

Metals in environmental media: A study of trace and platinum group metals in Thohoyandou, South Africa

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Abstract

A detailed study has been conducted to determine the contamination of Thohoyandou roadside soils, vegetation, sewage and river waters by Zn, Cu, Cr, Pb, Cd, Fe, Pt and Pd. The study further investigated the correlation between these trace metals in roadside soils and vegetation in order to infer the potential impacts of roadside trace metals contamination of vegetation. Collected surface soil and vegetation samples were analysed with atomic absorption spectrophotometer for Zn, Cu, Cr, Pb and Cd while water samples were analysed by inductively coupled plasma atomic emission spectrometry (ICP-OES) for Zn, Cu, Fe, Pt and Pd. A linear correlation was observed between soil and vegetation metal concentration, which suggests the same source of metals in the samples except for Cu. The findings also revealed a general reduction in soil and vegetation metal concentrations some distance away from road traffic. For both experimental soil and vegetation samples, the mean concentrations were found to follow the decreasing orders: Pb > Zn > Cr > Cu > Cd and Pb > Zn > Cd > Cr > Cu respectively. For water samples, trace metals were highest in raw sewage and lowest in river waters. The sewage system leaking directly into the rivers was found to be the major source of pollution by trace metals. The mean concentrations of the trace metals in the water bodies were found to follow the following decreasing order: Fe > Zn > Pt > Cu > Pd.

Keywords: trace metal contamination; roadside soil; vegetation; water; Thohoyandou, South Africa

Introduction

Zn, Cu, Pb, Fe, Cd and Cr are trace metals that commonly cause pollution of urban environments. Motor vehicles and sewage systems constitute some of the major sources that release these metals directly into the urban environments (Fatoki, 1996; Fatoki and Ayodele, 1991; Sörme and Lagerkvist, 2002). Metals from vehicle emissions are released into the atmosphere and are subsequently deposited into the surrounding soil, vegetation and water bodies. These metals can also leach from the roadsides during rains to surrounding water bodies. Poorly maintained sewage systems can also be a major source of trace metal contamination, especially if there are pipes leakages.

Several researchers (Fatoki, 1996; Fatoki and Ayodele, 1991; Sithole et al., 1993; Onyari et al., 2002; Okonkwo et al., 2003) have reported elevated concentrations of trace metals even as far as 250 m from the roadside. Vehicle exhausts, lubricating oils, tyres and plating materials have been cited as components that contain one or more of these metals (Lagerwerff and Specht, 1970; Ward et al., 1977). Roofing materials, food wastes, sewage system pipes and taps are among the major sources of trace metals in the sewage (Sörme and Lagerkvist, 2002). Under normal circumstances, the major sources of these metals are heavy industries such as mining and metal industries.

Zn, Cu, Fe and Cr are all essential elements for many plants, animals and man but at trace levels. At high concentrations, they are all potentially toxic (Nyriagu, 1988; Goyer, 1996). Pb and Cd are generally regarded as toxic elements even at trace levels (Goyer, 1996). It has been shown by Morton et al. (2001), Moldovan et al. (2001) and Ravindra et al. (2004) among oth-

ers that Pt and Pd released by automobile catalytic converters accumulate to contaminant concentrations with time in roadside soils, water and vegetation. Morton et al. (2001) reported concentrations of Pt, Pd and Rd in roadside soil samples from Mexico City of 300, 70 and 40 µg/l, respectively. Despite the low quantities of these Pt group elements (PGE) emitted from catalytic converters, the accumulation of these elements in soils, water and plants along heavily travelled roads rises with their use (Morton et al., 2001). Monitoring of these metals in urban environments is therefore critical as it gives vital information as to whether exposure concentrations can cause adverse effects especially to humans.

This study attempted to investigate the contamination of soil, vegetation and water bodies within Thohoyandou peri-urban town by Zn, Cu, Cd, Pb, Cr, Fe, Pt and Pd. The study further correlated the soil and vegetation metal concentrations in the study area. Similar studies (Mathee and Schirnding, 2002) have been concentrated in major cities in South Africa at the expense of small or peri-urban towns like Thohoyandou. The previous study by Okonkwo et al. (2003), investigated only Pb pollution in soil and vegetation along the major Thohoyandou roads. The study left out Zn, Cd, Cu, Cr and Pt group metals which are common trace metals and emerging contaminants, respectively. Okonkwo et al. (2003) study, did not investigate the level and presence of these contaminants in surface water bodies which is equally important since the surrounding community depend on it for household and agricultural activities. Okonkwo and Mothiba (2005) study on pollution levels of trace metals in rivers in Thohoyandou apart from not considering pollution in soil and vegetation also left out Pt group metals. None of the two studies directly investigated pollution link to sewage system. Thohoyandou town has also seen an increase in both population and traffic since the end of the old system of government. This is evidenced by the continued expansion of central business district, residential areas and traffic congestion at peak hours.

