Chapter 4

Potential Environmental Sources of Lead Exposure to Pregnant Women in the Serowe Palapye District, Botswana

4.1 Abstract

The study aims to determine lead (Pb) concentrations in water (PbW), soil (PbS) and in clays (PbC) in the Serowe Palapye District and compare lead levels between major villages and small rural villages. Pb levels were also compared to international maximum permissible standards to assess potential health impacts on pregnant women. Samples were collected in two major villages (Palapye and Serowe) and two small villages (Lerala and Maunatla). Three cosmetic clays, 28 surface soils (top 2-5cm) and drinking water samples (the first flush water from drinking water taps) were collected and analysed using Varian AAS. The mean PbC (±SEM) was 3.99±0.41ppm compared to 0.27±0.03ppm and 0.19±0.02ppm in soil and water respectively. Mean PbS (±SEM) in Palapye, Serowe and small villages (Maunatlala and Lerala) were 0.57±0.068ppm, 0.28 ±0.049ppm and 0.22±0.019ppm respectively below the recommended international residential permissible soil standards. Mean PbW (±SEM) in Palapye, Serowe and small villages were 0.32±0.01 ppm, 0.25±0.010 ppm and 0.12±0.025ppm respectively, all in excess of the WHO drinking water quality permissible Pb concentration of 0.01ppm. Major villages, had significantly higher Pb concentrations ($p<0.05$) in soils and water compared to small rural villages. PbW concentrations by far exceed permissible WHO drinking water-quality standards and therefore present a potential exposure source for pregnant women. Measurement of blood lead levels (PbB) among pregnant women are recommended to assess potential relationship between BLL and environmental levels. Assessment of plumbing materials used in household and communal drinking water taps and the lining of communal water storage tanks is recommended. Educating the public on potential environmental sources of lead exposure including policy makers in order to influence policy change in addressing Pb pollution issues is needed.

Keywords—Lead; Drinking water, Soil, Central District, Botswana

4.2 Introduction

Lead, occurring in various concentrations in rocks and soils, is one of the most pervasive and persistent heavy metals posing threats to the environment, soil quality and human health.[1-6] In the environment, lead occurs both naturally and from human activities such as mining, smelting, production, processing, recycling and waste disposal activities as well as emissions from auto exhausts.[7,8]

ATSDR (2010) has identified six major environmental sources of lead which include leaded paint, leaded petrol, stationary sources, dust/soil, food and water.[9] There is consensus in scientific and medical literature that the primary route of exposure to lead in children is oral ingestion of lead-based paint and lead contaminated dust and soil. For adults, the primary route of exposure is inhalation of lead containing dust and fumes from occupational settings. There is also mounting evidence that population groups are exposed to lead through many other unconventional sources such as traditional medicines,[10,11] adult soil ingestion (geophagia),[12,13] cosmetics,[14] and many other sources.[15]

Lead polluted soils constitute a major environmental problem. In recent years, there has been an increased recognition that lead contaminated soils are an exposure source to humans. Soil can enter the human body through inhalation,[16] eating soil (geophagia),[17] and through skin lesions[18]. Lead has been reported as a greater risk factor for elevated blood lead levels than lead-based paint not only to children engaging in hand-to-mouth and pica behaviour, but also to pregnant women who engage in geophagia.[19-23] Women of reproductive age who have had significant lead exposures may experience decrease in fertility,[5,24] hypertension,[25,26] preterm delivery and low birth weight.[27,28] Pregnancy may accelerate the release of lead stored in the woman's bones to other parts of the body.[29,30] Because lead is freely transported across the placenta, fetuses of mothers with high body lead burden are potentially exposed to significant concentrations of lead during the course of the pregnancy[31]. This may result with damage to the developing fetus in any trimester, in part due to the placental permeability and immature fetal blood–brain barrier and may have lifelong negative impacts on the woman and the unborn child.[32]

Clays, naturally occurring inorganic components of soil, have traditionally been used by humans for different purposes ranging from cosmetics to medicinal use. Clay slurries have often been used for beautification purposes and applied to the face or body or even drunk to cure systemic problems[33]. In a recent study by Mbongwe et al. (2012) (unpublished), 18% of pregnant women used traditional clays for beautification and medicinal purposes[34]. These clays are rich in minerals and often contain hazardous heavy metals including,[35] lead hence in developed nations, compositional, technical and specifications of clays to be used for pharmaceutical and cosmetic purposes have been developed[36].

