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# FROM CRADLE TO GRAVE…AND THEN WHAT? THE ROLE OF ENVIRONMENTAL FACTORS IN THE DISTRIBUTION OF POLLUTANTS AROUND THE CITY OF GWERU'S DUMPSITE

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## ABSTRACT

*Little has been documented on the hidden relationship between environmental factors and pollutants spreading from municipal dumpsites in Zimbabwe (DNR, 1993; Chenje et al, 1998; Masocha, 2004), yet such information can be useful for urban land use planning purposes to safeguard both people and the environment against pollution and its related effects. This study aims to evaluate the role of environmental factors in the distribution of pollutants around Gweru dumpsite. It also determined whether there is a significant ($p<0.05$) relationship between the concentration levels of lead (Pb), cadmium (Cd), and sulphides ($SO_2$) and environmental factors - specifically slope, soil bulk density, stream flow direction, soil infiltration rate, and distance from the dumpsite. Geographical Information Systems (GIS) was used to input process and analyze both spatial and attribute data. The Principal Components Analysis (PCA) revealed that there is a significant ($p<0.05$) relationship between the concentration levels of Pb and $SO_2$ and Principal Component 2 (PC2) consisting of slope and infiltration rate. This means that the spread of pollutants (Pb and $SO_2$) around the dumpsite can be traced back to the dump and is directly linked to both slope and soil infiltration rate. It is recommended that further research be done to find possible factors responsible for the spread of cadmium, which could not be explained by the Principal Components Analysis for city planners to get a fuller picture of the situation.*

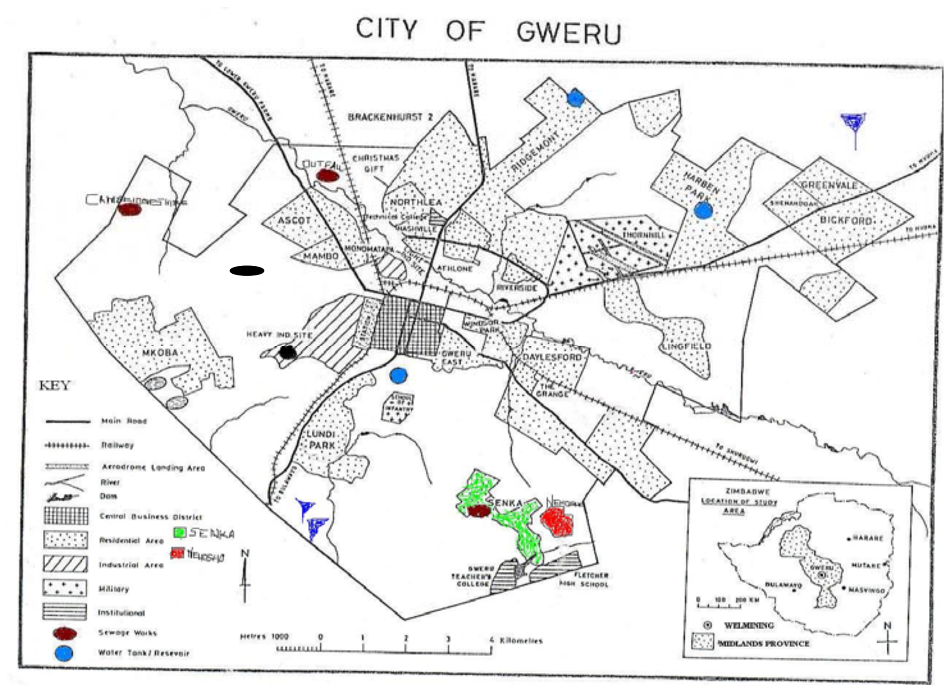
## INTRODUCTION

Hazardous waste sites, in particular, and potentially contaminated sites, in general, may pose significant risks to the public because of the potential health and environmental effects (Ellis, 1989; Asante-Duah, 1993; Tevera, 1995; Mariolakos *et al*, 2003). Apart from its immediate and direct health and environmental hazards, hazardous waste disposal could lead to the long-term contamination of the ambient air, soils, ground waters, and the food chain. When waste is deposited at dumpsites, it is usually forgotten yet it continues to interact with the environmental factors to become even more dangerous - to both people and the environment - through soil, water, and air pollution (William and Blackman, 1993; Lanphear *et al*, 2002; James, 2003). Heavy metals, like lead and cadmium, behave differently to different environmental factors, yet both are potentially poisonous.

