



Contamination of sediments in the floodplain wetlands of the lower uMngeni River, Kwa-Zulu Natal, South Africa

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This study describes the geochemical and physico-chemical characterization of contaminant status of six wetlands of the lower uMngeni River floodplain, KwaZulu-Natal Province, South Africa. At all sites, organic matter content, calcium carbonate and metal concentrations were highest within the fine-sediment dominated surface laminae, decreasing with depth. Exceptions were displayed by arsenic (As), nickel (Ni) and vanadium (V), presumed to be derived from normal geochemical processes. Geochemical indices indicated high contamination factors for lead (Pb) and V, pointing to moderate anthropogenic metal pollution contribution. Most conspicuous are the contamination high factors for Pb across most sites. Fe and Pb contamination is ubiquitous in all surface laminae, with contamination factors being either border-line, moderate or of high contamination. Enrichment factors for As, Mn and P at site S6 indicate possible anthropogenic sources. The data also shows a possibility of anthropogenic input of P and Zn at site S3. Apart from the enrichment factors established for Ni across all sites, all other metals indicate some degree of enrichment. A range of variable results for the mid to deeper laminae are indicative of natural processes with some human influence. Results of ANOVA confirm the above. Principal component analysis reveals a 46.4% variance from component 1 elements (Al, Ca, Cr, Cu, Fe, Mg, Mn and Zn) and a 17.8% variance from component 2 (Al, Cu and Fe). Given the rapid rate of development in this region, the protection of these floodplain wetlands must receive high conservation priority from the local municipality.

Keywords. Sediment core; contamination; enrichment.

1. Introduction

Coastal regions contain a multitude of natural resources and therefore epitomise hubs of human activity in both developed and developing countries alike (Cobelo-García and Prego 2004). Microecosystems, such as wetlands, which were once commonalities of coastal areas, are subjected to

progressive degradation and destruction over time by nations in pursuit of economic growth and development (Vitousek *et al.* 1997; Rana *et al.* 2016). The reduction of previously large functioning wetlands to scattered remnants is an obvious manifestation of unrestrained human influence in the past, and in many cases, its persistence in the present day (Walmsley 1992). Although

past perceptions of wetlands have been largely abandoned and increasing efforts are being made by government and non-governmental organisations to manage and protect wetland environment, development continues to pose a real and perilous threat to the health of existing wetland ecosystems (Gren *et al.* 1994).

The mounting pressure on wetland resources and functioning; elicited by increased urbanisation, injudicious agricultural practices and industrialisation, is further compounded by surges in human population and the concentration of anthropogenic activity in close proximity to wetland features (Brijlal 2005; Niu *et al.* 2015). Densely urbanised localities along the coast act as significant waste- and chemical-producing areas that contribute largely to the enrichment of wetland sediments by contaminants such as metals that typically comprise effluent discharges from industries, and leachate from sources of municipal waste and cultivated land (Cobelo-García and Prego 2003; Nabulo *et al.* 2008).

The correlation between the health and integrity of an environment and the sustainability of its soil ecosystem has been well documented. Sediment pollution is known to decrease soil quality and alter ecosystems in ways that prove detrimental to their biotic constituents and dependents (Ayeni *et al.* 2010). The danger of metals being present in wetlands in quantities exceeding those deposited *via* natural processes is primarily associated with the high potential for their release from sediments into surrounding waters subsequent to changes in prevailing physical and chemical characteristics in the water column (Kotze 2000). The implications are unattractive from an ecosystem health perspective given the reputed ability of metals to bio-accumulate and bio-magnify in wetland organisms, the consequences of which prove detrimental to affected biota as well as reliant human populations (Nomaan *et al.* 2012). The importance of maintaining acceptable soil quality in wetland ecosystems, and in other ecosystems alike, therefore arises from the need to maintain the capacity of sediments to sustain plant and animal productivity, provide refuge for dependent biota, and thereby support ecosystem functioning and human well-being (Karlen *et al.* 1997; Ahmed *et al.* 2015).

The effectiveness of utilising sediments as a sensitive indicator to monitor the level of metal pollution and trace contamination sources has been largely recognised, accepted by experts and the

larger scientific community (Soares *et al.* 1999; Harikumar *et al.* 2009). This realised efficacy is based on the ability of sediments to promptly adsorb and accumulate metals carried by the above-flowing water, allowing for a greater degree of accuracy in metal detection than the employment of alternative analysis methods, irrespective of water level at the given time (Soares *et al.* 1999). The adsorption capacity of wetland sediments, however, is highly variable based on the physical and chemical properties of sediment, principally, particle size and organic matter content (Sheoran and Sheoran 2006). Trace metals, for instance, naturally display a higher affiliation for finer-grained sediment, and sediment constituting a higher percentage of organic matter (Khechfe 1997). Furthermore, sediment cores have been useful in studying the behaviour of metals and broadly reflecting the sediment history, and thus the contamination history of an area (Harikumar *et al.* 2009).

In order to determine whether the concentration of detected metals in sediments are of natural or anthropogenic origin, and establish their level of acceptability regarding their contribution towards maintaining optimum functionality of the wetland, it is essential that results obtained are compared with standard background values for the region or geological type (Martínez-Carballo *et al.* 2007 and Chenhall *et al.* 2004 in Sukdeo *et al.* 2011). ‘Geochemical backgrounds’ or ‘Clarke values’ are values that indicate the normal quantity of each metal within a specific geographic location characterised by a certain geological pattern, and are preferentially used for comparative purposes as standard background values with the aim of identifying anomalies and thus deviations from the ‘norm’ (Bhuiyan *et al.* 2010).

This study was aimed at determining and comparing the concentration of specific potential metal contaminants in the soils of six selected sites of the floodplain wetlands of the lower uMngeni River, a region exposed to significant development in recent years.

2. Study area

The floodplain wetlands along the lower uMngeni River have become increasingly exposed to human activities (Water Research Commission 2002). It is located just north of the CBD of the city of Durban, an area that has experienced rapid

development in the past decade (Water Research Commission 2002). The uMngeni River originates in the foothills of the Drakensberg Mountains at an elevation of approximately 2000 m above sea level from where it traverses approximately 255 km before entering the Indian Ocean to the north of Durban Harbour (Van der Zel 1975; Cooper 1993). The geology of the catchment is largely belongs to the Karoo system of sedimentary rocks with sandstones of the Tarkastad and Estcourt formation, and shales of the Volksrust and Pietermaritzburg formations outcropping at varying altitudes (Rural Development Services 2002). The input of heavy metals into the lower uMngeni wetlands may be attributed to a multitude of catchment land uses, including commercial and small-scale subsistence farming, industrial activity, urban development, formal and informal settlements (Brijlal 2005; South Durban Community Environmental Alliance 2011). Considering the importance of the uMngeni River system in providing water to the greater Durban and Pietermaritzburg metropolitan communities in Kwa-Zulu Natal, the value of floodplain wetlands occurring along the channel should not be underestimated, as they may well serve to perform distinct functions that facilitate the creation and maintenance of favourable conditions in the adjacent river (Kotze 2000; Dickens *et al.* 2003) and the estuary further downstream.