Lead in water (PbW) is an important pathway for lead exposure for several reasons. First water lead levels can vary from dwelling to dwelling due to the variations in plumbing types as well as social factors.[37-39] Pockock *et al*. (1983) and Elwood *et al*. (1984) further report that even in areas where there is non-plumbosolvent water, appreciable lead levels have been observed.[40,41] For example, relatively high water lead levels have been observed in hard water, which is normally considered to have low lead levels compared to soft water.[41] The second, and probably the most important reason why PbW is an important pathway for lead exposure is due to its relatively efficient absorption by the body compared to other sources. A study by Heard (1983) found that volunteers retained 40-50% of radioactive lead marker added to water[42]. Additionally, lead is adsorbed from water onto vegetables during cooking[43]. In the United Kingdom, where more studies have been conducted in water more than in any other source, it is further estimated that water, both in its direct form and indirectly through adsorption contributes on average to at least 10% of dietary lead.[44] Pocock *et al*. (1983) and Elwood *et al*. (1984) similarly estimated that about 7% and 23% respectively, of the variance in blood lead levels could be attributed to PbW[40]. A more than doubling effect on mean blood lead levels has been reported by other studies in areas of plumbosolvency and old pipes.[38,45] The third reason why PbW must receive close attention is because high lead levels occur more often in older housing properties as well as in less privileged areas.[46]

4.2.1 Study area overview and context

Botswana is a landlocked, semi-arid country with an approximate area of 582 000 km^2 and has a population of 2,024,904.[47] It is located in the centre of Southern Africa, bordered to the north by Zambia, to the northwest by Namibia, to the northeast by Zimbabwe and to the east and southeast by South Africa. The country is an almost plateau with an average altitude of 1 000m; elevation ranges between 700m and 1300m. The lowest parts of the plateau surface are Ngami area and swamps of the Okavango River in the northwest (Figure 1), the salty pans of Makgadikgadi in the northeast and the area between the Shashe and the Limpopo Rivers in the east (Figure 1). The Okavango and Chobe Rivers are the only perennial rivers with their sources outside the country (Figure1). Most of the rivers and valleys are ephemeral and usually dry except after rains.

The study area, Serowe Palapye, is located 22° 44' 53" S and 26° 47' 15" E in the Central Administrative District of Botswana (Figure 1) with a total population of 180,500.[47] It is home to the only coal mine in Botswana, the Morupule Colliery, which supplies a coal-fired Murupule Power Station of the Botswana Power Corporation. According to Central Statistics Office (2007), Botswana has over 212,383 million tonnes of coal resources out of which 48,576 million tonnes are classified as measured, indicated or inferred reserves and the rest is of either hypothetical or speculative resources[48]. More than half of the locally produced coal (60% in both 2004 and 2005) is used to fire the BPC thermal plant.[48]

Toxic elements maybe released during mining, beneficiation and usage of coal operations. There is an increasing concern for the effects of toxic elements associated with power plant residues from bottom ash and fly ash as well as emissions.[49,50] Lead is of environmental concern because it is dispersed from power plant emissions.[50] It is recognised that during combustion of coal, the redistribution of trace elements into fly ash and bottom ash should be ascertained for each power plant to ensure that relevant decisions are made about the management of the residues.[49,50] It is on this basis necessary to assess trace elements in the environment around power stations at least about 20 km from power stations to ensure that trace elements from coal mining and usage are not harmful to the environment and human health.[50,51]

Currently, very little work has been done in the Serowe Palapye District and near the Morupule Power Station on trace elements contamination on soils or water. Zhai *et al.* 2009 assessed the distribution of heavy metals including lead near Palapye and found moderate contamination of soils around Palapye area.[52] No studies have been conducted to assess lead concentrations in water.[53,54] The relevance of this research in the context of coal mining in the Serowe Palapye area can therefore not be overemphasized with particular reference to pregnant women who have a tendency to engage in geophagea which in turn may result with undesirable birth outcomes.

This study is part of a study to develop a clinical assessment tool for assessing lead exposure during pregnancy. The goal of this study is to determine lead levels in environmental samples from selected villages of Serowe Palapye Administrative District. Specifically the study seeks to determine the distribution of lead levels in soils, cosmetic clays and drinking water from Serowe, Palapye, Lerala and Maunatlala villages. The study further seeks to compare lead levels in each of the environmental sample matrices by location and assess potential impact on pregnant women based on soil and water standards. The standards and specifications (maximum allowable limits) are shown on page Table 4.1.

Table 4.1: Standards/specifications for cosmetic clays, soils and water (ppm)

Environmental medium	Standard	Source
Cosmetic/medicinal clays (kaolinite)	≤10	USP[55]
Soil (Residential)	140	CCME[56]
Water (drinking water)	0.01	World Health Organization[57]

4.3 Materials and Methods

4.3.1 Topograpy of the study site

To study the distribution of lead in soils and water from the Serowe Palapye District, we sectioned the study area to distinguish areas in the vicinity of the coal mining area and the power station and those further away. Figure 1 shows the study areas. Serowe, a major village with a population of 50,820 is located approximately 30 kilometres west of the Morupule Colliery. Palapye, a moderately industrial major village, is situated approximately 7 km to the east of the Morupule Colliery with the main road between Palapye and Serowe (A14) lying south of the mine and a major highway lying west of the village. Highway A1 from Gaborone to Francistown runs between Palapye village and Morupule Colliery. Two small villages, Maunatlala with a population of 4552[47], and Lerala with a slightly higher population of 6871[47] were chosen and are approximately 65 km and 93 km respectively east of Palapye, the mine and the power station.

