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Comparative Spatial Assessment of Trace Metal(loid) Pollution in the Sediments of the Lower Olifants River Basin in South Africa

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Globally, many freshwater ecosystems are facing chemical pollution from both natural and anthropogenic sources. The Olifants River Basin in South Africa is experiencing degradation due to mining, industrial, agricultural, and domestic activities. The impacts of these activities coupled with climate change is likely to shift the hydrological cycle that may increase accumulation of toxic chemicals in the sediments. The aim of the study was to assess the contamination of As, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in the sediments collected at the upstream, midstream and downstream of four rivers of the Lower Olifants River Basin; the Blyde, Mohalpitsi, Ga-Selati, and Steelpoort rivers. The highest concentrations of most of the trace metal (loid)s assessed were from the Steelpoort River followed by the Blyde River. Significant differences in metal concentrations were found across study sites and rivers. The overall assessment of the sub-catchment, which is characterised mainly by mining and agricultural activities shows significantly elevated levels of As, Cr, Mn, and Ni in the sediments and may cause secondary pollution in the water. Using enrichment factor (EF) and geo-accumulation index (I_{geo}), some of the sediments were severely enriched and extremely contaminated respectively with As, Cr, and Ni. This may risk the lives of aquatic biota and humans, especially rural communities that rely on these rivers for drinking water. The findings provide baseline information for effective management control of metal(loid) pollution in the Olifants River Basin.

Keywords: trace metal(loid)s, climate change, sediment pollution, enrichment factors, geoaccumulation index

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INTRODUCTION

Many freshwater ecosystems are experiencing degradation due to increasing human demand for products and services (Ferreira et al., 2019; Islam et al., 2020; Khan et al., 2021). The degradation is mainly caused by discharges from industrial, mining, agricultural and domestic wastes, which contain among other pollutants, trace metals (Mimba et al., 2018; Chen et al., 2019; Addo-Bediako, 2020; Setia et al., 2021). Although some of these metals are essential as micronutrients, they can be toxic to the environment at high concentrations (Islam et al., 2020). Trace metal pollution has become a global concern in freshwater environments (Zeng et al., 2020), as they are resistant and non-degradable, and at high concentrations can be detrimental to the ecosystem, aquatic biota, and humans (Benzer, 2017; Zhang X. et al., 2017; Xu et al., 2018; Zeng et al., 2019; Addo-Bediako, 2020).

Many recent studies on freshwater ecosystems have reported an increase in pollution by organic and inorganic contaminants (Pandey et al., 2019; Islam et al., 2020; Khan et al., 2020). The pollution is mainly attributed to rapid economic development that has led to unplanned urbanization and the development of industries which are affecting freshwater ecosystems (Proshad et al., 2019, 2020; Namngam et al., 2021). An understanding of the impact of these changes on freshwater ecosystem warrant the study of the spatial distribution of pollutants, such as metals in surface water and sediments.

Besides the anthropogenic threats, climate change is emerging as the greatest threat to the functioning of aquatic ecosystems and biodiversity (IPCC, 2007). Potential climate change is likely to affect the frequency, duration, magnitude, and timing of the weather and climate extremes (Seneviratne et al., 2012). South Africa is a semi-arid region, with a mean annual rainfall of about 500 mm, which is below the world average of about 750 mm and the country has high evaporation rate. Many rivers in the country have seasonal flow with considerably high variability in runoff (Edokpayi et al., 2020; Remilekun et al., 2021). South Africa is projected to experience significant losses of runoff, with some areas being particularly impacted (Nkhonjera, 2017). The expected reduction in rainfall and high temperatures due to climate change would reduce already depleted water resources, contributing to an increasing drought in the country (UNDP, 2020). It is projected that with increasing water demand for mining, agricultural, industrial and domestic activities and poor management policies, together with climate change, many freshwater ecosystems would severely be affected (Addo-Bediako et al., 2021; Remilekun et al., 2021).

Sediments are essential and dynamic component of the river system, and serve as a sink for trace metals (Balzani et al., 2021) and can be released into the water column under changes in certain environmental conditions, such as pH, redox, conductivity, salinity, total dissolved solids, temperature, and turbidity (Chetty and Pillay, 2019). Sediment analysis is very effective to assess the metal contamination of freshwater ecosystems (Dahms et al., 2017).