Gweru waste disposal site is an open dump, which produces leachate that contain chemical contaminants including heavy metals, like lead (Pb) and cadmium (Cd) as well as sulphides ($SO_2$). The dumpsite is located in prime urban agricultural land where residents grow maize and other food crops for subsistence and they could be at risk from pollutants emanating from the dump. Although an Environmental Impact Assessment (EIA) was carried out before siting the dump, this was only partial and did not determine the hidden relationship between environmental factors and pollutant spreading from the municipal dump. This study, therefore, sought to determine whether there is a relationship between the concentration levels of cadmium (Cd), lead (Pb), sulphides ($SO_2$), and environmental factors - specifically, soil bulk density, soil infiltration rate, slope, and stream flow direction - around Gweru dumpsite. Such information can be useful for city land use planning and development purposes to safeguard both people and the environment against pollution. The dumpsite is the final resting place for all municipal and industrial solid waste (Jerie, 2005; Matsa, 2007). Metal smelting and refining industries, like Zimbabwe Castings Limited and Zimalloys, are potential lead sources, while Bata Shoe Company produces a lot of sulphides from hide processing. These are deposited at the municipal dumpsite.

## MATERIALS AND METHODS

### Location of the Study Area




The City of Gweru is located at 19°25'S 29°50'E. It is 168 km from Bulawayo and 280km from Harare along the major Harare-Bulawayo road and railway line. Gweru is the fourth largest urban settlement in Zimbabwe - after Harare, Bulawayo, and Chitungwiza - in terms of population size. It is the provincial capital of the Midlands Province, and is centrally located in the country.

Gweru straddles across 3 types of soils, namely black basalt soils, red loams, sands, and gravel. The city of Gweru lies on a watershed, which stretches from Rusape to Bulawayo and is at an altitude of about 1422 meters. The Municipal area is dissected by numerous streams most of which drain into the Gweru River, a tributary of the Gwayi River. The region is mostly affected by northeast prevailing winds, which are dominant from August to November during which their mean speed is in the range of 8.0 to 9.3 knots. The city covers approximately 26,113ha including the newly acquired land of Cambridgeshire and Clydesdale (City of Gweru, 1994).

Gweru dumpsite lies between the high density residential suburbs of Ascot, Mutasa, Mambo, and Mkoba 12. The area is unprotected and gently slopes in a westerly direction. Residents are lured to practice urban farming on the edges of the dump in all directions where they grow crops like maize, groundnuts, sweet potatoes, and sugar beans. Soils on site are mainly sandy and these may promote leachate movement.

## Data Collection Methods

Figure 1 shows a sampling point map of the study area with random points along transects. It is along these random points that samples to test for soil bulk density and infiltration rate were taken. Samples to test for sulphides, lead, as well as cadmium concentrations were also taken from the same points.