Table 4.2 classifies and describes the soils and topography of the sampling areas as laid out in the soil map (Figure 2). According to the Land Utilization Division of the Ministry of Agriculture (1985), Serowe is dominated by B1-B6 and R soils; Palapye is characterized by A13a and D1a soils while Maunatlala and Lerala are dominated by A11a and A4b soils (Figure 2, Table 1)[58]. Serowe Palapye district is therefore generally dominated by a low relief plain and featureless veldt with the major soil groups being mostly Arenosols and Luvisols, with small areas of Lixisols[48,59,60], mostly found on fine-grained and coarse-grained sedimentary rocks e.g. sandstone[61]. Luvisols of the Karoo super-group are known for the accumulation of clay (15-25%) and a higher fertility[62], while Arenosols made up of sandy soils with weak structure and low fertility[59,60]. In general the soils are sandy with a low clay content (<10%) the result of which is high water infiltration rates, low water holding capacity and fairly poor fertility[53,61,62]. Around the Colliery, the dominant soil types are Ferralic Arenosols and Arenic Ferric Luvisols (<3% clay)[53]. The pH of the soils generally ranges from 6.7 to 9.1[62].

On average, the temperature ranges between 2.65°C in winter and up to 41.35°C in summer. Rainfall occurs between the months of October and March, with the dry season commencing in mid-April continuing until September. The annual average rainfall recorded for the study area is 445 mm with the annual total evaporation estimated at ~2 520mm[48].