In the past two decades, the Lower Olifants River has faced rapid urbanization due to increasing mining activities in the area, especially chrome, and platinum. This has also resulted in an increase in human population, putting more pressure on the rivers due to more domestic waste discharged into the rivers. The development in the area has also affected the riparian vegetation which can have consequences on the ecological state of the rivers. Studies on metal contamination in the sediments are crucial in the catchment. Many of the rural communities depend on the rivers in the catchment for drinking water and food (fish), and degradation of these rivers may pose a health risk to the people and their animals. The aim of the study was to assess the pollution status of trace metal (loid)s (As, Co, Cr, Cu, Mn, Ni, Pb, and Zn) in the sediments of four rivers in the Lower Olifants River Basin; the Blyde, Mohlapitsi, Ga-Selati and Steelpoort rivers. The hypothesis of the current study was that the increasing mining, agricultural and other human activities in the area is polluting the rivers. The specific objectives of this study were: 1) to analyse the concentration and spatial distribution of metal(loid)s in river sediments and 2) to evaluate the degree of pollution of metal(loid)s by using the enrichment factor (EF) and geoaccumulation index (I_{geo}). The results may provide valuable information for the management of the basin and to implement measures to alleviate the impacts of chemical pollution and climate change on the rivers and human health.

MATERIALS AND METHODS

Study Area

The Lower Olifants sub-catchment stretches from the Drakensberg escarpment through the Kruger National Park to Massingir Dam in Mozambique. The sub-catchment is characterised by mining, agricultural and industrial activities (Heath et al., 2010). Although, the water quality of the Olifants River is negatively affected by human activities (Ballance et al., 2001), the Lower Olifants River receives water of good quality from the Blyde and Mohlapitsi rivers (DWAF, 2004). The climate of the basin is warm to hot sub-tropical, with seasonal rainfall occurring during the summer months (October to March), peaking in January. The amount of rainfall ranges from <600 mm per annum (lowveld) to about 800 mm per annum (highveld). Three sites representing the upstream, midstream and downstream of each of the four rivers were selected for this study (**Table 1**). The rivers/sites selected were the Blyde River (BL1, BL2, and BL3), Mohlapitsi River (MH1, MH2, and MH3), the Ga-Selati River (SL1, SL2, and SL3), and the Steelpoort River (ST1, ST2, and ST3) as shown in **Figure 1**.

Data Collection

Surface sediment samples were collected at four sampling campaigns during 2018–2019. The samples were collected at a depth of about 5–10 cm using a hand trowel. The hand trowel was washed with a detergent, rinsed, and dried before using it at each site to minimize contamination. At each site, five sub-samples were mixed together, forming a composite sample (Bervoets and Blust, 2003). The samples were placed in 10% nitric acid pre-treated polyethylene ziplock bags, transported to the laboratory and were frozen (−20°C) prior to chemical analysis (UNEP(DEC)/MED, 2006). Sediment samples were analysed for elements at an accredited (ISO 17025) chemical laboratory in Pretoria, South Africa. The samples were put in acid-washed polypropylene pre-weighed vials and dried at 60°C for 24 h. The samples were then sieved through a 2-mm nylon sieve to remove any stones and coarse debris. Then 0.1 g of each sediment sample was digested with 8 ml of 68% nitric acid (HNO_3) and 3 ml of 40% hydrochloric acid (HCl). It was then filtered through a membrane filter and the concentrations of As, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were analysed using inductively coupled plasma optical emission spectrometry (ICP-OES) (Perkin Elmer, Optima 2100 DV). Concentrations of the metals in the sediments were calculated and expressed as mg/kg dry weight. Analytical accuracy was determined using certified standards (De Bruyn Spectroscopic Solutions 500 MUL20-50STD2) and recoveries were within 10% of certified values.

Statistical Analysis

The mean and standard deviation of the metal(loid)s were calculated. Analysis of variance (ANOVA) was performed to determine

TABLE 1 | Description of the study sites of the selected four rivers in the Lower Olifants River Basin.

Site		Land use	Sources of Impact
BL1	24°30′59.46″S 30°47′56.14″E	Nature reserve, resorts	Sedimentation. Urban runoff
BL2	24°24′19.03″S 30°47′54.19″E	Hoedspruit bridge, recreational use	Urban runoff, partially treated sewage effluent
BL3	24°23′04.94″S 30°48′22.09″E	Residential, resorts, and Wildlife Estate	Urban runoff, fertilisers
MH1	24o9′54.016″S; 30o6′15.64″E	The Wolkberg Wilderness (partially protected area). The site is surrounded by vegetation, comprising of trees, shrubs and ferns, with no bank erosion	Riverbed trampling by animals, manure input
MH2	24o14′12.19″S; 30o4′40.22″E	A settlement (Ga Mafefe village). This site is used for sand mining, washing clothes and serves as source of drinking water for some villagers and their cattle	Sand mining, domestic wastes
MH3	24° 14′13.67″S, 30° 4′ 41.33748″E	Near the confluence of the Mohlapitse River and the Olifants River. The area is mostly surrounded by shrubs and grasses	Riverbed trampling by animals, manure input
SL1	24°8′30.81″S 30°18′11.63″E	Nature Reserve and agricultural activities	Fertiliser washed into the river, small weirs affect flow and sedimentation
SL2	23°58′36.61″S 30°59′03.95″E	Near Namakgale Township. Sand mining	Partially treated sewage effluent
SL3	24°02′16.93″S 31° 07′59.64″E	The FOSKOR mine and industrial complex	Urban runoff, mining effluent, industrial runoff
ST1	25° 6′20.87″S 29°51′7.40″E	Located upstream with little human activities, though the riparian vegetation is disturbed	Riverbed trampling by animals, manure input
ST2	24° 43′4.70″S 30° 12′3.40″E	mines and smelter	Mining effluent, runoff from lodges
ST3	24° 64′2.38″S 30° 30′ 4.19″E	Settlement and cattle grazing	Partially treated sewage effluent. manure input. riverbed trampling by animals

differences of mean metal(loid) concentrations among sites and rivers. The occurrence of a linear correlation between metal(loid) concentrations was evaluated by Spearman's correlation coefficient. All statistical analyses were done using Statistica (Version 10).

