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Impact of river water and sediment properties on the chemical composition of water hyacinth and hippo grass

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ABSTRACT

Water hyacinth and hippo grass are aquatic weeds that negatively affect freshwater bodies in sub-tropical and tropical areas. Using these weeds as soil amendments can help to reduce their spread, and improve soil fertility. Materials intended for use as soil amendments must have high levels of nutrients and low contaminant levels. It is important to understand how water and sediment properties influence the chemical composition of these weeds, to assist in choosing weeds that have high nutrient levels and low levels of heavy metals. This study aimed to investigate the effect of water and sediment characteristics on the chemical composition of water hyacinth and hippo grass and to assess the suitability of these aquatic weeds as soil amendments. We evaluated how the chemical parameters of water hyacinth and hippo grass varied across different rivers, and examined the relationship between the chemical composition of the aquatic weeds and the chemical composition of water and sediments in rivers where they occur. Plant, sediment, and water samples were systematically obtained from Kafue, Chongwe, Maramba and Kafubu Rivers in Zambia. These rivers are subject to different influences of anthropogenic activities and were therefore expected to differ in their levels of nutrients and heavy metals. Weeds collected from the Maramba River, which passes through human settlements, contained significantly higher concentrations of nitrogen and phosphorus, while weeds collected from Kafubu and Kafue Rivers which pass through industrial and mining areas contained significantly higher levels of zinc, cobalt, manganese, and copper. However, the concentrations of chromium, zinc, copper, manganese, and lead in the aquatic weeds from all four rivers were lower than the critical EU limits for compost. Concentrations of phosphorus and nitrogen in water hyacinth were positively correlated with levels in river water. In hippo grass, the levels of nitrogen and phosphorus were strongly and positively correlated with concentrations in sediments, but weakly correlated with concentrations in water. The results show that aquatic weeds from different locations vary in their nutrient and heavy metal contents, indicating that careful consideration needs to be taken when choosing sources of aquatic weeds intended for agronomic use. Maramba River was identified to be the best source of aquatic weeds for agronomic use because the weeds from this River had higher levels of macronutrients and lower levels of heavy metals.

1. Introduction

The rapid spread of aquatic weeds is increasingly becoming a serious challenge in most freshwater bodies (Wu et al., 2020; Mahmoud et al., 2021). In tropical and sub-tropical areas, non-native aquatic weeds like the hippo grass (*Vossia cuspidata (Roxb.) Griff*) and water hyacinth (*Eichhornia crassipes (Mart.) solms*) have caused serious ecological and socio-economic problems. These have included competition with indigenous aquatic life; interference with hydroelectric turbines; and blocking of waterways thus impeding activities such as fishing, irrigation, and water transport (Damtie et al., 2022; Githuki et al., 2012; Farahat et al., 2021). In Africa, these aquatic weeds have negatively

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affected the activities and functioning of freshwater bodies like the Nile River, Lake Victoria, and many others (Farahat et al., 2021; Nega et al., 2022). In Zambia, water hyacinth and hippo grass have invaded most of the water bodies among them the Zambezi, the Kafue, the Kafubu, the Chongwe, and the Maramba Rivers (Howard et al., 2016; Mbula, 2016; Nang'alelwa, 2008; Winton et al., 2020). Despite implementing various mechanical, chemical, and biological measures, eradicating aquatic weeds has proven to be extremely difficult (Nang'alelwa, 2008; Ilo et al., 2020).

Water hyacinth, which is one of the most dreaded and noxious aquatic weeds, has not been easy to eliminate because it proliferates rapidly and adapts easily to different environments (Abonyo et al., 2012; Ayanda et al., 2020; Githuki et al., 2012; Patel, 2012). Originating from South America, the weed has easily adapted to humid and warm environments around the world. Water hyacinth is a perennial aquatic weed belonging to the family *Pontederiaceae* (Higuti et al., 2016; Singh and Kalamdhad, 2013). Its roots grow suspended in water and their extensive fibrous system allows high uptake of nutrients from water (Fox et al., 2008). Water hyacinth propagates asexually by forming adventitious stolons, and also sexually through seed germination (Heard et al., 2000; Ongore et al., 2018; Villamagna et al., 2010). The weed forms associations with other aquatic weeds such as hippo grass, and in many instances can be seen floating together as mats or grass islands (Galal et al., 2021; Mahmoud et al., 2021).

Hippo grass is also an emergent perennial aquatic weed that is part of the family *Poaceae* (Githuki et al., 2012; Ongore et al., 2018). The weed propagates asexually by forming rhizomes that spread across the water with the roots embedded in sediments along the banks of water bodies (Galal et al., 2021; Gichuki et al., 2012).

The rapid and uncontrolled multiplication of water hyacinth and hippo grass has been enhanced by the enrichment of aquatic systems with nutrients associated with human activities (Coetzee 2012; Gao et al., 2016; Honlah et al., 2019; Wilson et al., 2005; Winton et al., 2020). The eutrophication of water bodies because of increased levels of nitrogen and phosphorus significantly contributes to the spread of aquatic weeds by providing the nutrients they need for their growth (Chola, 2010; Coetzee, 2012; Farahat et al., 2021). According to Sinkala et al. (2002), effluents from manufacturing and mining industries, farms, and domestic activities are largely responsible for freshwater pollution and eutrophication in Zambia. Despite the adverse effects associated with the infestation of water bodies by water hyacinth and hippo grass, studies have shown that these weeds play an important role in sequestering heavy metals and nutrients from polluted aquatic ecosystems (Galal et al., 2021; Ilo et al., 2020). Fox et al. (2008) showed that water hyacinth could take up as much as 60 – 85% of nitrogen from N-enriched water. Galal et al. (2021) and Farahat et al. (2021) also indicated that hippo grass was capable of taking up macronutrients and heavy metals from water and sediments through luxury consumption.

Finding innovative ways of using aquatic weeds can help manage and reduce their rapid spread in aquatic systems (Andika et al., 2016; Mohamed et al., 2020). The ability of aquatic weeds to absorb and sequester substantial amounts of nutrients from eutrophic rivers makes the weeds potential resources for improving soil fertility. They could be applied to the soil as amendments directly, or after composting or fermentation (Muktama et al., 2016; Su et al., 2018; Udume et al., 2022). Composting aquatic weeds can help to generate organic materials that are pathogen-free and that have carbon: nitrogen ratios that are favorable for enhancing microbial activity (Inckel et al., 2005; Singh and Kalamdhad, 2013). However, the heavy metal contents in the aquatic weeds and their final composted products may have detrimental effects on the environment and human health if the levels are too high (Ilo et al., 2020; Singh and Kalamdhad, 2013). Identifying aquatic weeds with low concentrations of heavy metals and high concentrations of plant nutrients may be the solution to the problem. It appears that not much research has been done on the use of aquatic weeds as nutrient sources for improving soil fertility and on assessing their potential risk as sources of heavy metal contamination (Balasubramanian et al., 2013; Oguike et al., 2001).

There is a need to identify rivers and locations along rivers where high-quality water hyacinth and hippo grass can be harvested for use as soil amendments. This however requires knowledge of how the chemical composition of the aquatic weeds relates to the chemical composition of the river water and of sediments in locations where they occur. In this study, the first objective was to establish whether nutrients and heavy metal concentrations of aquatic weeds collected from different rivers varied significantly. The second objective was to determine whether there were significant relationships between nutrient and heavy metal concentrations of aquatic weeds and those of sediments and water in the rivers. The study was carried out on four rivers in Zambia that are highly infested with water hyacinth and hippo grass. They included the Kafue, Chongwe, Maramba, and Kafubu rivers. It was expected that water and sediments from these rivers would differ significantly in their chemical properties because of differences in the dominant anthropogenic activities along the rivers and that this in turn would influence the chemical composition of aquatic weeds growing in these rivers.

It was hypothesized that the chemical composition of water hyacinth and hippo grass from different rivers would differ significantly. It was also hypothesized that aquatic weeds collected from rivers passing through human settlements would have significantly higher amounts of nitrogen, phosphorous, and potassium while weeds from rivers passing through industrial and mining towns would have significantly higher heavy metal concentrations. It was further hypothesized that a significant positive relationship exists between concentrations of nutrients and heavy metals in water hyacinth and the concentrations in river water, and that the nutrient and heavy metal concentrations in hippo grass are more related to the chemical composition of sediments than that of water. The determination of nutrient and heavy metal concentrations in water hyacinth and hippo grass would serve as a first step in assessing the potential suitability of using these weeds for soil fertility improvement.