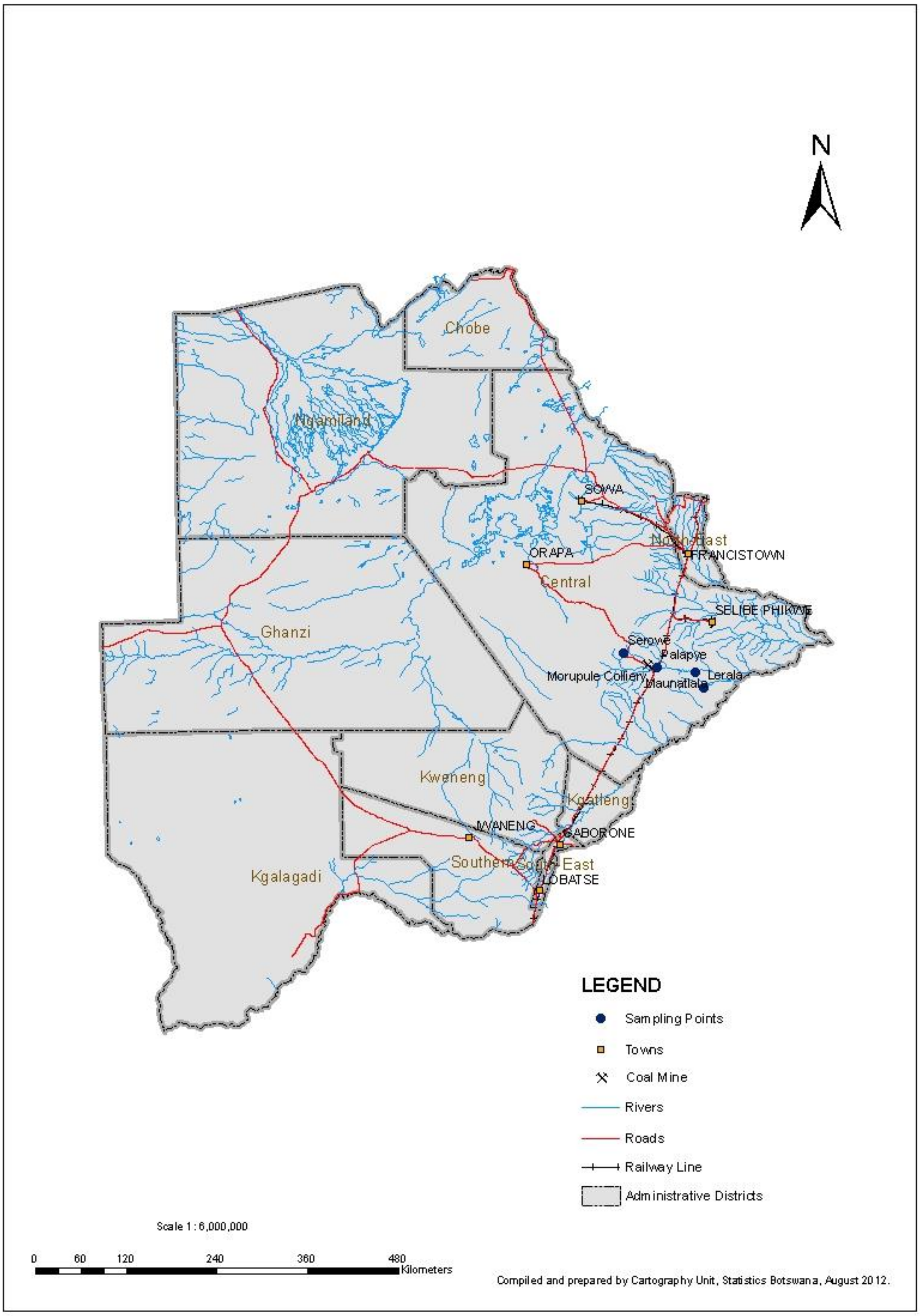

Figure 4.1 Map of Botswana Showing Administrative Districts and sampling locations

Table 4.2: Sampling Area Soil Description and Classification

Location	Soil Symbol	Soil Description and Topography	Soil Classification
Lerala and Maunatlala	A4b	Moderately deep to very deep, imperfectly drained, massive, gray to greyish brown to brown clay loam to clay	Calcic Cambisol
	A11a	Moderately deep to deep, moderately well drained, red to brown sandy loam to sandy loam	Ferric Luvisol, petric, petroferric
Palapye	A13a	Moderately deep to deep, moderately well drained, dark red to strong brown massive sandy clay loam to sandy clay	Chomic Luvisol
	D1a	Very shallow to moderately deep, well drained, yellowish brown, to reddish brown sandy loam to clay loam, undulating to hilly	Dystric Regosol. petric, partly lithic
Serowe	RR	Very shallow soils on steep hills, ridges and escarpments	
	B1	Very shallow to shallow, well to somewhat well drained, reddish brown to dark brown sandy loam to clay loam, undulating to hilly	Eutric Regosol lithic
	B1a	As B1 but almost flat	Eutric Regosol
	B1b	As B1 but calcareous	Calcaric Regosol
	B2	Shallow to moderate deep, well drained, red to strong brown sandy loam to clay loam	Chromic Luvisol, partly petric and lithic
	B3	Moderately deep to deep, moderately well to well drained, red to strong brown sandy loam to clay loam, almost flat to undulating (on dolerites)	Chromic Luvisol
	B4	Moderately deep to deep, moderately well to well drained, reddish brown to red sandy clay loam, almost flat to undulating (on dolerites)	Chromic Calcic Luvisol
	B5	Moderately deep to deep, moderately well to well drained reddish brown to strong brown sandy clay loam to clay. Undulating to rolling (on basalt)	Chromic Luvisol
	B5a	Shallow to moderately deep, well drained reddish brown to strong brown sandy clay loam to sandy clay. Undulating to rolling (mainly on basalt)	Chromic Luvisol, partly petric, some lithic
	B5b	As B5a, but with Cambic horizon	Chromic Cambisol
	B5c	As B5a, but with aridic moisture regime	Luvic Xerosol
	B5d	As 5b, but with aridic moisture regime	Calcic Luvisol
	B6	Moderately deep to deep, moderately well to well drained, dark brown to reddish brown clay loam to clay. Undulating to rolling (on basalt)	Calcic luvisol
	B6a	Shallow to moderately deep, well drained dark brown to reddish brown sandy clay loam to clay. Undulating to rolling (mainly on basalt)	Calcic luvisol, partly petric, some lithic
	B6b	As B6a, but with cambic horizon	Calcic Cambisol, partly petric, some lithic
	B6c	As B6a, but with aridic moisture regime	Calcic luvic, Xerosol, partly petric, some lithic
	B6d	As B6b, but with aridic moisture regime	Calcic Xerosol, partly petric, some lithic

Source: **Land Utilization Division of the Ministry of Agriculture (1985)**[58]