The enrichment factor (EF): Enrichment factor was used to evaluate the extent of trace metal (loid) contamination in the sediments (Zahra et al., 2014).

Enrichment factor (Barbieri, 2016; Hanif et al., 2016). EF is calculated as:

$$EF = \frac{\left(M_i/S_x\right)\text{sample}}{\left(M_i/S_x\right)\text{ reference,}}$$

where EF stands for the enrichment factor, M_i/S_x sample stands for the ratio of measured value (m/kg) of element i to measured value (mg/kg) of reference element x in the sample, (M_i/S_x) stands for the ratio of background value (mg/kg) of element i to the background value (mg/kg) of reference element x (Brady et al., 2014; Gao et al., 2014).

The average shale values of metal(loid)s were used as background value (Turekian and Wedepohl, 1961). To account for natural trace metal(loid) concentrations, EF is normalized using Al or Fe content. In this study, Fe was selected, as it has been used successfully to normalise trace metal contaminants (Bhuiyan et al., 2010). The EF are classified into 6 groups (**Table 2**).

Geo-Accumulation Index (I_{geo})

When assessing aquatic toxicity in the sediments, the geoaccumulation index (Igeo) matrix could be applied. The values of the geo-accumulation index were calculated after Muller (1969) by the following equation:

$$I_{geo} = \log_2\left(M_x/1.5B_n\right),$$

where M_x is the concentration of the examined metal in the sediment, B_n is the geochemical background value of a given metal in the shale (Turekian and Wedepohl, 1961) and the factor 1.5 is used to account for the possible variations in the background values. The I_{geo} index is grouped into seven classes (0–6) (**Table 2**).

RESULTS

Distribution of Metal(loid)s in the Sediments

The distribution of metal(loid)s along the four rivers of the Olifants River Basin is shown in **Table 3**. There were significant differences in the metal (loid)s among the rivers, As ($F = 30.09$; $p < 0.0001$), Cu ($F = 17.25$; $p < 0.001$), Fe ($F = 28.15$; $p < 0.001$), Mn ($F = 4.80$; $p = 0.03$), Ni ($F = 21.09$; $p < 0.001$), and Zn ($F = 5.24$; $p = 0.02$), except Cr ($F = 2.78$; $p = 0.11$). The mean metal(loid) concentrations in the sediments were found to vary among the sites; the highest mean concentrations recorded were as follows, As at BL2 (51.0 mg/kg), Cr at ST2 (2252.8 mg/kg), Cu at BL2 (74.0 mg/kg), Fe at STI (177173.8 mg/kg), Mn at MH4 (2581.5 mg/kg), Ni at BL3 (281.7 mg/kg), Pb at MH3 (10.0 mg/kg), and Zn at ST3 (92.0 mg/kg).

When compared with the average shale values and the sediment quality guidelines, the concentrations of As were below the average shale value at all the sampling sites and rivers, except in the Blyde River (BL1, BL2, and BL3) and the concentrations were above the sediment quality guideline (SQG) at MH1, MH2, BL1, BL2, and BL3. The concentrations of Cr

