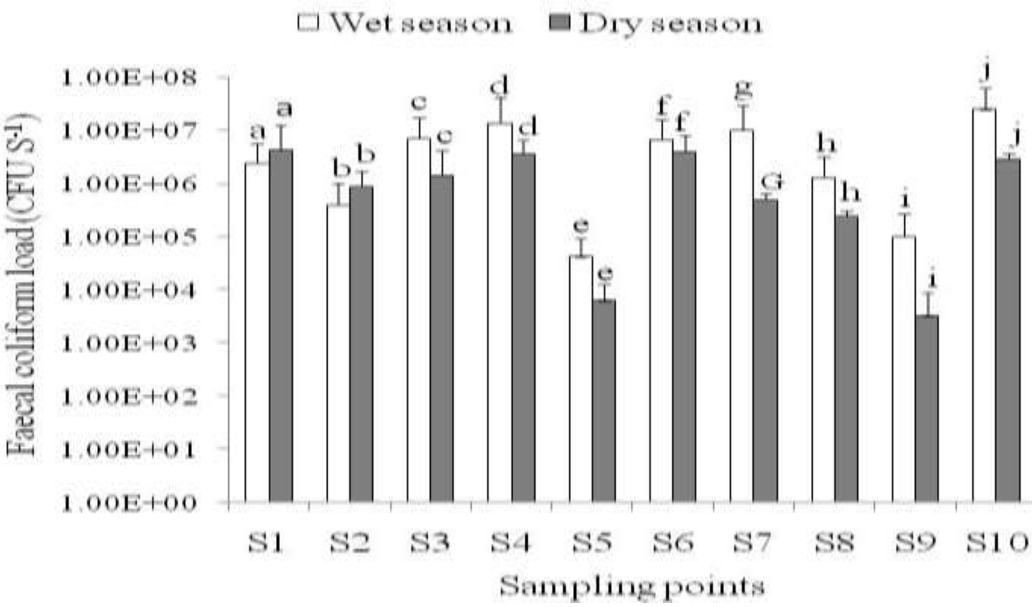

Figure 6. Faecal coliforms load in the inflow streams (S1-S9) and outflow stream (S10). Error bars indicate standard deviation (n = 6 for the wet season, n = 5 for the dry season) and logarithmic scale has been used. Similar letters in lower case for each site indicate no significant difference. Similar letters but in different cases for each site indicate significant difference.

Table 2. Seasonal physico-chemical parameters in the inflow streams (S1-S9) and outflow stream (S10) of Pece wetland (n = 6 for the wet season, n = 5 for the dry season).

Sampling point	TSS (mg/L)		EC (µS/cm)		Turbidity (NTU)	
	Wet	Dry	Wet	Dry	Wet	Dry
S1	152 ± 21.7	36 ± 15.7	334.5 ± 90.5*	224.8 ± 57*	355.7 ± 272	49.4 ± 10.4
S2	179.5 ± 0.7*	171.2 ± 66.8*	386 ± 19.8	231 ± 41	155 ± 106	117.2 ± 32.4
S3	63.6 ±15*	29.2 ± 6.5*	946.8 ± 192.8*	34.8 ± 4*	76.5 ± 21.8*	48.6 ± 9.4*
S4	76.4 ± 35.2*	41.6 ± 17*	325.9 ± 155	230.6 ± 53.8	94.7 ± 34*	44.8 ± 11.3*
S5	85.3 ± 28	20.8 ± 2.6	227.9 ± 178.6*	35.8 ± 11*	90.6 ± 30.3*	23.4 ± 4.9*
S6	90 ± 9.2	34.6 ± 10.2	181.5 ± 42.7*	72.4 ± 13*	105.8 ± 97.8	55.6 ± 13
S7	66.7 ± 63.9	44.4 ± 15	81 ± 19*	39.7 ± 12*	168.2 ± 167*	42.7 ± 9.5*
S8	57.5 ± 38.2	41.6 ± 7	68.7 ± 30	41.5 ± 13.6	94.2 ± 16	60.8 ± 25
S9	28.7 ± 3.4	33.8 ± 16.4	57.4 ± 30	30.4 ± 11	31.1 ± 29	24.7 ± 8
S10	49.7 ± 20.8*	29.2 ± 7.8*	117.2 ± 32*	51.1 ± 18.9*	63.1 ± 21*	35.1 ± 10.4*

*Means are significantly different between the seasons for each variable.

