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## Spatial Distribution of Iron in Soils and Vegetation Cover Close to an Abandoned Manganese Oxide Ore Mine, Botswana

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**Abstract:** This study aimed at establishing the spatial distribution of iron (Fe) in soils and vegetation cover within the periphery of the Kgwakgwe Manganese (Mn) oxides ore abandoned mine in Botswana. Four hundred soil samples and two hundred vegetation samples were obtained from a 4 km<sup>2</sup> area close to the mine. Determination of Fe concentrations after acid digestion of samples was performed using an atomic absorption spectrometer equipped with a deuterium background correction. Tests for soil pH and soil colour were complementary to soil chemical analysis. Results were processed using Geographical Information Systems (GIS) and Remote Sensing (RS) techniques with integrated Land and Water Information System (ILWIS), Geosoft Oasis Montaj, ArcGIS and Microsoft Excel software packages. Concentrations of Fe in soils was from 1116.59 to 870766.00  $\mu\text{g g}^{-1}$  with a mean of 17593.52  $\mu\text{g g}^{-1}$  and for leaves, levels were from 101.2 to 3758.09  $\mu\text{g g}^{-1}$  with a mean of 637.07  $\mu\text{g g}^{-1}$ . Soil pH values ranged from 2.92 to 7.26 and soil colour shades ranged from yellowish red to very dark grey. Gridded soils and vegetation maps show Fe anomalies in different parts of the study area. Values were low in areas located at the mine workings and in the Northwestern part of the study area and high in the north and southern part. Where concentrations of Fe were high in soils, correspondingly high figures were obtained for vegetation cover. Similar trends were obtained for soil pH distribution in the study area. Bedrock geology, topography, Mn mineralization, soil acidity and prevailing oxidizing conditions were governing factors that influenced the concentration and spatial distribution of Fe in the soils and vegetation. The findings further confirm that Fe distribution and its chemistry in the soils and environment around the Kgwakgwe abandoned Mn oxides ore mine have affected the vegetation cover.

**Key words:** Atomic absorption spectrometry, bedrock geology, contamination, Fe concentrations, geographical information system, Mn mineralization

### INTRODUCTION

Kgwakgwe, the study area, is located between latitudes 24°59' and 25°02' and longitudes 25°17' and 25°20' within the periphery of Kanye township, southeastern Botswana (Fig. 1) a semi arid to arid country. The geology, genesis and mineralogy of the rocks and sediments of the Kgwakgwe area have been established (Aldiss, 1986; Aldiss *et al.*, 1989; Carney *et al.*, 1994; Ekosse, 2001; Ekosse and Shemang, 2002; Gabaake, 1987; Modisi, 1995; Tombale, 1986). Its geology (Fig. 2, 3 and Table 1) spans from 2780 Ma to 1700 Ma±40 mA (Aldiss *et al.*, 1989; Ekosse, 2001). The Black Reef Quartzite Formation (BRQF) is the lowest stratigraphic unit of the Transvaal Supergroup and overlies the rhyolites of the Kanye Volcanic Formation (KVF) with unconformity. The Kgwakgwe Chert Breccia Formation (KCBF) directly overlies the Kgwakgwe Shale (KS) which consists of subunits of manganiferous and ferruginous