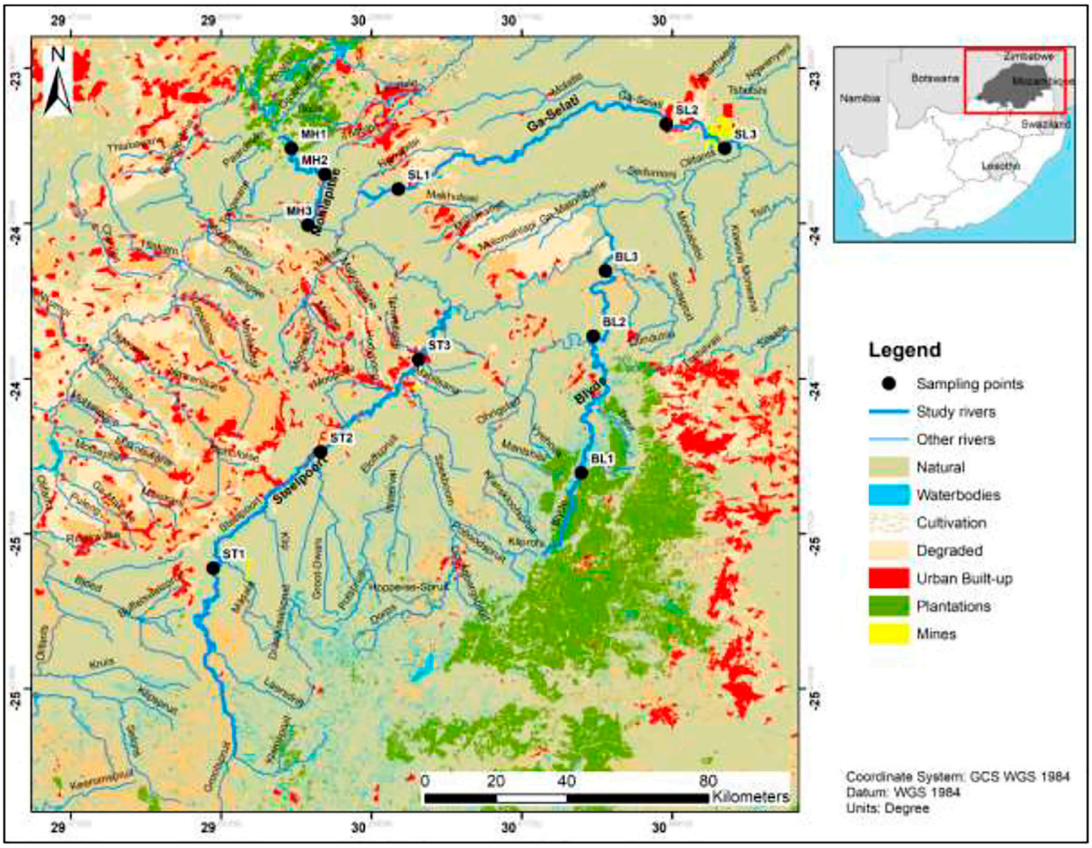

FIGURE 1 | Map showing the locations of the sampling sites of the four rivers in the Lower Olifants River.

exceeded the average shale values at all the sites and rivers, except at BL1, BL2, SL1, SL2, and SL3, whiles the concentrations were above the SQG at all the sites. The concentrations of Cu were below both the average shale and SQG values at all the sites except at BL1, BL2, and BL3. The concentrations of Fe exceeded the shale value at ST1, ST2, ST3, and MH2. The Mn concentrations were below the average shale value except at BL2, BL3, MH2, ST1, ST2, and ST3. The concentrations of Ni were above the shale value at BL1, BL2, BL3, MH3, SL1, SL2, SL3, ST2, and ST3. The concentrations of Pb and Zn at all sites/rivers were below the average shale and SQG values. The Spearman correlations highlighted a strong positive association between As and Cu; Cr and Mn and Pb; Fe and Mn; Fe and Pb; Fe and Zn; Mn and Pb, Pb and Zn ($p < 0.05$) (**Table 4**).

The cluster analysis (CA) was used to characterize the results of the metal(loid)s as shown in **Figure 2A**. The CA dendrogram is divided into three clusters: cluster 1 consists of only Mn; cluster 2 consists of only Cr, and cluster 3 includes As, Cu, Pb, Zn, and Ni. The CA also separates the Steelpooort River from the rest of the rivers (**Figure 2B**).

Enrichment Factor and Geo-Accumulation Index (Igeo)

The EF values for the metal (loid)s are shown in **Figure 3**. In the Blyde River, As was moderately to moderately severely enriched at all sites, Cr, Cu, and Mn showed minor enrichment at all the sites, Ni showed moderately

TABLE 2 | Classification standard of enrichment factor (EF) and geoaccumulation index (Igeo).

EF classes	Enrichment level	Igeo value	Igeo class	Contamination level
EF < 1	No enrichment	Igeo ≤0	0	Uncontaminated
EF = 1–3	Minor enrichment	Igeo = 0–1	1	Uncontaminated/moderately contaminated
EF = 3–5	Moderate enrichment	Igeo = 1–2	2	Moderately contaminated
EF = 5–10	Moderately severe enrichment	Igeo = 2–3	3	Moderately/strongly contaminated
EF = 10–25	Severe enrichment	Igeo = 3–4	4	Strongly contaminated
EF = 25–50	Very severe enrichment	Igeo = 4–5	5	Strongly/extremely contaminated
EF > 50	Extremely severe enrichment	Igeo >5	6	Extremely contaminated

TABLE 3 | Mean metal concentrations in the sediments of the four rivers, the average shale values and sediment quality guidelines.

