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PETROGRAPHIC AND PHYSICO-CHEMICAL CHARACTERISATION OF TAILINGS DUMP AND SOILS AROUND A NICKEL-COPPER MINING AND SMELTING ENVIRONMENT

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ABSTRACT

Recent concerns of mining and smelting of nickel-copper (Ni-Cu) in Selebi Phikwe, Botswana possibly affecting the environmental physico-chemistry motivated this study. Physico-chemical analyses which included particle size distribution (PSD), pH, electrical conductivity (EC), cation exchange capacity (CEC), color and descriptive petrography on samples of tailings dump and soils were performed in order to understand the significance of these properties on the surrounding physical environment. The PSD of soil samples revealed the average wt % of the $< 2\ \mu m$ fraction (clay fraction) was between 3 and 9 wt %, the $> 2\ \mu m$ to $< 50\ \mu m$ fraction (silt fraction) was between 34 and 44 wt %, and the $> 50\ \mu m$ to $< 250\ \mu m$ fraction (sand fraction) was between 47 and 63 wt %. Soil pH ranged from 3.5 to 6.0. Electrical conductivity values were significantly low, and the range was from 50 $\mu S/cm$ to 250 $\mu S/cm$. Soils with low pH correspondingly had low EC and were close to the mine. The CEC values occurred between 2 meq/100 g and 20 meq/100 g. Hand specimens of tailings dump viewed with a microscope and physical tests performed on the samples for hardness, cleavage, fracture, colour, streak, lustre, and crystal appearance depict albite, cristobalite, chalcopyrite, pyrrhotite, tremolite, and pentlandite to be contained in them. Soil colour varied from pale yellow, reddish yellow to dark reddish brown. Grains were poorly sorted, with subangular grains located further from the plant, which is indicative of windblown particles transported at a short distance. Reddish brown soils were closer to the tailings dump, mining areas and the smelter/concentrator plant. The observation is indicative of both Fe and Cu containing minerals enriching the soils of the study area. The findings of this study are indicative of increase in soil acidity due to mining and smelting of Ni-Cu at Selebi Phikwe area. High acidity favoured the leaching of heavy ions from tailings dump and related mining waste to the soils. Fewer exchange sites have resulted in a low CEC for ions adsorbed on the sediment surfaces, consequently they remain in solution and are bioavailabe for plant uptake.

KEYWORDS: tailings dump; soils; physico-chemistry; particle size distribution; petrography; environment

INTRODUCTION

Nickel-copper, (Ni-Cu) has been mined in Selebi Phikwe, Botswana since 1956, and it is suspected that the mining and smelting activities are having an effect on the immediate physical environment.

Previous studies of Ni-Cu orebodies (Nkoma and Ekosse, 1999; 2000) and soils (Ekosse et. al., 2003), and particulate air matter (Ekosse et. al., 2004) conducted on different samples obtained within the Selebi Phikwe area indicated mineral constituencies that reflected the presence of heavy metals emanating mainly from mining and smelting activities. Furthermore, studies on environmental chemistry of the Selebi Phikwe area depicted trends in heavy metals concentrations in soils and *Colophospermum mopane* (Ekosse et. al., 2004a) to be similar to those obtained for *Imbrasia belina* in the same study area (Ekosse et. al., 2004b) which were all related to the mining activities there.

However, no work has so far been reported on in literature regarding the petrographic and physico-chemical aspects of the tailings dump and soils surrounding the Selebi Phikwe Ni-Cu mining and smelting environment. In this study, an attempt was made to link information on mineralogy of the transition sulphide minerals from the ore bodies (Nkoma and Ekosse, 2000), to the physico-chemical characteristics of the tailings dump and soils around the Selebi Phikwe Ni-Cu mine area, Botswana. The primary objective of this study was to petrographically and physico-chemically characterise the tailings dump and soils in order to understand how mining and smelting activities affect the physico-chemistry of the environment.

MATERIALS AND METHODS

Study Area

Selebi Phikwe is one of the urbanized townships of Botswana, rated after Gaborone, Francistown, Maun, and Lobatse (Grant and Grant, 1995). The study area is located in the north-eastern part of the country between longitudes 27° 47'E and 27° 53'E, and latitudes 22° 55'S and 22° 00'S (Figure 1).

