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IMPACT OF PHYSICO-CHEMICAL CHARACTERISTICS ON AQUATIC BIODIVERSITY OF FIVE PROSPECTED WETLANDS FROM KIPUSHI MINING SITE IN HAUT-KATANGA PROVINCE IN THE DEMOCRATIC REPUBLIC OF THE CONGO

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Abstract. The development of mining industrialization is one of the factors that have favored the pollution of aquatic ecosystems. The main purpose of this study was to assess the influence of physico-chemical parameters of surface waters on the abundance of hydrophytes in 5 wetlands in Kipushi city, Haut-Katanga Province in DRC. Samples were collected from four rivers, of which: Kanyameshi, Kafubu, Kipushi, Kamarenge and Lake Kamarenge. The study used the presses for the preparation of herbariums as well as multifunction probe for physico-chemical analyses *in situ* and a spectrophotometer (415 nm) for some parameters. For environmental observations, the analysis of sediments allows to assess the pollution level by metallic trace elements, which breaks the ecological balance of this aquatic ecosystem. The abundance indices of plant species in each waterbody were subjected to a Factorial Component Analysis in order to identify the distribution of the elements of the dominant plant associations. Data analysis was performed using PAST software. The findings showed 29 species distributed in 26 genera, 13 families and 11 orders. The Confirmatory Factor Analysis showed the distribution of plant groupings following a gradient of mineralization of the zones as well as that of abundance-dominance. Physico-chemical parameters influence the distribution of hydrophytes in wetlands. They constitute indicators of toxicity having an adverse consequence on the aquatic ecosystem for these metallic elements are not biodegradable. The more there is accumulation of dissolved metals in water, the more they create an environmental hazard.

Keywords: invasive hydrophytes, physico-chemical parameters, impacts, kipushi mining city, DRC.

1. Introduction

Water use and energy consumption in mining have been identified as two key business risks by the mining industry. Mines and other process operations effluent and tailings management systems can impose long-term and sometimes permanent impacts on water resources (Mohapatra et al., 2017). Water is used in mining operations for processing of minerals, recovery of metals, dilution and to meet the domestic water requirements on site among others (Mohapatra et al., 2017). Mining drives growth, expansion and urbanization either in a small town or in a big city (Emuze, Hauptfleisch, 2014). Moreover, the waste disposal remains a worldwide concern because, as the urbanization process spreads in many developing countries, waste management becomes a public health and environmental issue in urban areas (Bisimwa et al., 2022).

The demographic growth and the development of mining industrialization are factors that have favored the pollution of aquatic ecosystems (Lindahl,

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2014). Mining has resulted in effluent discharges consisting of wastewater and solid wastes that are harmful to wildlife which impact negatively the environment (Noukeu et al., 2016). The outcomes of mining on the environment can occur at local, regional, and international tiers, through direct and oblique practices. These impacts can result in erosion, landslides, lack of biodiversity, soil pollution, groundwater, and surface water through chemical compounds launched from mining systems, and this contributes to the loss of the biodiversity (Rehman, et al., 2021). Mining produces a wide range of impacts that can affect the richness, abundance, and diversity of biotic communities, among the most important impacts of green removal which alters the availability of food, water, and wildlife habitat (Rehman et al., 2021).

In most African countries, rivers are subjected to physical and/or chemical disturbances, which cause the degradation of water quality (Bisimwa et al., 2022). These disturbances were highlighted in Togo during a study on the physico-chemical characterization and phytoplankton diversity on Lake Zowla (Atanle et al., 2012), while in Côte d'Ivoire, these disturbances were observed in four rivers in the South-East (Niamien-Ebrottié et al., 2012) and in Lake M'koa of Jacqueville (Kpidi et al., 2017). In Senegal, studies on the environmental control of primary production and the physico-chemical along with metallic parameters of wastewater in the East Channel leading to Hann Bay were also examined (Sane, 2006; Diagne et al., 2017). Similar studies were carried out on the municipal Lake and on the Kambo & Kondi rivers in Yaoundé and Douala respectively (Cameroon) (Kemka et al., 2004; Priso et al., 2012). However, the Democratic Republic of the Congo (DRC), through its hydrographic network, has a significant number of freshwater ecosystems, of which the quality is constantly deteriorating. In the South-East of the DRC, and precisely in the mining cities (Kipushi, Likasi, Kambove, Kolwezi and Lubumbashi), the wetlands (rivers and lakes) are increasingly polluted by industrial mining effluents. Since 2016, wetlands in south-eastern DRC have been targeted for designation as Ramsar sites in the Lufira Basin (ICCN/WWF-PARAP, 2016). As a result, an intensification of water eutrophication with undesirable effects such as a decrease in biodiversity and an increase in pollution tolerant species is observed (Roxane, Reinhard, 2015).

A wetland is an environment where water is the main factor determining and influencing the biotope and the development of the biocenosis (ecosystem). It can be permanent or temporary, stagnant or running, fresh, brackish or salty, natural or artificial (Medagam et al., 2018). Wetlands play a critical role in maintaining the quality of the environment by absorbing and processing waste products, they sequester (trap) and release carbon, regulating climate change as well they biologically cycle carbon dioxide, methane and hydrogen sulfide (Schuijt, 2002; McCartney et al., 2006). Globally, wetland peat deposits take up just 3 % of the land area but store 14–16 % of the soil carbon pool (McCartney et al., 2006). Wetlands support a rich diversity of plants and animals i.e. these species and their genetic diversity help to maintain wetland processes such as water storage, sediment trapping and nutrient cycling (McCartney et al., 2006). The difficulty in defining a wetland arises partly because of their highly dynamic character, and partly because of difficulties in defining their boundaries (Schuijt, 2002). Wetlands are complex ecosystems with multiple values, including ecological, socio-esthetical, intrinsic and economic values (Schuijt, 2003). The classification of wetlands is being performed according to their sources of water and nutrients, hydrological regime, soil type, vegetation structure, and geochemical status. Differences between these classifications stem from reasons and regions for which the classifications have been developed (Roggeri, 1995; Kellner, 2003).