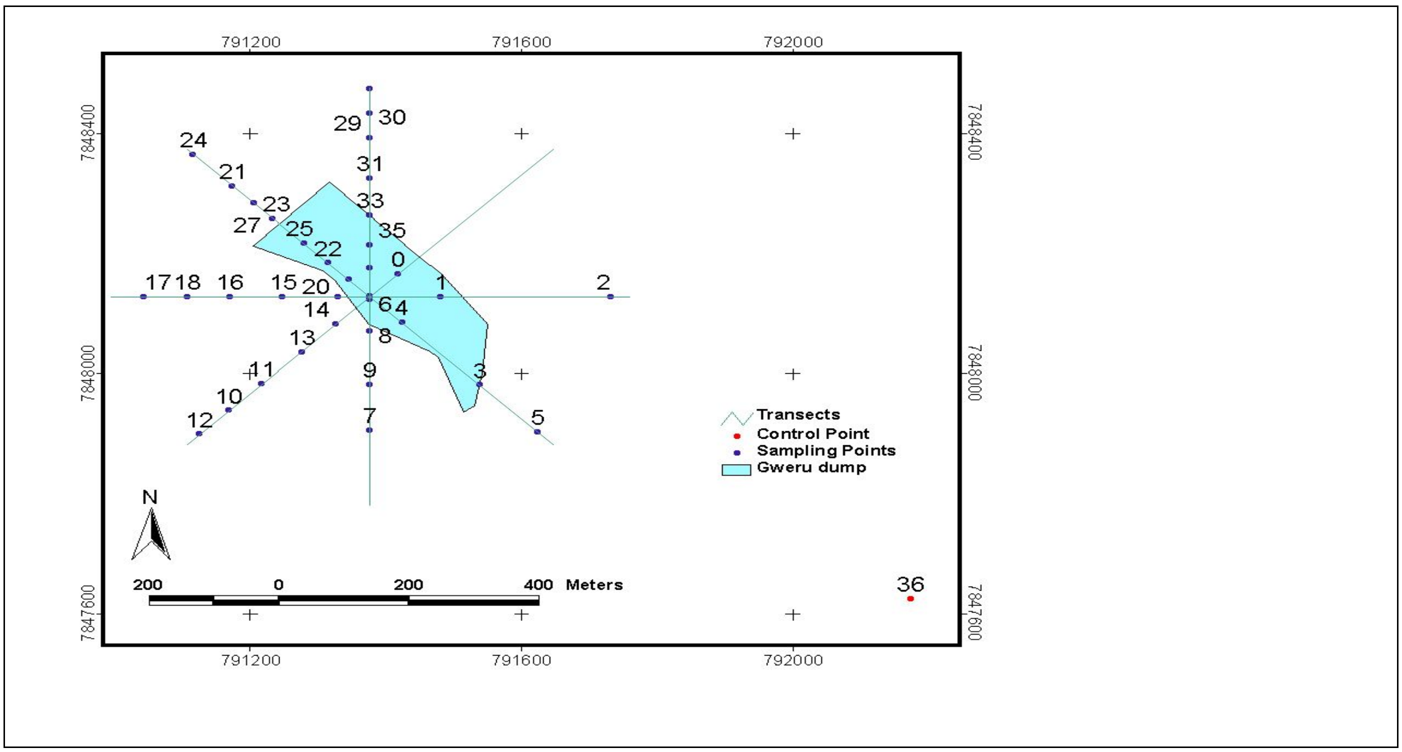



**Figure 1: Sampling Points Map of the Study Area**

## Determining Individual Environmental Factors

### *a) Soil Bulk Density*

The sampling cylinder and its base were weighed (W1). The cylinder's internal diameter and its height were also measured. The cylinder flush with the wet soil sample (W2) was then weighed and the volume of the sample was calculated from the inner volume of the sampling cylinder in $cm^3$ (V). The wet weight of the sample (W2-W1) was then divided by the calculated volume ($cm^3$) to get bulk density of the soil (Bd). (That is: $Bd=(W2-W1)/V=gcm^3$.)

### *Soil Infiltration Rate*

Considered was a "single ring" infiltration measurement in which a cylinder, 12cm in diameter and 12cm length, was driven into the soil. The cylinder was graduated with lines every 1.0cm. The cylinder was then filled with water and the level of water was monitored. The time taken by the water level to drop 1.0cm was recorded. Measurements were taken for a given amount of time (5 min) or until a steady state had been reached. The infiltration was then calculated using the formula: I= (ml of water infiltrated/time min) (1/area of the cylinder $cm^2$); where "I" is infiltration rate.

The direction of stream flow, as well as the slope of the dumpsite area, was determined on the Digital Elevation Model (DEM) of the study area using the Geographical Information Systems (GIS).

## Determining Chemicals Concentration around the Dumpsite

100g of soil samples were collected from 12 random points around the dump. Two adjacent points were systematically selected along each transect from the dumpsite in order to assess the concentration of each of the chemicals from one point to the adjacent one. Samples were also colleted from 3 randomly selected points from within the dump. These served as control points to ascertain the presence of the chemicals within the dump. Another control point to test the natural level of these chemicals in the soil was also determined from the prevailing windward direction (north-eastern side of the dump) and upslope to make sure that the natural mineral concentrations within the soil were not a result of pollution from the dump.