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Received 28 February 2005; accepted in revised form 21 June 2005.

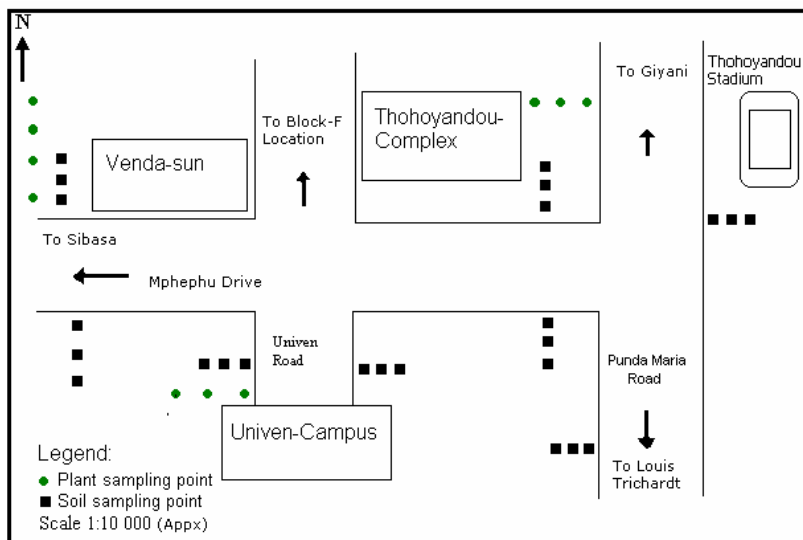


Figure 1
Plan of sampling site, showing roadways covered

Materials and methods

The study area and sampling

The roads that are all tarred (Sibasa, Univen and Punda Maria) and shown in the sampling plan (Fig. 1) were chosen for the study because they have the heaviest traffic in the town. The soils, the water and the plants in the neighbourhoods of these roads are likely to be threatened by pollution from motor vehicle exhaust emissions than those in the neighbourhoods of the other Thohoyandou roads with less traffic.

Twenty-four soil samples and ten plant samples excluding 'controls' were collected perpendicular to the roads at different selected sampling points (Fig. 1) in clean plastic bags. The soil sampling spots were cleared of all the debris before sampling. Only topsoil was sampled from a depth of 0.25 to 5 cm using a hand shovel. Soil samples weighing above 200g were then sealed in polythene plastic bags for laboratory analysis. Samples were collected from both sides of the Sibasa, Univen and Punda Maria roads as shown in Fig. 1. Six soil samples were collected at distances of 20 and 70 m away from the last experimental road points, in undisturbed sites, relatively unaffected by human activities. These 'control' samples were collected so as to validate the consistency in reduction of metal concentration with distance from the road and to eliminate other sources.

Fresh plant leaves from the *Lantana camara* species were collected at a height of 1m above the ground, using a pair of scissors. Plant samples were taken on both sides of the roads, except where the vegetation was cleared due to current settlement developments. *Lantana camara* was chosen because it is a plant species that grows along most of the roads in Thohoyandou area. The shrub can grow up to a height of 3 m. The species belong to the Verbenaceae family. Three 'control' plant samples were collected at distances of about 60 m from the last experimental road points.

Water samples from rivers (Mvudi, Madanzhe) within Thohoyandou peri-urban town (Fig. 2) were collected so as to study any leaching of the metals from the land into the rivers. Twenty samples were collected in clean plastic containers from streams and rivers within Thohoyandou as shown in Fig. 2. Each of these was achieved by lowering the container into the water about 100 to 300 mm below the surface with the open end facing

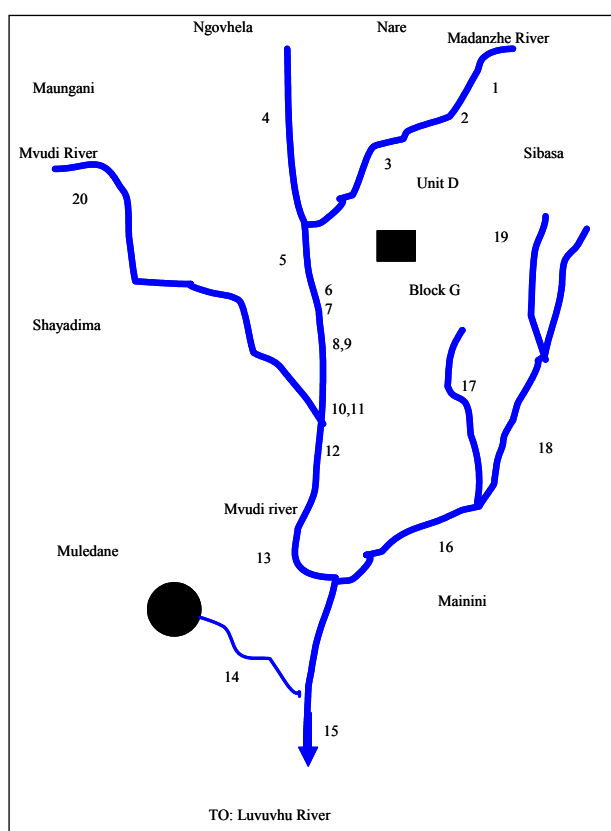


Figure 2
Locations of the sampling areas along the rivers and streams within Thohoyandou town residential areas.
Legend: ● biological wastewater treatment plant for the town, ■ location of the Thohoyandou city center.

against the current flow direction. If there was no current, it was created artificially by stirring the water. The containers were closed inside the water body.