2. Materials and methods

2.1. Description of the study area

Four rivers in Zambia documented to have problems of aquatic weed infestation were targeted. They were the Kafue, Chongwe, Maramba, and Kafubu Rivers, as shown in Fig. 1.

The Maramba River is a tributary of the Zambezi River, which drains a catchment area of about 510 Km^2. It passes through an urban settlement in Livingstone town and receives large amounts of effluents from domestic sewage and runoff from farms. Maramba River is reported to be highly infested with water hyacinth (Nang'alelwa, 2008; Winton et al., 2021) and hippo grass. Winton et al. (2020) reported high levels of eutrophication in the Maramba River associated with sewage waste.

The Kafue River is also a tributary of the Zambezi River and stretches over a distance of 1576 km. It runs through the major mining towns of Zambia in the Copperbelt Province where it receives effluents containing various heavy metals. Further downstream of the Copperbelt, the river passes through some areas with large-scale agricultural activities such as the Kafue fisheries and the Nakambala Sugar estates (Kambole, 2003; Sinkala et al., 2002). Effluents and runoff from these agricultural centers are believed to contribute to water pollution and consequently to the enhanced proliferation of aquatic weeds in parts of the river.

The Chongwe River is another tributary of the Zambezi River, which passes through the urban settlements of Chongwe, Lusaka, Chisamba, Chibombo, and Kafue districts. Agricultural activities are common along its' banks and contribute to the eutrophication of the water from fertilizer-enriched runoff (Tena et al., 2019; Winton et al., 2021).

The Kafubu River is a tributary of the Kafue River, which drains major industrial and mining areas in the Copperbelt of Zambia. Effluents from mine dumps containing cobalt, copper, and manganese have

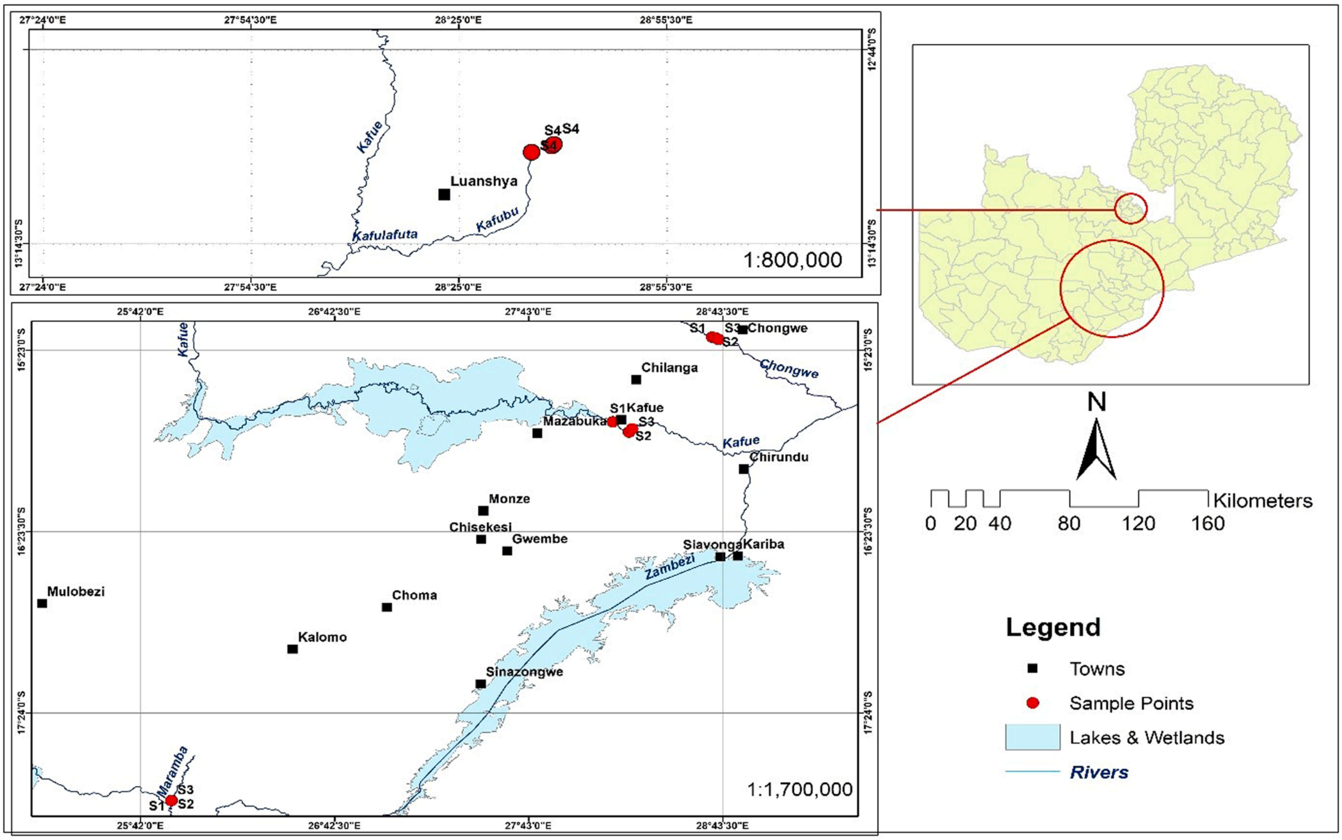

Fig. 1. Map of the study area in Zambia from where river water, sediment and plant samples were collected.

contributed to the heavy metal pollution in this river. It also receives domestic and sewage effluents from urban settlements in Ndola city, which contribute to high levels of eutrophication (Nkaka, 2000; JICA, 2011).

2.2. Water and water hyacinth sample collection

Surface water and water hyacinth samples were collected from Kafue, Chongwe, and Maramba Rivers in the dry season months of June-July in 2021. Three sampling points were picked systematically along each river. The selection of the first sampling point was based on the proximity to human activity centers and the presence of water hyacinth weeds while the subsequent points were sampled following intervals of approximately 1 km between sampling points. The surface water samples were collected in triplicate from a depth of 0 – 20 cm and placed in 1-liter plastic bottles that were initially rinsed with distilled water. Water hyacinth plants were also collected in triplicates from the location where water samples were collected and were then placed in plastic bags. The geographic coordinates of each sampling point were captured and recorded using a Global positioning system (GPS). The samples were stored in Cooler boxes before transportation to the laboratory.

2.3. Water, sediment and hippo grass sample collection

Water, hippo grass and sediment samples were obtained from Kafubu, Maramba and Kafue Rivers during the rainy season of 2022 in the months of February and March. Hippo grass was included after sampling water hyacinth and realizing that the two weeds occurred in association. Water hyacinth had already been sampled the previous year in the dry season and hippo grass was therefore sampled the following year in the rainy season. The period chosen to sample hippo grass was based on the feasibility of sampling and the availability of time and resources. Three sampling points were sampled systematically per river. The first sampling point was selected based on the proximity to human activity centers and the presence of hippo grass, while the subsequent points were sampled following intervals of approximately 1 km apart. From each sampling point; water, hippo grass and sediments were collected simultaneously. Surface water samples were obtained in triplicates at a depth of 0– 20 cm and then placed in 1-liter plastic bottles. Sediments were also collected in triplicates from the top 0–20 cm and stored in plastic bags. Hippo grass samples were physically uprooted from the sediments and stored in plastic bags. All the samples were later taken to the laboratory.

2.4. Sample preparation and laboratory analysis

All the chemical analyses on the sediment, water and plant samples were determined in triplicates. The reagents used for all the analyses were of analytical grade and they were obtained from Himedia laboratories. The glassware used during analyses were obtained from Duran laboratory bottles. Sediment samples were air-dried before sieving with a 2 mm sieve in preparation for various chemical analyses. The pH of the sediments was determined in water and read using an 8424 pH meter. The micro-Kjeldahl method was used to determine the total nitrogen concentration of sediments (Chapman and Pratt, 1961). The Walkley and Black method was used to determine the total carbon content of the sediments (Nelson and Sommers, 1982). The available phosphorus in the sediments was determined using the Bray 1 method (Olsen and Sommers, 1982). Total sulphur in the sediments was extracted using aqua regia and was read using UV-visible Spectrophotometer at a wavelength of 430 nm. Calcium (Ca), Magnesium (Mg), sodium (Na) and potassium (K) were extracted using 1N ammonium acetate. Strontium chloride was then added to the filtrate before reading the concentrations using a Perkin Elmer AAnalyst 400 Atomic Absorption

Spectrometer (AAS). The heavy metals (zinc, iron, manganese, copper, lead, cobalt, Chromium, and cadmium) were determined using DTPA extract and read using AAS (Miles and Parker, 1979).