2014). However, low diversity is also associated with low disturbance (Evangelista et al., 2012; Tao et al., 2008) that allow dominant species to thrive. For example, the papyrus plant in the wetland blocks light from reaching the undergrowth species, therefore, lowering equitability. However, the effect of tremendous burning in the downstream section of the wetland during the dry season cannot be ruled out. The survival of species like *Hyparrhenia rufa* in the downstream section could be attributed to their resistance to fire or regeneration after fire.

Succession processes have also been reported as presenting advanced plant stage with different species composition (Santos and Thomaz, 2008). The reported diversity indices in the areas further away from the main water channel (towards wetland edge) is attributed to the effect of succession phenomena. On the other hand, the highest macrophyte diversity in the upstream (T2) could

Table 3. Seasonal TSS load in the inflow streams (S1-S9) and outflow stream (S10) of Pece wetland (n = 6 for the wet season, n = 5 for the dry season).

Sampling point	TSS load (mg S^{-1})	
	Wet season	Dry season
S1	9,875.3 ± 7,185	2,711 ± 2,581
S2	5,840.3 ± 265	3,371 ± 2,581
S3	4,310 ± 2,887	2,239 ± 2,115
S4	2,210 ± 880	2,626 ± 2,578
S5	432.1 ± 426	344 ± 202
S6	14,492.9 ± 8,398	6,569 ± 737
S7	5,136.1 ± 957	2,990 ± 1,772
S8	731.8 ± 500	1,437.3 ± 468
S9	283.6 ± 42	516.9 ± 269
S10	26,331.1 ± 25,046	15,470 ± 805

Table 4. Retention of FC and TSS in Pece wetland during the dry and the wet seasons (n = 6 for the wet season and n = 5 for the dry season for both variables).

Variable	Season	Inflow load	Outflow load	Retention (%)
FC (CFU S^{-1})	Wet	$4.2 \times 107 \pm 3.4 \times 10^7$	$2.5 \times 10^7 \pm 3.7 \times 10^6$	41
	Dry	$1.5 \times 10^7 \pm 1.6\ 8 \times 10^6$	$2.5 \times 10^6 \pm 8.3 \times 10^5$	83
TSS (mg S^{-1})	Wet	45,696.8 ± 34,073	26,331.2 ± 18,021	42.4
	Dry	28,784.5 ± 9,707	15,469.9 ± 8,053	46.3

be ascribed to sediment accretion from the Gulu municipal run-offs and the massive wetland edge gardening. The run-offs concentrate alluvial soils at the wetland edge that provide adequate condition for subsistence farming (Tao et al., 2008). *H. esculenta* was a common agricultural plant at Pece wetland edge. Its occurrence as agricultural crop at the wetland edge has also been reported by Jogo and Hassan (2010).

The low equitability downstream was in the areas of small channel flow of about 4 to 5 m. Chappuis et al. (2014) reported association between species equitability and water body area. Therefore, hydrological gradient, such as water table depth does not only influence species distribution but also spatial distribution of vegetation across topographical gradients (Silvertown et al., 1999). The higher diversity in the dry season compared to the wet season could be due to wetland flooding in the wet season which may not favor macrophytes that are less water tolerant. The water regime during the different seasons is important in determining aquatic macrophyte species (Chappuis et al., 2014). Therefore, reduced flooding of wetlands margin results into higher abundance, richness and diversity of plants that do not tolerate high water level (Andrew et al., 2015). The higher diversity in the dry season could also be due to anthropogenic disturbances (edge gardening). Tao et al. (2008), reported higher diversity in disturbed areas, with only fugitive species surviving, and lower in undisturbed areas with only the competitive dominant species surviving.