Site	As	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BL1	50.8	41.5	63.6	25333.0	685.3	109.9	7.5	42.8
BL2	51.0	80.4	74.0	28108.8	949.8	115.1	7.2	48.3
BL3	45.0	108.0	63.4	46210.0	1299.0	281.7	7.4	38.6
MH1	6.6	260.5	21.7	12001.5	567.8	64.7	5.9	16.2
MH2	8.0	245.0	16.4	74664.5	2581.5	49.2	8.5	20.3
MH3	4.8	416.3	20.3	34761.0	682.3	72.0	10.0	54.5
SL1	3.8	61.8	0.0	14400.0	254.5	79.5	0.0	11.0
SL2	2.0	52.5	0.0	15000.0	270.5	144.7	0.0	29.5
SL3	1.7	46.8	0.0	12700.0	209.0	88.3	0.0	29.0
ST1	0.9	106.3	25.3	177173.8	1167.8	16.6	5.4	89.1
ST2	0.4	2252.8	13.7	133291.8	1560.8	92.0	4.1	47.5
ST3	1.9	1096.3	21.2	135981.5	1783.8	119.5	17.0	92.0
Av. Shale value*	13.0	90.0	45.0	47200.0	850.0	68.0	20.0	95.0
SQG	5.9	37.3	35.7				35.0	123.0

*Turekian and Wedepohl (1961); SQG, Sediment Quality Guideline (CCME, 2012).

TABLE 4 | Spearman correlation matrix between metal(loid) concentrations of the sediments.

	As	Cr	Cu	Fe	Mn	Ni	Pb	Zn
As	1.000							
Cr	−0.273	1.000						
Cu	0.613**	0.021	1.000					
Fe	−0.280	0.531**	0.268	1.000				
Mn	0.056**	0.608**	0.394	0.846**	1.000			
Ni	0.217	−0.154	0.127	−0.035	0.035	1.000		
Pb	0.222	0.568**	0.412	0.635**	0.751**	0.459	1.000	
Zn	−0.196	0.350	0.451	0.727**	0.469	0.175	0.579**	1.000

**correlation is significant at the $p < 0.05$.

enrichment, Pb and Zn showed no enrichment. In the Mohlapitsi River, all the metal(loids) showed no enrichment to minor enrichment, except for Cr which showed severe enrichment and Ni was moderately enriched at MH1. In the Ga-Selati River, all the metal(loid)s showed only up to minor enrichment at all the sites, except Ni which showed moderately enriched at SL1 and SL3 to moderately severe enrichment at SL2. In the Steelpoort River, As, Cu, Mn, Ni, Pb, and Zn showed no enrichment at all sites, however, Cr showed moderately and moderately severe enrichment at ST3 and ST2 respectively.

The I_{geo} index values are shown in **Figure 4**. In the Blyde River, there was no contamination for all the metal(loid)s, except for As which showed moderately contamination at the three sites, and Ni showed moderately contamination at BL1 and BL3 and strongly contamination at BL2. In the Mohlapitsi River, Cr concentration showed moderately contamination at all the three sites, whiles the rest of metal(loid)s showed no contamination. In the Ga-Selati River, all the elements were in class 0, thus no contamination, except Ni, which showed a moderately contamination at SL2. In the Steelpoort River, Cr

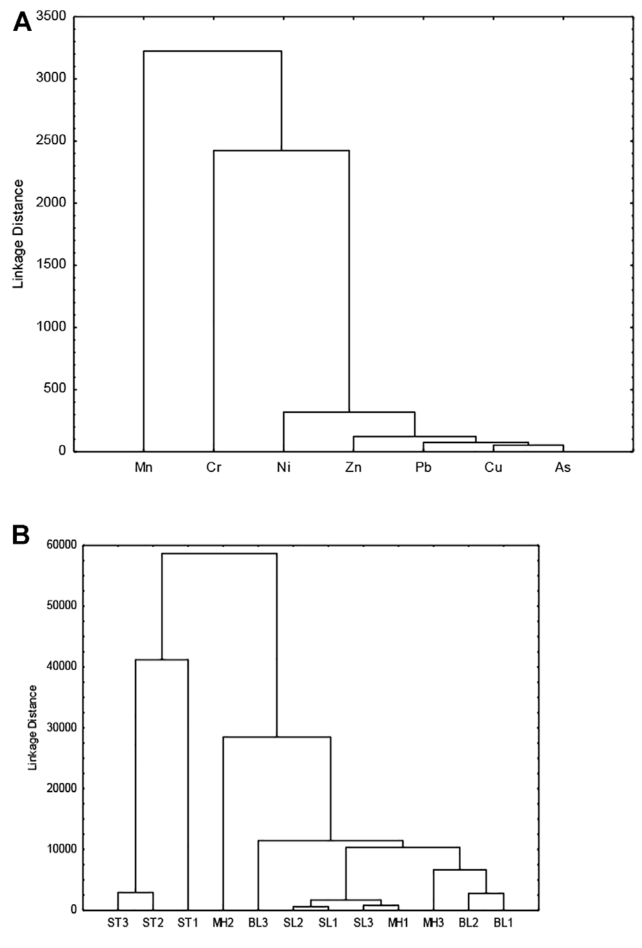

FIGURE 2 | (A) Cluster analysis of sediment for different metal(loid)s from the Blyde, Mohlapitsi, Ga-Selati, and Steelpoort rivers. **(B)** Cluster analysis of metal(loid)s in the sediments from different sites of the Blyde, Mohlapitsi, Ga-Selati, and Steelpoort rivers.