Despite this difficulty of classification, The Ramsar Convention adopted the Ramsar Classification of Wetland type at the Conference of the Parties in 1990 (Schuijt, 2003). This convention divides wetlands into three main categories as a broad framework to aid rapid identification of wetland habitats, of which: (1) Marine/Coastal Wetlands; (2) Inland Wetlands and (3) Man-Made Wetlands. The marine and coastal wetlands include estuaries, intertidal marshes, brackish, saline and freshwater lagoons, mangrove swamps, as well as coral reefs and rocky marine shores such as sea cliffs (Millenium Ecosystem Assessment, 2005). Inland wetlands refer to such areas as lakes, rivers, streams and creeks, waterfalls, marshes, peat lands and flooded meadows. Lastly, man-made wetlands include canals, aquaculture ponds, water storage areas and even wastewater treatment areas (Schuijt, 2003; Millenium Ecosystem Assessment, 2005). Several types of wetlands are present in this country, namely: marshes, swamps, wet meadows, flooded plains and clearings, lakes, rivers (Medagam et al., 2018). The proliferation of hydrophytes (Helophytes) could be attributed to intense anthropic activities (industrial and artisanal mining, market gardening along the valleys, etc.), with the following impacts: loss of biodiversity, difficult navigation, fragmentation of habitats, bad quality of water, and so on (Priso et al., 2010).

Water quality monitoring has long been based on physico-chemical analyses to identify pollution (Buchez et al., 2010). Species (plants or animals) that integrate this phenomenon experienced by ecosystems appear to be relatively reliable markers of environmental changes (Sauberer et al., 2004). In conditions of stability and enrichment of the environment in favorable or disturbed nutrients, the analysis of the distribution of plant and animal species is a function of the physico-chemical characteristics of the water. The hypothesis of this study is to verify the influence of physico-chemical parameters of wetlands in the region on the richness of hydrophytes and their environmental impacts. This study constitutes, on the one hand, a proof of commitment of the University of Kinshasa and the Institut Congolais pour la Conservation de la Nature (ICCN) to the achievement of the Aichi objective 9 of the ten-year strategic plan for biodiversity 2011–2020. On the other hand, it improves the knowledge of the Congolese South-Eastern wetland hydrophytes, part of which has just been included in the list of wetlands to be designated as Ramsar sites of the Lufira basin. Moreover, this study is a challenge for mining, energy and environmental operators, researchers and decision makers in the search for appropriate solutions for the sustainable management of invasive plants in the region. The study of invasive vegetal species in Kipushi would be pioneering in this area. It provides information on both the extent of chemical pollution of the rivers by industrial mining effluents and the danger of aquatic plants in suffocating the rivers of Kipushi. The main purpose of this study was to assess the influence of physico-chemical parameters of surface waters on the abundance of hydrophytes in 5 wetlands, of which 4 rivers (Kipushi, Kafubu, Kamarenge and Kanyameshi) and a lake (Kamarenge) in Kipushi city, Haut-Katanga Province in DRC.

2. Theoretical part

2.1. Study area

The map showing the location of Kipushi city in Haut-Katanga Province in DRC is shown in Fig. 1.