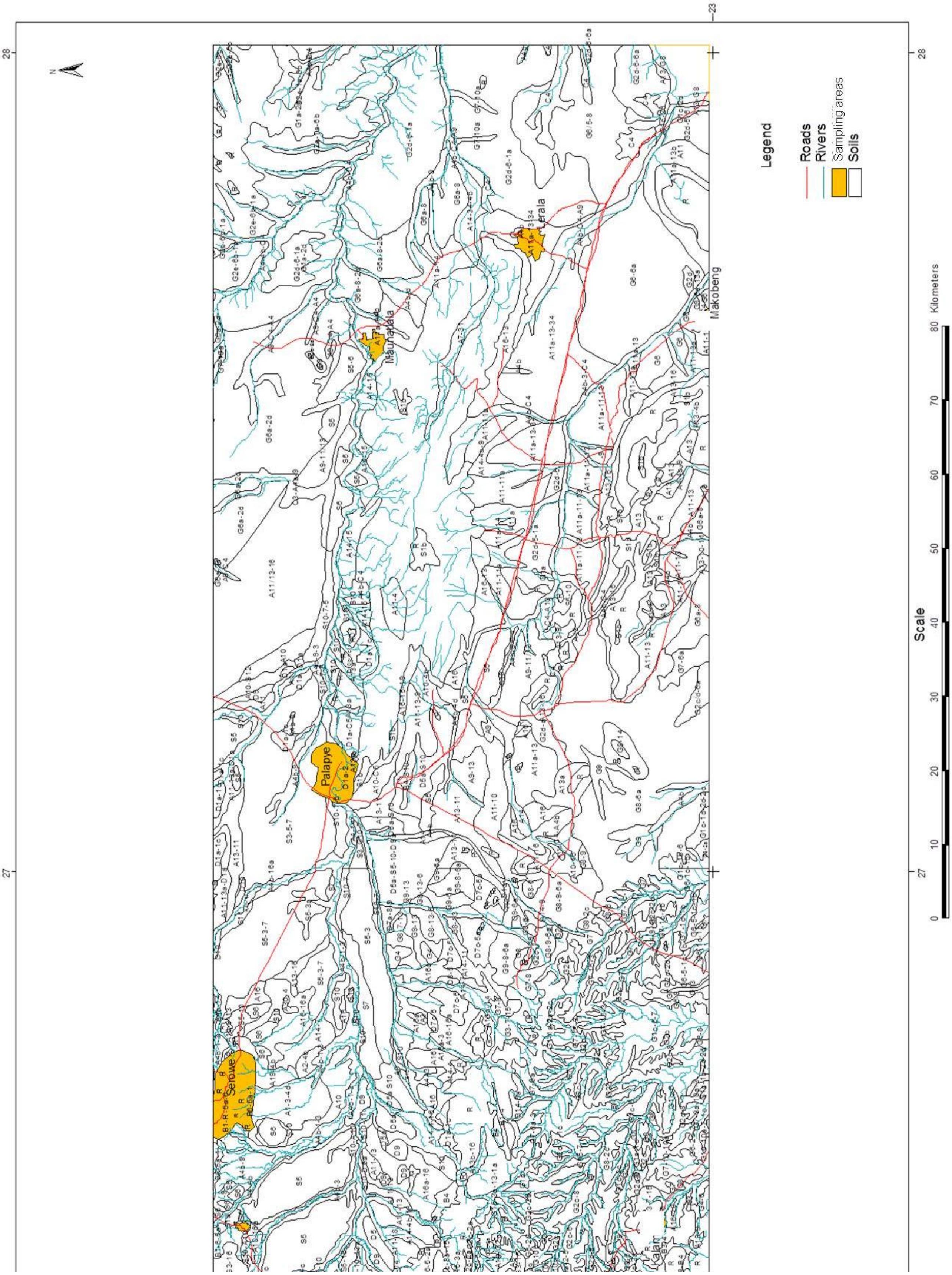

Figure 4.2: Geographical map of the Study Area Showing Soil Types

4.3.2Drinking water supply sources

Botswana is generally an arid country, with approximately 34% of the total water supply sources from surface water and 66% from groundwater[54]. Drinking water from the study area is solely supplied by means of underground borehole water through communal standpipes and private household tap water.[54] Table 3 presents average Total Dissolved Solids (TDS), total hardness (measured as $CaCO_3$), pH and selected minerals in water from the two major villages.[54]

Table 4.3:Average pH, total Hardness, Total dissolved Solids, and minerals in water from Serowe and Palapye

Location	pH	Total Hardness (as $CaCO_3$)	TDS (ppm)	Manganese (ppm)	Magnesium (ppm)	Phosphorus (ppm)	Calcium (ppm)	Chloride (ppm)	Iron (ppm)	Nitrate	Chlorine residual (ppm)
Palapye	6.52	268.87	350	2.128	38.01	2.13	56.94	91.7	11.72	5.94	0.71
Serowe	7.54	317.92	518	0.02	82.90	NQ	75.2	41.56	0.22	47.81	NQ
Maunatlala/ Lerala	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ	NQ

NQ=Not Quantified
Source: Department of Water Affairs[54]

4.3.3 Sampling:

Sampling was conducted in November 2010 and February 2011 with a few additional clay cosmetic powders purchased from vendors in May 2011. In total 28 water and soil samples each and 3 cosmetic clay powders were collected. Throughout this paper Serowe and Palapye are referred to as major villages and Maunatlala and Lerala are referred to as small villages.