For the water samples, the pH and Electrical Conductivity (EC) were determined using a Hanna HI 8424 pH and EC meter, respectively. Concentrations of the metallic cations: potassium, sodium, magnesium, calcium and the heavy metals: manganese (Mn), lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), cobalt (Co), zinc (Zn)) were measured using a Perkin Elmer AAnalyst 400 Atomic Absorption Spectrometer (AAS). The molybdenum blue method, a colorimetric method was used to determine the phosphate concentrations in water (Murphy and Riley, 1962). The phosphate concentrations were measured at a wavelength of 882 nm using a Jenway 6305, UV-Visible Spectrophotometer. Sulphate (SO_4) concentrations were determined by adding $BaCl_2$ to the water samples and reading the concentrations at a wavelength of 430 nm on a Jenway 6305 Spectrophotometer. The micro-Kjeldahl method was used to determine concentrations of ammonium (NH_4) and nitrates (NO_3) in the water samples (Bremmer and Mulvaney, 1982).

The aquatic weeds were initially rinsed with distilled water and then placed in an oven at 75 °C for 48 h. The dry plant samples were then ground using an electric plant grinder. Two grams of ground plant samples in crucibles were placed in a muffle furnace for ashing at 500 °C for 24 h. After ashing, 20 ml of 1 M HNO_3 was added to the ash and then left to boil on a hotplate. After cooling, the mixture was filtered and the filtrate was placed into a 100 ml volumetric flask to which distilled water was added to the 100 ml mark. Concentrations of Ca, Mg, Na, K, Pb, Cr, Zn, Cd and Co in the extract were measured using Atomic Absorption spectrometry (AAS). Phosphate (P) concentration in plant samples was determined using the molybdenum blue method and read on a Jenway 6305 Spectrophotometer. Sulphur was determined by ashing and read on a UV-visible Spectrophotometer at a wavelength of 430 nm. The Walkley and Black method was used to determine the organic carbon content of the aquatic weeds (Nelson and Sommers, 1982). The micro-Kjeldahl method was used to determine the total nitrogen (N) content of the aquatic weeds (Chapman and Pratt, 1961). The plant dry mass was measured by oven-drying 1 kg of fresh aquatic weeds at a temperature of 75 °C for a period of 48 h. The dry mass was measured using a balance.

2.5. Statistical analysis

Statistical analysis was done using R version 4.2.0. To test for normal distribution of the data, the Shapiro-Wilk test was done. Levene's test was also performed to check for equal variances across samples. Significant differences among the various parameters of sediments, water and aquatic weeds were determined using one-way analysis of variance (ANOVA) and the least significant difference (LSD) was performed as a post -hoc test to compare and separate means of parameters. The Pearson correlation analysis was also performed to determine the correlation between various chemical characteristics of the plants and the river water or sediments. The significant differences for all the parameters were tested at a P value < 0.05.

3. Results

3.1. Properties of water from the different rivers

When water was sampled during the dry season, the concentration of water nitrate (NO_3) in the Maramba River was approximately 53% higher than that of the Chongwe River, and 64% higher than that of the Kafue River (Table 1). Similarly, the concentration of water ammonium (NH_4) was between 52% and 62% higher in the Maramba River compared to Kafue and Chongwe Rivers. Notably, the water NO_3 concentration in the Maramba River exceeded the WHO thresholds for drinking water, whereas the NO_3 concentration in the Kafue and Chongwe Rivers was below the threshold. Additionally, the Maramba River had phosphorus (P) concentrations nearly three times higher than the concentrations in the Kafue and Chongwe Rivers. The P concentration in all the rivers exceeded the WHO threshold for drinking water, as shown in Table 1. Unlike P and N, the concentration of K in the water of the Chongwe River was about four times higher than that in the Maramba River and twice as high as that in the Kafue River. The Ca and Mg concentrations in the water from the Maramba River was not significantly different with the concentrations from the Chongwe Rivers. However, the Kafue River water had nearly half the concentration of Ca and Mg compared to the levels found in the Maramba and Chongwe Rivers.

Table 1
Means and standard errors of the pH and concentrations of elements of river water at locations where water hyacinth was collected, with WHO permissible limits for drinking water. Values of mean + SE, n = 9 per river. Significant differences ($p < 0.05$) within rows are indicated by different letters.

Elements/ Nutrients	Across Rivers	Maramba River	Chongwe River	Kafue River	WHO limits
pH	7.67 ±0.14	8.25±0.06 a	8.14±0.05 a	6.67 ±0.05 b	6.5-8.5
NO_3 (mg/L)	46.74 ±3.10	62.78±2.73 a	40.99±5.19 b	38.23 ±3.54 b	50
NH_4 (mg/L)	11.39 ±0.66	15.19±0.46 a	9.40±1.01 b	10.00 ±0.66 b	
P (mg/L)	1.81 ±0.30	3.33±0.63 a	1.07±0.13 b	1.04 ±0.11 b	0.1
Ca (mg/L)	59.43 ±4.98	70.56±7.96 a	73.69±7.17 a	34.03 ±2.43 b	75
Mg (mg/L)	12.36 ±1.16	15.36±2.66 a	13.08±1.75 ab	8.64 ±0.20 b	30
K (mg/L)	4.35 ±0.54	1.55±0.49 b	6.17±0.87 a	3.77 ±0.44 b	
SO_4 (mg/L)	6.25 ±1.32	3.33±0.26 b	13.08±2.85 a	2.35 ±0.14 b	400
Na (mg/L)	17.49 ±2.13	15.55±2.05 b	28.93±3.40 a	8.00 ±0.47 c	200
Zn (mg/L)	0.01 ±0.00	0.01±0.00 a	0.01±0.00 a	0.01 ±0.00 a	3
Cu (mg/L)	0.07 ±0.00	0.078±0.00 a	0.061±0.00 ab	0.058 ±0.00 b	1
Cr (mg/L)	0.21 ±0.02	0.12±0.02 b	0.23±0.02 ab	0.27 ±0.04 a	0.05
Pb (mg/L)	0.26 ±0.01	0.22±0.02 a	0.27±0.03 a	0.28 ±0.01 a	0.01
Fe (mg/L)		nd	nd	nd	0.3
Mn (mg/L)		nd	nd	nd	0.4
Co (mg/L)		nd	nd	nd	0.05
Cd (mg/L)		nd	nd	nd	0.003

nd = not detected, Detection limits: Fe = 0.01 mg/L, Mn = 0.01 mg/L, Co = 0.01 mg/L, Cd = 0.001 mg/L

When water was sampled in the dry season, some of the heavy metals such as iron (Fe), cadmium (Cd), manganese (Mn) and cobalt (Co) were below detectable limit in the water (Table 1). However, lead (Pb) and chromium (Cr) in water samples from all the rivers were above the WHO limits for drinking water. Chromium (Cr) concentrations in the Kafue and Chongwe Rivers did not differ significantly, but the Maramba River had a notably lower concentration of Cr (Table 1). The zinc (Zn) concentration was very low (0.01 mg/L) across all the rivers at the time of sampling, while copper (Cu) concentrations were in the range of 0.058 to 0.078 mg/L across the rivers.

During the rainy season sampling for water, the water NO_3 concentration in the Maramba River was 39% and 49% higher than the NO_3 concentration in the Kafue and Kafubu Rivers respectively (Table 2). Additionally, the water P concentration in the Maramba River was almost six times more than the water P concentration in the Kafue River and two times higher than the Kafubu River. However, the NO_3 concentrations in all three rivers were below the WHO threshold, while the water P concentrations in all three rivers exceeded the WHO limit for drinking water (Table 2). Water K was significantly higher in the

Table 2
Concentration of elements (mg/L) and pH of water in three rivers where hippo grass was collected, and WHO permissible limits. Values of mean + SE, n = 9 per river. Significant differences ($p < 0.05$) are indicated by different letters in the table rows.