Water samples were collected upstream, mid-stream and downstream. These sampling sites were systematically chosen after an initial site survey. The site survey revealed that there were leakages from sewage system pipes between residential areas and the treatment plant. The leakages were observed

to discharge directly into the water bodies. The sewage as it emerged from broken pipes was also collected and it allowed determining how much of the heavy metals pollution into the rivers came from the sewage system. The collected samples were stored in the refrigerator at 4°C until sample testing time.

Sample preparation procedures

The sample preparation procedure previously used by Ndou (2002) was followed for soil and plant samples. In brief, soil samples were first dried at room temperature. They were later ground using clean mortar and pestle and then passed through a laboratory test sieve with 500 µm apertures to obtain fine soil particles. One gram of each soil sample was taken in a 250 ml clean conical flask and moistened with a few drops of water to prevent any sputtering. Then 10 ml of concentrated HNO₃ was added to the soil. The mixture was digested on a hotplate inside a fume hood to bare dryness. The soil residue obtained was then digested with a mixture of concentrated acids containing HNO₃ (5 ml), HCL (5 ml) and HClO₄ (5 ml) for 10 min at room temperature. The mixture was digested further on a hotplate inside a fume hood to a final volume of 5 ml and filtered using the Whatman No.1 filter paper into a 100 ml volumetric flask. The contents of the flask were then diluted up to the mark with distilled deionised water. Soil samples for 'control' were treated with the same procedure as the experimental samples.

Plant leaves were washed with deionised water to remove any particulate matter that may have been deposited on the leaves from the atmosphere, and then dried at room temperature. The dried plant leaves were repeatedly crushed in a clean pestle and mortar and passed through a brass laboratory test sieve with 500 µm apertures to obtain fine leaf particles. About 1 to 2 g of sieved leaf samples were weighed into 250 ml conical flasks. The samples were then digested with a mixture of HNO₃ (20 ml) and HClO₄ (8 ml) in a fume hood to a final volume of 5 ml. Some deionised water was added and the solution filtered with Whatman No. 1 filter paper into a 100 ml volumetric flask. Samples were later diluted to the mark with deionised water. Plant samples for 'control' were treated in the same way as experimental samples.

A method previously described by Okonkwo and Mothiba (2005) was used for preparing water samples for analysis. In brief, collected river water samples were filtered through Whatman No. 1 filter paper into clean plastic containers and stored in the refrigerator at 4°C until analysis. A sample aliquot of 50 ml of raw sewage was transferred into 500 ml Pyrex conical flask and 2.5 ml of concentrated nitric acid (HNO₃) was added to it. The sample was then boiled until clear solution appeared on the heating mantle in the fume cupboard. It was allowed to cool and then filtered using Whatman filter paper, its volume measured and stored in plastic containers in the refrigerator at 4°C until analysis.

pH, total dissolved solids and conductivity measurements

The pH measurements of the soil were determined using sieved soil samples. Three grams of soil samples were weighed in clean 50 ml glass beakers. Deionised water was added to form a slurry solution from which pH measurements were made with the pH meter. Before use, the pH meter was calibrated with standards

with buffers of pH solutions pH 7 and 4. The pH and the conductivity of the water samples were done immediately after sample collection in the laboratory by immersing the calibrated pH and conductivity meter probes into the samples until the readings stabilised.

SS was determined as follows: A clean filter paper was placed in the oven and heated to 100°C for 10 min to remove any moisture. It was then placed on the weighing balance and its weight recorded upon which 50 ml of the sample was filtered using a funnel containing filter paper. The filter paper was then placed in the oven, heated as above, cooled and re-weighed. The first weight was subtracted from the second one to obtain the total suspended solids for the particular sample.

Sample analysis

The flame atomic absorption spectrophotometer (Varian Spectra AA 220) was used to measure the concentration of total trace metals in the soil and plant samples. Calibration was done using certified standards from Industrial Analytical (Pty) Ltd. (Johannesburg, South Africa). Working standards of 0.5 to 10 mg/l concentrations were prepared from 1000 mg/l stock solutions. All solutions were prepared in deionised water. For water samples, an inductively coupled plasma emission spectrometer (ICP-OES) from Spectro Analytical Instruments Inc, Kleve-Germany was used. Concentration range of the standards was from 0.030 to 1.0 mg/l. Analyses were carried out in triplicates.