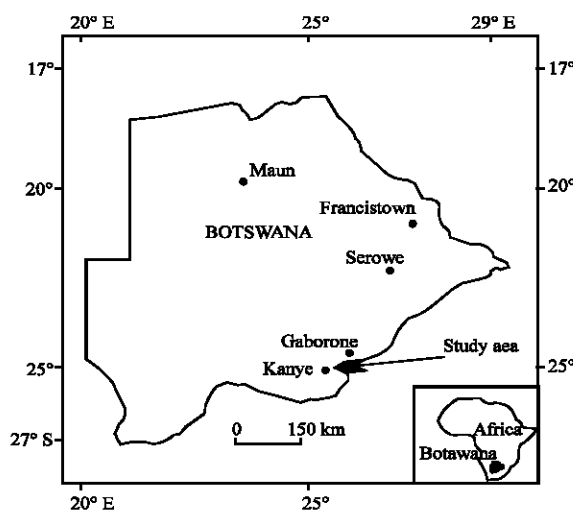


Fig. 1: Map of Botswana showing location of proposed study area

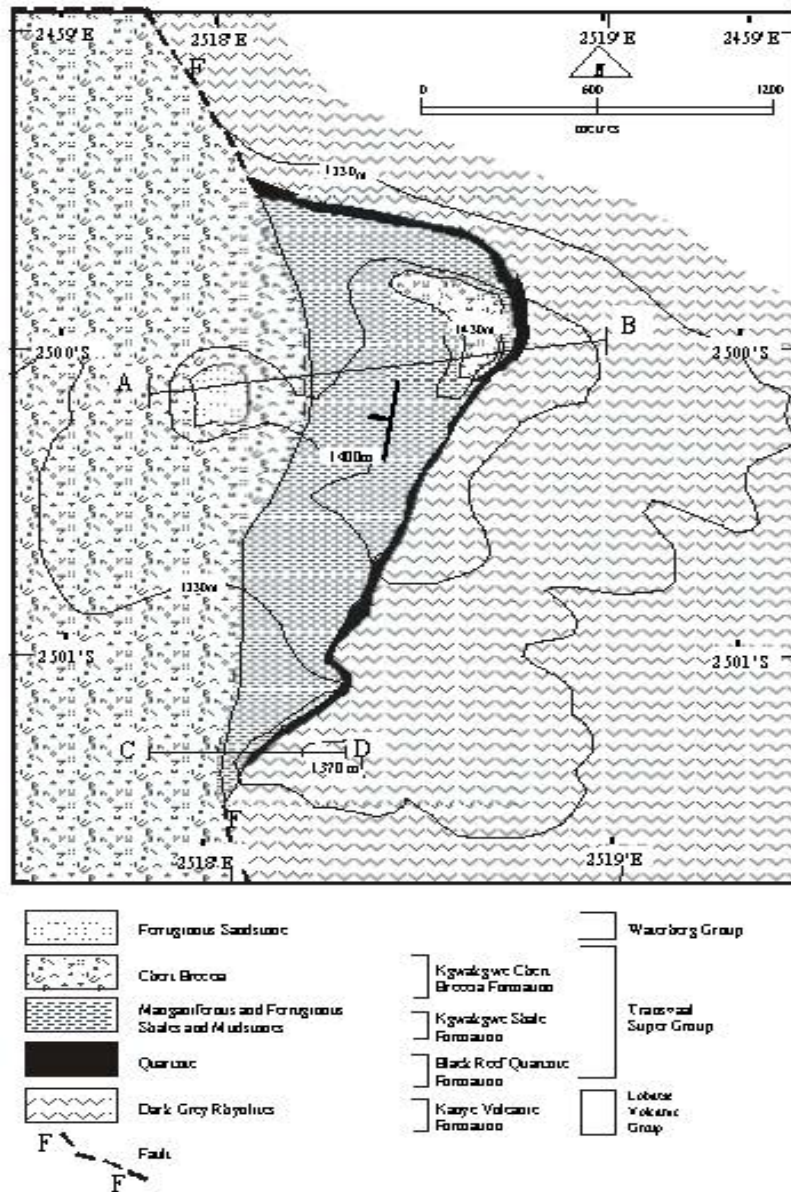


Fig. 2: Geology map of the Kgwakgwe basin (Ekosse and Vink, 2001)

shales. The BRQF, the Timpone Dolomite Group (TDG) and the KCBF dip about 10° to the WNW. The KCBF is partially overlain by the younger sandstones of the Waterberg group.

Kgwakgwe area adjoins Kanye township, which is situated on a plateau with an altitude ranging from 1300 and 1400 m above mean sea level. The plateau consists of igneous rocks and makes contact with dolomitic plains, part of which this study area covers. Elongated hills on

the eastern edge of the dolomite complex area are formed by pinkish to whitish quartzites of the Black Reef Quartzite Formation. Chert breccia caps most of the hills around Kgwakgwe. The dolomitic rocks, which are less resistant to weathering, become predominant in the flat areas. Quite distinctly are the positive relief chert rich dolomites, which alternate with the negative relief chert free dolomites. The Transvaal Dolomite has been identified in the study area as the main aquifer body.

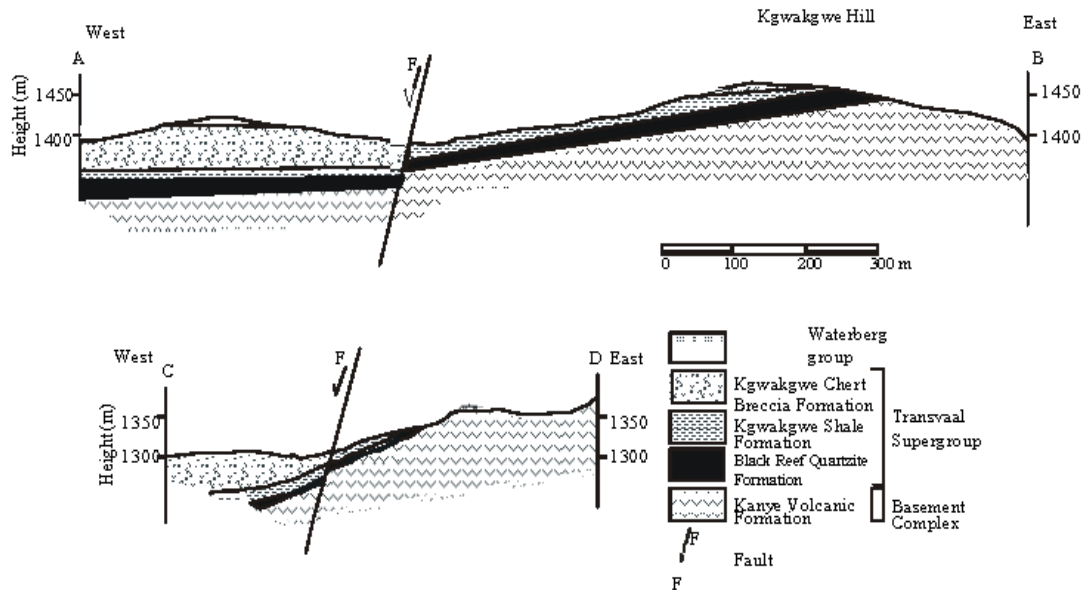


Fig. 3: Cross section of A-B and C-D in Fig. 2 (Ekosse and Vink, 2001)

Table 1: Lithostratigraphy of the Kgwakgwe basin (Modisi, 1995)

Lithology	Formation	Group	Supergroup	Age (Ma)
Sandstones		Waterberg		1700
Chert clast breccia	Kgwakgwe Chert Breccia	Taupone dolomite		
Vanicolored manganeseiferous and ferruginous shale	Kgwakgwe Shale (KS)		Transvaal	2500
Quartzite, shale conglomerate	Black Reef Quartzite (BRQF)			
Feldspathic rhyolites	Kanye Volcanic	Lobatse Volcanic (LVG)		2780

No prominent surface river is found in the study area. Excessive run-off of storm water after torrential rains are typical of the environment. Cattle and game drink from stream water, which may contain high concentrations of Mn. During the dry season, the streams are void of running water. Small streams in the area constitute part of the drainage system. The margins of the drainage channels on the flat lying terrains have been affected very extensively by soil erosion. Several large areas have been rendered derelict due to erosional activities resulting in exposure of bedrock and the formation of gullies; some could be as deep as 3 m.