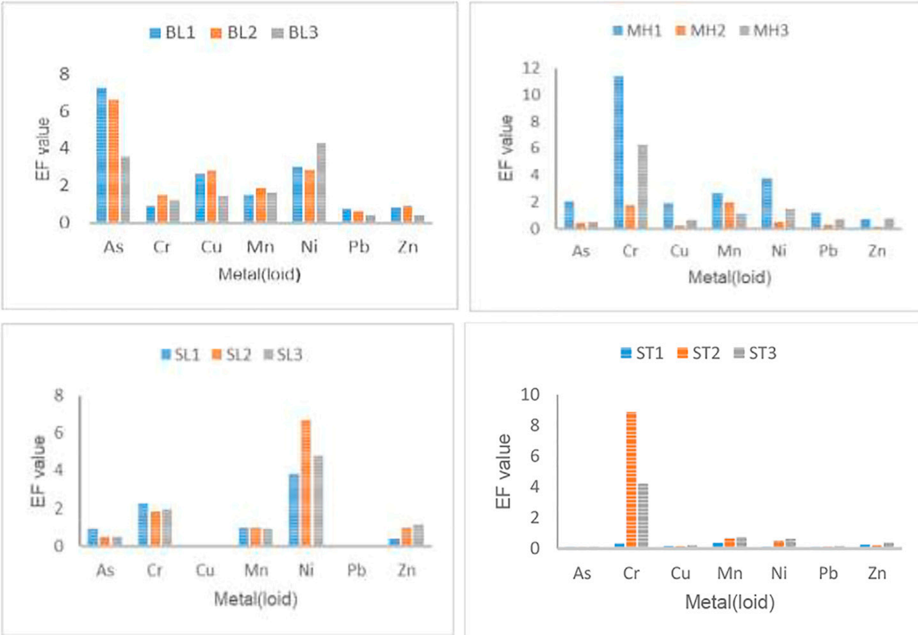

FIGURE 3 | Enrichment factors (EF) of metal(loid)s collected from different sites of the four rivers in the Olifants River Basin.

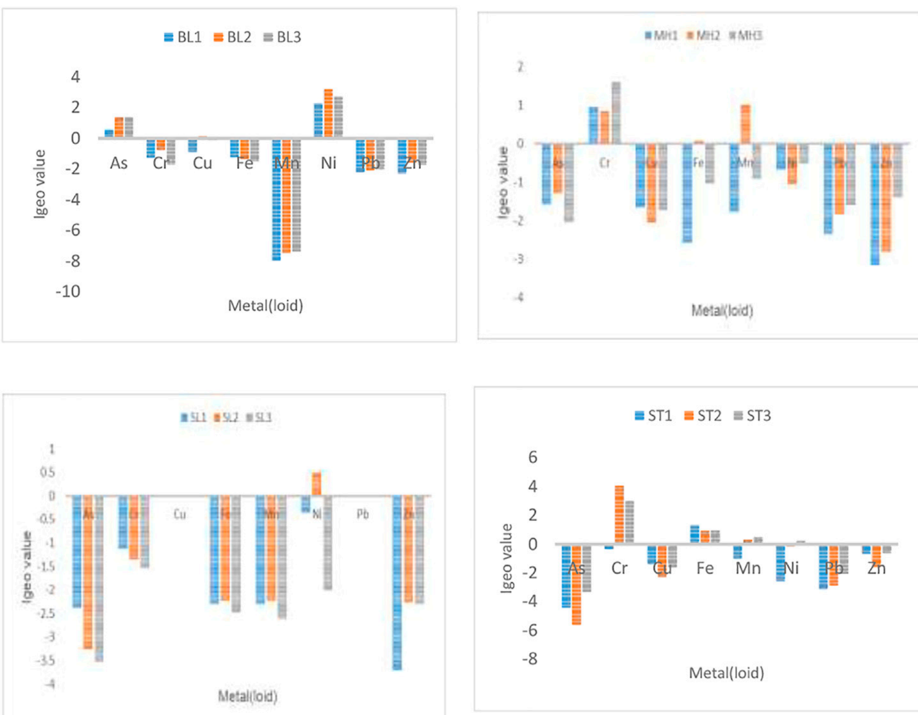

FIGURE 4 | Geo-accumulation index (Igeo) of metal(loid)s collected from different sites of the four rivers in the Olifants River Basin.

concentration showed strongly contamination at ST2 and ST3, Fe and Mn showed moderately contamination at ST2 and ST3, and Ni moderately contamination at ST3.