3. Materials and methods

3.1 Wetland sediment cores

Sediment cores were collected from each of six identified floodplain wetlands along the uMngeni River as illustrated in figure 1. The sites were selected based on factors of accessibility, the pliability of the soil for penetration, and their location within three distinctly differing land use regions, namely residential, industrial and estuarine. This was done with the intention of enabling comparison between the results attained for each region to infer deductions related to the potential source of pollutants.

Sediment cores were collected from the selected sites in November 2011. The cores were collected by establishing a transect line across the selected wetlands from approximately 30 m up-bank towards the river channel, along which between one and three cores were collected at equidistant intervals. At sites S3 and S5, two cores were collected, while only one core was collected at S1, S2, S4 and

S6 respectively due to a visible narrowing of the wetlands and the presence of resistant soils. Core depths reached 1–1.8 m, and varied according to the thickness of soil horizons and depth to the water table in each case. Land uses adjacent to sampling sites were S1 – informal housing and light industry; S2 – sports fields; S3 – golf course; S4 – light industry; S5 and S6 – broad wetland with undisturbed vegetation, a grassed buffer zone of approximately 50 m bordered by industries.

The cores were collected using a 40 mm diameter poly-vinyl-compound (PVC) pipe with the assistance of a hand auger. On extraction of the pipe containing the sediment core, the pipe was appropriately labelled indicating site and transect number, date and time. GPS co-ordinates of each site were recorded and both ends of the pipe were securely sealed.

The cores were split longitudinally in half and sediment laminae carefully logged based on compositional characteristics, such as texture, colour, lamination and organic material. Two sub-samples were taken from each layer based on texture and composition, one for the determination of physical properties and the other for chemical analysis. Soil moisture content was determined by drying; organic matter content by both ignition loss and the Walkley–Black method and calcium carbonate content by ignition loss.

The standard dry sieving method was utilised for grain size determination using a Retsch[®] sieve shaker. Elemental concentrations of aluminium (Al), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni), phosphorous (P), sulphur (S), vanadium (V) and zinc (Zn) were detected using inductively coupled plasma-optimal emission spectroscopy (ICP-OES), ion chromatography and flame photometry as prescribed by Skoog and West (1982). Analysis of Variance (ANOVA) was used to assess the variance of elemental concentrations at the sites and of the geochemical indices. Principal Component Analysis (PCA) was used to gain insight into the contribution of elements to contamination and subsequent pollution loading at each site.

3.2 Assessing contamination using pollution indices

The level of sediment contamination by metals can be assessed by specific pollution indices. In this study, the contamination factor and enrichment

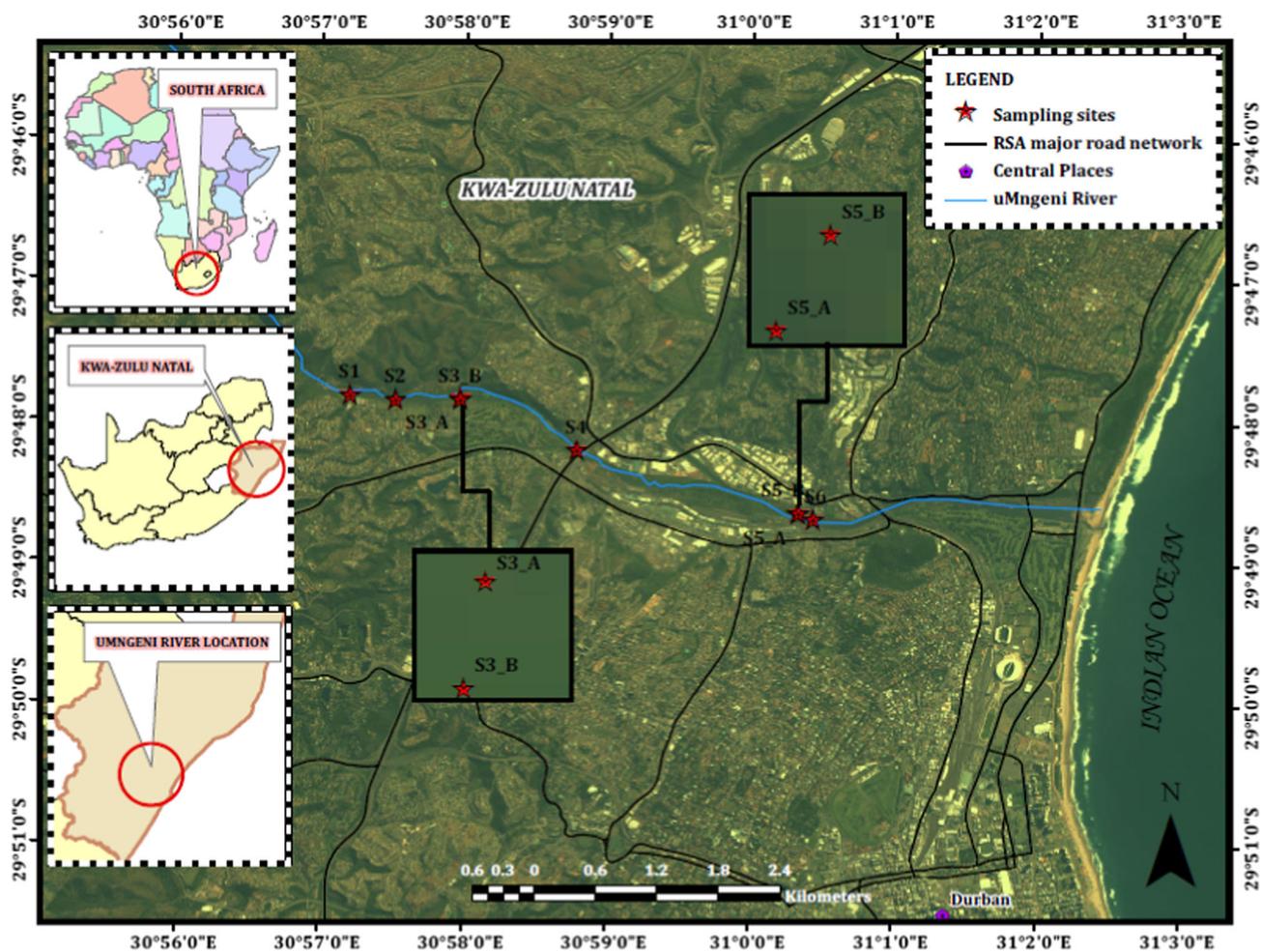


Figure 1. Map of the core sampling sites along the floodplain wetlands of the uMngeni River.