Elements/ Nutrients	Across Rivers	Maramba River	Kafubu River	Kafue River	WHO limits
pH	7.50 ±0.03	7.42±0.06 b	7.65 ±0.06 a	7.41 ±0.02 b	6.5-8.5
NO_3 (mg/L)	23.99 ±1.49	30.22±2.52 a	20.34 ±2.14 b	21.70 ±1.86 b	50
NH_4 (mg/L)	5.88 ±0.29	6.50±0.64 a	5.23 ±0.40 a	5.90 ±0.42 a	
P (mg/L)	1.69 ±0.23	3.20±0.20 a	1.30 ±0.10 b	0.59 ±0.15 c	0.1
Ca (mg/L)	26.82 ±2.54	32.67±4.22 a	35.42 ±2.08 a	12.39 ±1.07 b	75
Mg (mg/L)	12.54 ±1.21	18.78±1.46 a	13.69 ±0.42 b	5.14 ±0.32 c	30
K (mg/L)	4.85 ±0.13	5.26±0.21 a	4.25 ±0.19 b	5.05 ±0.04 a	
SO_4 (mg/L)	4.88 ±0.78	4.58±1.67 a	6.97 ±1.47 a	3.09 ±0.29 a	400
Na (mg/L)	12.43 ±0.81	18.13±0.53 a	9.49 ±0.23 b	9.65 ±0.03 b	200
Cu (mg/L)	0.03 ±0.00	0.02±0.00 b	0.03 ±0.00 ab	0.04 ±0.00 a	1
Zn (mg/L)		nd	nd	nd	3
Cr (mg/L)		nd	nd	nd	0.05
Pb (mg/L)		nd	nd	nd	0.01
Fe (mg/L)		nd	nd	nd	0.3
Mn (mg/L)		nd	nd	nd	0.4
Co (mg/L)		nd	nd	nd	0.05
Cd (mg/L)		nd	nd	nd	0.003

nd = not detected, Detection limits: Fe = 0.01 mg/L, Mn = 0.01 mg/L, Co = 0.01 mg/L, Cd = 0.001 mg/L, Zn = 0.001 mg/L, Cr = 0.001 mg/L, Pb = 0.001 mg/L

Maramba and the Kafue Rivers and lowest in the Kafubu River. Furthermore, the water Ca and Mg concentrations were more than two-fold higher in the Maramba River compared to the Kafue River. Concentrations of water Ca did not vary significantly between the Maramba and the Kafubu Rivers (Table 2).

In the rainy season, the concentration of heavy metals Pb, Cr, Zn, Fe, Mn, Co, Cd in the water were all below the detection levels across the Maramba, Kafubu, and Kafue Rivers (Table 2). However, Cu levels ranged from of 0.02 – 0.04 mg/L across the different Rivers, and these were all below the WHO limit for drinking water of 1 mg/L.

3.2. Properties of sediments from the different rivers

The total N concentration of the river sediments obtained from the Maramba River was approximately three times higher than the total N concentration of sediments from the Kafubu and Kafue Rivers (Table 3). However, the total P concentration in sediments from the Kafubu River was 139 % higher than the P concentration of sediments from the Maramba River and about 55 % higher than the P concentration of the sediments from the Kafue River. The sediment concentration of Ca and K did not vary significantly across the rivers (Table 3). Sediment sulphate (SO_4) concentrations in the Kafubu River were more than double those of Kafue River, and more than ten times those of the Maramba River.

Generally, the levels of Cu, Pb, and Zn in the Kafubu River sediments were significantly higher compared to the levels in sediments from the Kafue and Maramba Rivers. Meanwhile, the sediments in Maramba River had higher concentrations of Mn compared to the other Rivers (Table 3). Concentrations of Cu in sediments from the Kafubu River were about five times the concentration of Cu in sediments from Maramba and Kafue Rivers. Furthermore, the concentration of Zn in sediments from Kafubu River was approximately thrice that of sediments from Kafue River, and about five times that of sediments from Maramba River. Also, the concentration of Pb in sediments from Kafubu River was about four times that of sediments from Kafue River, while it was not detectable in sediments from Maramba River. The concentration of Fe of sediments from the Kafue River was approximately 40% higher than the Fe concentration of sediments from the Kafubu and Kafue Rivers, while sediment Mn concentrations did not differ significantly between the Kafue and Maramba Rivers (Table 3). The concentrations of Cd, Co and Cr were below detection levels in all the rivers.

Table 3
Concentration of elements and pH of sediments in three rivers where hippo grass was collected, and EPA guidelines. Values of mean + SE, n = 9 per river. Significant differences ($p < 0.05$) are indicated by different letters in the table rows.

Elements/ Nutrients	Across Rivers	Maramba River	Kafubu River	Kafue River	EPA Guidelines
pH	7.08 ±0.06	7.08±0.13 a	7.04 ±0.06 a	7.12±0.1 a	
N (g/kg)	7.24 ±1.16	13.49 ±1.41 a	4.30 ±1.56 b	3.29 ±0.41 b	
P (g/kg)	0.017 ±0.002	0.011 ±0.002 b	0.025 ±0.006 a	0.016 ±0.003 ab	
K (g/kg)	0.04 ±0.00	0.04±0.00 a	0.04 ±0.00 a	0.03 ±0.00 a	
Ca (g/kg)	2.30 ±0.19	2.87±0.40 a	2.20 ±0.25 a	1.84 ±0.27 a	
Mg (g/kg)	0.41 ±0.05	0.71±0.08 a	0.18 ±0.03 b	0.33 ±0.04 b	
Na (g/kg)	0.06 ±0.01	0.10±0.01 a	0.05 ±0.01 b	0.04 ±0.00 b	
SO_4 (g/kg)	1.19 ±0.27	0.21±0.07 b	2.32 ±0.52 a	1.00 ±0.16 b	
Cu (mg/kg)	14.16 ±2.89	6.67±0.45 b	32.13 ±4.44 a	3.66 ±0.47 b	25
Zn (mg/kg)	2.82 ±0.40	1.08±0.13 c	5.50 ±0.23 a	1.87 ±0.33 b	123
Cr (mg/kg)		nd	nd	nd	25
Pb (mg/kg)	1.13 ±0.26	nd	1.87 ±0.64 a	0.39 ±0.10 b	40
Fe (mg/kg)	36.31 ±2.59	30.88 ±2.33 b	32.50± 5.85 b	45.56 ±3.10 a	
Mn (mg/kg)	19.41 ±1.38	24.47 ±0.42 a	13.62 ±2.23 b	20.15 ±2.42 a	300
Co (mg/kg)		nd	nd	nd	
Cd (mg/kg)		nd	nd	nd	6

nd = not detected, Detection limits: Co = 0.02 mg/kg, Cd = 0.002 mg/kg, Cr = 0.002 mg/kg

3.3. Water hyacinth characteristics in relation to river water quality

The P and N concentrations of water hyacinth collected from Maramba River were about twice those of water hyacinth from Chongwe River (Table 4). Meanwhile, the levels of P and N in water hyacinth from Kafue River were in between those of plants from Maramba and Chongwe Rivers. There were no significant differences in the concentrations of Mg and Ca in water hyacinth obtained from the different rivers. However, water hyacinth from the Kafue River had significantly higher concentrations of K, Na and S compared to water hyacinth from Maramba and Chongwe Rivers.

Zinc concentrations in water hyacinth obtained from the Kafue River were three times those of plants obtained from Chongwe River, and about 1.25 times those obtained from the Maramba River. Additionally, the concentration of Cobalt (Co) in water hyacinth from the Kafue River was about 44% greater than that of water hyacinth from Maramba River, but not significantly different from the levels of Co in water hyacinth from Chongwe River. Conversely, the water hyacinth from the Chongwe River had approximately two times the Mn concentration of water hyacinth from the Kafue and Maramba Rivers. Lead (Pb) concentration of water hyacinth from the Maramba River was about 60% higher than that of water hyacinth from the Kafue River, but did not differ significantly with the water hyacinth from the Chongwe River. Concentrations of Cr

Table 4

Physical and Chemical characteristics of water hyacinth in relation to the rivers where the plants were collected. Values are mean + SE, n = 9 per river. Significant differences ($p < 0.05$) are indicated by different letters in the table rows.