Results and discussion

Recovery test and precision

The recovery test and reproducibility of the method were not fully investigated. However, the same procedure as that of Ndou (2002) was followed for soil and plant samples. Ndou (2002) did a similar study in the same area on soils and plants but restricted it to Pb metal pollution of soils and vegetation in Thohoyandou. The sample preparation procedure was found to be efficient and reliable with mean percentage recoveries greater than 95 and percentage standard deviations less than 5.

pH of the soil

The pH of the soil samples measured averaged 6.6, which is slightly acidic. Soil pH generally plays an important role in metal bioavailability, toxicity and leaching capability to surrounding areas especially in summertime. Heavy metals are mostly more soluble and leach out in acidic pH (Alloways, 1995). This makes them also less bioavailable to plants since they are easily washed away during rains. A soil pH of 6.6 could indicate that heavy metals remain in the roadside soil for a long time exposed to plants and other organisms that come into contact with them.

Calibration curves

The calibration curves for the metal ions yielded good correlation coefficients (r²) ranging from 0.9871 to 0.9993. This implies that the instruments responded very well to the standard analyte of interest and therefore would respond to the analyte in the samples.

| Road Name | Distance from road (m) | Concentrations (mg/kg) | | | | |
|-------------|------------------------|------------------------|------|------|-------|------|
| | | Cu | Zn | Cr | Pb | Cd |
| Sibasa | 50 | 0.21 | 0.42 | 0.23 | 4.13 | 0.11 |
| Sibasa | 100 | 0.12 | 0.27 | 0.18 | 10.22 | 0.14 |
| Mean | | 0.16 | 0.34 | 0.20 | 7.18 | 0.12 |
| Univen | 50 | 0.83 | 0.22 | 0.41 | 3.23 | 0.10 |
| Univen | 100 | 0.61 | 0.21 | 0.21 | 1.34 | 0.24 |
| Mean | | 0.72 | 0.21 | 0.31 | 2.28 | 0.17 |
| Punda Maria | 50 | 0.63 | 0.42 | 0.28 | 4.53 | 0.10 |
| Punda Maria | 100 | 0.19 | 0.23 | 0.10 | 2.23 | 0.23 |
| Mean | | 0.41 | 0.32 | 0.19 | 3.38 | 0.16 |

| Road name | Mean concentrations (mg/kg) | | | | |
|--------------|-----------------------------|------|------|-------|------|
| | Cu | Zn | Cr | Pb | Cd |
| Sibasa | 0.42 | 0.84 | 0.43 | 21.04 | 0.18 |
| Univen | 0.28 | 0.85 | 0.55 | 13.31 | 0.23 |
| Punda Maria | 0.52 | 1.05 | 0.38 | 26.07 | 0.66 |
| Overall mean | 0.41 | 0.91 | 0.45 | 20.14 | 0.36 |

| Road name | Distance from road (m) | Concentrations (mg/kg) | | | | |
|-------------|------------------------|------------------------|------|------|------|------|
| | | Cu | Zn | Cr | Pb | Cd |
| Punda Maria | 100 | 0.22 | 0.33 | 0.12 | 4.12 | 0.12 |
| Sibasa | 100 | 0.11 | 0.21 | 0.13 | 3.23 | 0.13 |
| Univen | 100 | 0.13 | 0.23 | 0.11 | 4.31 | 0.12 |

| Road name | Concentrations (mg/kg) | | | | |
|--------------|------------------------|------|------|-------|------|
| | Cu | Zn | Cr | Pb | Cd |
| Sibasa | 0.21 | 0.37 | 0.37 | 12.12 | 0.45 |
| Univen | 0.17 | 0.17 | 0.24 | 10.55 | 0.23 |
| Punda Maria | 0.13 | 1.13 | 0.13 | 20.73 | 0.23 |
| Overall mean | 0.17 | 0.56 | 0.25 | 14.47 | 0.30 |

Metal levels in plants and soil

The mean concentrations of Cu, Zn, Cr, Pb and Cd in both the 'control' and the experimental samples are shown in Tables 1 to 4. All five elements show higher mean concentrations in the experimental samples than in the 'controls' for most of the road studies except for Cu in samples obtained from Univen roadside soil ('control'=0.72 and exp.=0.28) and Punda Maria roadside vegetation ('control'=0.22 and exp.=0.13) and Zn in samples obtained from Univen roadside vegetation ('control' = 0.23 and exp = 0.17). The overall mean 'controls' for Cu and Zn concentrations in these samples were slightly higher than the experimental samples. This suggests the possibility especially for Cu and Zn that in some cases, other sources