Samples and Sampling

Samples for laboratory analyses were obtained from ten sites, of which nine were in the study area (Figure 2), and the tenth site being the control site located 56 km from the study area (Table 1). Fourteen sampling trips were made, and during each sampling trip, three representative samples were chosen. Of the three representative samples, two were obtained close to the sides and one was taken from the centre of the tailings dump, making a total of 42 tailings dump samples collected for analyses. A hand shovel and a trowel were used to obtain the samples. Sampling was done at about 5 cm from the surface of the tailings dump mount

Random (Jewell et. al., 1993) and judgmental (Crèpin and Johnson, 1993) sampling techniques were used in obtaining soil samples from the ten sampling sites. One hundred and forty samples were collected for analyses. Grab soil samples (Tan, 1996), were obtained by shallow sampling techniques using a machete, a trowel and/or a shovel. Samples were taken at a depth of between 0 cm and 20 cm. Both samples of tailings dump and soils were put in an oven at 60 °C overnight to allow moisture to escape.

Laboratory Analyses

Granulometric Analyses

The particle size (PS) and particle size distribution (PSD) of soil samples were determined in two stages: the first stage was using a mechanical/electrical shaker with a nest of sieves, and the second stage was using an automatic particle size analyzer (PSA). The principle of operation is based on Stoke's law of sedimentation of individual spherical particles falling freely at a steady velocity under the influence of gravity,

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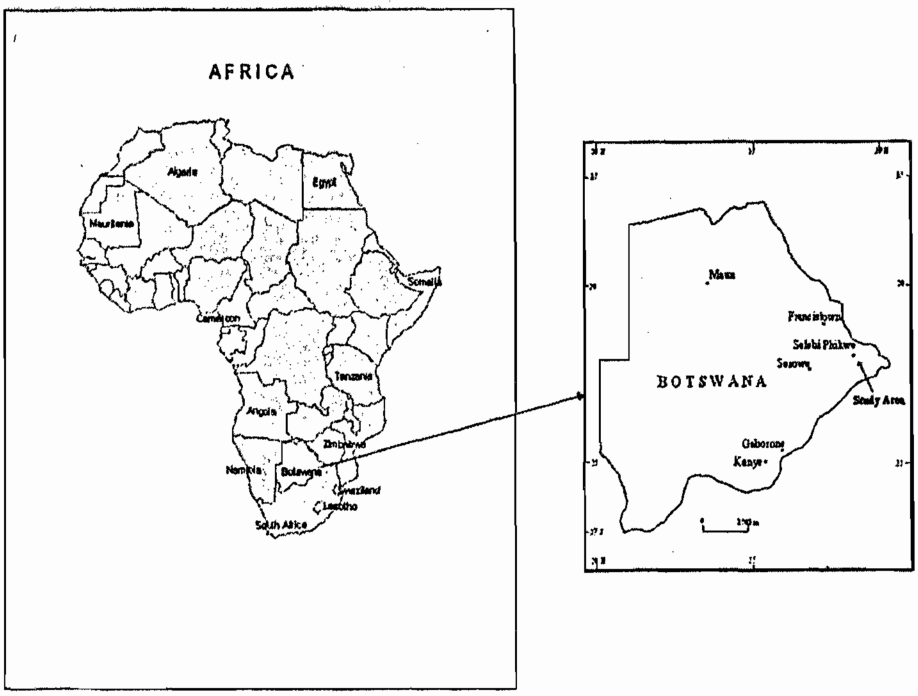


Figure 1: Map of Africa indicating Botswana, and of Botswana showing where Selebi Phikwe is located

Table 1: Location/Characteristics of sampling sites at the Selebi Phikwe township area

Sampling site	Location/Characteristics
1	Industrial area (150 m after the railway crossing)
2	Bosele Hotel (Commercial area) and new township
3	Between the township stadium and the mine (behind the Botswana Power Corporation, BPC)
4	Between the Township boundary and the railway line (directly behind a Community Junior Secondary School, CJSS)
5	Opposite the Mine hospital, close to old township
6	Between the mine and explosive storage facilities (close to old township)
7	Towards the airport (about 250 m from the Airport-Sefophe-Selebi Phikwe Road juncture)
8	Off untarred road leading to the Selebi North mine (100 m out of township boundary, adjacent to the new township)
9	Off last but one bridge before entering into the Selebi Phikwe township
10	Control site located close to the road juncture leading to Selebi Phikwe from the Gaborone-Francistown main road

resisted only by the viscous drag of the medium (Gaspe et. al., 1994), and is mathematically expressed as:

$$V = [2r^2(d_p-d_w)g]/9\eta \qquad (1)$$

where V = rate of settling of particles (cms^{-1}), r = radius of particles (cm), d_p = density of liquid medium (gcm^{-3}), d_w = density of water (gcm^{-3}), η = coefficient of viscosity (poise) (gcm^{-1}s^{-1}) and g = acceleration due to gravity (981sec^{-2}).

The mechanical/electrical shaker was set at 60 strokes per minute (spm), and the nest of sieves consisted of the following particle size ranges in μm: 500, 425, 355, 300, 250, 180, 150, 125, 106, and 53. The < 53 μm size fraction of surface sediments samples were analyzed using the 1993 model Shimadzu SA-CP4 automatic particle size analyzer (PSA). The analyzer was set at 240 revolutions per minute (rpm). The particle sizes were automatically measured by the PSA.