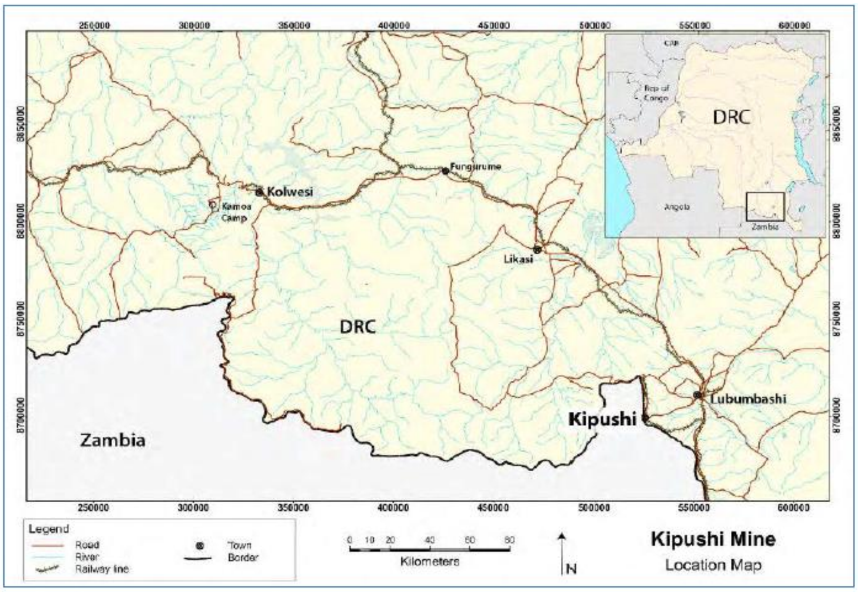

Fig. 1. Location of Kipushi city in Haut-Katanga province, DRC

Kipushi mining city, bordering Zambia, is a deconcentrated entity belonging to Haut-Katanga province located in DRC. Its surface area is 12 059 km^2, with a heterogeneous population of 526.446 inhabitants and a density of 47 inhabitants/km^2 (IUCN, 2009). Kipushi, has a mining company formerly known as Gécamines-Kipushi, which was converted into the Compagnie Minière du Sud Katanga (CMSK), before becoming Kipushi Corporation SA (KICO), exploiting zinc, copper, cobalt, zinc, silver, lead and germanium. A single regularly maintained main road of approximately 30 km connects it to Lubumbashi city, the economic city of DRC. In addition to industrial mining activities, the population lives from artisanal mining, road tolls, slash-and-burn agriculture, transportation of goods and people by vehicle, not to mention banking and telecommunications operators.

The study used the presses for the preparation of herbariums as well as multifunction probe for physico-chemical analyses *in situ* (HANNA (HI 98127)), and a spectrophotometer (415 nm). The PVC jars were used to collect water and sludge from different prospected sites.

Samples were collected from four rivers, of which: Kanyameshi, Kafubu, Kipushi, Kamarenge and Lake Kamarenge, all located in Kipushi city, Haut Katanga province, DRC between April and October 2021.

2.2. Data collection

2.2.1. Floristic data

A total of five plots of 50 m x 50 m, selected with the help of Landsat satellite images were set up at a rate of one wetland zone: Kipushi, Kafubu, Kamarenge, Kanyameshi rivers and Lake Kamarenge. The majority of plant species collected were identified in the field and confirmed, after verification, by comparison with dried plant specimens at the Laboratory of Botanical Systematics and Ecology located in the Department of Biology, University of Kinshasa.

The list of all species and especially families was established according to the APG III phylogenetic classification (2009). The method used for the description of wetland vegetation is the Picardy method which is based on the principles of the so-called “sigmatist” phytosociology (from the school of the International Station of Mediterranean and Alpine Geobotany called Sigma Mr. Braun Blanquet).

2.2.2. Physico-chemical parameters of water

Water samples were collected at the different wetlands during the short rainy season, with a total of 32 water samples for each wetland. The depth of sampling in the open water was approximately 20 cm. All samples were placed in 250 ml polyethylene bottles. After collection, they were placed in a cooler and stored at 2 to 5 °C until they were sent to the University of Kinshasa for further physico-chemical analysis (Berryman, 2006).

It should be noted that the physico-chemical analyses of water, such as pH and temperature, were measured *in situ* by a HANNA multiparameter probe (HI 98127). Dissolved oxygen saturation was also measured *in situ* with a HANNA oximeter (HI 9146) and the conductivity with a HANNA conductivity meter (HI 87722). The method for the determination of nitrite was the sodium salicylate method and the reading was performed at 415 nm (Berryman, 2006). The colorimetric method with ammonium molybdate is used for the determination of phosphates. The spectrophotometer reading was at 440 nm (Masens, 1997). Biological oxygen demand (BOD_5) is obtained by carbon dioxide trap in a concentrated soda solution using a metering pump (Priso et al., 2010).

2.2.3. Observation of environmental data

The standards developed by the General Framework of Brussels Institute for Environmental Management established the basic quality of water. These standards are applicable to all surface waters of the public hydrographic network (waters of navigable waterways, non-navigable watercourses and permanent or intermittent flow channels as well as running and stagnant waters of the public domain).

Moreover, these standards can be completed by the analysis of sediments (sludge), which constitute a "memory" of the life of rivers, especially episodes of pollution by metallic trace elements, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) or other non-biodegradable organic matter. All these elements allow to evaluate the degree of pollution of the watercourses and to appreciate their capacity to purify themselves. Concerning the study on the hydrophytes, the following parameters were considered: pH, temperature (°C), dissolved oxygen (O_2), Biological Oxygen Demand (BOD_5), Ammonia nitrogen concentration (NO^{2-}), Total Phosphorus (PO_4^{2-}) and metallic trace elements (Cu, Pb, Zn, Cr, and Ca).

2.3. Data analysis

The determination of coefficients of abundance and dominance of plant species was based on those described by Nshimba, (2008), of which the main ones are: +, 1, 2, 3, 4, 5. Three ecological trends of hydrophytes in wetlands emerge, namely: hydrophytes euryèces, sténoèces and tolerant. The Shannon-Weaver index (H') and the Piélou equitability (EQ) were used to quantify the floristics data.

The Shannon-Weaver index (H') is presented in the following formula:

$$H' = -\sum_{i=1}^{s} \frac{Ni}{N} * \log_2\left(\frac{Ni}{N}\right) \qquad (1)$$

where N_i is the number of individuals of a given species; *i* is the I ranging from 1 to *s* (total number of species); N is the total number of individuals; log is the decimal logarithm.

The equitability index of Piélou is described in the following formula:

$$EQ = \frac{H'}{\log_2 No} \quad (2)$$

where N_o is the total number of species; H' is the Shannon Weaver index.

Jaccard's coefficient of similarity (Sjij) emphasizes the presence of two species at the same location, and it is given in the following formula:

Sjij = [a/(a+b+c)] with 0 < Sjij< 1 (3)

where a is the number of species common to both enviroments; b is the number of species present in environment A and absent in environment B; c is the number of species present in environment B and absent in environment A.