are responsible. For the experimental soil samples, the overall mean concentrations of the five metals for the Thohoyandou roadsides were found to follow the following decreasing order: Pb > Zn > Cr > Cu > Cd (Table 2). For the vegetation experimental samples, however, the five metals were found to follow the following decreasing order: Pb > Zn > Cd > Cr > Cu (Table 4). Other researchers have reported similar trends in related studies (Lagerwerff and Specht, 1970; Ward et al., 1977; Fatoki, 1996). Lagerwerff and Specht (1970) reported the following decreasing order; Pb > Zn > Ni > Cd in a study on contamination of roadside soil and vegetation in the US while an order of Pb > Zn > Ni > Cu > Cr > Cd was found by Ward et. al. (1977) in a study on heavy-metal pollution from automotive emissions and its effects on roadside soils and pasture species in New Zealand. In a study by Fatoki (1996) on the levels of Zn and Cu concentrations on roadside surface soils and vegetation in Alice, South Africa, Zn levels were found to be much higher than Cu in both sample types.

The concentration levels (Tables 2 and 4) found in this study are lower than those of other studies reported (Lagerwerff and Specht, 1970; Ward et al., 1977; Fatoki, 1996). As examples, Fatoki (1996) reported Zn and Cu concentrations of about 20 and 7 mg/kg for both soil sample and plant samples respectively; Lagerwerff and Specht (1970) reported concentrations ranging from 540 to 7.5 mg/kg for Pb, 162 to 8.3 mg/kg for Zn, 1.82 to 0.18 mg/kg for Cd for roadside soils depending on the traffic density and the distance from the roadside. Thohoyandou Town though is experiencing population and traffic increase it is still not as highly industrialised and urbanised. Major roads therefore do not have very high traffic densities compared to other industrialised towns within South Africa such as Johannesburg. Seasonal variation can also cause significant difference in the levels of metals found on roadside soil and vegetation as observed by Fatoki (1996). In the study conducted by Fatoki (1996), lower values were obtained for November samples than May. This was attributed to a wash-out process of metal deposition by rain during the summer months. This study was carried out in February 2002, the middle of summer in South Africa, when heavy fall was common. The mean Pb results in both plant and soil samples are lower than those reported by Okonkwo et al. (2003). Okonkwo et al. (2003) carried out a similar study in the same area but only for Pb. Samples were collected in August 2000 which is the end of dry winter season and obtained concentrations above 200 mg/kg for Pb in both the soil and the plant samples. The marked difference with Pb results obtained in this study again can be attributed to wash-out process of deposited metals by rain.

Metal levels and distance from the roadside

The studied metal concentrations in soils generally decreased with distance from the road thus indicating their main source as motor traffic except for Cd in Punda Maria roadsides, Cu in Univen roadsides and Cr in Univen and Punda Maria roadsides (Fig. 3a-e). Univen roadside soil samples did not show consistent decrease in Cu concentration with distance like the other roadside soil samples (Fig. 3a). Univen and Punda Maria roadside soil samples also did not show consistent decrease in Cr concentrations with distance (Fig. 3c). Cd in Punda Maria roadside samples either remained the same or increased with roadside distance (Fig. 3e). The gradient of concentrations with distance from the roadside for soil samples generally decreased in the order Pb > Cu > Cr > Zn > Cd.

The metal concentrations in plant samples also generally decreased with distance from the road except for Cu, Zn in Sibasa and Univen, Cr in Sibasa and Punda Maria, Pb in Sibasa, and Cd in Sibasa and Punda Maria (Fig. 4). In exceptional cases the concentrations of specific metals in plants either increased or remained the same between sampling points.

The concentrations of each metal in plants and soil were also observed to vary from one road to another. For example, in Tables 2 and 4 the highest concentrations of Pb in soils and plants was from Punda Maria roadside while the highest concentrations of Cr in soils and plants was from Univen and Sibasa, respectively. This has been observed in similar studies by Lagerwerff and Specht (1970) and Fatoki (1996). The mean metal concentrations for both Punda Maria soil and plant samples were generally the highest. This is expected since Punda Maria road handles more traffic volume in the study area than the other two roads. Ward et al. (1977) studied in detail the relationship between traffic density and resulting roadside metal pollution. Roads that were found to have high traffic densities resulted in high levels of roadside pollution of Cu, Zn, Pb, Ni, Cr and Cd and *vice versa*.

Soil metal and plant metal correlation

An attempt was made to investigate any relationship between the metal in the soil to that found in the plant in the Sibasa roadside samples. This was chosen because the concentrations of a number of metals decreased with distance from the road. A strong relationship was found between its soil metal and plant metal. The correlation coefficients varied and were 0.991 for Cu, 1.000 for Zn, 0.867 for Cr, 0.995 for Pb and 0.982 for Cd. These values indicate the same metal source. This suggests motor traffic as the major source of these metals especially given that the concentrations decrease as one moves away from the roadside. Fatoki (1996), in a related study investigated the relationship between soil Zn and plant Zn and found values of correlation coefficients ranging from 0.961 to 0.995. Since the Cu concentration of plant roadside samples from Punda Maria road did not decrease with distance, attempts were also made to correlate its soil metal to plant metal. A correlation coefficient of 0.397 was obtained. This suggests another source of Cu other than motor traffic in plant samples along this roadside. The correlation between trace metals in soil to that in the plant is very important from the human health aspect. In the study area, lots of vegetable crops are grown along the roadsides as a source of food. Further research is therefore needed to find out the levels of these metals in vegetable crops.