DISCUSSION

Distribution of Metal(loid)s in the Sediments

The results obtained in the study indicate that trace metal(loid) concentrations in surface sediment of the four rivers were elevated. Generally, the midstream and downstream sites were more polluted compared to the upstream sites of the rivers due to increasing human activities in the midstream and downtream. The spatial trends of the metal(loid)s showed increasing localized concentrations of all the rivers, thus the concentrations were higher close to mining, industrial, agricultural and domestic activities, and gradually decreased away from these point sources. When compared with standard values, most of the concentrations of As, Cr, and Cu exceeded the guideline values across the different rivers (CCME, 2012).

The highest concentrations of As, Cu and Ni were recorded in the Blyde River, especially in the midstream of the river, where there are many agricultural activities, such as commercial citrus and maize farming, which use fertilizers and pesticides (Zhou et al., 2018; Islam et al., 2020; Kumar et al., 2021).

The highest concentrations of Cr, Fe, and Zn were recorded in the Steelpoort River. The high metal concentrations in the Steelpoort River were attributed to various mining activities and smelters in the catchment (Addo-Bediako., 2020). The highest Cr concentration was observed in the midstream and downstream of the river and this might be due to the production and processing of chrome in the area (Crafford and Avenant-Oldewage, 2011). The concentrations recorded at all the sites of the Steelpoort River far exceeded the permissible limit (CCME, 2012). The highest Fe concentration in this river might also be attributed to runoff from chrome mines and smelters in the area. Furthermore, the high concentration of Ni recorded in the Steelpoort River could be due to combustion of fossil fuels especially many mining and construction trucks in the area (Addo-Bediako, 2020). The diversity of mining activities especially platinum and chrome, and metal smelters, and transportation have been reported to contribute to trace metal pollution in the environment (Tytła and Kostecki, 2019; Tan et al., 2021). The highest Zn concentration was recorded at downstream of the Steelpoort River. Sources of Zn in the environment include mining, domestic and industrial runoff, and vehicular emissions. However, the low level of Zn recorded is in an indication that it originated mainly from natural sources (Sojka et al., 2019).

The main source of high Ni concentration in the Ga-Selati might be from agricultural wastes, domestic discharges, urban activities (Li, 2014; Kumar et al., 2020), and combustion of fossil fuels (, Wang et al., 2020; Li et al., 2021). The highest Mn concentration was recorded in the downstream of the Mohalpitsi River and could be attributed to release from organic matter, fertilizers, and fungicides (Khan et al., 2020; Li et al., 2021). The area especially the midstream is characterised by many small scale agricultural activities.

A correlation analysis showed a relationship between the metal(loid)s and highlighted that some of the metal(loid)s in the sediments were positively and significantly correlated with each other. A high correlation among the different metal (loid)s is an indicative of a common source and mutual dependence (Kalita et al., 2019). The dendrogram, generally indicated a close relationship between sites of specific rivers in their response to the metals. The cluster analysis showed the three sites of the Steelpoort River in the same group and all the sites of the Blyde, Mohlapitsi and Ga-Selati rivers to be in one group, with the exception of MH2. The multivariate analysis (i.e., cluster analysis) indicates that those grouped together have common sources of metal contamination (Dalu et al., 2018; Kalita et al., 2019; Zhang G. et al., 2017). It was also observed in the cluster analysis that there were differences in the rivers and sites, with a strong separation between the Steelpoort River and the rest of the rivers. The differences could be attributed to differences in land use activities in the catchments, which might cause variations in metal concentrations. Thus, the cluster separation of these elements suggests a different origin or the current position of the elements in the sediments.

Comparing the results with other related studies (**Table 5**), the levels of Cu detected in this study in the Blyde River far exceeded levels determined by other studies. The Cr concentration recorded in the Steelpoort river exceeded that of other studies. Copper concentration in the four rivers only exceeded the concentrations from the Strzyza River in Poland (Nawrot et al., 2020), Calore River in Italy (Zuzolo et al., 2017), Nile River in Egypt and Ipojuca in Brazil (Silva et al., 2019). The highest concentration of Fe was recorded in the Steelpoort River and far exceeded the results of the other rivers. The Mn concentrations recorded in this study were lower than the concentration recorded in Tigris River, Turkey (Varol and Sen, 2012). The highest concentration of Ni in this study was from the Blyde River but it was lower than the concentrations recorded in Dongbao River, China (Wu et al., 2016) and Tigris River, Turkey (Varol and Sen, 2012). The highest Pb and Zn concentrations recorded in this study exceeded only the concentrations in Nile River (Omar and Mahmoud, 2017). The differences in the concentrations of metal(loid)s between the sediments in this study and those from international rivers could be attributed to variations in the levels of contamination, regional characteristics, and anthropogenic activities (Fabio et al., 2021).

The elevated concentrations of Cr, Fe, and Mn in the Steelpoort River is an indication that the aquatic biota and humans depending on the river for drinking water and food (e.g. fish) are at risk of elevated heavy metal contamination. The main activity in the Steelpoort River catchment is mining and could have contributed to the metal pollution in the river (Addo-Bediako, 2020; Emenike et al., 2020).