factor were calculated and ‘Clarke values’ for sedimentary rocks, the dominant catchment geology, were utilised as background concentrations (Martinez *et al.* 2007). Contamination factors are used to determine whether measured concentrations of metals in a sediment sample are of natural or anthropogenic origin, and are calculated as:

$$CF = \frac{[\text{Concentration of element in the sediment}]}{[\text{Background value of element}]} \quad (1)$$

Contamination factors range in value from 0 to 6, with a value of zero indicating no contamination and a value of six, signifying strong contamination (Bhuiyan *et al.* 2010). More specifically, values less than 1 imply low contamination, values between 1 and 3 imply moderate contamination, and values between 3 and 6 indicate significant contamination (Harikumar and Jisha 2010). Enrichment factors are used to ascertain

the abundance of a specific metal in a sediment sample in relation to the average concentration in the earth’s crust (Harikumar and Jisha 2010).

This calculation can be expressed as equation (2) below:

$$EF = \frac{[\text{Concentration of element}][\text{Concentration of Fe}]}{[\text{Clarke value of element}][\text{Clarke value of Fe}]} \quad (2)$$

In the above equation, [Concentration element] refers to the mean concentration of the metal of interest (ppm), [Concentration Fe] is the mean concentration of Fe in the sediment sample (ppm), [Clarke element] is the Clarke value of the metal of interest (ppm) and [Clarke Fe] is the Clarke value of iron (ppm). Iron was used as the reference element for geochemical normalisation due to its geochemical similarity to many other trace metals, its natural high concentrations and the usual uniformity of its natural concentration (Bhuiyan *et al.* 2010). According to Harikumar

and Jisha (2010), values between 0.5 and 1.5 indicate metal input from natural sources, values >1.5 indicate possible input from anthropogenic sources, and values >5 imply contamination.

4. Results and discussion

4.1 Physical properties of core sediments

At all six sites, organic matter content (OMC) and calcium carbonate (CaCO_3) were highest within the first three laminae of sediment cores, then fluctuated with a generally decreasing trend for subsequent laminae. These percentages are inversely related to the sediment mean grain size (ϕ) calculated for each lamina such that finer mean sediment grain size contain higher percentages of OMC and CaCO_3 detected within the lamina. The percentage of moisture content (MC) is also shown to be high within the first three laminae of sediment cores, as finer sediments retain more water; and high within deeper lamina due to increasing proximity to the water table.

These relationships are illustrated in figure 2(a–p). Figure 2(a, c, e, g, i, k, m and o) depicts the sediment mean grain size variations with core depth; and figure 2(b, d, f, h, j, l, n and p) shows the percentage MC, OMC and CaCO_3 variations with core depth at sites S1, S2, S3(T1), S3(T2), S4, S5(T1), S5(T2) and S6, respectively. The high content of fine grained material (silt and clay), and hence low sediment mean grain size (ϕ), in the upper laminae are to be expected in floodplain wetlands that are regularly exposed to overbank flooding. Fine material carried in suspension in flood waters covering the floodplain gradually settle out as a mud layer as floodwaters recede. There is generally a coarsening of grades with depth within such layers and this has also been detected with several of the laminae of the cores taken in this study. In general, however, it can be noted that the sediment mean grain size in laminae across all sites did not reach a ϕ value of 3. The implication is that these wetlands are dominated by medium to fine silt and clay particles, which in turn suggest a high propensity for metal ion accumulation. Highest OMC was measured at site 3 located adjacent to the golf course. At this site, river morphology for accumulation of organic debris and riparian vegetation was particularly well established. Further downstream at site 5, which is characterized by dense natural

vegetation, OMC increases again in the first two laminae. Calcium carbonate content is low with some variability across sites. Some increases are noted at the golf course, site 3, where considerable amounts of fertilizers are regularly applied, and at sites 5 and 6. The latter sites are largely pristine and the observed concentrations are likely due to natural geochemical processes. In all cases, soil moisture was high in the first two to three laminae, which also increases with depth as is expected in an environment where the water table is located close to the surface.

4.2 Chemical properties of core sediments

Figure 3(a–n) plots mean metal concentration with respect to the depth for each of the six sites. Given that the thickness of each lamina within various cores differs considerably, depths at which comparisons amongst metal levels were made were standardised. The mean metal concentrations are thus illustrated using these standardised depths. Hence, line graphs of figure 3 begin at a depth of 10 cm (mid-point of first segment).

Clearly, a general trend of decreasing metal concentration with increasing core depth is observed, correlating well with the vertical distribution of organic matter and fine sediment. This collates with the known high affinity of organic matter and fine sediment for adsorbing metal ions. Exceptions to the trend are displayed in concentration change of arsenic (As), nickel (Ni) and vanadium (V). At site 6, arsenic levels in the sediment increases with soil depth. Since this site contains relatively pristine wetland vegetation, with no visible sign of anthropogenic effluent contamination, the high As is presumed to be an anomalous, naturally occurring concentration. The high Ni and V detected at Sites 2 and 3, respectively are presumed to be derived from normal geochemical processes and represent anomalous high natural concentrations.

Geochemical indices using mean values of the relevant sites were used to further infer deductions relating to the anthropogenic contribution of contaminant enrichment at each of the sites. Table 1 presents the contamination factors (CF) calculated for the measured concentrations of specific elements within sediments at each sampling point. The CF values obtained for most elements were in the range of zero and one, indicating minimal baseline pollution of the wetlands. However, contamination factors for lead (Pb) and



Figure 2(a-p). Sediment mean grain size (phi) in relation to percentage MC, OMC and CaCO₃ contained in core laminae at each site.