Metal levels in water bodies

Table 5 shows the levels of trace metals detected in water and sewage water samples. The metals levels were found to follow the following decreasing order; Fe > Zn > Pt > Cu > Pd. Pb and Cd were not determined in the water samples while Fe, Pt and Pd were included. This is because in a study on the assessment of the biological wastewater treatment system in Thohoyandou (Manungufala, 2005) in which, Pb, Cu, Fe, Zn and Cd were determined in the influent, effluent, upstream and downstream waters, Pb and Cd were found in very small quantities. The

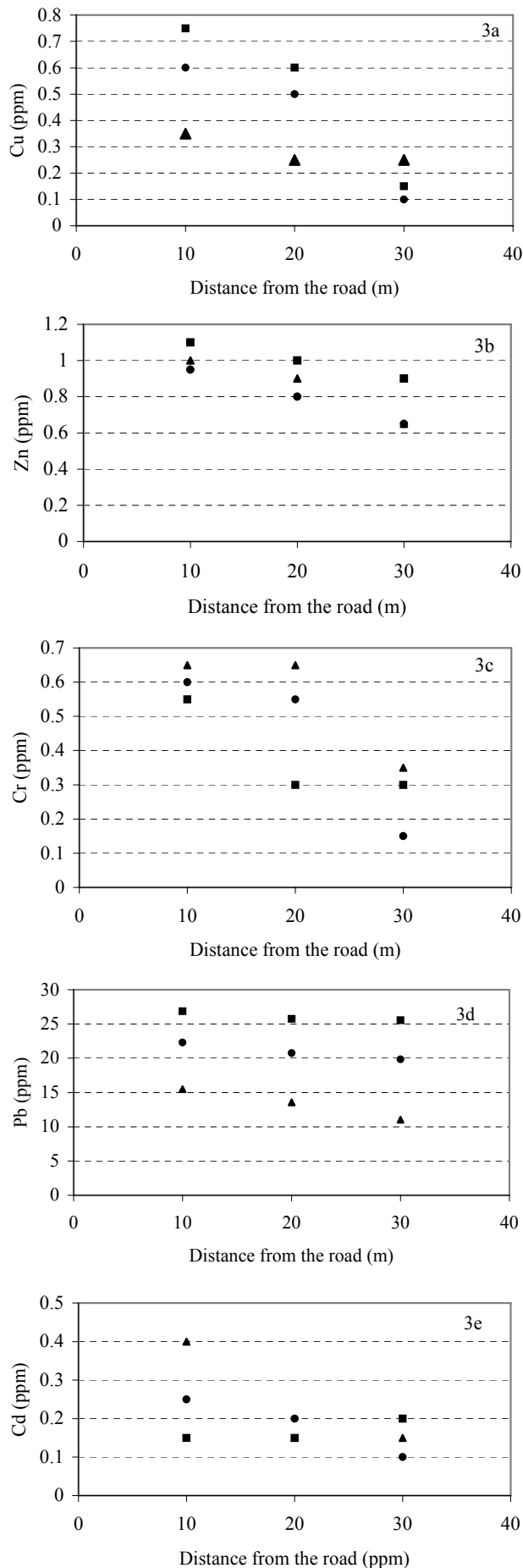


Figure 3a-e (right)

Concentration of Cu, Zn, Cr, Pb and Cd in soil samples along Sibasa, Univen and Punda Maria roads. Legend: ● Sibasa road, ▲ Univen road, ■ Punda Maria road