4.3.4 Soil and clay sampling, preparation and analysis

The 28 soil samples were collected from Serowe, a major village (N=12), Palapye, a major but semi industrial village (N=5), Maunatlala a small rural village (N=4) and Lerala, a small rural village (N=7). In line with the objectives of the study, sampling was confined and restricted to the vicinity of household dwellings. The general soil types of the sampling areas are elaborated in Table 1. Samples were collected from the top 2-5 cm of the surface within residential clusters (referred to as *kgotlas*). All samples were air dried for 24 hours and passed through a 53 µm-nylon sieve to separate and remove unwanted debris and coarse material. The <53µm fraction was retained as a working sample whereas the rest of the sample was discarded. To ascertain a representative sample, subsamples were collected at distances of 2, 10, 20, 50 and 100 m intervals and combined into a composite sample of approximately 3-5 kg. Samples were collected into air tight self-sealing Ziploc bags and transported to the University of Botswana (Department of Chemistry) for analysis.

Three samples of cosmetic clays were bought from a vendor in Palapye. The samples consisted of red, brown and yellow clay from Makoro.

The soils and clays were assayed for pseudo-total Lead (Pb) content following the conventional method by Tessier *et al.* (1979),[63] however, though this method is widely used for sequential extraction of heavy metals in soils, for purposes of this study the method was used to determine pseudo-total metal content which recommends extraction of metals by digestion with aqua regia solution. Extraction of lead (Pb) was achieved by weighing 1g of soil into a 250mL borosilicate beaker to which 8mL of aqua regia (HCl and HNO3, 3+1 v/v) was added. The suspension was subsequently digested by heating at 120˚C for 2h, using a Labcon laboratory heater. The digests were then quantitatively put into 100 ml volumetric flasks followed by assaying using a flame atomic absorption spectrophotometer (Varian-FS220, SpectrAA, Australia).

4.3.5 Water sampling and analysis

Water samples (100 ml) were collected in Nalgene® plastic bottles at the same time the soil samples were collected in the sampling areas. The samples were collected from public standpipes (60%) and residential homes (40%). The general characteristics of the water in the two major villages are described in Table 4. Temperature, pH and Total Dissolved Solids (TDS) were measured at each sampling point. To be realistic we did not flush the taps prior to water collection[46,64]. Samples were acidified with 1ml of nitric acid (1 M) and the bottles sealed immediately and stored in ice while in the field. Upon arrival at the laboratory the samples were stored in a refrigerator at 4°C prior to analysis at the University of Botswana, Department of Chemistry. To a 200mL borosilicate beaker, 50ml sample aliquot was combined with 50mL aqua regia reagent (HCl and HNO3, 3+1 v/v) and heated in a Laboratory heater for 2h to solubilize the metallic ions. The digest was then poured in a 100 ml volumetric flask and diluted to the mark using ultra-pure water followed by assaying for pseudo-total Pb content using the Varian AAS (SpetrAA FS220).

4.3.6 Reagents and standard solutions

Analytical-reagent grade hydrochloric acid, nitric acid and lead nitrate salt were obtained from Sigma-Aldrich, South Africa. A stock standard lead solution (1000 mg l^{-1}) was prepared by dissolving 1.5985g lead in a 500mL beaker followed by adding 5 ml concentrated nitric acid to ensure solubility of the salt and diluted to the mark in a 1L volumetric flask with distilled, de-ionised water. Calibration standards were obtained by appropriate dilution of this stock standard solution.

4.3.7 Data Treatment and Statistical Analysis:

Data were analysed using SPSS 20.0.0. The collected samples from Maunatlala and Lerala were pooled to make one small village instead of two. The rationale follows that the two villages are approximate from one another and that they had similar characteristics in terms of soil (Figure 2, Table 1). Clay samples were not included in the analysis but reported separately. The rationale for this is that these samples were collected in Palapye only.

To achieve the study objective, ANOVA was used to compare mean Pb levels in soils and water between the major villages (Serowe and Palapye) and small villages (Maunatlala and Lerala combined). When the assumptions of normality, homogeneity and independence of residuals were not met, a nonparametric analysis (Kruskal Wallis) was used.

4.4 Results

4.4.1 Pb Concentrations in clay, soils and water:

Table 4.4 shows lead values in clays, soil and water in parts per million (ppm), water pH, temperature and Total Dissolved Solids (TDS) measured in parts per million. Pb concentrations ranged from 0.02 ppm in water to 4.53ppm in cosmetic clays. Lead concentrations in cosmetic clays were on average 15 and 21 times higher than concentrations in soil and water respectively. The mean Pb concentration in cosmetic clays (±SEM) was 3.99±0.41ppm compared to 0.27±0.03ppm and 0.19±0.02ppm in soil and water respectively.