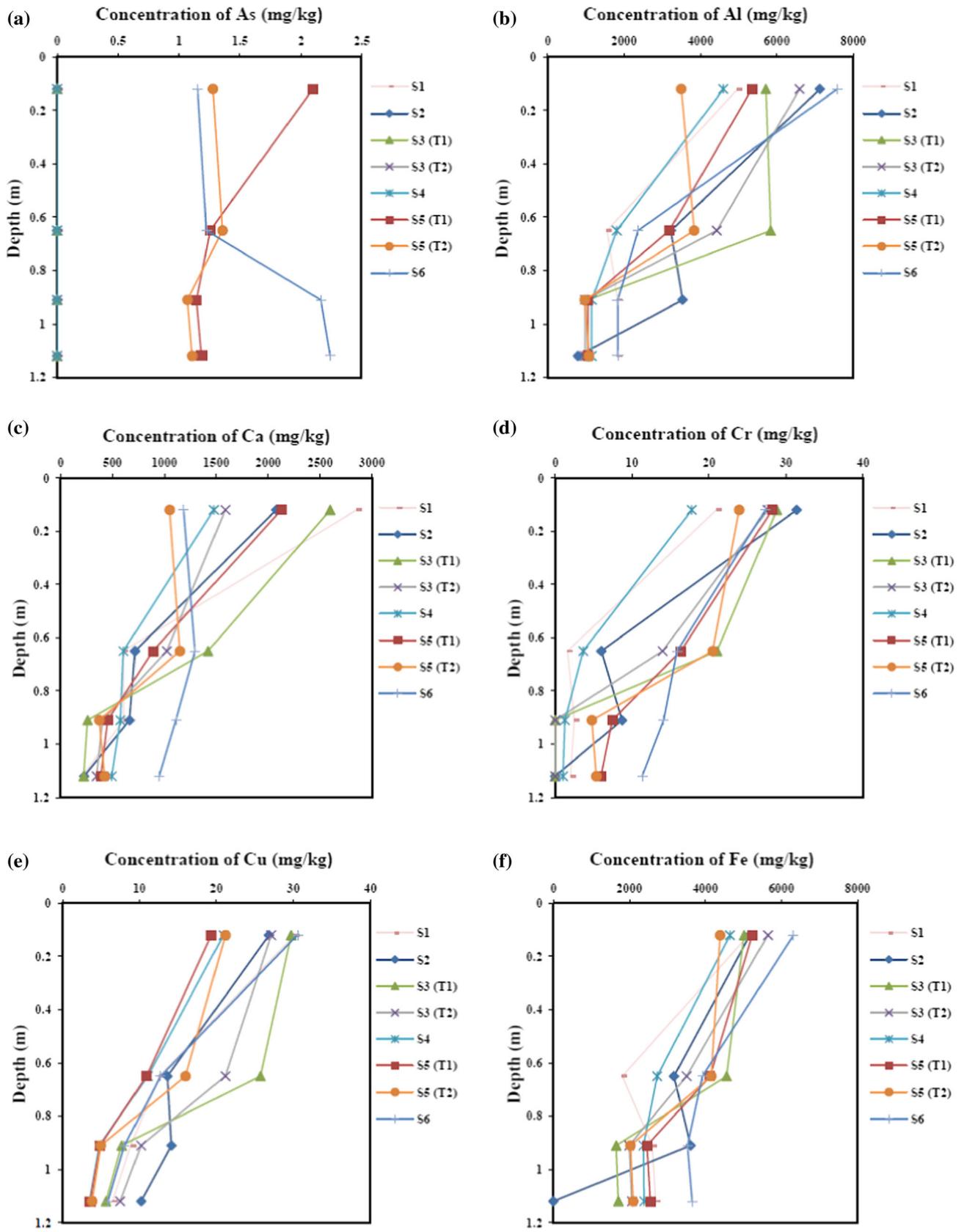


Figure 3(a-n). Change of element concentrations with depth at each of the study sites.

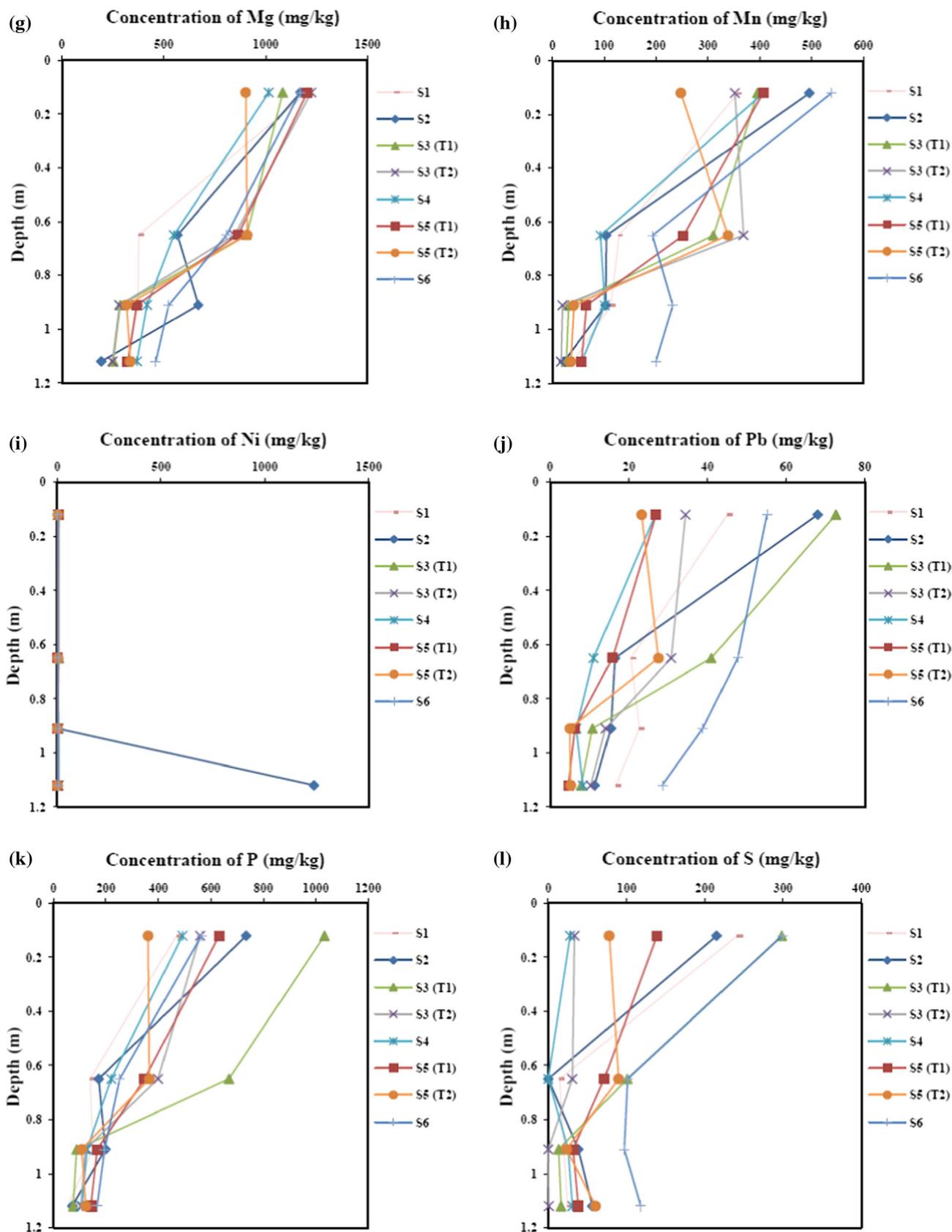


Figure 3. (Continued.)