There was highest turbidity at S1 during the wet season. Such high turbidity have been related to the increased amount of run-offs which is common in municipal areas (Löptien and Meier, 2011). Agricultural activities in and around wetlands contributing to increased turbidity has also been reported (Carrasco et al., 2013) and this explains the high values at S7 and S8. During the wet season, the high turbidity at S2 may perhaps be due to inadequate treatment of TSS in the lagoon prior to discharge. In addition, greater inflow volume into the lagoons also reduces TSS treatment performance (Borne et al., 2013). The low turbidity at S9 may be due to the fact that S9 has underground water source that is filtered by the soil particles.

Furthermore, flow velocity is an important parameter which influences TSS removal within wetlands (Yahyapour and Golshan, 2014). The wetland streams recorded a lower flow velocity during the dry season, a reason for lower load of TSS during the season. The highest TSS load at S2, a point source may be as a result of low TSS sedimentation or high development of algal plants in the lagoons. On the other hand, the high TSS load in the outflow (S10) is the accumulation from the inflow streams and also the contribution from the detrital decomposition in the wetland.

The high EC values at S1 and S3-S6 during the wet season could be due to run-offs from municipality. But also during the dry season, the fertilized cropping of tomatoes and cabbages increase ionic content of water flowing into the wetland (Brodie and Mitchell, 2005). The cultivation in the wetland during the dry seasons enhances nutrients released at the outflow stream (S10) during the wet season. Implying mineralization (organic decomposition) that frees particulate nutrients is high during ploughing and nutrients are flushed off from the wetland during high water levels. On the other hand, high EC at S2 may be explained by the mineralization effect of organic wastes in the lagoons.

Although, FC numbers at S4 and S1 were above the standards of 10,000 FC/100 ml (ULRC, 1999) during both seasons, the retention range was 41 to 83%, which is within that reported for a tropical wetland in Tanzania (43 to 72%) (Kaseva, 2004). High retention of FC is a result of increased water retention time in the wetland which allows for adequate attachment of FC to the rhizomes of wetland plants and also detrital sedimentation of the microbes (Sundaravadivel and Vigneswaran, 2001; Kansiime and Nalubega, 1999). The rooted papyrus increased the removal of FC in the mat by providing oxygen in the rhizosphere (Kyambadde et al., 2004) which encourages the biological removal mechanism that include antibiosis, predation by protozoa, nematodes and protists (Jasper et al., 2013).

Physical factors (mechanical filtration by the rooted zone and attached biofilm, and sedimentation) and chemical factors (oxidation, exposure to biocides which may be excreted and adsorption to organic matter) could have contributed to the FC retention (Stefanakis et al., 2014). The wetland recorded high coliforms retention during the dry season. The high retention during the dry seasons is also due to the lethal effect of solar radiation (Ansa et al., 2012).

TSS retention in wetlands were reported to range from 22 to 57% for United State Kingdom (Ockenden et al., 2012), a range which falls within the TSS reduction efficiency of Pece wetland. However, Opio et al. (2002) reported 96% treatment efficiency for Kinawataka wetland in Kampala, Uganda. The differences could be due to climatic variability, and the types of macrophyte species involved in the treatment, streams discharge and the flow dynamics within the wetlands.

This study reveals that random discharge of pollutants and changes in water levels in wetlands due to human activities are able to induce great changes in the rate of aquatic vegetation community succession (Chow-Fraser et al., 1998). Sustainable use of wetland is particularly challenging in tropical environments in areas of dense human settlement (Balmford and Bond, 2005). Wetlands in Africa are being modified or reclaimed, often driven by economic and financial motives (Schuyt, 2005). Protection and restoration of wetlands are essential for future sustainability of the planet and the overall well-being of society (Clarkson et al., 2013).

However, Pece wetland still has diverse species of grasses and herbs with very few species of shrubs and trees. The equitability index in some transects and plots were above 0.5, an indication that the wetland still has species fairly distributed although some sites had FC counts and physico-chemical values that were above National Environmental Management Authority (NEMA) standard for discharge of effluent into water or on land. Therefore, the agricultural activities in the wetland should be done in line with Uganda wetland policy so that the ecological functions of the wetland are not interfered with.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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