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Table 4.4: pH, Temperature (°C), Conductivity (µS/cm), Total Dissolved Solids (TDS), Pb (ppm)

Location	Location Type	Type of sample	Sample ID	pH	Temp . °C	Conductivity µS/cm	TDS	Pb (ppm)
Lerala	Small Village	Soil	MpeoLS1	_	_	_	_	0.22
Lerala	Small Village	Soil	MpeoLS2	_	_	_	_	0.10
Lerala	Small Village	Soil	MoatsheLS3	_	_	_	_	0.21
Lerala	Small Village	Soil	MonnengLS4	_	_	_	_	0.22
Lerala	Small Village	Soil	MothalaganeLS5	_	_	_	_	0.16
Lerala	Small Village	Soil	SegoleLS6	_	_	_	_	0.23
Lerala	Small Village	Soil	SegoleLS7	_	_	_	_	0.23
Lerala	Small village	Water	MpeoLW1	7.3	28.1	219	153	0.16
Lerala	Small village	Water	MpeoLW2	7.5	32.8	214	150	0.18
Lerala	Small village	Water	MoatsheLW3	7.4	28.5	215	151	0.17
Lerala	Small village	Water	MonnengLW4	7.4	31.6	220	167	0.21
Lerala	Small village	Water	MothalaganeLW5	7.3	28.2	215	150	0.14
Lerala	Small village	Water	SegoleLW6	7.4	28.2	217	158	0.20
Lerala	Small village	Water	SegoleLW7	7.3	28.3	214	150	0.13
Maunatlala	Small Village	Soil	ThamagaMS1	_	_	_	_	0.32
Maunatlala	Small Village	Soil	RaphiriMS2	_	_	_	_	0.27
Maunatlala	Small Village	Soil	MokueleloMS3	_	_	_	_	0.24
Maunatlala	Small Village	Soil	MagadingwaneMS4	_	_	_	_	0.20
Maunatlala	Small Village	Water	ThamagaMW1	6.9	36.6	99.2	69.4	0.03
Maunatlala	Small Village	Water	RaphiriMW2	6.1	33.6	75.1	52.5	0.04
Maunatlala	Small Village	Water	MokueleloMW3	6.7	29.6	99.2	69.4	NQ*
Maunatlala	Small Village	Water	MagadingwaneMW4	6.4	33.2	106.1	58.5	0.04
Palapye	Major Village	Soil	SeroromePS1	_	_	_	_	0.49
Palapye	Major Village	Soil	Serorome PS2	_	_	_	_	0.50
Palapye	Major Village	Soil	Extention8PS3	_	_	_	_	0.08
Palapye	Major Village	Soil	Extention1PS4	_	_	_	_	0.50
Palapye	Major Village	Soil	OldMallPS5	_	_	_	_	0.77
Palapye	Major Village	Water	SeroromePW1	6.7	31.4	366	253	0.30
Palapye	Major Village	Water	Serorome PW2	6.4	29.0	246	287	0.32
Palapye	Major Village	Water	Extention8PW3	6.5	32.9	333	245	0.29
Palapye	Major Village	Water	Extention1PW4	6.5	35.0	409	294	0.30
Palapye	Major Village	Water	OldMallPW5	6.7	32.9	321	223	0.34
Palapye	Major Village	Red cosmetic clay (*letsoku*)	LetsoRed	_	_	_	_	3.18¶
Palapye	Major Village	Brown cosmetic clay (*letsoku)*	LetsoBrwn	_	_	_	_	4.53¶
Palapye	Major village	Yellow cosmetic clay *(letsoku)*	LetsoYell	_	_	_	_	4.26¶
Serowe	Major village	Soil	MokolojnSS1	_	_	_	_	0.35
Serowe	Major village	Soil	GoosesmoSS2	_	_	_	_	0.22
Serowe	Major village	Soil	MokwenaSS3	_	_	_	_	0.02
Serowe	Major village	Soil	NewTwnSS4	_	_	_	_	0.27
Serowe	Major village	Soil	SebinanyaneSS5	_	_	_	_	0.5
Serowe	Major village	Soil	BokhurutsheSS6	_	_	_	_	0.21
Serowe	Major village	Soil	MogorosiSS7	_	_	_	_	0.07
Serowe	Major village	Soil	BotalaoSS8	_	_	_	_	0.26
Serowe	Major village	Soil	GooleinaSS9	_	_	_	_	0.28
Serowe	Major village	Soil	MorwamokwnSS10	_	_	_	_	NQ
Serowe	Major village	Soil	PhokelaSS11	_	_	_	_	0.47
Serowe	Major village	Soil	TalaojnSS12	_	_	_	_	0.07
Serowe	Major village	Water	MokolojnSW1	7.7	34.0	523	376	0.27
Serowe	Major village	Water	DinokwaneSW2	7.7	31.0	476	333	0.26
Serowe	Major village	Water	MokwenaSW3	7.7	31.5	473	329	0.20
Serowe	Major village	Water	MorwamokwenSW4	7.8	29.5	489	333	0.27
Serowe	Major village	Water	RakgomoeSW5	7.5	28.4	465	325	0.25
Serowe	Major village	Water	MogorosiSW6	7.3	28.7	652	465	0.21
Serowe	Major village	Water	BrigadeSW7	7.4	28.2	462	324	0.13
Serowe	Major village	Water	MMualfPrimSW8	7.4	27.6	569	396	0.3
Serowe	Major village	Water	BokhurutsheSW9	7.5	29.2	458	316	0.24
Serowe	Major village	Water	NewtownSW10	7.4	27.7	480	331	NQ
Serowe	Major village	Water	PhokelaSW11	7.6	29.4	489	392	0.25
Serowe	Major village	Water	TalaojnSW12	7.5	28.5	473	387	0.10