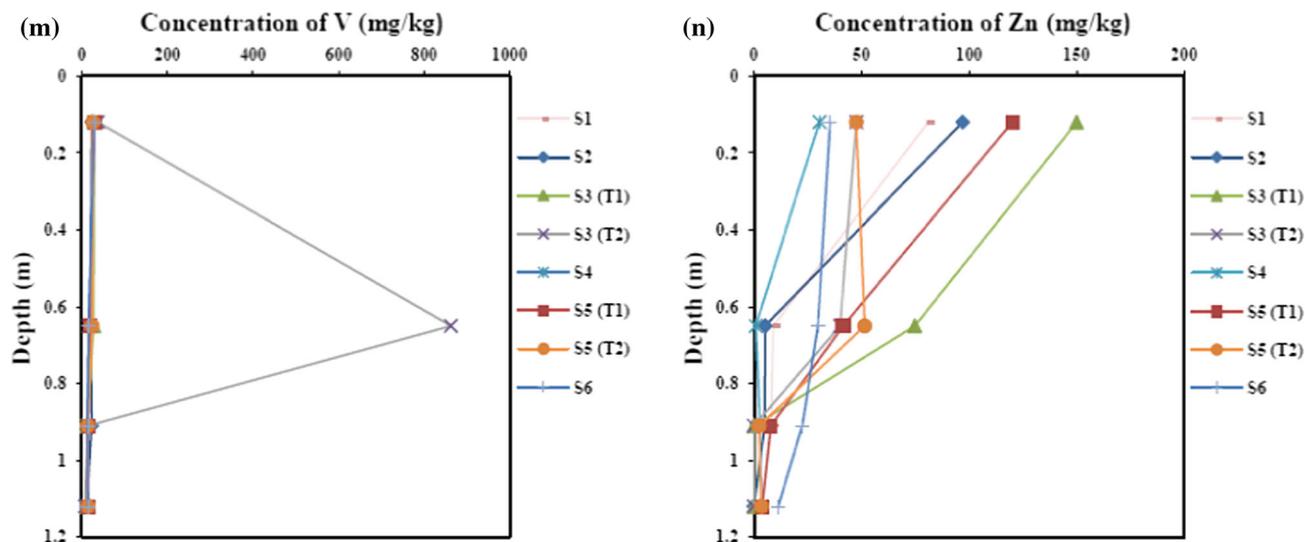


Figure 3. (Continued.)

Table 1. Contamination factor of mean concentration of elements present within sediments at each sample site.

Element	Clarke value	S1	S2	S3(T1)	S3(T2)	S4	S5(T1)	S5(T2)	S6
Al	81300	0.031	0.045	0.042	0.040	0.027	0.033	0.029	0.042
As	5	NE	NE	NE	NE	NE	0.284	0.241	0.339
Ca	36300	0.029	0.025	0.031	0.023	0.022	0.027	0.021	0.031
Cr	200	0.034	0.058	0.062	0.052	0.030	0.072	0.068	0.086
Cu	70	0.208	0.231	0.246	0.236	0.144	0.138	0.164	0.205
Fe	50000	0.061	0.060	0.065	0.066	0.061	0.072	0.063	0.087
Mg	20900	0.027	0.031	0.030	0.031	0.028	0.033	0.029	0.035
Mn	1000	0.160	0.181	0.191	0.189	0.165	0.196	0.166	0.291
Ni	80	0.009	0.020	0.046	0.023	0.045	0.023	0.019	0.042
P	1180	0.172	0.249	0.379	0.251	0.201	0.273	0.203	0.250
Pb	16	1.640	1.740	2.068	1.402	<i>0.827</i>	<i>0.841</i>	<i>0.956</i>	2.658
V	150	0.115	0.126	0.136	1.549	0.121	0.133	0.128	0.121
Zn	132	0.193	0.204	0.426	0.166	0.072	0.329	0.199	0.188

NE: No enrichment.

vanadium (V) exceed one at certain sites, implying moderate metal pollution derived from anthropogenic sources. Results of ANOVA confirm that, although the variances for all elements are low, the highest for this suite of metals were recorded for Pb (0.419) and V (0.253).

The contamination factor for vanadium is highest at site S3(T2) and although its source is unknown, it might be related to the ongoing fertilization and maintenance activities at the golf course. The most conspicuous, however, are the contamination factors of lead, which are shown to be high in sites 1, 2, 3 (transect 1 and 2) and 6 being most contaminated. It must also be noted that Pb input at sites S4, S5(T1) and S5(T2) in particular;

have shown border-line to moderate contamination levels.

Table 2 presents the highest contamination factors calculated for each lamina of sediment cores. These are compared to enrichment factors calculated using mean values displayed in table 1.

From table 2, it can be seen that the contamination factors for Fe and Pb are highest in the 1st, 2nd and 3rd laminae of each sediment core. Contamination factors for Zn, P and V on the other hand are highest in the 1st and 2nd laminae, 2nd lamina, and 3rd lamina, respectively. This corresponds to the highest variance of 1.40 for Pb in L1; 1.96 for Pb in L2 and 17.94 for V in L3.

Table 2. Contamination factor of particular elements present within the laminae of sediment cores at each sample site.

Ion	Clarke value	L	S1	S2	S3(T1)	S3(T2)	S4	S5(T1)	S5(T2)	S6
Fe	50000	1	1.028	1.035	1.005	1.129	0.930	1.048	0.878	0.785
Pb	16	1	2.813	4.253	4.540	2.151	1.674	1.684	1.454	2.980
Zn	132	1	0.614	0.736	1.137	0.362	0.232	0.910	0.361	0.226
Fe	50000	2	0.510	0.636	1.291	0.872	0.429	0.502	1.353	0.706
Pb	16	2	1.610	1.030	4.609	2.022	0.636	0.401	3.117	2.426
Zn	132	2	0.082	0.040	1.272	0.397	0.000	0.045	0.760	0.171
P	1180	2	0.134	0.146	1.246	0.486	0.155	0.129	0.536	0.165
Pb	16	3	1.153	0.966	2.341	1.827	0.749	1.583	0.327	n/a
Fe	50000	3	0.578	0.723	0.843	0.531	0.665	1.149	1.353	n/a
V	150	3	0.112	0.153	0.164	11.343	0.135	0.184	0.074	n/a
Pb	16	4	1.078	0.710	0.734	0.883	0.420	0.397	0.316	n/a
Pb	16	5	1.700	n/a	0.676	n/a	0.456	n/a	0.344	n/a
Pb	16	6	1.140	n/a	n/a	n/a	0.590	n/a	n/a	n/a

Table 3. Enrichment factors of the mean concentration of elements present within sediments at each sample site.