Manganese (Mn) occurrences at Kgwakgwe hill are associated with goethitic ochre and kaolin (Ekosse and Mulaba-Bafubiandi, 2003; Ekosse and Nkoma, 2002; Ianzincka, 1992), as well as ferruginous minerals namely hematite, Fe<sub>2</sub>O<sub>3</sub> and goethite, FeO<sub>2</sub>OH and manganese rich

minerals which include bixbyite, Mn<sub>2</sub>O<sub>3</sub>; cryptomelane, K<sub>2-x</sub>Mn<sub>6</sub>O<sub>16</sub>; ramsdellite, MnO<sub>2</sub>; pyrolusite, β-MnO<sub>2</sub>; and braunite, Mn<sup>+2</sup>Mn<sup>+3</sup>SiO<sub>12</sub> (Ekosse and Vink, 2001). During mining of Mn ore at Kgwakgwe, anthropogenic activities were carried out to the extent that aeolian, aquatic and terrestrial distribution of Fe bearing minerals (hematite and goethite) covered a wider area than the mining premises. Consequently, concentration levels of Fe in soils and vegetation cover within susceptible contaminated areas may have increased.

Due to complaints from residents of the Kgwakgwe area regarding decreasingly sparse vegetation cover, the researcher made several field visits to interact with the community in an effort of understanding the problems and suggesting ways of curbing it. The study area has lain fallow for several years without any particular land use. With rapidly growing and widely spreading population within the Kanye area and particularly shifting to Kgwakgwe, there is strong pressure from the local community land board for the allocation of more land including the one in question. A drawback though is its closeness to the abandoned Mn mine. Several related studies were therefore carried out in an effort to advise on possible land use (Ekosse and Fouche, 2005a). The focus of this particular work was to investigate Fe levels in the soils and vegetation with the primary objective of understanding its relative concentration, extent and spatial distribution.

Soil contamination with metals including Fe may disrupt the physical, chemical and biological balance of the soil (Alloway, 1990). Iron exists in many forms in soils and its soil content affects plant growth and promotes soil acidity (Ptacek and Bowles, 1992), which could lead to plant toxicity. Toxic effects occur primarily in acid soils (<pH 5.0). The first symptoms of Fe toxicity are necrotic spots on the leaves (Vitosh *et al.*, 1994). Symptoms are more severe in the older leaves that have had the longest time to accumulate Fe. With high levels of Fe, the symptoms can be most prominent in the younger leaves. Under Fe toxicity conditions, levels of cell Fe concentrations become very high, such that control of Fe activated enzymes is lost (Helyar, 2007) and plant biochemistry is upset to cause cell chlorosis, which could lead to death.

At the time of inception of the mining project at Kgwakgwe, no Environmental Impact Assessment (EIA) studies were conducted and no environmental mitigation programmes were put in place. Consequently, no decommissioning and no rehabilitation exercise were carried out. Negative effects have therefore emanated which apart from waste accumulation, often are sources of ecological danger. The soils, surface and ground waters, atmospheric air and vegetation become contaminated. Whereas findings on the environmental chemistry and mineralogy of Mn have been documented (Ekosse and Fouche, 2005b; Ekosse *et al.*, 2006), nothing has been reported on the same for Fe. This study aimed at investigating the concentration levels of and spatial distribution of Fe in the soils and vegetation cover occurring at Kgwakgwe.

## MATERIALS AND METHODS

**Sampling:** Sampling was done over a period of one month and there were two sampling areas, which included a chosen control site located 4 km south of the study area. The control site had an area of 900 m<sup>2</sup> (30×30 m). This control site was chosen because it was at the other side of a paleotopographic barrier where no Mn mineralisation is present (Ekosse and Vink, 1998). The soil lithology and vegetation cover at the control site were very similar to those of Kgwakgwe area. Detailed soil and vegetation grids of 2×2 km were established. Taking into consideration the financial resources which were available and the data point sets required to generate significantly detailed spatial representation of laboratory results, soil samples were taken at 100 m intervals and vegetation samples at 200 m intervals. The coordinates and the grids where soils and vegetation were sampled are reflected on

the satellite image and topographic map which were produced from the Quick bird 2.4-2.8 m resolution with zero cloud cover multispectral standard satellite image (Fig. 4a, b).

**Soil samples:** The soil types at the study area are ferric and calcic luvisols. The soils are characterised as moderate, moderate-well to well drained, brown to yellowish brown sandy loam to sandy clay soils (Mitchell, 1976; Reemelwaal, 1988). The bedrock geology of the Kgwakgwe area has already been discussed (Aldiss *et al.*, 1989; Camey *et al.*, 1994; Ekosse, 2001) and soils overlie the granitic, rhyolitic and doleritic rocks of the Basement Complex and dolerite intrusions. The soils at Kgwakgwe are considered to be high in Fe because of the ferruginous shales of the KS (Ekosse and Vink, 2001).

Random techniques highlighted by Jewell *et al.* (1993) and judgmental techniques described by Crépin and Johnson (1993) were used in obtaining soil samples from both the study area and the control site. Grab soil sampling method as explained by Tan (1996, 1998) was used to obtain the samples with the aid of a machete, a trowel and/or a shovel. Soil samples were taken at a depth of between 0 and 20 cm. A total of 400 samples were collected from the study site and nine samples from the control site for analyses. The obtained samples were placed in an oven at 60°C overnight for the release of surface soil moisture, prior to analyses.

**Vegetation samples:** Vegetation cover at the Kgwakgwe area includes acacia plants which include *Acacia tennispina*, *Acacia mellifera*, *Acacia karoo*, *Acacia hereroense*, *Acacia caffra* and *Acacia tortillis*. Other dominant species are *Combretum apiculatum*, *Euclea undulata* and *Terminalia sericea* (Timberlake, 1980). Interspersed areas of hardveld are covered with woodland and tree savannah type vegetation on less acid soils. These plants include *Rhus lancea*, *Rhus leptodictya*, *Ziziphus mucronata* and *Tarchonanthus camphorates*. However, the vegetation cover appeared to be sparse.