Descriptive Petrography and Color Determination

Tailings dump and soil samples for descriptive petrography and color determination were aerated for 24 hours. Clayey aggregates were separated using a mortar and pestle to single particles. With a spatula, the samples were mounted on white cardboard sheets provided by the Munsell Color Company Inc., MD 21218, USA. The color descriptions, which comprise the hue, value/chroma and color of the mounted samples, were obtained by visually comparing them to those of standard surface sediments recorded in the Munsell Soil Color book (1992). Optical microscopy technique was used for descriptive analyses of the tailings dump and the non-clay fraction of the surface sediments. A Leitz Ortholux II Pol-BK petrographic microscope was used for the analyses.

The pH and Electrical Conductivity

Van Reeuwijk (1993), Okalebo *et al.* (1993) and Barnard *et. al.* (1990) described the methods for pH and EC analysis of soils. Finely ground/pulverized soil samples were used for pH and EC determination. Aliquots of 2.5 g of sample were placed in three centrifuge tubes and suspended in 25 ml of distilled H_2O. After shaking on a horizontal shaker for about 30 minutes, the tubes were centrifuged for five minutes. Average values were calculated and recorded for each sample analyzed. The pH and EC of the supernatant of the samples were analyzed with a Jenway 3020 pH meter and a Jenway 4020 EC meter. The temperature of the samples at the time of analyses was recorded.

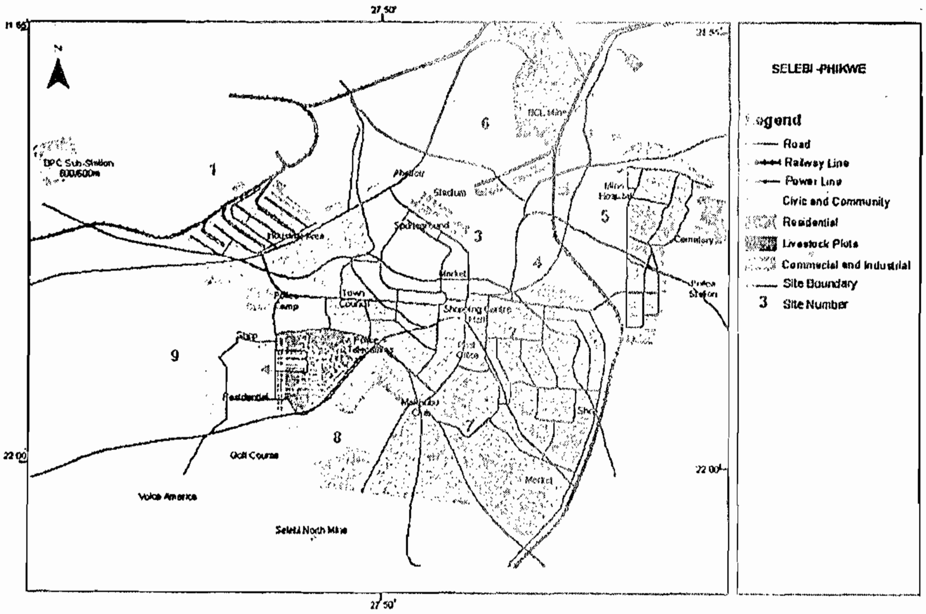


Figure 2: Map of Selebi Phikwe showing the different sampling sites

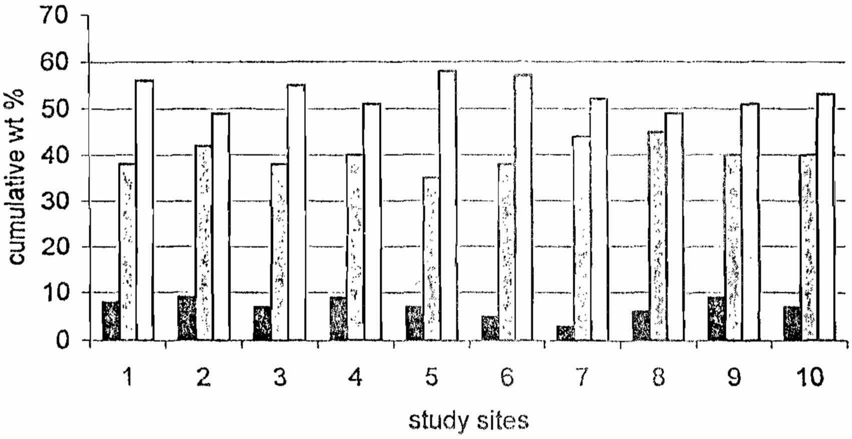


Figure 3: Mean cumulative wt % of clay, silt and sand fractions of samples. (Note that for each study site in the figure, the first bar is for clay, the second is for silt and the third is for sand).