Element	Clarke value	S1	S2	S3(T1)	S3(T2)	S4	S5(T1)	S5(T2)	S6
Al	81300	0.158	0.189	0.183	0.175	0.129	0.135	0.130	0.265
As	5	NE	NE	NE	NE	NE	1.170	1.084	2.148
Ca	36300	0.149	0.106	0.135	0.102	0.105	0.109	0.093	0.198
Cr	200	0.171	0.241	0.272	0.228	0.143	0.298	0.307	0.543
Cu	70	1.051	0.967	1.074	1.034	0.695	0.570	0.740	1.295
Fe	50000	NE	0.250	0.283	0.290	0.293	0.296	0.285	0.552
Mg	20900	0.138	0.130	0.132	0.136	0.136	0.136	0.133	0.224
Mn	1000	0.810	0.758	0.836	0.831	0.795	0.805	0.748	1.840
Ni	80	0.046	0.085	0.201	0.102	0.218	0.094	0.085	0.268
P	1180	0.872	1.042	1.657	1.101	0.971	1.124	0.914	1.581
Pb	16	8.294	7.269	9.037	6.149	3.994	3.464	4.303	16.833
V	150	0.582	0.528	0.594	6.794	0.583	0.549	0.575	0.768
Zn	132	0.978	0.851	1.861	0.730	0.347	1.354	0.898	1.190

NE: No enrichment.

Fe and Pb contamination is ubiquitous in the surface laminae across all six sites, with contamination factors being either border-line, moderate or of high contamination. Noteworthy are the contamination factors of Pb at sites S2 and S3(T1), indicating significant metal pollution. Sediment pollution resulting from high levels of zinc is shown to be less problematic across sites, with moderate contamination detected at S3(T1), and border-line contamination occurring at S5(T1).

Contamination factors for Fe show border-line contamination at site S3(T2), and moderate contamination at sites S3(T1) and S5(T2). Pb contamination is shown to be moderate across all sites except S4 and S5(T1), and S3(T2) and S5(T2), which signify low and high contamination respectively.

The 3rd lamina of the sediment cores shows low Pb contamination at S5(T2), border-line contamination at S2 and S4 and moderate contamination across the remaining sites. Fe contamination is moderate at sites S5(T1) and S5(T2), moderate at site S3(T1), and low in the remaining sites.

In the 4th, 5th and 6th laminae of sediment cores, Pb is the only metal showing border-line moderate to high contamination levels.

In the 4th lamina, there is moderate Pb contamination at site S1, border-line moderate contamination at site S3(T2) and low contamination in the remaining sites. Pb contamination in the 5th layer is calculated to be moderate at S1, low at sites S3(T1), S4 and S5(T2), and none at the remaining sites. Likewise, in the 6th lamina of cores, Pb contamination is moderate only

Table 4. Enrichment factor of particular elements present within laminae 1, 2 and 3 of sediment cores at each sample site.

Ion	Clarke value	L	S1	S2	S3(T1)	S3(T2)	S4	S5(T1)	S5(T2)	S6
Cu	70	1	4.190	3.701	4.225	3.430	3.214	2.636	3.445	2.323
Pb	16	1	27.371	41.088	45.190	19.057	18.002	16.069	16.565	37.974
Zn	132	1	5.976	7.106	11.320	3.202	2.489	8.685	4.112	2.880
Ni	80	1	0.352	0.787	0.876	0.591	0.141	0.598	0.355	0.641
Cr	200	1	1.018	1.516	1.433	1.222	0.954	1.344	1.363	1.011
As	5	1	NE	NE	NE	NE	NE	4.005	2.911	3.124
V	150	1	1.912	1.468	1.895	2.209	1.994	1.884	1.947	1.306
P	1180	1	3.866	6.015	8.710	4.195	4.477	5.104	3.484	2.732
Mn	1000	1	3.483	4.788	3.938	3.122	4.378	3.878	2.823	2.462
Cu	70	2	3.764	3.063	4.958	4.208	3.568	1.683	2.865	1.631
Pb	16	2	31.547	16.204	35.689	23.191	14.841	7.991	23.035	34.363
Zn	132	2	1.599	9.850	4.555	5.614	2.425	0.900	5.614	2.425
Ni	80	2	NE	NE	1.799	0.611	NE	NE	0.658	0.589
Cr	200	2	0.172	0.473	1.631	1.096	NE	0.646	1.408	1.001
As	5	2	NE	NE	NE	NE	NE	3.928	2.649	6.127
V	150	2	2.153	2.059	2.139	1.836	2.241	1.839	1.815	1.285
P	1180	2	2.627	2.298	9.652	5.577	3.606	2.579	3.964	2.342
Mn	1000	2	2.492	1.644	5.616	3.826	1.713	1.506	4.803	3.285
Cu	70	3	3.177	2.800	3.409	4.476	2.460	1.980	2.232	n/a
Pb	16	3	19.950	13.364	27.778	34.412	11.251	13.779	10.550	n/a
Zn	132	3	1.468	0.542	4.485	3.977	0.212	5.089	0.712	n/a
Ni	80	3	NE	NE	0.563	NE	NE	0.504	NE	n/a
Cr	200	3	0.265	0.601	1.078	0.834	0.550	0.693	0.781	n/a
As	5	3	NE	NE	NE	NE	NE	2.661	5.959	n/a
V	150	3	1.946	2.114	1.951	213.68	2.029	1.598	2.379	n/a
P	1180	3	2.235	2.325	3.581	3.579	3.289	4.002	2.710	n/a
Mn	1000	3	2.522	1.427	1.880	7.607	1.700	3.746	0.905	n/a

at S1, low at S4 and none in the remaining sites.