Elements/ Nutrients	Across Rivers	Maramba River	Chongwe River	Kafue River	EU Limits for compost
N (g/kg)	11.87 ±0.80	15.71 ±0.93 a	7.47±0.70 c	12.44 ±0.75 b	
P (g/kg)	2.42 ±0.24	3.11±0.38 a	1.71±0.24 b	2.45 ±0.50 ab	
K (g/kg)	35.45 ±3.13	21.98 ±2.70 b	28.51 ±1.40 b	55.86 ±2.30 a	
Ca (g/kg)	0.68 ±0.06	0.54±0.05 a	0.75±0.08 a	0.76 ±0.13 a	
Mg (g/kg)	0.14 ±0.01	0.13±0.02 a	0.14±0.01 a	0.14 ±0.01 a	
S (g/kg)	0.18 ±0.02	0.14±0.01 ab	0.13±0.01 b	0.25 ±0.06 a	
Na (g/kg)	5.34 ±0.57	3.92±0.57 b	3.38±0.77 b	8.72 ±0.33 a	
Zn (mg/kg)	16.65 ±1.49	17.78 ±0.87 b	7.50±0.84 c	24.67 ±1.19 a	290
Fe (mg/kg)	1439 ±312	1656±870 a	958±108 a	1703 ±368 a	
Mn (mg/kg)	207.2 ±18	183.8 ±28.50 b	288.4 ±27.20 a	149.5 ±16.80 b	
Cu (mg/kg)	54.39 ±3.03	63.17 ±5.21 a	51.0±5.95 a	49.0 ±3.53 a	90
Co (mg/kg)	6.28 ±0.36	5.0±0.44 b	6.61±0.64 ab	7.22 ±0.54 a	
Cr (mg/kg)	35.74 ±2.15	48.31 ±1.70 a	27.27 ±1.78 b	31.65 ±2.83 b	50
Pb (mg/kg)	19.15 ±0.87	22.80 ±0.80 a	20.38 ±0.65 a	14.26 ±1.25 b	100
Cd (mg/kg)		nd	nd	nd	1
C (g/kg)	388.6 ±12.20	318.7 ±10.10 a	439.1 ±16.4 a	408 ±9.71 a	
C/N	39.32 ±4.13	20.93 ±1.58 b	63.31 ±6.41 a	33.72 ±2.15 b	
DM(g)/kg FW	102.62 ±5.02	130.88 ±4.33 a	101.2 ±2.26 b	72.42 ±1.83 c	

nd = not detected, Detection limits: Cd = 0.05 mg/kg, DM/FW = Dry matter weight per fresh weight

of water hyacinth from the Maramba River were approximately 77% and 53% higher than the Cr concentrations of water hyacinth from the Chongwe and the Kafue Rivers respectively. Further, there were no significant differences in the concentrations of Fe and Cu of water hyacinth obtained from the different rivers (Table 4).

The total N concentrations in water hyacinth had a strong positive correlation (r = 0.724) with the N (NH_4+NO_3) concentrations in river water (Fig. 2). Additionally, the P concentration of water hyacinth had a fairly strong positive correlation (r = 0.547) with the P concentrations of river water. The concentration of K of water hyacinth was poorly and non-significantly correlated (r = 0.350) with K concentrations of the river water.

For the heavy metals, the Cu concentration of water hyacinth correlated strongly (r = 0.779) with the Cu concentration of the river water. However, there was a very weak negative correlation (r = -0.024) between the water hyacinth Pb concentration and the concentration of Pb in river water. Similarly, Cr concentrations in water hyacinth were weakly correlated (r = -0.190) with Cr concentrations of river water (Fig. 2).

3.4. Hippo grass characteristics in relation to river water and sediment quality

The total N concentration of hippo grass from the Maramba River was approximately two times higher than the N concentration of hippo grass from the Kafue River but did not differ significantly from the N concentration of hippo grass from the Kafubu River (Table 5). The P concentration of hippo grass did not differ significantly among the three rivers. Additionally, hippo grass from the Kafubu River had Na and S concentrations that were approximately two times higher than the concentration of Na and S of hippo grass from the Maramba and the Kafue Rivers. The concentration of Mg of hippo grass from the Maramba River was about 55% higher than the Mg concentration of hippo grass from the Kafue River, but did not differ significantly with the hippo grass from the Kafubu River. Also, the concentration of Ca of hippo grass from the Maramba River was approximately 48% more than the Ca concentration of hippo grass from the Kafue River but did not differ significantly with the weeds from the Kafubu River.

The Zn and Cu concentrations of hippo grass from the Kafubu River were approximately double the concentrations found in hippo grass from the Maramba and Kafue Rivers (Table 5). The concentration of Mn of hippo grass from the Kafubu River was more than twice compared to the Mn concentration of hippo grass from the Kafue River. However, no significant differences were found in the Mn concentration of hippo grass from the Kafubu and the Maramba Rivers. Moreover, hippo grass from the Maramba, Kafubu and Kafue Rivers had no significant differences in their Fe concentrations. Also, the levels of heavy metals (Pb, Cr, Co, Cd) in hippo grass from all the rivers were below the detection level (Table 5).

The total N concentration of hippo grass had a non-significant positive correlation (r = 0.390) with the NO_3 and NH_4 concentration of river water (Fig. 3). Also, the total P concentration of hippo grass had a weak positive correlation (r = 0.136) with the concentration of P in water. Further, a negative and non-significant correlation (r = -0.337) was found between the K concentration of hippo grass and the K concentration of water. This was also true for plant Cu and Na which were found to have very low and non-significant relationships with the concentrations in water (Fig. 3). However, the Ca concentration of hippo grass had a strong and significant positive correlation (r = 0.767) with the Ca concentration in river water.

In contrast to the river water, the concentration of N of hippo grass had a strong positive correlation (r = 0.700) with the concentration of N in river sediments (Fig. 4). Also, the P concentration in hippo grass correlated strongly (r = 0.82) with the P concentration of river sediments. However, the K concentration of hippo grass showed a negative and significant correlation (r = -0.419) with the concentration of K in river water.

In terms of heavy metals, the Zn concentration of hippo grass had a strong positive correlation (r = 0.785) with the concentration of Zn in river sediments. Also, the concentration of Cu of hippo grass was strongly and positively correlated (= 0.813) with the concentration of Cu in river sediments. However, a weak negative correlation (r = -0.093) was found between Mn concentration of hippo grass and the Mn concentration of river sediments (Fig. 4).

4. Discussion

4.1. Macronutrients

In the current study, the first objective was to establish whether the nutrient and heavy metal concentrations of aquatic weeds collected from different rivers varied significantly. The second objective was to determine whether there were significant relationships between the nutrient and heavy metal concentrations of aquatic weeds and those of river sediments and water. As hypothesized, we found that the N and P concentrations of water hyacinth differed significantly across the different rivers and related positively to the levels of these elements in the river water. Particularly, water hyacinth collected from Maramba River, which passes through a highly populated area, contained about twice the amount of N and P compared to water hyacinth collected from the Chongwe River. Also, the concentrations of both N and P in water hyacinth from the Maramba River were approximately 26% more than