### *Sulphides Determination by Leco Machine*

A 1g sample was weighed in a Leco crucible and mixed with 2 spatulas of leco accelerator, which enhances the sample ignition. The sample was loaded onto the sample holder and introduced into a furnace in which the sample was burnt and emitted the entire sulphur dioxide in it. The released sulphur dioxide was measured by the machine which gave the results on the read-out (screen).

***b) Lead and Cadmium Determination by Atomic Absorption Spectrometer***

5g samples were weighed in a Phillips beaker by analytic balance. 20ml of nitric acid ($HNO_3$) and 20 ml of perchloric acid ($HCLO_4$) were added. The solution was heated to fuming. It was then digested for 5 minutes on a hot plate and then cooled. The solution was then transferred into a 100ml volumetric flask and topped with distilled water to the 100ml mark. It was closed, shaken, and then allowed to settle. Atomic absorption spectrometer readings for both Pb and Cd were then taken.

## DATA ANALYSIS AND DISCUSSION

### Relationship between Chemicals Concentration and Environmental Factors

The Principal Component Analysis (PCA), which is a technique for simplifying a data set, by reducing multidimensional data sets to lower dimensions for analysis, was used to try to find out possible relationships between the environmental factors and the concentration of the chemicals under study. PCA was, thus, used for dimensionality reduction in the data sets while retaining those characteristics of the data sets that contributed most to its variance by keeping lower order principal components and ignoring higher order ones.

The Principal Component Analysis grouped environmental factors into principal component 1 (PC 1) and principal component 2 (PC 2) as shown in Table 1.

**Table 1: Component Matrix**

| Environmental factor | Component | |
|---|---|---|
| | 1 | 2 |
| Bulk density | 0.794 | 0.187 |
| Infiltration rate | -0.342 | 0.846 |
| Slope | -0.362 | -0.642 |
| Distance | 0.856 | -0.327 |
| Flow direction | 0.494 | 0.382 |

Extraction Method: Principal Component Analysis.

PC 1 comprised mainly of distance from the dump which had the highest positive factor loading of 85.6%, followed by soil bulk density with another positive factor loading of 79.4 %. Flow direction, slope, and infiltration rate had lower loadings and, therefore, did not contribute much to the analyses in which PC 1 dominated. On the other hand, PC 2 was dominated by infiltration rate with a high positive factor loading of 84.6%, as well as slope which had a negative high factor loading of -64.2%. Loadings by flow direction and soil bulk density were low for PC 2.

**Relationship between Soil Bulk Density and Distance (PC 1) and Cadmium**

Figure 2a shows that Principal Component 1 comprising soil bulk density (79.4%) and distance (85.6%) did not significantly ($p>0.05$) explain the spread of cadmium ($r^2=0.129$ and $p=0.251$).