Analysis of Exchangeable Cations

The CEC of the surface sediments was determined using the barium chloride-triethanolamine $(BaCl_2\text{-}CH_3\text{-}CH_2OH)_3N$ method which is described in Inglethorpe *et. al.*, (1993), and also described in Ma and Eggleton (1999). Five grams of soil sample were put in 100 ml centrifuge and buffered with $BaCl_2$ for an hour with four or five stirrings periodically. The centrifuge tube was set to make 30 000 rounds at 2000 rpm. After centrifuging, the supernatant was decanted and an additional 100 ml of $BaCl_2$ added. All the unabsorbed ions of Ba were washed off using deionized water. 100 ml of 0.05 M $MgSO_4.7H_2O$ was added to each of the weighed contents in the tube and the mixture was allowed to react for at least two hours. Centrifuging of the mixture was done for another hour, and 10 ml of the supernatant was collected into a 100 ml conical flask. Twelve drops of 1M NH_3 of SG 0.91 and six drops of catechol violet indicator were added to the suspension, which was titrated with 0.02 M Di-Na EDTA. The CEC was calculated from the titrant values.

RESULTS

Granulometric Analyses

Based on the classification scheme of particle sizes for the *Association Internationale Pour Les Etudes d'Argiles* (AIEA) (International Association for Study of Clay Minerals), particles that are ≤ 2 μm in euhedral spherical diameter (esd) are classified as clay, particles that are > 2 μm ≤ 50 μm are taken to be silt, and particles > 50μm ≤ 250 μm are considered to be sand. Particles > 250 μm were discarded because their mineralogy is mainly grain quartz which does not affect the chemistry of the surface environment (Kralik, 1999).

The distibution pattern of soil particles showed an apparent homogeneity within the study area, althogh slight variations were detected. The mean wt % for the soil samples occurred at between 100 μm and 120 μm. Average trend of distribution of particles revealed clay fraction to be between 3 and 9 wt %

Table 2: Descriptive petrography of minerals contained in tailings dump from the Selebi Phikwe Ni-Cu orebodies.

Mineral	Hard- ness (Mohr scale)	Cleav age	Fracture	Color	Streak	Lustre	Crystal appearance
Actinolite	5 - 6	Good	Uneven to subconchoid	Light to blackish green	White	Vitreous	Monoclinic
Albite	6 - 6.5	Distinct	Uneven	White to colorless	White	Vitreous to pearly	Triclinic
Cristobalite	7	None	Conchoidal	Color-less to gray	White	Vitreous	Tetragonal
Chalcopyrite	3.5 - 4	Poor	Uneven to conchoidal	Brassy yellow	Green to black	Metallic	Tetragonal
Malachite	3.5 - 4	Good	Uneven	Emerald green	Light green	Vitreous to silky	Monoclinic
Pyrite	6 - 6.5	None distinct	Conchoidal to uneven	Pale yellow	Green to black	Metallic	Cubic
Pyrrhotite	3.5 - 4.5	None	Uneven to subconchoidal	Bronze yellow	Dark gray to black	Metallic	Hexagonal
Tremolite	5 - 6	Good	Uneven lo subconchoidal	Colorless white	White	Vitreous	Monoclinic
Pentlandite	3.5 - 4	None	Uneven to conchoidal	Light bronze yellow	Bronze to brown	Metallic	Isometric

with a mean of 7 wt %, silt portion to be between 34 and 44 wt % with a mean of 39 wt %, and sand portion between 47 and 63 wt % with a mean of 51 wt %. The wt % of clay size fraction along study sites was almost uniformly distributed as revealed in Figure 3. The mean PSD curves of soils from the ten sites are given in Figure 4. Sites two, four and nine were the most clayey sites with mean average of 9 wt %. These sites were close to water runways and a stream (site nine) where leaching of ions for clay mineral formation was prevalent. Clay contents in sites six, seven, and eight were less than the mean wt % of clay at the study area. The 7 wt % of clay in soil samples from sites three, five and ten corresponded to the mean wt % of clay fraction at the study area.

The siltiest samples were from sites two, seven and eight with values which approached 44 wt %, whereas the least silty samples were from site five with 35 wt % as indicated in Figure 3. The sites where the siltiest samples were found were located near gravelled motorways where particle reworking had been promoted by traffic as well as other factors, such as wind, rain and topography. The silt fraction obtained from soil samples at sites one, four, nine and ten were consistent and approximated at 40 wt %. The values for silt fraction from sites three and six exceeded 35 wt % but were below 40 wt %. Sites five and six shown in Figure 4, were the most sandy and site two was the least sandy, with a value of 47 wt %. All other sites had mean values of their sand fraction to between 48 wt % and 58 wt %. Trends in sandiness of surface sediments samples deviated slightly from trends for silt and clay fractions of the samples.