| Sample no | pH | TSS (mg/ℓ) | Conductivity (µs/cm) | Zn (mg/ℓ) | Cu (mg/ℓ) | Fe (mg/ℓ) | Pt (mg/ℓ) | Pd (mg/ℓ) |
|---|------|------------|----------------------|-----------|-----------|-----------|-----------|-----------|
| 1.Madanzhe-Sibasa RWMS | 7.00 | 96 | 194 | nd | nd | 0.0425 | 0.0074 | nd |
| 2.Madanzhe-Nare RWMS | 6.83 | 52 | 282 | 0.0164 | nd | 0.1429 | 0.0075 | 0.0036 |
| 3.Madanzhe RW | 7.79 | 152 | 62 | 0.0208 | nd | 0.1354 | nd | nd |
| 4.Madanzhe-Ngovhela RW | 7.54 | 29 | 77 | 0.1543 | nd | 0.926 | nd | 0.0033 |
| 5.Madanzhe- Univen RWMS | 7.21 | 30 | 169 | 0.110 | nd | 0.0718 | 0.0102 | nd |
| 6. RWMS 15 M from Univen Pipe leaking | 6.65 | 108 | 210 | 0.0163 | nd | 0.1013 | 0.0069 | nd |
| 7. RWMS 50 M from Univen Pipe leaking | 6.53 | 80 | 194 | 0.0112 | nd | 0.1001 | 0.0055 | nd |
| 8.Univen RWMS | 7.70 | 260 | 444 | 0.2364 | nd | 1.303 | 0.0346 | 0.0059 |
| 9.Univen S | 8.31 | 230 | 393 | 0.3774 | nd | 2.2645 | 0.0240 | 0.0261 |
| 10.Mvudi RWMS | 7.67 | 80 | 154 | 0.0147 | nd | 0.0898 | 0.0090 | nd |
| 11.Mvudi RWMS | 7.67 | 28 | 91 | 0.0489 | nd | 0.2691 | 0.0043 | nd |
| 12.Mvudi park S | 8.54 | 66 | 367 | 0.3265 | 0.1594 | 2.1141 | 0.0285 | nd |
| 13.Mvudi stadium RWMS | 6.94 | 100 | 90 | 0.0214 | nd | 0.1284 | 0.0093 | nd |
| 14.Sewage treatment effluent | 7.65 | 194 | 285 | 0.0267 | 0.1077 | 0.1429 | 0.0804 | 0.0036 |
| 15.15 M from sewage treatment outlet pipe | 7.31 | 180 | 112 | 0.0182 | nd | 0.0160 | 0.0075 | nd |
| 16. Manini RW | 6.87 | 60 | 163 | 0.0105 | nd | 0.063 | 0.0044 | nd |
| 17. Block G RW | 7.74 | 19 | 209 | 0.015 | 0.0034 | 0.0942 | 0.0104 | 0.0032 |
| 18. Acacia Park RW | 6.78 | 40 | 276 | nd | nd | 0.0360 | 0.0053 | nd |
| 19. Unit D RW | 6.98 | 30 | 290 | 0.0124 | nd | 0.0621 | 0.0053 | nd |
| 20. Mvudi RW | 6.28 | 38 | 139 | 0.0167 | 0.1564 | 0.1035 | nd | nd |

levels of trace metals in all the samples in the preceding study could be arranged in the following decreasing order: Fe > Zn > Cu > Pb > Cd. This is similar to the one determined above and suggests similar source. The decreasing order of the levels of trace metals in the water is different from that found in the roadside soil samples above of Pb > Zn > Cr > Cu > Cd. This further suggests that very few metals from the roadside leach to the surrounding water bodies. The levels of trace metals in the water is below the South African Bureau of Standards (SABS) guidelines for fresh waters except for Fe which was higher than the standard value of 0.3 mg/ℓ in some samples. There is also a high chance that most trace metals deposit on the riverbeds as part of the sediment.

The pH of the water bodies (Table 5) generally tends towards alkaline. This is because of the leakage of the sewage in many parts directly into the rivers. High conductivity and total dissolved solids values support this. Since the pH is alkaline, it means most trace metals are highly adsorbed to dissolved solids. The pH of the water was within the SABS guidelines for drinking and domestic uses of water of between 6 and 9 pH range that has also been validated by Okonkwo and Mothiba (2005). However, conductivity in most samples was higher than the SABS recommended value of 70 µs/cm.

Sources of metals in the roadside soils and sewage system

Roadside soils

The source of Pb is obviously leaded gasoline as has been established in the literature. This has also been recently reported by Okonkwo et al. (2003). According to South African national government, leaded gasoline is supposed to be phased out in the year 2006 because of pollution problems. Unleaded petrol,

which was introduced into the South African market in 1996 (WHO, 2002), will therefore become the sole commercial gasoline. Currently, filling stations have options for either leaded or unleaded gasoline. Approximately 75% of motor traffic is still using leaded gasoline (WHO, 2002).

The study by Lagerwerff and Specht (1970) has suggested that motor traffic lubricating oils are the major sources of Zn and Cd as part of additives and impurities, respectively. Zn and Cd were also reported in the motor traffic car tyres by the same authors. Cr is used in chrome plating of many motor traffic parts while Cu is also a common constituent of many motorcar components such as engines and chassis (Ward et al., 1977). The fact that these metals were found along roadside soil and vegetation is probably due to mechanical wear and tear that deposits these metals in the fine dust of the roadway from the surrounding environment.