Vegetation samples in this study refer to leaves of *Combretum apiculatum*, *Euclea undulata* and *Terminalia sericea*. The leaves from the three types of plants were represented in equal proportions in samples that were analysed. Mature dark green leaves with leaf diameter ranging from 2 to 4 cm within both the study and control sites were harvested for laboratory analyses. Between 100 and 200 leaves depending on the leaf diameter, which constituted a sample set, were sampled per sampling area. A total of 200 sample sets from the

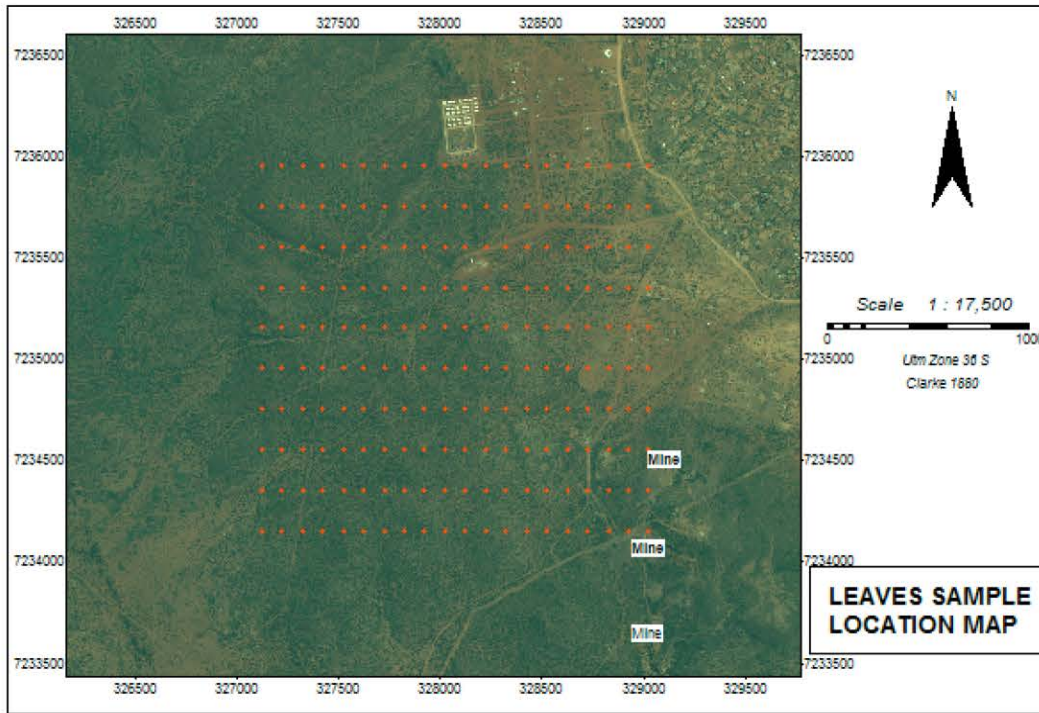


Fig. 4a: Satellite image showing location of vegetation samples

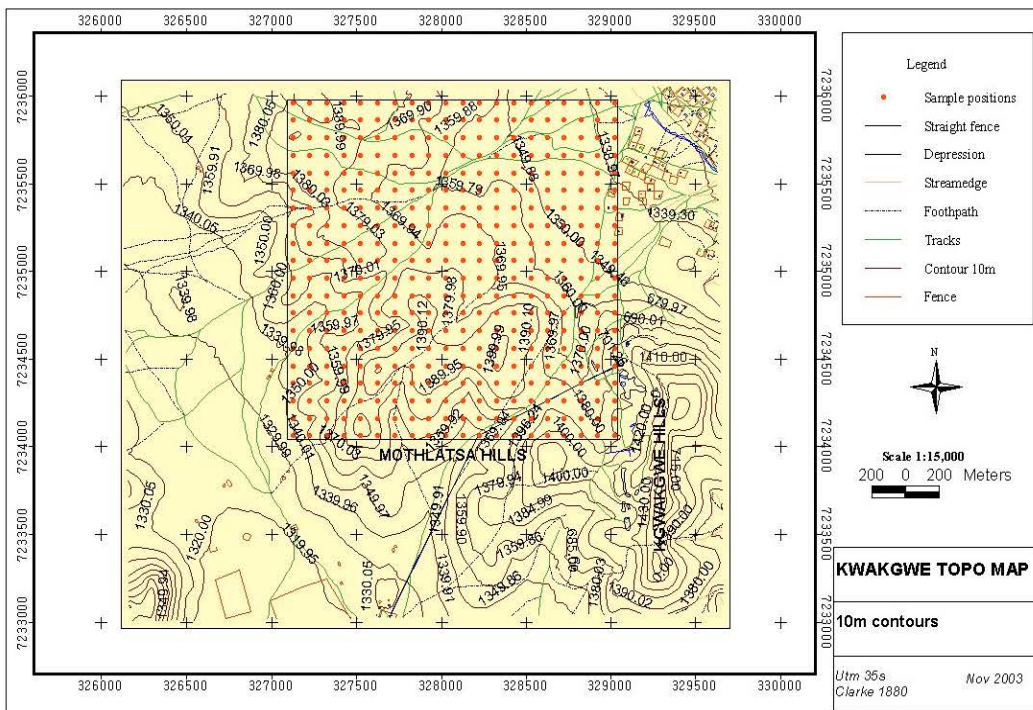


Fig. 4b: Topographic map showing location of soil samples

study area and four sample sets from the control site were obtained during the sampling period. Before laboratory analyses were performed, vegetation samples had to be aerated for one week or more, until there was release of moisture from the leaves.