Descriptive Petrography and Color Determination

Hand specimens viewed with a microscope and physical tests performed on the samples for hardness, cleavage, fracture, color, streak, lustre, and crystal appearance depicted albite, cristobalite, chalcopyrite, pyrrhotite, tremolite, and pentlandite in the samples. Small, dark and brassy yellow pseudo-tetragonal crystals of chalcopyrite and acircular green films of malachite could visibly be detected as mineral constituents of the tailings dump.

Actinolite, $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$; albite, $NaAlSi_3O_8$; cristobalite, α-SiO_2; chalcopyrite, $CuFeS_2$; malachite, $Cu_2(CO_3)(OH)_2$; pyrite, FeS_2; pyrrhotite, $Fe_{(1-x)}S$; tremolite, $Ca_2Mg_5Si_8O_{22}(OH)_2$; and pentlandite $(Fe,Ni)_9S_8$ were identified and have been described as observed petrographically in Table 2. Hand specimen of the tailings dump samples, observed by using a hand lens, showed sub-angular quartz grains and crystals of grayish green amphiboles. These mineralogical observations are in conformity with previous work (Nkoma and Ekosse, 1999; 2000).

The quartz grains of surface sediments were poorly sorted, and were subangular at the sites close to the smelter/concentrator plant. Further away from the plant, where wind blown fluvially deposited particles were found, the grains were well sorted, semi-rounded to round. When observed under the microscope, the surface sediments were generally semi-rounded to rounded with low to high sphericity in shape. The quartz grains, which constituted part of the surface sediments, were angular to subangular with high sphericity.

The surface sediments had varied color distribution pattern ranging from pale yellow, reddish yellow to dark reddish brown. A summary of the surface sediments color according to the study sites is given in Table 3. The surface sediments from sites four, five, six and seven were light colored compared to those from the other sites. Whitish gray to reddish gray

Table 3: Color distribution pattern of representative surface sediments samples from the sites of the Selebi Phikwe study area.

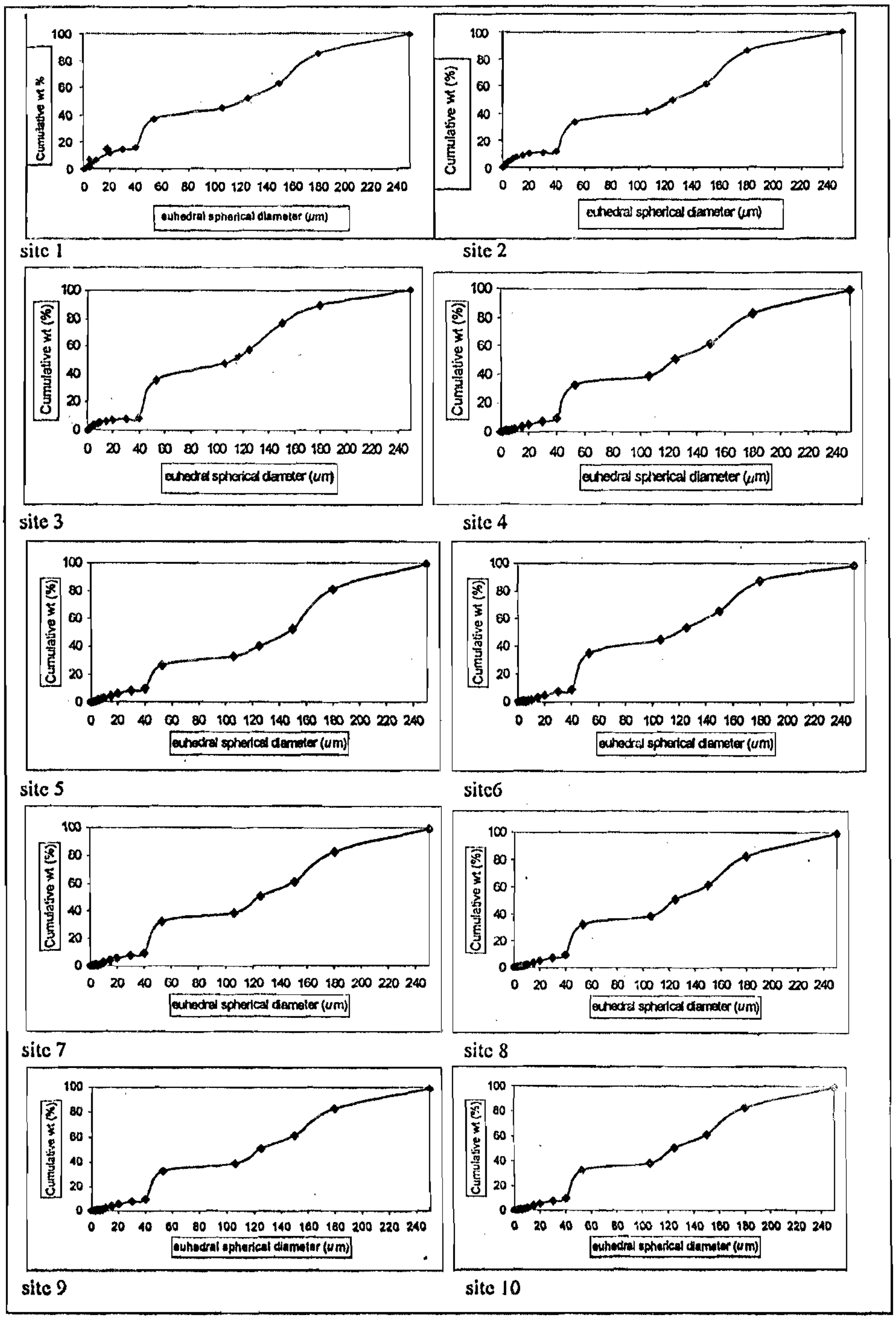
Site Number	Hue	Value/Chroma	Color
1	7.5 YR	5/8	Strong brown
2	5 YR	¾	Dark reddish brown
3	10 R	6/3	Pale red
4	7.5 YR	7/6	Reddish yellow
5	10 YR	7/6	Yellow
6	10 YR	8/3	Very pale brown
7	7 YR	7/6	Reddish yellow
8	10 YR	8/4	Very pale brown
9	10 YR	¾	Dark reddish brown
10	10 YR	3/1	Very dark gray