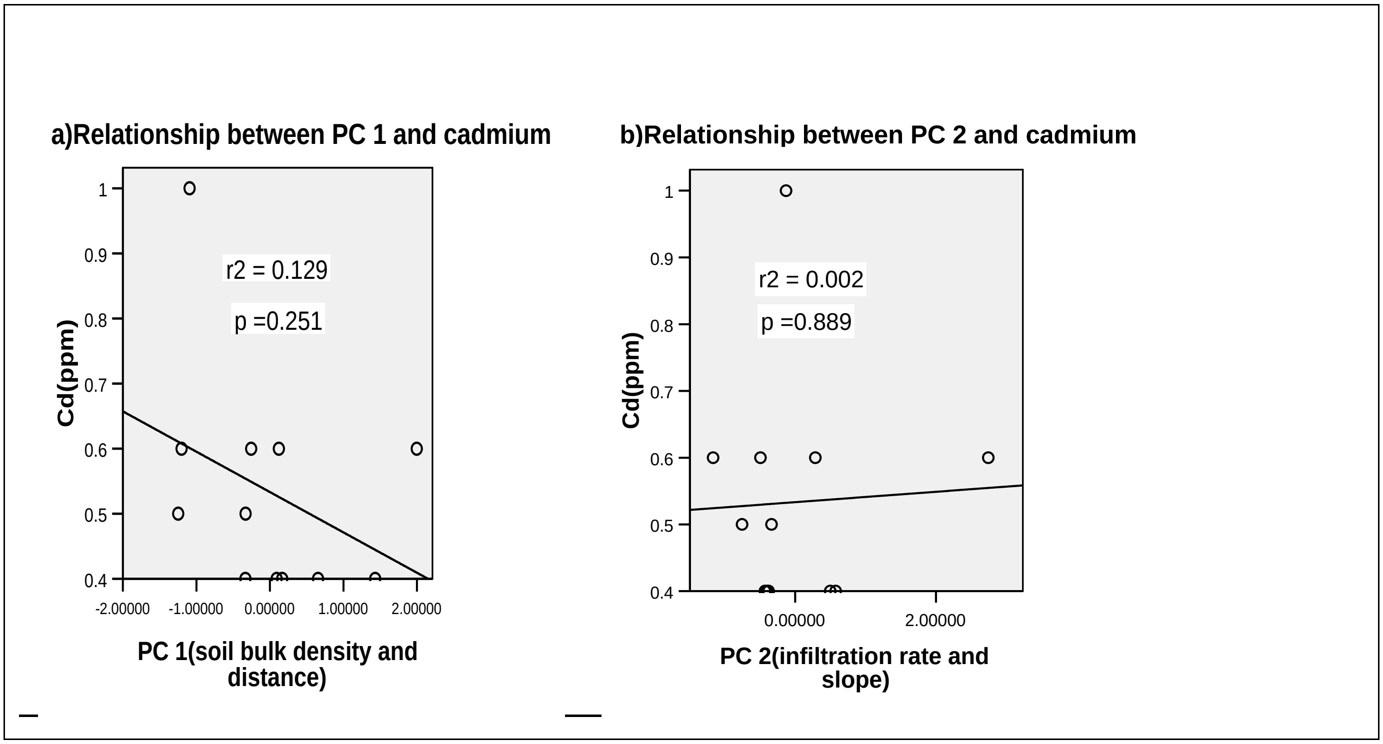



**Figure 2: Relationships between Cadmium and PC 1 and PC 2**

**Relationship between Soil Infiltration Rate, Slope (PC 2), and Cadmium**

Figure 2b shows that Principal Component 2 comprising soil infiltration rate (84.6%) and slope (-64.2%) did not significantly ($p>0.05$) explain the spread of cadmium ($r^2=0.002$ and $p=0.889$).

**Relationship between Soil Bulk Density, Distance (PC 1), and Lead**

Figure 3a shows that Principal Component 1 (soil bulk density and distance) did not significantly ($p>0.05$) explain the spread of lead ($r^2= 0.002$ and $p=0.884$).