**Chemical analyses and data interpretation using GIS:**

The determination of Fe concentrations in the soil and vegetation samples after acid digestion of samples was performed on a Varian Spectra AA-220 FS atomic absorption spectrometer (Varian, Australia) equipped with a deuterium background correction. The procedure for sample digestion is as reported by Jones and Case (1990) and Page *et al.* (1982). About two to three grams of soil or plant sample was weighed and dried at 110°C in an ecotherm<sup>e</sup> oven for four hours. The dry samples were manually ground using an agate pestle and mortar and then sieved through a stainless steel sieve with mesh aperture of 63 mm. 0.50 g of each sample was weighed into 250 mL pyrex conical flasks using an analytical balance. Ten millilitres of a 3:1 mixture of concentrated nitric acid (70 wt. %) and perchloric acid (70 wt. %) were added and then gently heated on a hot plate, with swirling to incipient dryness indicated by the production of dense white fumes of perchloric acid. It was then cooled to room temperature after which 10 mL of 0.5 M hydrochloric acid was added to dissolve the residues. The dissolved residues were filtered through a 0.45 mm cellulose nitrate filter membrane. The filtrate was quantitatively transferred into 50 mL volumetric flasks and made to the mark with ultra pure water. Iron was determined using Flame Atomic Absorption Spectrophotometry (FAAS) at 248.3 nm wavelength.

The data obtained with the Varian SpectrAA 220 FS AAS interfaced to Pentium 4 PC (Veriton 7500, Vic, Australia) was manipulated by the software, Spectr AA CFR (2001). The latter used the equation by Jones and Case (1990) to calculate concentrations of metal in  $\mu\text{g g}^{-1}$  of soil or plant sample. The concentration ( $\mu\text{g g}^{-1}$ ) values are accompanied by the errors expressed as Standard Deviation (SD) automatically generated by the software from which the percent Relative Standard Deviation (%RSD) were calculated.

Clayey aggregates of soil samples were separated using a mortar and pestle to single particles. With a spatula, the samples were mounted on white cardboard sheets and soil colour descriptions of the mounted samples, were obtained by visually comparing them to those of standard soils recorded in the Munsell Soil Color Book (1992). The pH of the soil samples were determined using the method described by Van Reeuwijk (1993).

Three main software packages were used for classification and processing of the data and these were ILWIS version 3.0 for processing satellite images, Geosoft Oasis Montaj<sup>TM</sup> for processing data and ArcGIS version 8.2 for the distribution map. The main aim of the distribution map was to use GIS so as to show location and spatial variation of Mn and Fe concentrations in the soils.

**RESULTS AND DISCUSSION**

**Results:** A summary of statistics of the results of analyses of Fe assays of soil and leaf samples from the study area is shown in Table 2 and these include median, mode, sum and count for Fe. The range of concentrations of Fe in soils was from 1116.59 to 870766.00  $\mu\text{g g}^{-1}$  with a mean of 17593.52  $\mu\text{g g}^{-1}$  and the range of concentration levels of Fe contained in the leaf samples was from 101.2 to 3758.09  $\mu\text{g g}^{-1}$  with a mean of 637.07  $\mu\text{g g}^{-1}$  and is shown in Table 2. Table 3 shows the concentrations of Fe in soils and leaves from the control area. As could be shown from Table 3, the concentrations of Fe in the control area were significantly lower than the mean concentrations of Fe in soils and leaves from the study site.

There were eleven different colours as classified in the Munsell Soil Colour Book (1992) which were observed and these were yellowish red, red, dark red, brown, reddish brown, dark reddish brown, dark brown, strong brown, dark reddish grey, very dark grey and light brown (Fig. 5). At the control site, only one colour was observed

Table 2: Statistical parameters for the iron concentrations of the soils and leaf samples from the study area

Parameters	Fe in soils	Fe in leaves
	----- ( $\mu\text{g g}^{-1}$ ) -----	
No. of samples	400	200
Type of distribution	Lognormal	Normal
Mean	17593.52	67.07
Standard error	2397.55	36.33
Median	14026.31	502.99
Mode	21256.5	197.99
Standard deviation	47950.98	513.84
Range	1116.59-870766	101.27-3758.09
Sum	7037406.42	127413.24
Threshold	22500	950

Table 3: Concentrations of iron in soils and leaves obtained from the control area

Sample No.	Fe in soils ( $\mu\text{g g}^{-1}$ )	RSD (%)	SD	Fe in leaves ( $\mu\text{g g}^{-1}$ )	RSD (%)	SD
One	7415.98	2.7	200.23			
Two	2547.42	3.4	86.61	296.43	2.2	148.00
Three	4884.91	2.9	141.67			
Four	7887.87	2.0	157.75	334.61	0.5	1.67
Five	2541.49	3.3	86.59			
Six	3281.71	3.4	111.58	444.89	2.6	11.57
Seven	7687.87	1.9	148.75			
Eight	2546.42	3.4	86.51	605.29	1.3	7.87
Nine	2551.49	3.4	86.61			

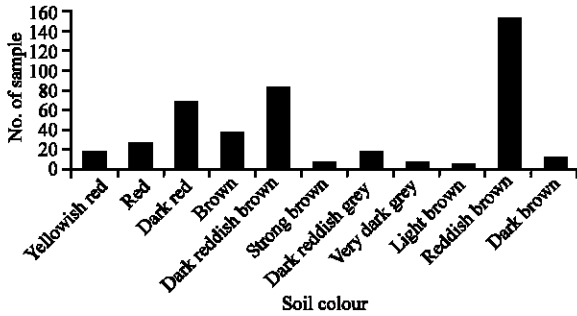


Fig. 5: Soil colour abundances in soil samples from the study area

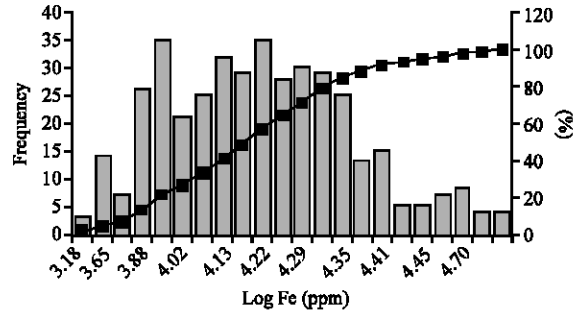


Fig. 7: Log Fe concentrations versus frequency in soil samples from the study area