precipitates were found on soils close to the smelter/concentrator plant. In areas where surface sediments were tinted with whitish gray precipitates, the strong smell of sulphur was detected, and there was no vegetation cover. At sites nine and ten, the surface sediments were dark reddish brown and very dark gray; dark color being influenced from organic matter deposition resulting from decayed plants and fluvial activities. Cement, sand and concrete formed an integral part of the surface sediments at the control site.

The pH and Electrical Conductivity

The average pH and EC values at ambient temperature, for the soil obtained from all the sampling sites are given in Figure 5. The pH values ranged from 3.5 to 9.0. Slightly basic to basic pH values were obtained from surface sediments from sites seven, eight, nine and ten. The pH values obtained for samples from sites three, four five and six were prominently lower than those for samples from other sites of the study area.

The samples obtained from the ten sites of the study area were grouped into three based on their EC values. Samples from sites four and five had EC values, which were $< 50\ \mu\ \mathrm{Scm}^{-1}$. Samples obtained from sites one, two, seven, eight and nine had EC values $\geq 50\ \mu\ \mathrm{Scm}^{-1} \leq 150\ \mu\ \mathrm{Scm}^{-1}$. The third group of samples was obtained from sites three, six and ten and had EC values $\geq 100\ \mu\ \mathrm{Scm}^{-1} \leq 250\ \mu\ \mathrm{Scm}^{-1}$.



site 1

site 2

site 3

site 4

site 5

site6

site 7

site 8

site 9

site 10

Figure 4: Mean cumulative frequency distribution of representative soil samples from the study sites

Cation Exchange Capacitance

The CEC values of the soil samples were between 2 meq/100 g and 20 meq/100 g (Figure 6), which is typical of 1:1 clay minerals that are found dominantly in kaolinitic surface sediments. The mineral content of the soils could have included minor/trace quantities of 2.1 clay minerals such as smectite and illite. It should be pointed out that the soils from site eight had a remarkably low CEC; with an average value of ≤ 2 meq/100 g. The soils from sites one, three and six had CEC values slightly higher than15 meq/100 g.

The average CEC value for site one was 20 meq/100 g, site three was 16 meq/100 g and site six was 17 meq/100g. With low pH values and high CEC values for soils from site six, it is likely that acidification could have taken place significantly more compared to other sites of the study area.

DISCUSSION

Granulometric Influence on the Environment

The PSD of soil samples revealed the < 2 μ m fraction (clay fraction) to be in the range of 3 and 9 wt %, the > 2 μ m to < 50 μm fraction (silt fraction) was between34 and 44 wt %, and the > 50 μ m to < 250 μ m fraction (sand fraction) was between 47 and 63 wt %. This observed uniformity of PSD created equal opportunity for ions of heavy metals to migrate and to adhere to the clay fraction; thereby promoted similar soil contamination trends. Distance of source of contaminants may have played a major role at determining the quantitative aspects of the contaminants in the soils. Grains were poorly sorted, with subangular grains located further from the plant, which is indicative of windblown particles transported at a short distance (Ringrose et. al., 1995). Finer particles from the tailings dump could be windblown to distant environments, and eventually affect the ecosystem.