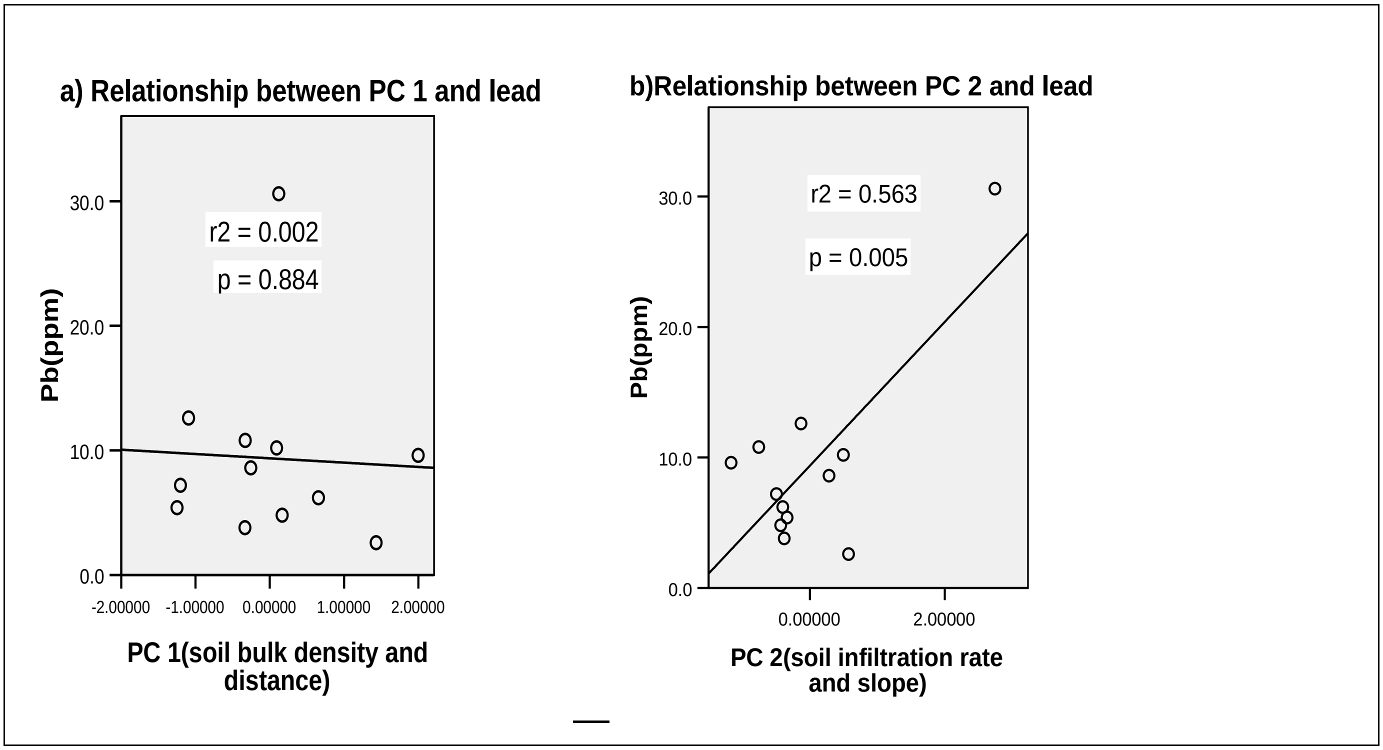



**Figure 3: Relationships between Lead and PC 1 and PC 2**

**Relationship between PC 2 and Lead**

Figure 3b shows that Principal Component 2 (soil infiltration rate and slope) managed to significantly ($p<0.05$) explain the concentration of lead ($r^2=0.563$ and $p=0.005$). This suggests that lead concentration can be explained more by infiltration rate which has a higher positive factor loading of 84.6%. As infiltration rate increases, Pb concentration also increases around the dump since water (or leachate) is the medium through which chemicals are transported. However, with a negative factor loading of -64.2%, slope has a negative relationship with Pb concentration. As slope decreases around the dump, Pb concentrations increase. This could be because lead-carrying leachate has more time to infiltrate as the terrain becomes gentler. Incidentally, it is on these gentle slopes where residents grow their crops. Residents may, therefore, be at risk from the lead which they get through crops from around the dumpsite. Lead toxicity may lead to manganism, a Parkinson disease-like neurological disorder with symptoms of mental difficulties and impairments in motor skills (Andrew and Jackson, 1998; Jarup, 2003; Kusangaya, 2006).

### 3.2.2: Relationship between PC 1 and Sulphides

Figure 4a shows that Principal Component 1 (soil bulk density and distance) did not significantly ($p>0.05$) explain the spread of sulphides ($r^2=0.016$ and $p=0.696$).