From table 3, it can be seen that Ca, Mn, P, Pb, V and Zn are likely to have been derived from anthropogenic sources. Enrichment factors for As, Mn and P at site S6 indicate possible anthropogenic sources, while the enrichment factor for Pb at site S6 is more conclusive. The data also show a possibility of anthropogenic input of P and Zn at site S3(T1), while all other detected elements for this site were naturally derived. Further, the enrichment factors for Pb across all sites imply either possible anthropogenic input or definite contamination. This is consistent with contamination factor data displayed in table 1, which shows border-line moderate or moderate Pb contamination across the sample sites. Results of ANOVA showed high variance for Pb (18.67) as well as V (4.81). The latter reflective of the anomalous high V measured at site 3(T2).

Tables 4 and 5 display the enrichment factors determined using actual concentrations of

metals detected within each lamina of sediment cores.

In tables 4 and 5, it can be seen that apart from the enrichment factors established for Ni across all sites, which imply metal input from natural origins, all other metals indicate some degree of enrichment. Similar to Ni, Cr is naturally derived at all sites with the exception of site S2, in which concentrations are potentially anthropogenically derived. Apart from Ni and Cr, it is evident that all metals detected within the 1st layer of sediment cores have possible anthropogenic origins; however, the enrichment factors established for Pb across all sites, V at sites S1–S3(T1) and S5(T1) and P at site S2–S3(T1) and S5(T1), which show definite enrichment are of particular concern. It is also noteworthy that As concentrations were undetected at sites S1–S4, but were found to be anthropogenically enriched at sites S5(T1)–S6 wherever detected.

The enrichment factors calculated for the 2nd lamina of all sediment cores show similar trends to

Table 5. *Enrichment factor of particular elements present within lamina 4, 5 and 6 of sediment cores at each sample site.*

Ion	Clarke value	L	S1	S2	S3(T1)	S3(T2)	S4	S5(T1)	S5(T2)	S6
Cu	70	4	4.596	5.907	2.904	3.653	1.445	1.420	1.755	n/a
Pb	16	4	30.172	28.75	12.19	22.09	8.838	8.047	7.781	n/a
Zn	132	4	1.050	NE	0.843	NE	0.464	1.214	0.463	n/a
Ni	80	4	NE	NE	0.150	NE	NE	NE	NE	n/a
Cr	200	4	NE	NE	0.237	NE	0.701	0.753	0.589	n/a
As	5	4	NE	NE	NE	NE	5.307	4.635	5.266	n/a
V	150	4	2.388	2.843	1.992	2.368	1.927	1.004	2.154	n/a
P	1180	4	2.573	2.471	2.537	2.593	2.289	2.867	2.245	n/a
Mn	1000	4	3.157	0.908	0.817	0.494	2.133	1.340	1.028	n/a
Cu	70	5	1.081	n/a	3.331	n/a	1.327	n/a	0.896	n/a
Pb	16	5	28.084	n/a	20.43	n/a	9.352	n/a	7.928	n/a
Zn	132	5	1.114	n/a	NE	n/a	0.369	n/a	0.802	n/a
Ni	80	5	NE	n/a	NE	n/a	NE	n/a	NE	n/a
Cr	200	5	0.299	n/a	NE	n/a	0.702	n/a	0.681	n/a
As	5	5	NE	n/a	NE	n/a	5.011	n/a	5.280	n/a
V	150	5	2.057	n/a	2.455	n/a	2.006	n/a	2.239	n/a
P	1180	5	2.338	n/a	2.255	n/a	2.135	n/a	2.716	n/a
Mn	1000	5	2.138	n/a	0.954	n/a	0.859	n/a	0.692	n/a
Cu	70	6	4.316	n/a	n/a	n/a	0.771	n/a	n/a	n/a
Pb	16	6	26.111	n/a	n/a	n/a	12.57	n/a	n/a	n/a
Zn	132	6	1.245	n/a	n/a	n/a	0.759	n/a	n/a	n/a
Ni	80	6	NE	n/a	n/a	n/a	NE	n/a	n/a	n/a
Cr	200	6	0.159	n/a	n/a	n/a	0.710	n/a	n/a	n/a
As	5	6	NE	n/a	n/a	n/a	3.393	n/a	n/a	n/a
V	150	6	2.213	n/a	n/a	n/a	1.775	n/a	n/a	n/a
P	1180	6	2.589	n/a	n/a	n/a	1.730	n/a	n/a	n/a
Mn	1000	6	2.227	n/a	n/a	n/a	1.536	n/a	n/a	n/a

those of the 1st lamina such that Pb contamination occurs across all sites, and all metals except Ni and Cr indicate possible anthropogenic input or enrichment in each core. Metal contamination within lamina 2 results from the input of Zn at sites S2, S3(T2) and S5(T2); the input of P at sites S3(T1)–S3(T2) and the addition of As and Mn at sites S6 and S3(T1), respectively.

The enrichment factors calculated for the 3rd and 4th laminae of sediment cores show Pb contamination across all sites. Unlike in the 3rd lamina, however, Zn concentrations in the 4th lamina are also of natural origin across all sample sites. Furthermore, As is also shown to be possibly anthropogenically enriched at site S5(T1) in the 3rd and 4th laminae, at site S4 in the 4th lamina and at site S5(T2) in the 3rd lamina. Signs of enrichment to note in the 3rd lamina result from the input of Zn at site S5(T1), As at site S5(T2), and V and Mn at site S3(T2).

Cu enrichment occurs in the 4th lamina at site S2.

Cores collected from sites S1, S3(T1), S4 and S5(T2) comprise a 5th lamina, but the consistent trend of high Pb enrichment across sample sites within preceding sediment layers is displayed in this laminae as well. Nickel was undetected within this layer across all sample sites, and the enrichment factors for all other elements at each site indicate either natural origins with possibly some minor anthropogenic enrichment.

Amongst the sediment cores of interest in this study, only those collected at sites S1 and S4 contain a 6th lamina. Similar to data obtained for the 5th lamina, Ni concentrations were undetected across all sites and Pb values indicate contamination at both sites. Enrichment factors calculated for the remaining metals at each site indicate that the concentrations are either naturally derived or possibly sourced from anthropogenic activities.