Environmental Aspects of Descriptive Petrology and Color

The grains of tailings dump observed at Selebi Phikwe were subangular, depicting limited transportation from source (Bain et. al., 1995), and also indicative of less aggressive leaching activities taking place (Singh et. al., 1999). Mineral ore bodies and tailings dump release particles to the atmosphere through convectional forces with wind energy as vector agent (Buseck and Posfai, 1999). Smelting processes release gases. Most significant are wastes released from tailings dump into the surface sediments, which eventually influence the concentrations of heavy metals contained in living organisms (Kozák et. al., 1995). Due to the fact that tailings dump are main sources of acid mine drainage (AMD) (Galan et. al., 1999), adequate control measures are necessary in limiting the spread of contaminants in the surrounding environments. The steps obviously taken by the mining authorities in containing their tailings dump are in conformity to basic principles of environmental management of tailings dump as described to by Galan *et al.* (1999), and Jambor and Bowles (1998).

The color of soils reflects Fe content (Dixon, 1989), which is contained in pyrite and pyrrhotite (Nkoma and Ekosse, 1999; 2000). Color changes influence variation in mineral and chemical compositions of the soils (Tan, 1996). Whitish gray sediments in some soil samples were due to precipitation from saturated ions of dissolved salts rich in heavy metals (Robertson et. al., 1997; Shaw et. al., 1998). In these environments, the surface sediments were deprived of vegetation cover and dead zones formed. Remaining aggregates used during road construction, which were not removed from the area, have weathered, and might also have influenced surface sediments color at the control site.

Influence of pH and Electrical Conductivity on the Environment

The pH of soils ranged from 3.5 to 9.0 with very acidic soils located close to the smelter/concentrator plant. The low pH values at these sites (three, four, five and six), could be attributed to their closeness to the smelter/concentrator plant, the tailings pond and the tailings dump where very high concentrations of SO_4^{2-}, Cd, Co, Cr, Cu, Fe^{2+}, Ni, Se, and Zn as described by Bowles *et. al,* (1998), occur. Very high concentrations of Fe^{2+} and SO_4^{2-} increase acidity in the environment, and there is the tendency of acid expansion due to probable depletion of the acid-neutralizing capacity of the soils (Shaw et. al., 1998). Eventually, the pH values at sites seven, eight, nine and ten could drop as the surrounding soils are contaminated with heavy metals.

High acidity could favour the leaching of heavy ions from the tailings dump and related mining waste to the soils. High acidity of soils is reflected by on-going acid mine drainage (AMD) activity which is depicted by areas of poor or no vegetation cover and are referred to as dead zones (Hantong-Fong et. al., 1997). A similar phenomenon occurred at the Ni mine area, near Sudbury, Ontario, Canada (Hantong-Fong et. al., 1997). Low pH of soils, furthermore, could promote the leaching and precipitation of ions including those of heavy metals namely Cd, Co, Cr, Cu, Fe, Ni, Se and Zn. The pyrrhotite (Fe_7S_8-FeS) and pyrite (FeS_2) in the tailings dump as explained by HolmstrÖm and Öhlander (1999) and HolmstrÖm *et al.* (1999), are oxidised on exposure to water to form sulphate and sulphuric acid

Electrical conductivity values obtained for the soil samples

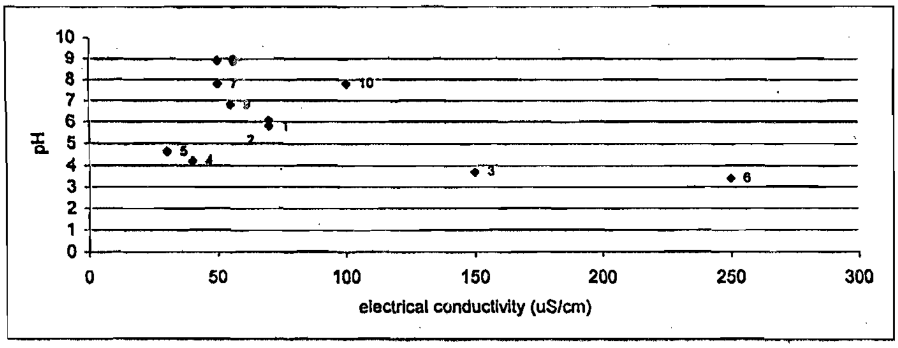


Figure 5: Average pH and electrical conductivity values of whole surface sediments samples from the different sampling sites at the Selebi Phikwe area. (Note numbers in graph depict sampling sites).