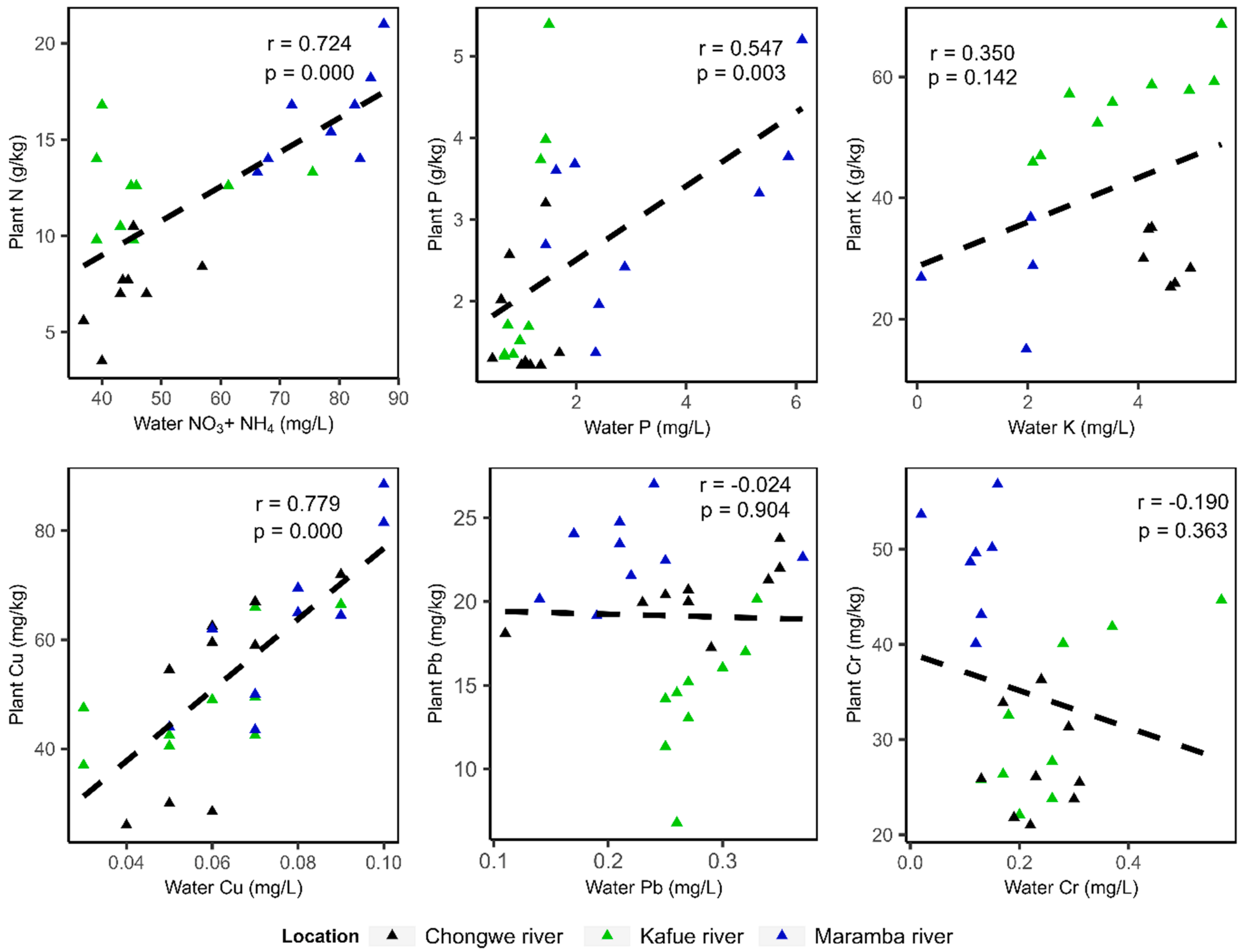

Fig. 2. Correlation between water parameters and selected chemical parameters of water hyacinth.

the concentration of these nutrients in water hyacinth from the Kafue River. Similarly, hippo grass from the Maramba River had the highest N concentration, compared to hippo grass obtained from the Kafue and the Kafubu Rivers. Across the rivers, the N and P content in hippo grass related mostly to the concentrations of those nutrients in the sediments rather than the concentrations in the water, which was in line with our expectations.

The elevated amounts of N and P in the water hyacinth from the Maramba River may be attributed to the elevated levels of N and P in the river water, as indicated in Table 1 and Fig. 2. The Maramba River has been subject to high levels of eutrophication because of sewage effluents from the urbanized town of Livingstone. The Maramba River is a relatively smaller water body and tends to be highly concentrated with nutrients, especially in the dry season when water levels are low. The high concentration of nutrients such as N and P has led to the excessive proliferation of water hyacinth in the River (Nang'alelwa, 2008; Winton et al., 2020). According to Dersseh et al. (2022), water hyacinth growth is largely influenced by the levels of N and P in water, with minimum concentrations of about 5.5 mg N/L and 1.66 mg P/L supporting its growth. The same author also indicates that maximum growth of water hyacinth has been observed at N and P concentrations of 20 mg/L and 3 mg/L respectively. In the current study, N concentrations of water from all the rivers exceeded the concentration required for maximum growth during the sampling of water hyacinth.

Several authors have reported the ability of water hyacinth to take up more N and P than is required for its growth (Coetzee and Hill, 2012; Fox et al., 2008; Ting et al., 2018; Wilson et al., 2005). According to Fox et al. (2008), as water hyacinth takes up more N from the water, there is an increase in the total N concentration and the biomass of water hyacinth, leading to more N uptake by the roots to meet the demand. In the present study, there were positive correlations between the concentration of N and P in water hyacinth and the respective concentrations of these nutrients in water. These results were in line with the research by Reddy et al. (1989) and Xie and Yu (2003) who reported positive correlations between the concentration of N and P in water hyacinth and the concentration of N and P in water. Since the chemical composition of water hyacinth is influenced by the environment in which it occurs (Gunnarsson et al., 2007), several authors have reported different N and P concentrations of water hyacinth. Fitrihidajati et al. (2021) reported the concentration of N in water hyacinth to be about 0.28% while Begum et al. (2022) reported maximum N concentrations of water hyacinth to be about 3.2%. Also, P concentrations of water hyacinth were reported to be between 0.2% and 0.7% (Heard et al., 2000; Su et al., 2018). In the present study, the N concentration of water hyacinth was in the range of 0.7% to 1.6%, while the P concentration was in the range of 0.17% to 0.31% across the different rivers.

Hippo grass collected from the Maramba River had notably higher concentrations of N compared to the hippo grass from the Kafue River, although no significant differences in N concentrations were found when compared to the hippo grass from the Kafubu River. The high N concentration of hippo grass from the Maramba River corresponded with the high N concentration of the river sediments. Overall, there was a

Table 5
Physical and Chemical characteristics of hippo grass in relation to the rivers where the plants were collected. Values are mean + SE, n = 9 per river. Significant differences ($p < 0.05$) are indicated by different letters in the table rows.

Elements/ Nutrients	Across Rivers	Maramba River	Kafubu River	Kafue River	EU Limits for compost
N (g/kg)	11.45 ±0.95	15.17±1.09 a	11.39 ±1.95 ab	7.78 ±0.54 b	
P (g/kg)	1.41 ±0.12	1.29±0.07 a	1.78 ±0.23 a	1.16 ±0.24 a	
K (g/kg)	5.06 ±0.25	4.58±0.20 b	6.23 ±0.40 a	4.50 ±0.44 b	
Ca (g/kg)	0.42 ±0.03	0.46±0.05 a	0.51 ±0.04 a	0.31 ±0.03 b	
Mg (g/kg)	0.26 ±0.02	0.28±0.02 a	0.33 ±0.02 a	0.18 ±0.03 b	
S (g/kg)	3.29 ±0.40	1.5±0.18 c	5.73 ±0.40 a	2.63 ±0.39 b	
Na (g/kg)	0.28 ±0.03	0.22±0.03 b	0.44 ±0.04 a	0.19 ±0.05 b	
Zn (mg/kg)	30.19 ±3.36	24.44±6.31 b	44.78 ±1.83 a	21.33 ±5.12 b	290
Fe (mg/kg)	852 ±167	652±296 a	704.6 ±78.3 a	1200 ±394 a	
Mn (mg/kg)	224.5 ±28	272.1±48 ab	281.2 ±53.7 a	120.3 ±20.1 b	
Cu (mg/kg)	14.50 ±1.52	11.61±2.59 b	21.61 ±2.01 a	10.28 ±1.53 b	90
Pb (mg/kg)		nd	nd	nd	100
Cr (mg/kg)		nd	nd	nd	50
Co (mg/kg)		nd	nd	nd	
Cd (mg/kg)		nd	nd	nd	1
C (g/kg)	302.5 ±17.8	345.6±20.4 a	312.7 ±29.9 a	249.3 ±34.4 a	
C/N	31.02 ±2.67	24.87±3.94 a	30.09 ±5.30 a	38.88 ±3.67 a	
DM (g)/kg FW	308.49 ±9.69	323.92 ±9.28 a	279.5 ±11.2 b	323.8 ±22.2 a	

nd = not detected, DM/FW = Dry matter weight per fresh weight, Detection limits: Co = 0.5 mg/kg, Cd = 0.05 mg/kg, Cr = 0.05 mg/kg, Pb = 0.05 mg/kg

strong positive correlation between the N concentration of sediments and the N concentration of hippo grass across the rivers. However, a weak correlation was found between N concentration of hippo grass and the N concentration of river water (Figs. 3 and 4). According to Schneider et al. (2018), emergent macrophytes such as hippo grass obtain their nutrition from sediments, and therefore, the concentration of elements in sediments has a more direct impact on their growth and development. The sediments act as reserves of nutrients deposited from water and eventually become a source of nutrients for emergent aquatic weeds (Flefel et al., 2020; Galal et al., 2021). Therefore, the concentration of nutrients in hippo grass is influenced by the chemical composition of sediments, which are dependent on the type of effluents and runoff entering the aquatic system. As such, the content of nutrients such as N and P of hippo grass will vary in different environments. Galal et al. (2021) reported N concentrations of hippo grass between 0.4% and 0.9%, while N concentrations of between 0.7% and 1.5% were found in our current study.