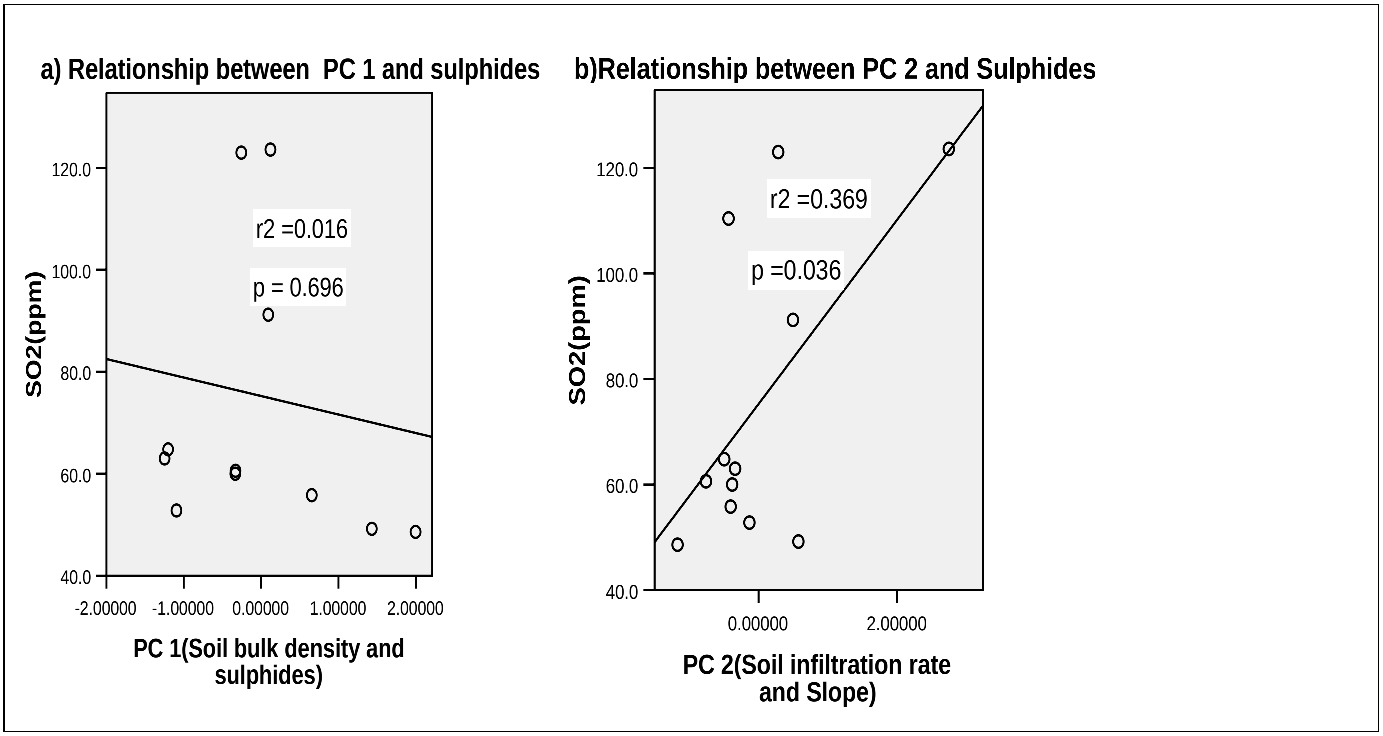



**Figure 4: Relationships between Sulphides and PC 1 and PC 2**

### 3.2.3: Relationship between PC 2 and Sulphides

Figure 4b shows that Principal Component 2 (soil infiltration rate and slope) managed to significantly ($p<0.05$) explain the spread of sulphides ($r^2=0.369$ and $p=0.036$). Like lead, sulphides concentration can also be explained more by infiltration rate and slope. As infiltration rate increases, more sulphides could be transported within the soil medium from the dump. However, as slope decreases, sulphide concentration around the dump increases, as a result. Areas around the dump are fertile because of the waste from the dump and it is for this reason that these areas are heavily cropped. Apart from being exposed to lead, residents may also be at risk from sulphides through contaminated crop intake.

Exposure to sulphides may result in lower respiratory tract illness and chronic lung disease (Boulding, 1995; SCEE, 1999).

The results between soil infiltration rate and slope (Principal Component 2) and sulphides and the same environmental factors and lead confirm the earlier stated hypothesis that there is a significant relationship between environmental factors and the concentration of the stated chemicals.

**CONCLUSION**

Principal Component 2 (PC 2), comprising soil infiltration rate and slope, managed to significantly ($p<0.05$) explain the concentration of lead. As infiltration rate increases, lead concentration also increases and as slope decreases, lead concentration increases from the dump.

Principal Component 2 (soil infiltration rate and slope) also managed to significantly ($p<0.05$) explain the spread of sulphides. As infiltration rate increases, more sulphides are transported within the soil medium from the dump. However, as slope decreases, sulphides concentration increases from the dump since a gentler slope gives leachate more time to infiltrate.

There was, however, no statistically significant ($p>0.05$) relationship between individual environmental factors and cadmium concentration nor between combined environmental factors (Principal Components) and cadmium concentration. This means that cadmium concentration would need the exploration of other environmental factors other than those selected for this study.

Given the high significant relationships between environmental factors and the toxic pollutants (lead and sulphides), it is recommended that residents be discouraged from growing crops around the dump, as there is a high possibility of pollution.

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