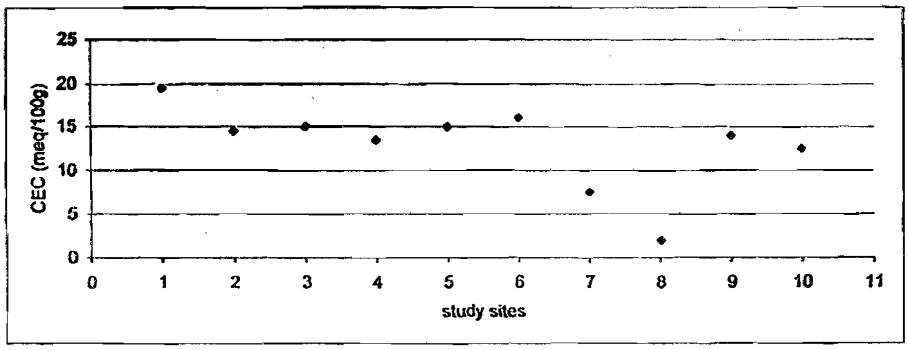


Figure 6: Average values of CEC of whole surface sediments samples from the different sampling sites at the Selebi Phikwe area.

were significantly low, and ranged from 50 μ s cm^{-1} to 250 μ Scm^{-1}. The amount of total dissolved solids (TDS) in soils can be estimated from their EC values (Murray, 1986). The EC is used to estimate the presence of dissolved salts such as sulfates, carbonates, phosphates and chlorides. The TDS of given sample may not be reflected by its pH because the salts are generally neutral. Soils with low pH correspondingly had low EC.

The rocks become acidic in a low pH environment, leading to precipitation of ions including those of heavy metals. Pyrhotite (Fe_7S_8-FeS) and pyrite (FeS_2) in tailings dump are oxidized on exposure to water to form sulphate and sulphuric acid as indicated in equations 2 and 3 (Al et. al., 1994; 1994a; Benner et. al., 1997; Bowles et. al., 1995):

$$2FeS_2 + 16H_2O \rightarrow 2FeSO_4 + 2H_2SO_4 + 14H^+ \quad (2)$$

$$4FeSO_4 + 10H_2O + O_2 \rightarrow 4Fe(OH)_3 + 4H_2SO_4 \quad (3)$$

The acidification reactions could be accelerated by the bacterium *Thiobacillus ferroxidans*, the absence of neutralizing minerals such as calcite ($CaCO_3$), and release of heavy metals into their ionic state (Bowles *et. al.*, 1998). Piles of tailings dump stay for years probably without proper disposal. During stockpiling, ions of heavy metals leached into the soils and water bodies, and could eventually be absorbed by plants.

Influence of Cation Exchange Capacity on the Environment.

The CEC values for soil samples obtained were between 2 meq 100g^{-1} and 20 meq 100 g^{-1}. These values are typical for kaolin minerals intercalated with smectites in soils (Dixon, 1989). Samples with high EC also contained illite. Finer clayey particles tend to adsorb heavy ions of elements on their surfaces as demonstrated by Song *et al.* (1999). In the soil samples, fewer exchange sites resulted in a low CEC for ions adsorbed on the surfaces of the soil particles, consequently they remained in solution and are bioavailabe for plant uptake.

Values obtained for CEC at the study area reflected cation exchange sites for ions of heavy metals to either have been adsorbed on the surface of clay mineral structure, or absorbed by isomorphous substitution. Whereby heavy metal ions are either adhered on or absorbed into the clay mineral structure, the surface sediments were contaminated with the corresponding heavy metals, and eventually got polluted.

CONCLUSIONS

This study has attempted to petrographically and physico-chemically characterise the tailings dump and soils surrounding a Ni-Cu mining and smelting environment in Botswana. The primary objective was to establish any influence on the environmental physico-chemistry as a result of mining/smelting activities. Physico-chemical analyses which included particle size distribution (PSD), pH, electrical conductivity (EC), cation exchange capacity (CEC), color and descriptive petrography on samples of tailings dump and soils were performed in order to understand the significance of these properties on the surrounding physical environment.

Results depicted in-put of contaminants from tailings dump and mining/smelting activities to the soils. High acidity of soils is reflected by on-going acid mine drainage (AMD) activity which is depicted by the formation of dead zones. Pyrrhotite (Fe_7S_8-FeS) and pyrite (FeS_2) in tailings dump are oxidized on exposure to moist environments forming sulphate and sulphuric acid. Fewer exchange sites have resulted in a low CEC for ions adsorbed on the surfaces of soil particles; consequently they remain in solution and are bioavailabe for plant uptake. .

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