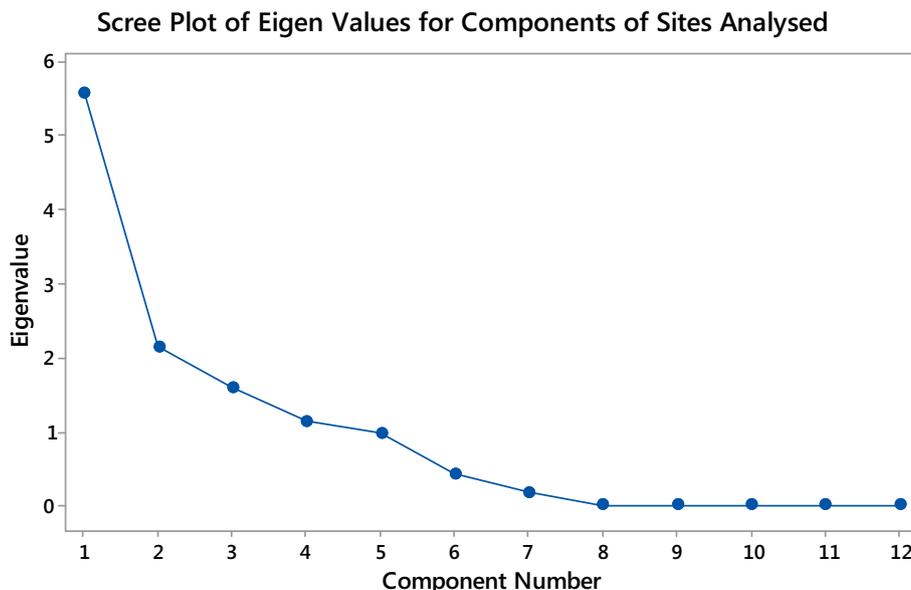


Figure 4. A Scree Plot indicating eigenvalues for components contributing to pollution loading using the *MiniTab17 Software Programme*[®].

4.3 Statistical analysis

4.3.1 ANOVA

Results of ANOVA confirm the above. Highest three variances for each of the lamina are as follows: L1: Pb (145.54) > Zn (9.93) > P (3.46); L2: Pb (100.03) > Zn (8.57) > As (3.09); L3: V (6401.09) > Pb (84.23) > As (5.44); L4: Pb (98.70) > Cu (2.97) > Mn (0.86); L5: Pb (91.40) > Cu (1.27) > Mn (0.44) and L6: Pb (91.68) > Cu (6.28) > P (0.34).

4.3.2 Principal component analysis (PCA)

PCA has been implemented to gain a proper understanding of the contribution of elements to contamination and subsequent pollution loading at each site. The calculated Eigen values shown in figure 4, reveal a 46.4% variance contributed from elements associated to component 1 (shown in table 6) which include elements Al, Ca, Cr, Cu, Fe, Mg, Mn and Zn. In addition, a 17.8% variance was contributed from elements associated to component 2, which include Al, Cu and Fe only. A total of 64.2% variation in elements contributing to the contamination was accounted by components 1 and 2 as shown in table 6, which is an acceptable representation of the contribution to pollution loading from the elements at each site.

Table 6. *Element loadings of principal components 1 and 2.*

Variables	Principal component 1	Principal component 2
Al	0.328853	0.303076
Ca	0.316976	
Cr	0.326331	
Cu	0.195742	0.537873
Fe	0.328873	-0.392949
Mg	0.345046	
Mn	0.364673	
Ni		
P		
Zn	0.346304	

The score plot in figure 5 indicates variation in the contribution of contaminating metals at all sites. This has been observed from the wide distribution of sites as shown in the score plot of figure 5. Sites S6 and S3 have high values in component 1 (Al, Ca, Cr, Cu, Fe, Mg, Mn and Zn), while S1, S4 and S5 have low values in component 1 as shown in the score plot of figure 5. Sites S2, S3(T2) and S5(T1) are shown to have average values of component 1 (figure 5).

S1, S2, and S3 have high values in component 2 as shown in figure 5 while S4, S5(T1), and S5(T2) have low values of component 2 which include the elements Al, Cu and Fe.

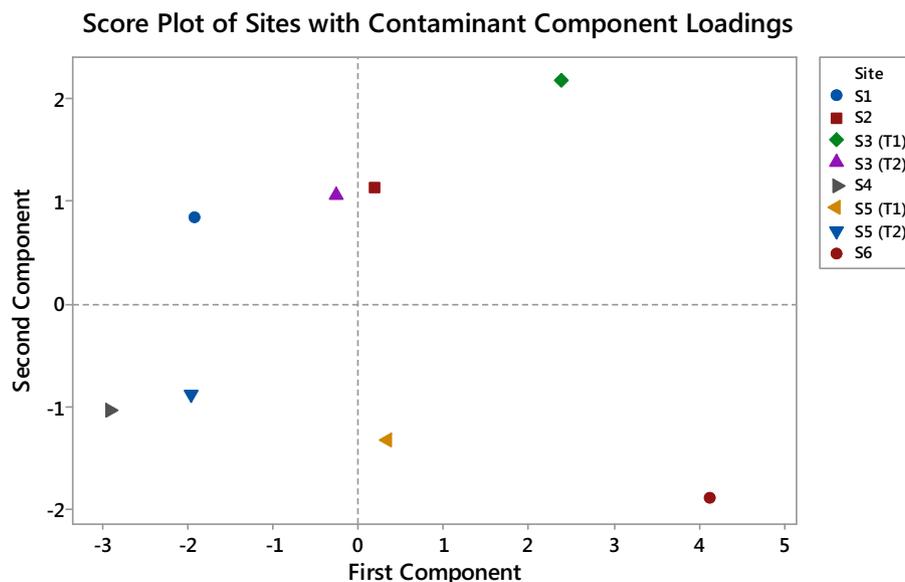


Figure 5. Score plots showing component loadings at different sites using the *MiniTab17 Software Programme*[®].

5. Conclusion

Overall, the tabulated data above displays a general decreasing trend of metal contamination with each subsequent lamina (Wuana and Okieimen 2011). The highest levels of anthropogenic contamination have been detected within the first three layers of sediment cores such that moderate to high contamination levels are most widespread in the 1st lamina and decreases with each of the following laminae. Of particular concern is the high concentration of Pb across the wetlands of interest, particularly within the first three layers of sediment, showing significant contamination levels at S2, S3(T1) and S5(T2) in the first two laminae of sediment cores. The prevalence of moderate and high contamination factors for Pb is concomitant to the dominance of fine-particled sediment and high percentages of organic matter within the first three laminae of sediment cores. Enrichment of other elements analysed for displays no uniform pattern but contamination of different elements at varying laminae and wetland site is present. It can therefore be concluded that anthropogenic input of metals into the Lower uMngeni wetlands had occurred in recent times, persists to the present and possible exacerbation of the situation is likely have given the relative fast pace of development in the vicinity of the wetlands and in the hinterland of the catchment. Given this situation, it is of utmost importance that the local municipality develops and implements proper management measures that are focused on curtailing the current

pollution levels and so minimising the risk of future degradation.

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