Unlike N, no significant differences were found in P concentrations of hippo grass collected from different rivers, despite significant differences in sediment P concentrations. We can suppose that there were no limitations in P supply from the sediments across all the rivers, and thus there was sufficient sediment P to meet the hippo grass P demand. Concentrations of sediment P across the different rivers were in the range of 0.011 g/kg to 0.025 g/kg, which was above the minimum threshold (0.005 g/kg – 0.010 g/kg) for P limitation in soils (Nguemezi et al., 2020).

In terms of K, the water hyacinth collected from the Kafue River had approximately two times more K concentration compared to the water hyacinth from Chongwe and Maramba Rivers. However, K concentrations in water were highest in the Chongwe River and much lower in the Kafue and Maramba Rivers at the time of sampling. The high K concentration of water hyacinth may be an indication of periodically high K concentrations in water from the Kafue River. The Kafue River is known to receive fertilizer-rich effluents and runoff from commercial farms such as the Nakambala Sugar Estate and Kafue fisheries, as well as fertilizer manufacturing industries such as the Nitrogen Chemicals of Zambia (Kambole, 2003; Sinkala et al., 2002). According to Skowron et al. (2018), agricultural runoff, effluents from industries and sewage waste are among the major anthropogenic contributors to K pollution in natural water bodies.

In the current study, K concentration of water hyacinth across the different rivers was in the range of 2.2% to 5.6%. Zhou et al. (2007) reported that water hyacinth is among the aquatic weeds known to have a very high demand for K, and can reach tissue K concentrations of up to about 5%. A weak and non-significant positive correlation was observed between concentrations of K in water hyacinth and that of water (Fig. 2). This was in contrast with the findings of Reddy et al. (1991) who reported a strong positive correlation between K concentrations in water hyacinth and K concentrations in water. However, Reddy et al. (1991) carried out the research in a controlled environment, which may have had most external factors under control. The current study was done under natural conditions and other external factors may have affected the expected positive relationship between the K concentration of water hyacinth and the concentration of K in water. These notable factors may include the presence of elements such as Ca and Mg that are antagonistic to K; unfavorable water pH affecting K uptake by water hyacinth and also the competition for limited K when the plant density of water hyacinth is high (Babourina., 2010; Boyd and Vickers, 1971; Rhodes et al., 2018).

4.2. Heavy metals

Heavy metals zinc and cobalt were significantly higher in water hyacinth collected from the Kafue River compared to water hyacinth collected Maramba and Chongwe Rivers. Meanwhile, there were no significant differences in the concentration of Cu and Fe in water hyacinth plants collected from all the rivers. Water hyacinth from the Maramba River had significantly higher concentrations of Pb and Cr while water hyacinth from the Chongwe River exhibited higher levels of Mn. However, the concentration of all the heavy in water hyacinth was below the EU thresholds for composted materials.

It was expected that water hyacinth from the Kafue River would have higher concentrations of Co and Zn, because the River transects mining regions of the Copperbelt Province, which are known for Cu, Co and Zn mining (Mbewe et al., 2016; Mkandawire et al., 2017; Sracek et al., 2012). Various mines discharge effluents with heavy metals into the Kafue River, some of which are taken up by aquatic weeds. Furthermore, runoff from commercial farms and manufacturing industries contributes to heavy metal pollution in the Kafue River, making it one of the most polluted water bodies in Zambia (Mbewe et al., 2016).

Unexpectedly, Cu concentrations in water hyacinth did not differ significantly across the rivers. Being a micronutrient, Cu is required by most plants and can be taken up from soil and water. Cruz et al. (2022) reported normal Cu concentrations in plants to be between 2 mg/kg and 20 mg/kg. In this study, Cu concentrations in water hyacinth from the different rivers were in the range of 49 mg/kg to 63 mg/kg, indicating luxury consumption. The fact that there were no significant differences in Cu concentrations of water hyacinth obtained from different rivers showed that the supply of Cu was adequate to meet the Cu demand in all the locations. A strong positive correlation was observed between Cu concentrations in water hyacinth and Cu concentrations in water, indicating that river water was probably the main source of Cu for the water hyacinth. Similar studies by Adelodun et al. (2020) and Hammad (2011) also found a strong and positive correlation between the concentration of Cu in water hyacinth and the concentration of Cu in water.

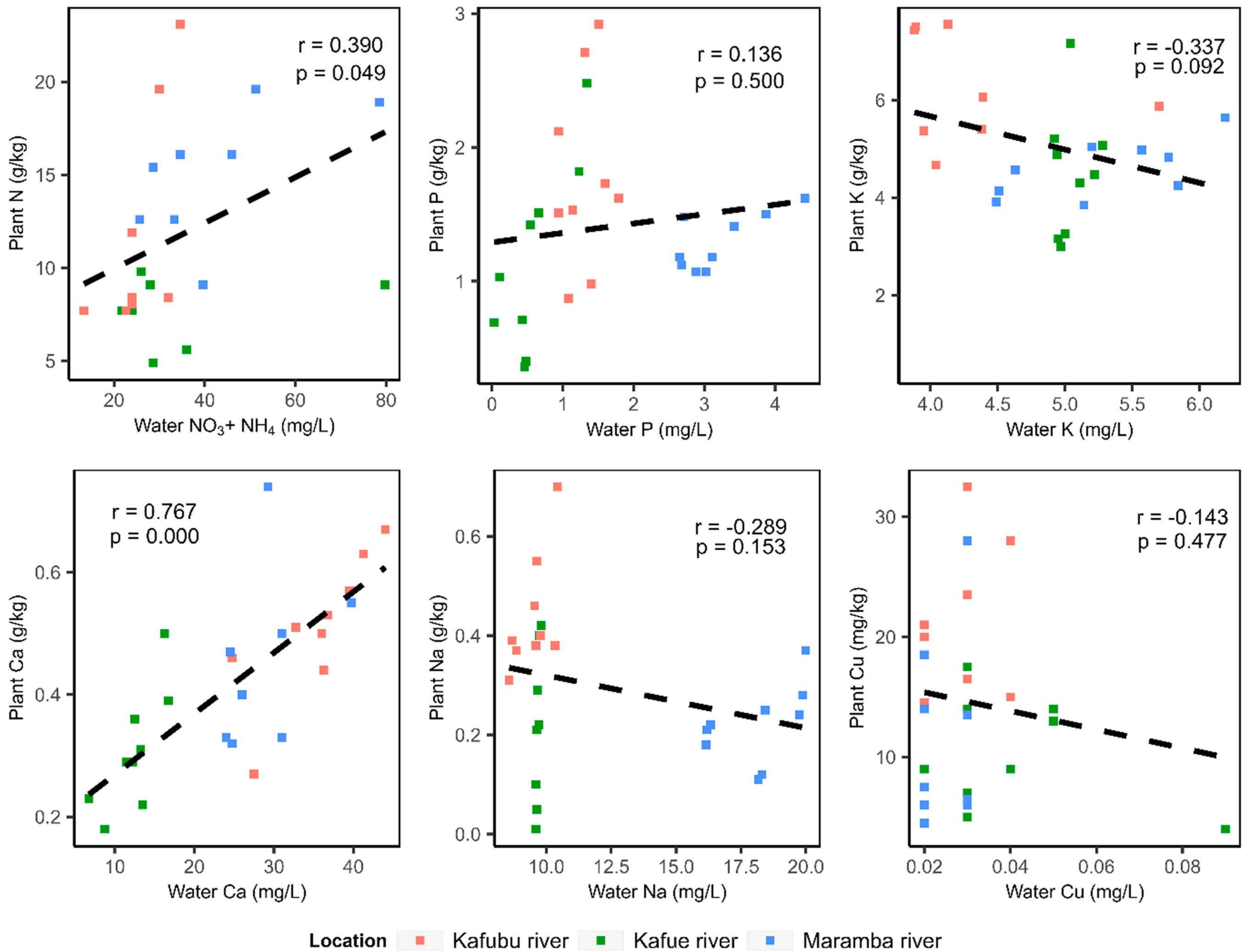

Fig. 3. Correlation between water parameters and selected chemical parameters of hippo grass.