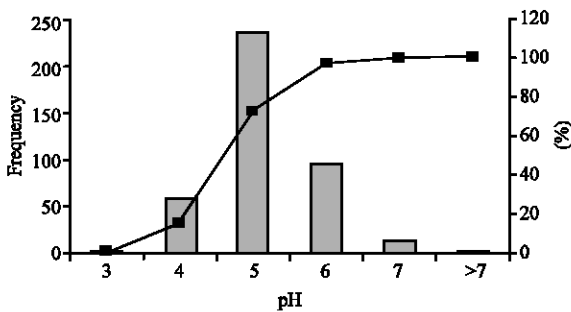


Fig. 6: The pH values of soil samples from the study area

for the nine samples and it was yellowish red. Soil pH values obtained for samples from the study area ranged from 2.92 to 7.26, with a mean of 4.64 (Fig. 6), whereas those from the control site ranged from 4.27 to 4.99. The values are distributed in a staggered plot with pH of 3, 4, 5, 6 and 7. The pH 5 is the most dominant one showing in 233 samples, followed by pH 6 with about 100 samples. The results depicted a strongly acidic to slightly acidic environment.

**Spatial distribution of iron in soil:** From Fig. 5, it is shown that only 15 soil samples were yellowish red which was the colour obtained for all the soil samples from the control site. Therefore, all the other ten colours of soil observed in the rest of the samples could have been a result of in put of wind blown particles and migration of Mn and Fe ions from the mining areas. Figure 7 shows the distribution of Fe concentrations as illustrated by the plot of frequency versus log Fe concentrations. The log normal distribution is polymodal in nature revealing at least three populations. Threshold is at 22500  $\mu\text{g g}^{-1}$  whereby there are about 47 points above this threshold value.

This distribution pattern is also demonstrated by a non contoured map (Fig. 8). Low Fe concentrations were prominent in the southwestern part of the study area to

the west of the mine workings whereas the medium to high Fe concentrations were observed in soil samples located further away from the mine workings. The low concentrations of Fe at the sites enriched with Mn could be attributed to the closeness of the mine workings and areas of topographic lows. Concentrations of Fe significantly increased as one moved away from the mine workings, Mn orebodies and stockpiles. This trend of Fe concentrations in soils was confirmed by the soil colour distribution pattern.

The colours reflected in the non contoured map presented in Fig. 8 as bluish, greenish, yellowish, brownish and reddish colour shades depicting different concentrations of Fe. Colour gradation reflected from blue for the low Fe concentration level progressively to green, yellowbrown, red and pink for the high Fe concentration level in the study site. From the mine workings, located in the southern part of the study area, the soils were dark coloured and the colour became lighter as one moved away from the workings. It was distinctly observed that the darker colours imparted on the soils of the area were as a result of the Mn oxide ore particles from the mine mixing up with the soils. In the northern part of the study area where no mine workings are located, the soils were yellowish red to light brown. At the control site, the soils were slightly light yellowish red.

Spatial soil colour distribution pattern was indicative of darker soil colours located close to the mine workings and to areas where Fe concentrations were high (Ekosse and Fouche, 2005b). Also in these areas, soil particles were relatively finer and clayey compared to the other areas (Ekosse *et al.*, 2006). Dark brown to reddish brown soil colour was indicative of very high Fe levels in the soils which were contributory to the low soil pH in the environment. Colour gradation in the non contoured map for soil pH (Fig. 9), is reflected from blue for the low soil pH values progressively to green, yellow, brown, red and pink for the high soil pH values in the study site. High acidity in this environment favoured the leaching of Fe



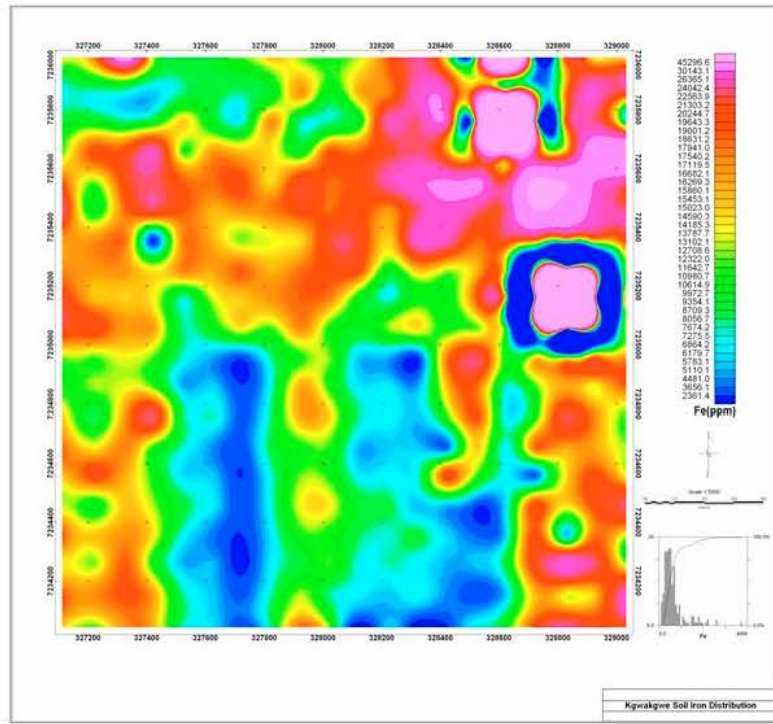


Fig. 8: Non contoured map of spatial distribution of iron concentration in the soils of the study area