The abundance indices of plant species in each waterbody were subjected to a Factorial Component Analysis (FCA) in order to identify the distribution of the elements of the dominant plant associations according to the physico-chemical parameters. Data analysis was performed using PAST software. Shannon Weaver diversity index (H') along with Piélou Equitability average values for different sites were compared using t-test and R software was used for these comparisons. Pearson's correlation matrix was used to determine the most significant correlation coefficients between abiotic and biotic variables.

3. Results and Discussion

3.1. Floristic data

General insight of floristic species of five prospected wetlands following the phylogenetic classification is presented in Table 1.

Table 1

Floristic list of identified species found in different prospected wetlands

Clade/Phylum	Orders	Families	Species	A	B	C	D	E	F	%
1	2	3	4	5	5	6	7	8	9	10
PTERIDOPHYTA	Blechnales	Thelypteridaceae	*Cyclosorus striatus* (SCHUM.) CHING	1	2	2	x	x	3	60
MONOCOTS	Commelinales	Pontederiaceae	*Eichhornia crassipes* (MART.) SOLMS	x	x	x	x	3	1	20
	Alismatales	Araceae	*Colocasia antiquorum* SCHOTT	2	1	1	1	1	5	100
	Poales	Cyperaceae	*Cyperus alternifolius* L.	2	2	3	1	1	5	100
			Cyperus latifolius Poir	1	1	2	2	2	5	100
			Cyperus papyrus L.	x	x	x	x	2	1	20
			Fimbristylis gabonica Cherm.	1	2	x	x	2	3	60
			Rhynchospora triflora Vahl	2	1	1	2	2	5	100
			Schoenopletus subulatus Vahl	2	x	1	1	2	4	80
		Poaceae	*Echinochloa pyramidalis* (LAM.) HITCH. & CHASE	2	x	2	x	2	3	60
			Echinochloa stagnina (RETZ.) P. BEAUV	x	2	x	x	1	2	40
			Leersia hexandra SW.	x	2	2	x	2	3	60
			Loudetia simplex (Nees) C.E. Hubb	x	2	2	x	2	3	60
			Hyparrhenia bracteata (Humb.& Bonpl.ex Willd.) Stapt	x	x	2	1	2	3	60
			Pennisetum purpureum K. SCHUM.	2	2	1	x	x	3	60
			Phragmites mauritianus KUNTH	4	3	2	4	4	5	100
			Vossia cuspidata (Roxb.) Griff	x	x	2	2	2	3	60
			Imperata cylindrica P. BEAUV.	3	x	x	x	x	1	20
		Thyphaceae	*Typha domingensis*(Pers,) Steud	3	3	3	2	4	5	100
	Zingiberales	Marantaceae	*Thalia welwitschii* RIDLEY	x	x	x	x	1	1	20

Continuation of Table 1

1	2	3	4	5	5	6	7	8	9	10
EUDICOTS	Myrtales	Onagraceaea	*Ludwigia abyssinica* A. RICH	x	1	x	x	1	2	40
			Ludwigia leptocarpa (NUTT.) HARA	2	2	2	x	1	4	80
	Fabales	Fabaceae	*Acacia polyacantha* Willd	1	x	x	x	x	1	20
			Aeschynomene elaphroxylon (GUILL. & PERR.) TAUB.	x	x	x	x	1	1	20
	Caryophyllales	Poligonaceae	*Polygonum senegalense* MEISNER	x	1	x	1	1	3	60
	Solanales	Convolvulaceae	*Ipomoea aquatica* FORSSK	x	x	1	x	1	2	40
	Gentianales	Rubiaceae	*Hallea stipulosa* (DC.) LEROY	1	1	x	x	x	2	40
			Oldenlandia affinis (ROEM. & SCHULTES) DC.	2	x	x	x	1	2	40
	Asterales	Asteraceae	*Tithonia diversifolia* (HEMSL.) A. GRAY	2	x	x	x	x	1	20
Total	**11**	**13**	**29**	**18**	**16**	**16**	**10**	**20**		

In general, the specific richness of the invasive hydrophytes of different wetlands includes 29 species distributed in 26 genera, 13 families and 11 orders which are divided into 4 orders of monocotyledons and 6 orders of dicotyledons belonging to 2 clades as well as a phylum of pteridophytes. The most diverse family is the Poaceae with 9 species, followed by Cyperaceae (6), Fabaceae (2), Onagraceae (2), Rubiaceae (2), Asteraceae (1), Convolvulaceae (1), Araceae (1), Marantaceae (1), Pontederiaceae (1), Thyphaceae (1), Polygonaceae (1) and Thelypteridaceae (1).

Following hydrophytes species have been identified in all the prospected wetlands, *Colocasia antiquorum* SCHOTT, *Cyperus alternifolius* L., *Cyperus latifolius* Poir, *Rhynchospora triflora* Vahl, *Phragmites mauritianus* KUNTH and *Typha domingensis* (Pers,) Steud. While *Tithonia diversifolia* (HEMSL.) A. GRAY, *Acacia polyacantha* Willd and *Imperata cylindrica* P. BEAUV. Have been identified specifically in site A (river of Kafubu) and *Aeschynomene elaphroxylon* (GUILL. & PERR.) TAUB., *Thalia welwitschii* RIDLEY, *Cyperus papyrus* L. and *Eichhornia crassipes* (MART.) SOLMS were specific to site E (Kamarange lake). *Eichhornia crassipes* has been known as an invasive alien species with its potential of absorbing heavy metals.