Sewage system

Sorme and Lagerkvist (2002) reported in detail the major sources of trace metals like Cu, Zn, Ni and Cr in sewage. In their study, the largest sources of Cu in sewage were found to be tap water and roofs. For Zn, the largest sources were found to be galvanised household materials and car washes. The levels were found to follow the following decreasing order; Zn > Cu > Ni > Cr > Pb > Cd > Hg. Among the household items that were found to contain high amount of trace metals are food, pipes, taps and drinking water. These findings could in part explain why sewage water is the major source of trace metals in the rivers within Thohoyandou. The presence of Pt and Pd is, however, interesting since they have not been reported before in the sewage system to our knowledge. It could be due to the fact that these metals are now used as components of household items such as jewellery that later find their way into the sewage system. They may also

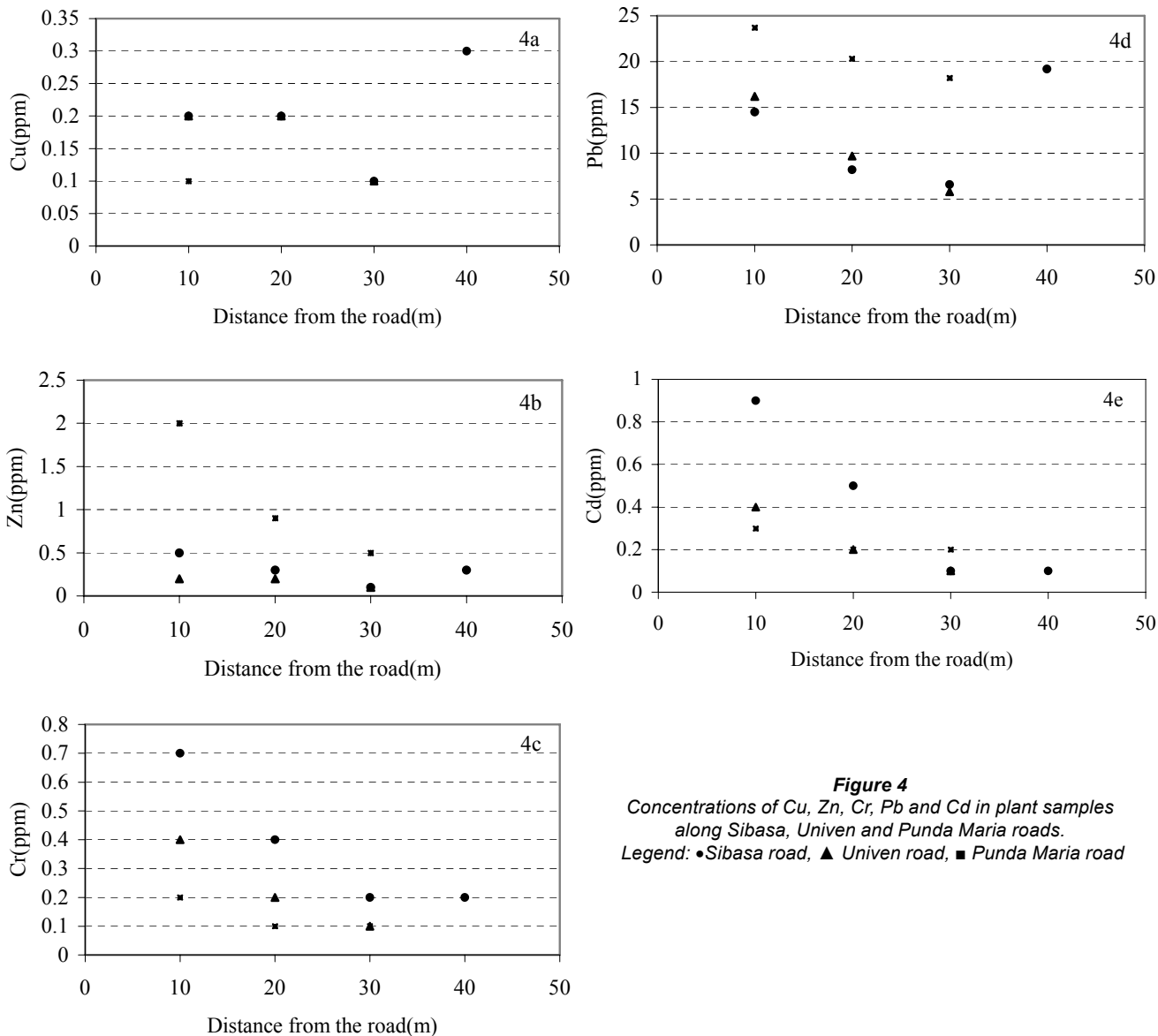


Figure 4
Concentrations of Cu, Zn, Cr, Pb and Cd in plant samples along Sibasa, Univen and Punda Maria roads.
Legend: ● Sibasa road, ▲ Univen road, ■ Punda Maria road

have been released by automobile catalytic converters and found their way into sources of water supply or open sewer drainage systems.

Acknowledgements

The authors would like to thank the following: National Research Foundation of South Africa for funding, Prof. Jonathan Okonkwo of Tshwane University of Technology (South Africa) for initial support and advice, and Dr Bobby Naidoo of the Limpopo University (South Africa) (formerly University of the North) for help in the analysis of soil and vegetation samples.

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