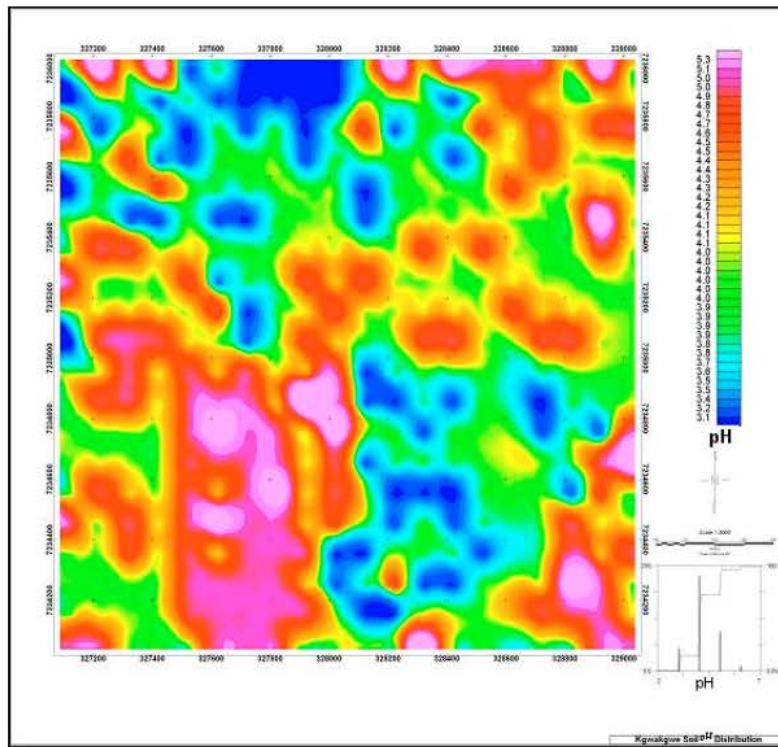


Fig. 9: Non contoured map of spatial distribution of the soil pH in the study area

ions from exposed geological outcrops constituting ferruginous shales as well as Mn oxide ore to the soils, consequently they remain in solution and are bioavailable for plant uptake.

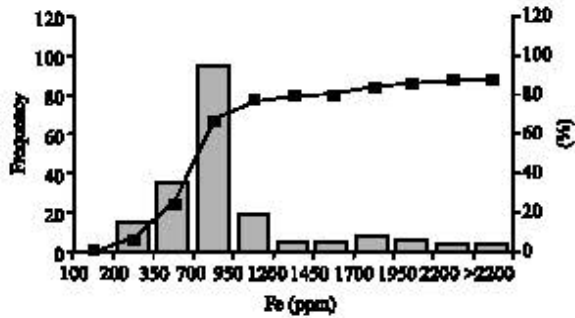


Fig. 10: Iron concentrations versus frequency in samples of leaves from the study area

**Spatial distribution of Fe in vegetation cover:** Iron concentrations in the samples of leaves obtained were significantly high as shown in the histogram in Fig. 10 and the non contoured map in Fig. 11. The Fe concentrations in the leaves display a unimodal normal with a skewness of 2.57. The distribution has a threshold around 950  $\mu\text{g g}^{-1}$  whereby there were 25 samples above the threshold level. The colours reflected in the non contoured map presented in Fig. 11 as bluish, greenish, yellowish, brownish and reddish colour shades were unevenly spatially distributed and depicted prograded Fe concentration levels. Colour gradation is reflected from blue for the low Fe concentration level progressively to green, yellow, brown, red and pink for the high Fe concentration level in the study site.

Low Fe concentrations in leaves were prominent in the southwestern part of the study area to the west of the mine workings whereas the medium to high Fe concentrations were observed in samples of leaves

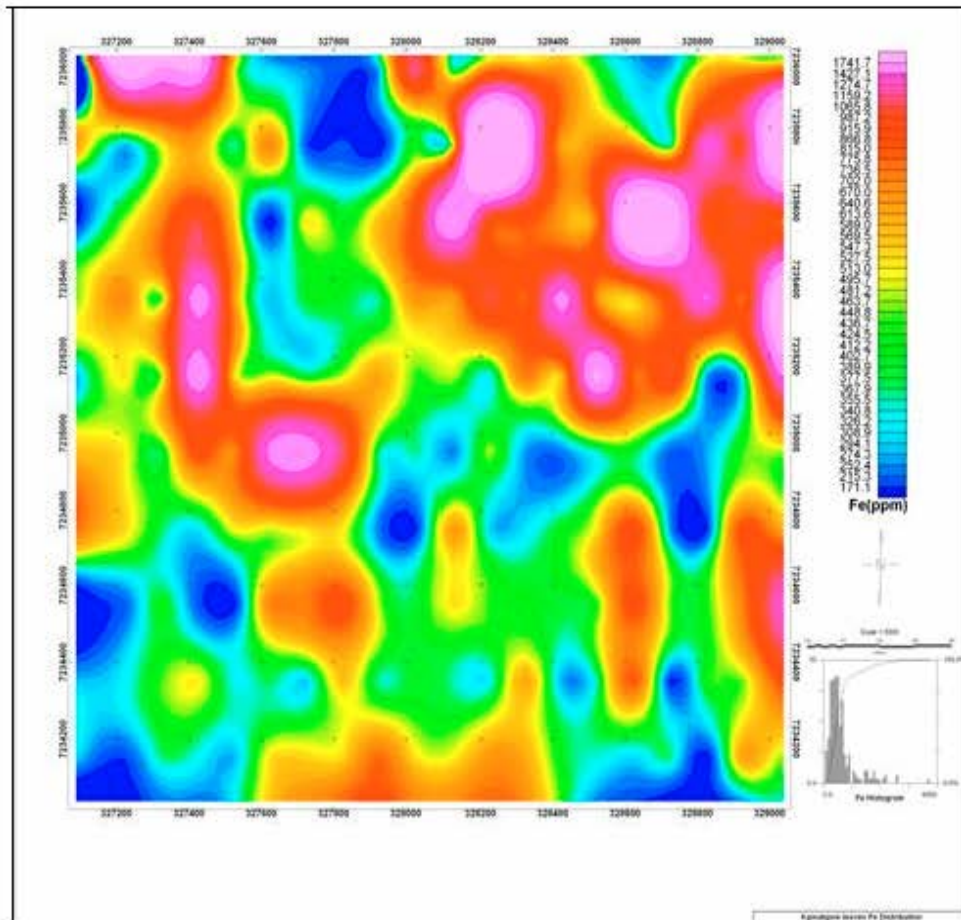


Fig. 11: Non contoured map of spatial distribution of iron concentration in the leaves from the study area