3.2. Diversity of hydrophytes

The specific richness of identified hydrophytes following Shannon Weaver index (H') and Pielou equitability (E) values are presented in Table 2.

It was observed that among hydrophytes, ($t = 21.5$; $df = 4$; p-value = 2.753e-05) and Pielou equitability from 0.977 to 0.96($t = 18.6$; $df = 4$; p-value = 5.634e-09). The predominant ecological factors are not the same for all species.

The vegetation studied is organized into plant groupings in which species cohabit under favorable conditions (Fig. 2).

Table 2

Specific richness according Shannon Weaver index (H') and Pielou equitability (E)

	KAFUBU	KANYAMESHI	KAMANGERE	KIPUSHI	LAKE KAMANGERE
Taxa_S	18	16	16	10	20
Shannon_H	2.802	2.701	2.71	**2.181**	**2.885**
Equitability_J	0.9696	0.9741	**0.9773**	0.9471	**0.963**

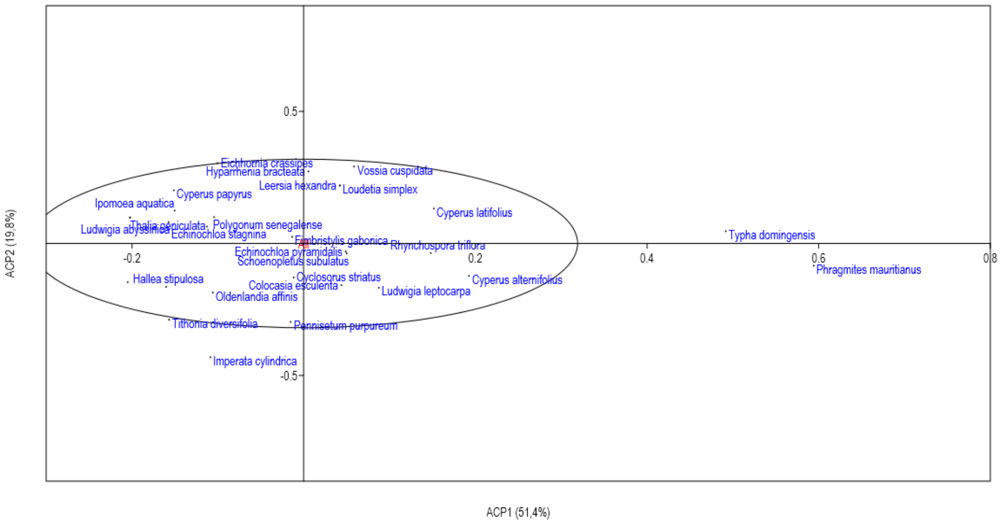

Fig. 2. Grouping of species by Principal Component Analysis (PCA)

The plant grouping results from the juxtaposition of groups of species each linked to the variation of the Principal Component Analyses (PCA), i.e. 71.2 %, where the calculations are based on a choice of association matrix (Fig. 2). The first grouping is constituted (2 species): *Phragmites mauritianus* and *Typha domingensis*. The second grouping makes the rest of the species (27 species): *Colocasia esculenta*, *Cyperus alternifolius*, *Cyperus latifolius*, *Rhynchospora triflora*, *Schoenopletus subulatus*, *Ludwigia leptocarpa*, *Cyclosorus striatus*, *Fimbristylis gabonica*, *Echinochloa pyramidalis*, *Leersia hexandra*, *Loudetia simplex*, *Hyparrhenia bracteata*, *Pennisetum purpureum*, *Vossia cuspidata*, *Polygonum senegalense*, *Echinochloa stagnina*,*Ludwigia abyssinica*, *Ipomoea aquatica*, *Hallea stipulosa*,*Oldenlandia affinis*, *Eichhornia crassipes*, *Cyperus papyrus*, *Imperata cylindrica*, *Acacia polyacantha*, *Tithonia diversifolia*, *Thalia welwitschii* and *Aeschynomene elaphroxylon*.

3.3. Physical-chemical parameters of waters of different study stations

Physico-chemical parameters of waters from different prospected wetlands are presented in Table 3.

Table 3

Physical-chemical parameters of wetlands

Parameters	Units	A	B	C	D	E	Means	Standard deviation
pH		7.6	7.7	8	7.5	8.5	7.86	0.40
T(A)	°C	25.3	24.8	24.3	24	25.2	24.72	0.56
T(Z)	°C	24.2	24.1	24.1	24	24.3	24.14	0.11
O_2	$mg.L^{-1}$	4.22	4.02	5.32	3.95	4.23	4.348	0.56
BOD_5	$mg.L^{-1}$	2.02	2.09	2.3	2	2.51	2.184	0.22
NO^{2-}	$mg.L^{-1}$	0.46	0.25	0.36	0.06	0.42	0.31	0.16
PO_4^{2-}	$mg.L^{-1}$	0.09	0.11	0.12	0.07	0.17	0.112	0.04
Cu	$mg.L^{-1}$	066	0.99	0.72	4.55	0.44	1.472	1.73
Pb	$mg.L^{-1}$	0.44	0.62	0.52	2.96	0.25	0.958	1.13
Zn	$mg.L^{-1}$	0.22	0.25	0.72	2.24	0.45	0.776	0.84
Cr	$mg.L^{-1}$	0.29	0.54	0.43	4.45	0.24	1.19	1.83
Ca	$mg.L^{-1}$	6	12	11	64	10	20.6	24.37

The ambient temperature (TA) shows an average of 24.72°C and the wetland temperature (TZ) is 24.14°C. The level of oxygen is of 4.48 mg/l, BOD_5 values are 2.184 mg.L-1. The nitrite values (NO^{2-}) are of 0.31 mg.L-1. Total phosphorus (PO_4^{2-}) shows an average of 0.112 mg.L-1. In relation to the levels of metals, Copper (Cu) has 1.472 mg/l, lead (Pb) shows 0.958 mg.L-1, Zinc (Zn) shows 0.776; Chromium (Cr) of 1.19 mg.L-1 and Calcium with an average of 20.6 mg.L-1.