Enrichment Factor and Geo-Accumulation Index (Igeo)

Generally, the results of the study demonstrated a high degree of metal(loid) contamination in the sediments across sites and rivers, as evidenced by the high EF values of As and Pb in the

TABLE 5 | Comparison of metal(loid)s in sediment (mg/kg dw) with other international studies.

River, location	As	Cr	Cu	Fe	Mn	Ni	Pb	Zn	References
Blyde River, South Africa	32.7	44.6	43.9	20938	532.4	90.6	4.9	30.1	This study
Mohlapitsi River, South Africa	4.9	230.5	14.6	30357	959.9	46.5	6.1	22.8	This study
Ga-Selati River, South Africa	1.9	40.3	—	10525	183.5	78.1	—	17.4	This study
Steelpoort River, South Africa	0.8	863.9	15.1	111612	1128.1	57	3.7	57.2	This study
Xihe River, China	11.2	35.6	45.3			35.1	21.9	205.7	Liu et al. (2021)
Dongbao River, China		71.3	2602			412	69.9	646	Wu et al. (2016)
Xixiang River, China		89.6	168.8			69.5	63	310.3	Liu et al. (2020)
Korotoa River, Bangladesh	22.0	99	71			86	54		Islam et al. (2015)
Tigris River, Turkey	12.4	515.6	2860		1681	534.6	660	1061	Varol and Sen, (2012)
Strzyza River, Poland		18.2	36.6			8.68	45.9	149.5	Nawrot et al. (2020)
Calore River, Italy	7.3	19.7	34.3			24.6	24	65.9	Zuzolo et al. (2017)
Pra River, Ghana	0.18	118.3		1355	183.9	72.7	335.8	118.3	Duncan et al. (2018)
Nile River, Egypt			4.5	1141	227		4.6	17	Omar & Mahmoud (2017)
Ipojuca, Brazil			4,4	3002	762	25.6	36.7	63	Silva et al. (2019)

Blyde River, Cr and Ni in the Mohlapitsi River, Ni in the Ga-Selati River, and Cr, Cu, and Pb in the Steelpoort River. The high EF values of Cr and Ni in almost all the rivers may be due to human activities occurring in the catchment (Duncan et al., 2018). However, the low EF values of Mn despite the high mean concentrations recorded is an indication that it originates mainly from natural sources (Sojka et al., 2019).

The high I_{geo} index for As, Cr, Ni, and Pb in the rivers reflect increasing human activities in the river catchments. The high I_{geo} values of Cr, Pb, and Ni showed that some of the sites received a considerable amount of contamination of these metal(loid)s (Bing et al., 2019), this could be due to unregulated mining and agricultural activities occurring in the catchment (Islam et al., 2015).

Future Perspectives

The Lower Olifants River Basin is experiencing degradation due to chemical toxicity from mining, industrial, agricultural, and domestic discharges. In the past two decades, there has been increasing mining operations in the area and has put more pressure on the water resources in the area. It is estimated that more mining operations would be established in the region in the coming years, and will increase the demand for water. Climate change will further stress the system as low rainfall, drought, and high temperatures are projected across the Olifants River Basin (IPCC, 2007; UNDP, 2020). Under climate change, river discharges are expected to become more frequent, and increase accumulation of chemical substances. Low river discharge also means limited dilution of chemical substances and with high temperatures during summer/autumn would elevate metal levels (Iordache et al., 2022). When rainfall occurs, it is predicted to be mainly of torrential rain which may lead to enhance runoff and accelerate leaching resulting in enhanced metal loads (Wijngaard et al., 2017). It is therefore important for organized cross-sectoral measures and research to alleviate the impact of the climate change and metal(loid) pollution in the basin.

CONCLUSION

The trace metal(loid) concentrations in the sediments of the Blyde, Mohlapitsi, Ga-Selati, and Steelpoort rivers were analyzed and evaluated by various metal pollution indices. The results showed that concentrations of Cr, Ni, and Mn in all the rivers, and As concentration in the Blyde River are of great concern, as they exceeded the average share values, and sediment quality guidelines. The Enrichment factor and geoaccumulation index (Igeo) confirm strong As and Ni contamination in the sediments of the Blyde River, Cr, Mn, and Ni in the Mohlapitsi River, Cr and Ni in the Ga-Selati river and Cr in the Steelpoort River. The high concentrations of these trace metal(loid)s in the sediments of the rivers are mainly associated with the various mining and agricultural activities in the area. Climate change is also likely to increase metal concentrations in sediments of rivers in semi-arid countries like South Africa, where it is predicted to prolong the dry season. It is therefore important that freshwater ecosystems should be given a proper attention when implementing measures to alleviate impacts of climate change.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

AA-B did the collection of data, analysis and write-up.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.882393/full#supplementary-material

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