Water hyacinth has been reported to have a hyper-accumulation capacity for most heavy metals including Pb and Cr. Because of their ability to accumulate and tolerate high levels of heavy metals, aquatic weeds such as water hyacinth have been used for phytoremediation of contaminated wastewater (Flefel et al., 2020; Pereira et al., 2014). Concentrations of Pb in water hyacinth from the different rivers were in the range of 14 – 23 mg/kg, which were above the WHO recommended limits of Pb (2mg/kg) for aquatic plants as reported by Flefel et al. (2020). Also, concentrations of Pb in water from which the water hyacinth were obtained were above the WHO thresholds for drinking water. Adelodun et al. (2020) and Akçin et al. (1994) showed that the concentration of Pb in water hyacinth increased with the increase in the Pb concentration in water. However, no distinctive relationship was observed between the Pb concentration of water hyacinth and that of water in this study.

Generally, water hyacinth had higher concentrations of nutrients and heavy metals compared to hippo grass. Water hyacinth has the advantage of having a comparatively long and fibrous root system that facilitates the rapid uptake of nutrients and heavy metals from the surrounding water. Additionally, as water hyacinth floats and does not root in the sediment, it obtains its nutrients directly from water and thus water characteristics such as water pH and concentration of various elements in the water greatly influence nutrient and heavy metal uptake (Dersseh et al., 2019). On the other hand, hippo grass grows in sediments and the uptake of its nutrients and heavy metals is more influenced by sediment properties such as sediment pH and the levels of nutrients and heavy metals in the sediments (Galal, 2021).

When it came to hippo grass, some of the heavy metals (Pb, Cr, Cd, Co) could not be detected in the weeds. However, Zn, Mn, Fe and Cu were found to be present in the hippo grass across the different rivers. In particular, hippo grass from Kafubu River was found to have significantly higher levels of Zn and Cu compared to hippo grass from the Kafue and Maramba Rivers. The Kafubu River is heavily polluted with heavy metals coming from mining industries of the Copperbelt Province (Nkaka, 2000). However, the concentration of heavy metals in the sediments from the Kafubu and the rest of the rivers were all below the EPA thresholds for pollution. Concentrations of Zn and Cu in hippo grass had a strong positive correlation with the concentration of these metals in sediments, respectively. Average concentrations of Zn and Cu in hippo grass from the different rivers were 30.19 mg/kg and 14.50 mg/kg respectively. Farahat et al. (2021) reported average concentrations of Zn and Cu in hippo grass to be in the range of 13.5 – 21.5 mg/kg and 8.1 – 14 mg/kg respectively.

In this study, it has been established that both water hyacinth and hippo grass accumulate important nutrients such as N, P and K which can be beneficial for soil fertility improvement if the weeds are used as soil amendments. It has also been established that these weeds do accumulate heavy metals from their environment. However, the current levels of heavy metals present in the weeds do not pose a risk of heavy metal pollution when applied to the soil. The levels of all the heavy metals tested in the weeds were below the EU standards for heavy metal concentrations permitted for compost materials. Although heavy metals

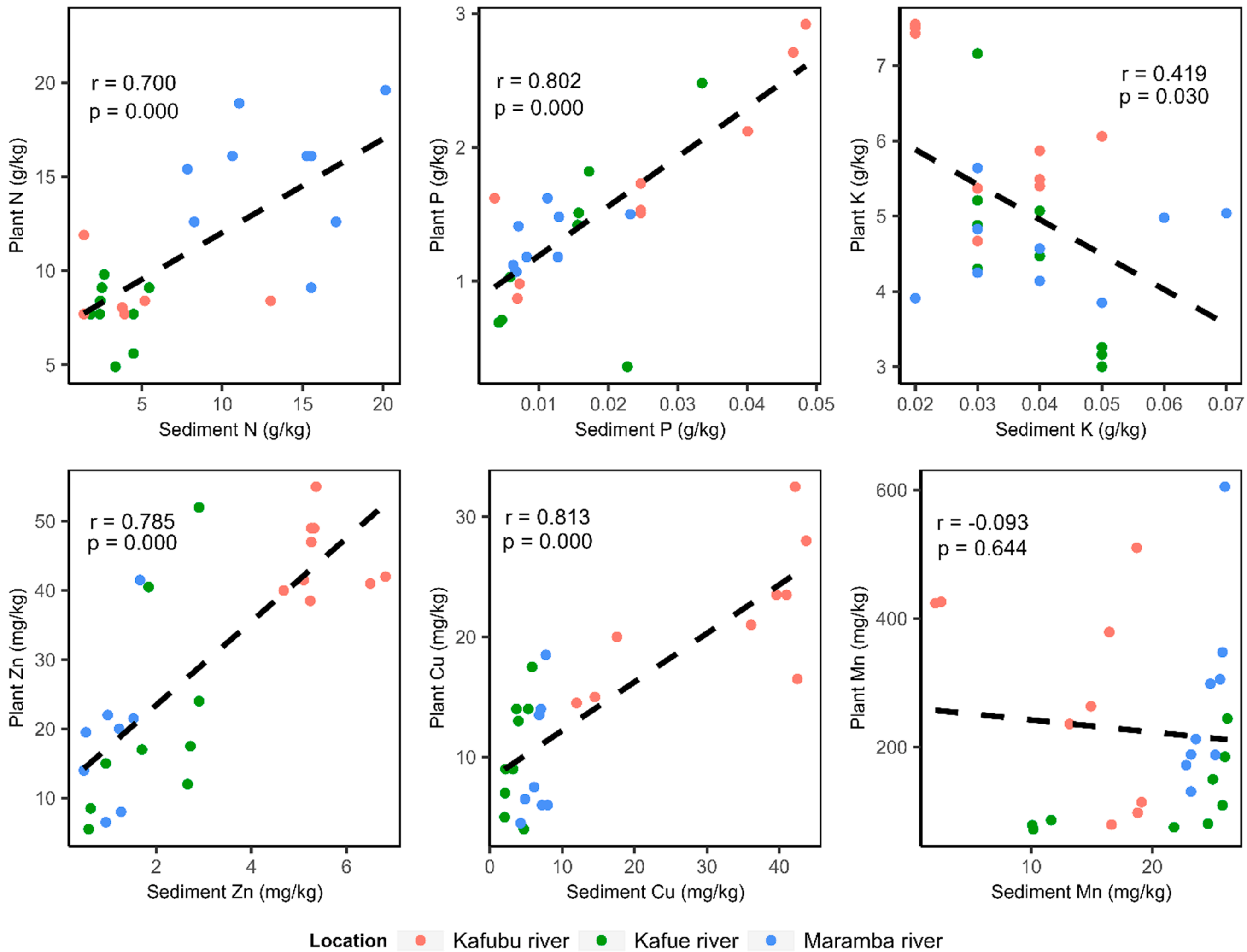

Fig. 4. Correlation between the chemical parameters of river sediments and the chemical composition of hippo grass.

were present in all the aquatic weeds collected, the concentrations of the metals were below limits considered to warrant concern for the use of these materials as soil amendments. It is worth noting that heavy metals are natural constituents of aquatic environments and are therefore expected to be present in aquatic weeds. The concern should arise when levels in the weeds exceed the limits considered to be safe for materials intended for use as soil amendments.

When selecting aquatic weeds to use for agronomic purposes, it is important to understand how the chemical composition of aquatic weeds is related to the environment in which they occur, and how the environment is influenced by anthropogenic activities. Ideally, weeds containing high concentrations of plant nutrients and low concentrations of potentially toxic elements should be targeted as resources for improving soil health. In this study, aquatic weeds from the Maramba River were found to be most suitable for use as soil amendments as they generally had higher concentrations of plant nutrients and lower concentrations of heavy metals compared to weeds from Kafue, Chongwe and the Kafubu Rivers.

5. Conclusion

The study showed that there are significant differences in the chemical composition of water hyacinth and hippo grass obtained from different rivers. It has also been established that the chemical composition of weeds is related to the chemical composition of water and sediments in rivers. Higher concentrations of nitrogen and phosphorus were found in aquatic weeds obtained from Maramba river which passes through highly populated human settlements. Aquatic weeds collected from Kafue and Kafubu Rivers which pass through mining and industrial areas had higher concentrations of Co and Zn compared to Chongwe and Maramba Rivers. Heavy metal concentrations in water hyacinth and hippo grass in this study, were below EU thresholds for compost indicating that heavy metals concentrations in the aquatic weeds would not pose a risk if used for making compost. Among the weeds studied, those obtained from Maramba River were found to be more suitable for use as soil amendments because they had higher levels of plant nutrients and lower levels of heavy metals.

Declaration of competing interest

The authors declare that they have no known competing financial or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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