Pearson's correlations show that the variables are significantly correlated two by two at $p > 0.05$. The values of the correlation coefficients are close to or equal to 1 if the correlation is positive between different wetlands, but it is strongly negative if it is far from 1. The Pearson's correlation of different prospected wetlands is presented in Fig. 3.

It was observed that the Kipushi wetland displays a negative correlation with respect to all wetlands, with the highest correlations observed between the Kafubu, Kanyameshi, Kamarenge and Lake Kamarenge.

The Factorial Component Analysis (FCA) provides 98.73 % of the total information of two axes. The variable analysis on the factorial planes of the FCA revealed that the Kipushi wetland correlated negatively with axes and it applies for the following sentences of this small section: 1, 2 and 3 meanwhile Lake Kamarenge correlated negatively with axis 2 and 4. Kafubu (axis 2 and 3) and Kamarenge (axis 3 and 4) (Fig. 4).

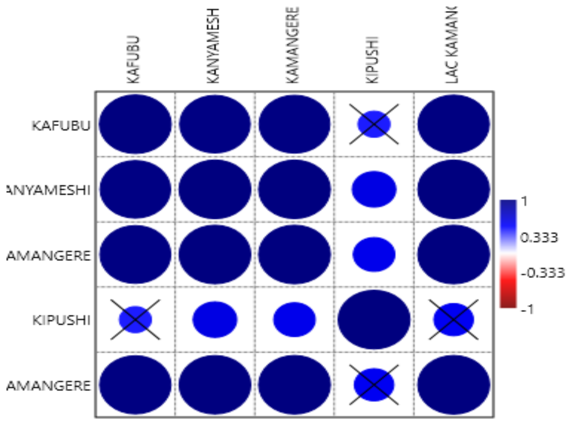

Fig. 3. Pearson's linear correlation

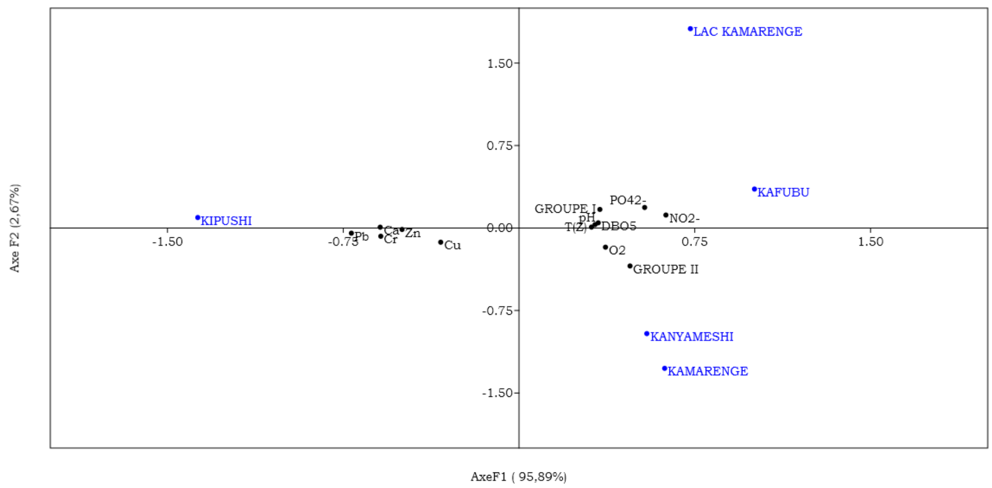

Fig. 4. Axis F1 x Axis F2 factorial design (CFA) of physico-chemical variables according to wetlands and plant groupings

The Axis F1 x Axis F2 factorial designs of the FCA provides 98.73 % of the information set (Fig. 3). The analysis of the organization of variables on the Axis F1 x Axis F2 factorial planes revealed that the factorial axis F1 opposes two sets of variables.

Considering the F1 axis, it was observed that the following wetlands: Lake Kamarenge and Kafubu are wetlands represented more by the species of grouping 1 having as physico-chemical parameters: PO_4^{2-} ($r = 0.96$, $p < 0.01$); NO^{2-} ($r = 0.96$, $p < 0.01$); COND and BOD_5 ($r = 0.95$, $p < 0.05$). Then Kanyameshi and Kamarenge wetlands are wetlands which were represented by the species of grouping 2 with following physico-chemical parameters: O_2 and BOD_5. Grouping 1 is the one that is dependent on physico-chemical parameters such as NO^{2-} and PO_4^{2-}, observed in Lake Kamarenge and Kafubu River. These physico-chemical parameters are important nutrient indicators for wetlands and they go along with parameters like O_2, BOD_5, pH and T (Z), which are considered as activators of the biodegradation phenomena of organic compounds (Nitrogen and Phosphorus).