located further away from the mine workings as depicted on the non contoured map in Fig. 8. The low concentrations of Fe in leaves at the sites enriched with Mn could similarly be attributed to the closeness of the mine workings and areas of topographic lows. Similar to Fe concentrations in soils, those of vegetation cover significantly increased as one moved away from the mine workings, Fe- rich Mn orebodies and stockpiles.

Plant leaves changed in colour from light reddish yellow around the mine workings area to green in the valleys and close to settlements. Leaves of plants located at the periphery were more colour affected than others. Peripheral leaves were the first to alter in colour. Where discoloration of leaves occurred, it was noticed that the young leaves started out as green but changed progressively in colour to light reddish yellow and eventually to golden yellow. In areas where Mn oxide ore occurred and/or was mined, either there was no vegetation cover observed or the area was covered with sparse vegetation. In these mine working areas, the plants were stunted and conspicuously shorter than their distant neighbours within the study area and the control site. Mature leaves of plants in areas of darkly coloured soils were between 2 cm and 2.5 cm in length compared to areas where soils were light brown to yellow in colour with plants having fresh broad leaves exhibiting full growths both in colour (green) and length (6 to 7 cm).

**Environmental implications:** An attempt was made to correlate the Fe concentrations between the leaves and the soils. The correlation of Fe in leaves to Fe in soils was -0.02. There was a negative correlation between the Fe in the soil and in the leaves. The Fe concentration values in samples of leaves and soils from the study area were plotted and the graph presented in Fig. 12, reflected one major population with a couple of outliers.

Soil colour variation is an influence of changes in mineral and chemical compositions of the soil (Tan, 1996). The colour causing metals namely Fe and Mn held within the structural octahedral sites of the clay size fraction and particularly the clay minerals contained in the soils influence the colour of soils (Dixon, 1989). Consequently, clay minerals with octahedral sites taken over by these metals contain less structural water (Fellman, 1996) and hence will impart their colours in the soils. The soil colour at Kgwakgwe varied depending on the concentrations of Fe in the soils and reflects its content, which is, contained in the Fe minerals present in the soils (Ekosse and Modisi, 1999; Nkoma and Ekosse, 1999).

Medium to high pH values were prominent in the southwestern part of the study area to the west of the mine workings whereas the low to medium pH values were

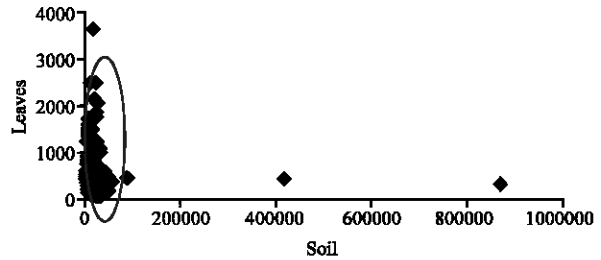
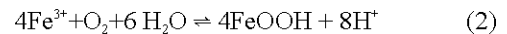
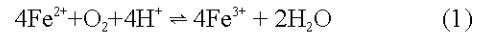


Fig. 12: Iron concentrations in samples of leaves versus soil samples from the study area

observed in soil samples located further away from the mine workings. However, low to medium pH values were also observed at sites considered to be more affected with Fe and Mn contamination. Low pH values at these sites could be attributed to their closeness to the mine workings and areas of topographic lows. In acidic oxidizing environments, hematite is easily altered to goethite as depicted in equations 1 and 2 as follows:



According to Bowles *et al.* (1992), very high concentrations of Fe and Mn ions increase soil acidity in the environment and there is the tendency of acid expansion due to probable depletion of the neutralising capacity of the soils (Shaw *et al.*, 1998). Eventually soil pH could drop as the surrounding soil acidity increases within the environment. According to Fouche (1979), acid cations such as  $\text{Fe}(\text{OH})^{+2}$  form complexes with organic materials. The high acidity in mining environments could influence the leaching of Ca and Mg ions caused by Fe/Mn replacement from the mine workings and Fe-rich Mn oxides ore bodies to the soils. At Kgwakgwe, high acidity favoured the leaching of Fe ions from exposed geological outcrops constituting ferruginous shales as well as Fe-rich Mn oxide ore to the soils, consequently they remain in solution and are bioavailable for plant uptake. Fe toxicity in plants can cause shortening of roots, leaf scorch, nutrient deficiency and increased vulnerability to insect attack. Unless removed completely from the soil, Fe will persist indefinitely (Roane and Miller, 1994). The effects of high concentrations of Fe in the soils at Kgwakgwe were reflected on the vegetation cover which was sparse, stunted growth and discolored leaves.

## CONCLUSION

This study has addressed the environmental mining impact of soils and vegetation around the abandoned Kgwakgwe Mn oxides mine, Botswana with special

emphasis on the concentrations of Fe. The concentrations of Fe in samples of soils and vegetation in the study area were significantly higher than levels obtained for samples from the control site. Complementary results from soil pH and soil colour further elucidated on Fe concentration and distribution in the Kgwakgwe soils. Spatial presentation and statistical results of chemical analysis depicted a similar concentration trends between Fe in soils and Fe in vegetation.

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