The axis F2 indicates that the Kipushi River correlated negatively to the other wetlands and did not represent any vegetation grouping. The physico-chemical parameters that correlated with the area are: (Cu): 1.47 mg.L-1; (Pb): 0.95 mg.L-1; (Zn): 0.7 mg/l; (Cr): 1.19 mg.L-1 and Ca: 20.6 mg.L-1 (Fig. 4). These physico-chemical parameters are indicators of the toxicity of the wetland with harmful consequences on the life of the vegetal biodiversity along with the animal one, because these metallic elements are not biodegradable and more these dissolved metals accumulate in water constitute the cause of environmental hazard.

3.4. Physico-chemical parameters of different prospected sites

The pH value (7.86) in the wetlands indicates a neutrality of the water during the study period; the observed value would be related to the strong presence of fixed hydrophytes. Moreover, at the level of wetlands, humic acid that comes from the decomposition of dead hydrophytes would contribute to lower the pH (Atanle, 2012). Hade (2002) reported that when the pH is high, NO^{2-} becomes toxic while for a pH lower than 8, ammonia nitrogen has little influence on the aquatic biodiversity (fauna and flora). Nitrite (NO^{2-}) is a very important source of nitrogen for the growth of hydrophytes because it is a function of pH (Wetzel and Likens, 2000).

Elements such as nitrogen (N) and phosphorus (P) are essential nutrients for plants. Compounds containing them, such as phosphates and nitrates, are therefore the nutrients of choice for plants (Priso et al., 2010). Phosphates are used in the composition of many detergents. They must be degraded and hydrolyzed by bacteria into orthophosphates to be assimilated by other aquatic organisms. The total phosphorus content includes not only orthophosphates but also polyphosphates (detergents, industrial waste) and organic phosphates (Hade, 2002). Trace metals dissolve very well in acidic water (low pH) while in neutral or basic waters, they precipitate and accumulate mainly in the solid phase (sludge). Zinc toxicity is influenced by water hardness, oxygen content and temperature, and is mainly related to plants and algae. Copper toxicity to the aquatic environment is highly dependent on alkalinity, pH and the presence of organic matter (Diagne et al., 2017). It should be noted that metals can both accumulate in and adhere to crops via contaminated water, soil or air (Lindahl, 2014). Furthermore, there is a need to know that wastewater discharges from neighboring settlements are characterized by high levels of PO_4^{3-} and NH_4^+. The source of NH_4^+ would refer to organic waste biodegradation, heeding contributions from domestic, industrial, and agricultural sources or fecal contamination (Bisimwa et al., 2022). However, NH_3, which exists in water as NH_4^+, is one of the major pollutants of leachate as it can persist in the aquatic environment for a long time and poses a threat to both human and aquatic species (Parvin and Tareq, 2021, Bisimwa et al., 2022). Human behaviour, influenced by socio-economic circumstances and individual choices, co-determine the extent of exposure, i.e. the *Pressures*, and whether or not the total of *Pressures* over time, the exposome, ultimately results in ill health (Boelee et al., 2019).

Heavy metals are toxic and pollutants to living organisms and the environment. In fact, acidic mine water is dissolved in water due to heavy metals such as Cu, Zn, Mn, As, Pb, and Cd in coal mines and surrounding rocks. If it flows into a highly biological river, it will cause serious damage to the ecosystem, the acid-base balance will be broken, many aquatic organisms will die, nearby soil will be compacted, and production cuts in farmland crops will affect the biodiversity (Wang et al., 2021). This pollution causes serious damage to the drinking water system in the living area, which worsens the disparity between supply and demand of water resources and affects human health (Wang et al., 2021). A study conducted in Ghana showed that most rivers, streams, and other water sources are contaminated due to the small-scale mining activities which constitutes the major contributor to water contamination in this land and in Africa (Zhou et al., 2022). The population of Katanga living around those wetlands are exposed to several biological hazards from this polluted environment, even the aquatic plants which invade these wetlands.

3.5. Hydrophyte diversity

Shannon Weaver diversity index values (2.885 to 2.181 bits) reflect a high specific diversity, and Piélou's equitability (0.977 to 0.96) indicates a good distribution of individuals within species (Table 3). These findings are consistent with Dibong and Ndjouondo (2014) who observed the same gradient of macrophyte distribution in the Kambo and Kondi River. As to the floristic richness of the wetlands surveyed, Lake Kamarenge dominates with 20 species, followed floristically by the Kamarenge River (16 species). This abundance would be due to the abundance of organic matter reported by the discharge of household water into the lake and runoff from the city of Kipushi (Bisimwa et al., 2022) reported that the urban runoff can adversely alter the chemical quality of rivers, as it carries along with suspended sediment materials with adsorbed N and P nutrients, as well as other pollutants that pile up on roads and car parks during periods of low rainfall. Compared to studies conducted in Kinshasa, in the Pool Malebo where it was observed that invasive alien species disturb physico-chemical parameters, thus break the ecological balance of the aforementioned aquatic ecosystem (Mbale et al., 2019; Mukendi et al., 2021). Furthermore, these authors indicated that the most abundant species was *Eicchornia crassipes* while the findings of the current research showed the abundance of *Typha domingensis*, which is a species, ubiquitous and widespread in the southern part of DRC, unlike its northern cousin, *Typha australis*.

3.6. Grouping of hydrophytes in relation to the environment

The vegetation of the wetlands studied is composed of plant groups in which the criterion of abundance-dominance or species that find favorable conditions in the environment are present (Fig. 1). The first grouping is formed by helophytic species (*Phragmites mauritianus* and *Typha domingensis*), which are plants that grow at the edge of the water, rooted in the bottom. Their base is submerged while the assimilating organs are, at least partially, carried above the water body. Dibong and Ndjouondo (2014) reported the specific richness of macrophytes, which is dominated by Poaceae and Asteraceae.

A total of 29 hydrophyte species were identified in the five wetlands. These different observations can be explained by the fact that the plant groups can be distributed according to the stage of evolution of the vegetation. Thus, not only physical-chemical factors are responsible for the distribution of the main groups, but also abiotic factors and abundance-dominance criteria (Barnabe and Barnabe-Quet, 2000; Ngueguim et al., 2010).

3.7. Impacts of physico-chemical water parameters on hydrophytes and the environment

Urban rivers share several features in terms of contemporary landscapes, and the implications of urbanization on aquatic ecosystems are complex, with many physico-chemical and biological consequences (Bisimwa et al., 2022). Furthermore, urban wastewater and effluents from mining industries contain mineral and organic matter. These contaminants can be quantified through measurements such as trace metals (copper, zinc, lead) (Tardat-Henry, 1984; Gray, Becker, 2002). As to Lester (1987) and Agoro et al. (2020), metals are present in effluents from mining industries, many household products that may be discharged to the sewer such as edibles, ointments, cleaning products, medicines, paints, water residues, etc. It should be noticed that cleaning water, and in particular that of clothing, is also the main source of metals in domestic wastewater (Grommaire-Mertz, 1998). Since vegetables and fruit constitute a significant part of the local diet, the ingestion of these trace elements is a pathway for human exposure of potentially toxic metals (Lindahl, 2014). Some authors give average metal concentrations in strictly domestic wastewater in accordance with the general regulations for discharges of wastewater into ordinary surface waters, public sewers and artificial waterways (Rozkosny et al., 2014; Agoro et al., 2020; Sylwan, Thorin, 2021).

When a series of measurements is available, ordered in an increasing or decreasing manner, the use of the median rather than the average makes it possible to avoid the situation where a single measurement highlights an exceptionally high concentration of a pollutant. Therefore, there is an increased volume of heavy metals within the encircling area of mining sites due to the discharge and disposal of waste materials into the environment in several forms like elemental, organic and inorganic (Rama et al., 2021). All of these elements make it possible to evaluate the degree of pollution of the watercourses and to assess their capacity for self-purification (Grommaire-Mertz, 1998; Colandini, 1997). The impacts of toxic compounds on plants and the environment are diverse and important, like: tendency to bioaccumulate, variations in surface water flow, etc (Priso et al., 2010). In addition, it was reported that these heavy metals are persistent in the environment, contaminate the food chains, and cause different health problems due to their toxicity. Chronic exposure to heavy metals in the environment is a real threat to living organisms and destroys the aquatic ecosystem (Hazrat et al., 2019). Monitoring trace element concentrations is particularly important given their toxicity and ability to bioaccumulate along food chains (Wang et al., 2021). The monitoring of heavy metals concentration in the aquatic environment has been done through determination of their concentrations in lotic and lentic water systems or wastewater discharge, especially sewage treatment sites, effluent, sludge, sediments, and the phytoplankton community (Rayori et al., 2022).

Unlike organic pollutants, metals cannot be biologically or chemically degraded These variations in surface water flow have a significant impact on water quality. When flows decrease while discharges and withdrawals remain constant, pollutants become concentrated and water quality decreases (Priso et al., 2010; Hamdhani et al., 2020; Akhtar et al., 2021). During storms, stream flows increase significantly but water quality declines. Deposits of sludge and accumulated dirt are evacuated by the strong water pressure and, in addition, runoff water is loaded with pollutants from the leaching of land and the road network (diffuse pollution). The particles thus suspended affect the transparency of the water and adsorb certain toxic substances such as organic compounds and heavy metals (Garnaud, 1999; Bisimwa et al., 2022). Furthermore, the links between causes and effects are often uncertain. The more that is known about how a wetland functions and the ways in which it supports livelihoods, the greater the confidence in assessing potential hazards. Therefore, policymakers and planners will have to make major policy decisions to determine how wetlands will be used in the present and in the future in order to protect the aquatic biodiversity and the neighboring population.

4. Conclusion

Waste disposal remains a worldwide concern, as the urbanization process spreads in many developing countries, waste management becomes a public health and environmental issue in urban areas. The increased level of heavy metal discharge into the environment and their associated risks has necessitated in-depth research into their occurrence in waste waters, precisely on the aquatic vegetation.

Considering the findings of this study, Kipushi wetlands are abundant but also exposed to accumulate trace elements. There is a need of performing an in-depth study on the identification of all species of these wetlands and extend to other wetlands. The PCA analysis showed that only the Kipushi wetland correlated negatively with axis: 1, 2 and 3 while Lake Kamarenge correlated negatively with axis 2 and 4. This negative correlation reveals that the ecological balance of this wetland is broken, and this disturbance favors the growth of invasive alien species than native species of this ecosystem. The disturbance of physico-chemical parameters are indicators of the toxicity of the wetland, which has negative consequences on the life of the aquatic biodiversity because these metallic elements in the Kipushi region are not biodegradable, the more the bioaccumulation of dissolved metals in the water, the more they are considered as hazards for the environment. It should be noted that developing countries in particular lack information on the biodiversity and ecological attributes of individual wetlands. This makes the evaluation of ecological hazards highly subjective.

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