***NQ – Not Quantified**
¶Not included in the statistical analysis

Table 4.5 shows Pb concentrations between and within locations. Within locations Pb concentrations were compared between old and new settlements (areas where communities were recently allocated land in ≤ 1 year ago). Mean PbS (±SEM) in older settlements were 0.31± 0.035 ppm compared to 0.13±0.034 ppm in newer settlements (p=0.03). No significant difference (p>0.05) was observed in PbW concentrations despite higher absolute values found in older settlements (mean PbW (±SEM) 0.20 ±0.020ppm in older settlements compares to 0.13± 0.047ppm).

Table 4.5: Mean±SEM of Lead concentration between locations and between old and new settlements within the locations

Location	Sample type	Pb (Old settlement)	Pb (New settlement)	Total Pb	% greater* than recommended standard
Palapye	Soil	0.57±0.068 (n=4)	0.08 (n=1)	0.47±0.111 (n=5)	0
	Water	0.32±0.01 (n=4)	0.29 (n=1)	0.31±0.009 (n=5)	100
Serowe	Soil	0.28 ±0.049 (n=9)	0.11± 0.040 (n=3)	0.24±0.431 (n=12)	0
	Water	0.25±0.010 (n=9)	0.077±0.039(n=3)	0.21±0.11 (n=12)	91
Small Villages (Maunatlala/Leral)	Soil	0.22±0.019 (n=10)	0.23 (n=1)	0.22±0.017 (n=11)	0
	Water	0.12±0.025(n=10)	0.13 (n=1)	0.12±0.023 (n=11)	64
All locations	Soil	0.31 ±0.035 (n=23)	0.13± 0.034 (n=5)	0.27±0.032 (n=28)	0
	Water	0.20 ±0.020 (n=23)	0.13± 0.047 (n=5)	0.19±0.019 (n=28)	82

***Recommended standard =0.05ppm**[65]

When PbS and PbW from major and small villages were compared (after pooling the data for small villages - Lerala and Maunatlala), a significant difference was observed (p=0.009 and p=000 for PbS and PbW respectively). Mean PbS concentrations from Palapye were twofold compared to values from Serowe and from small villages. With respect to PbW concentrations, Palapye had the highest values (three to fourfold than small villages) followed by Serowe (Table 4 &5). Figure 3 shows a graphical view of mean PbS and PbW concentrations by location.

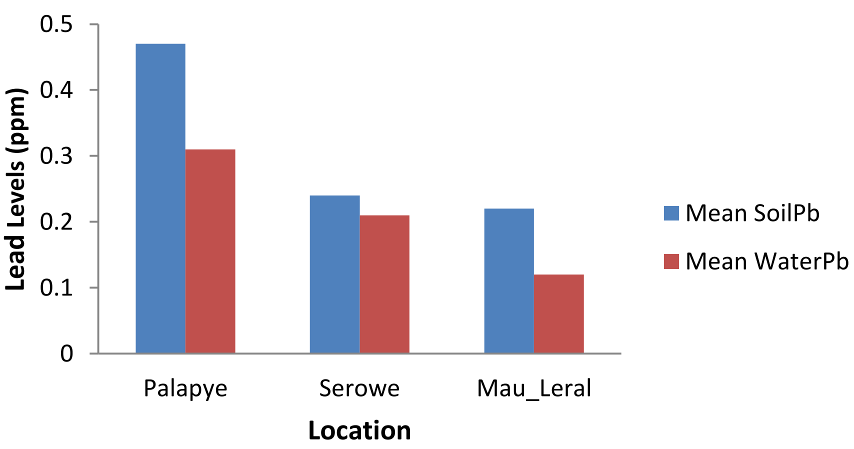

Figure 4.3: Mean soil and water lead levels by location

4.4.2 Associations between Pb concentrations and location

Figure 4.4 is a scatter plot showing the relationship between the PbS and PbW. There was a significant relationship between PbW and PbS (p=0.028) and the linear regression model for the correlation between PbW levels and soil lead levels:

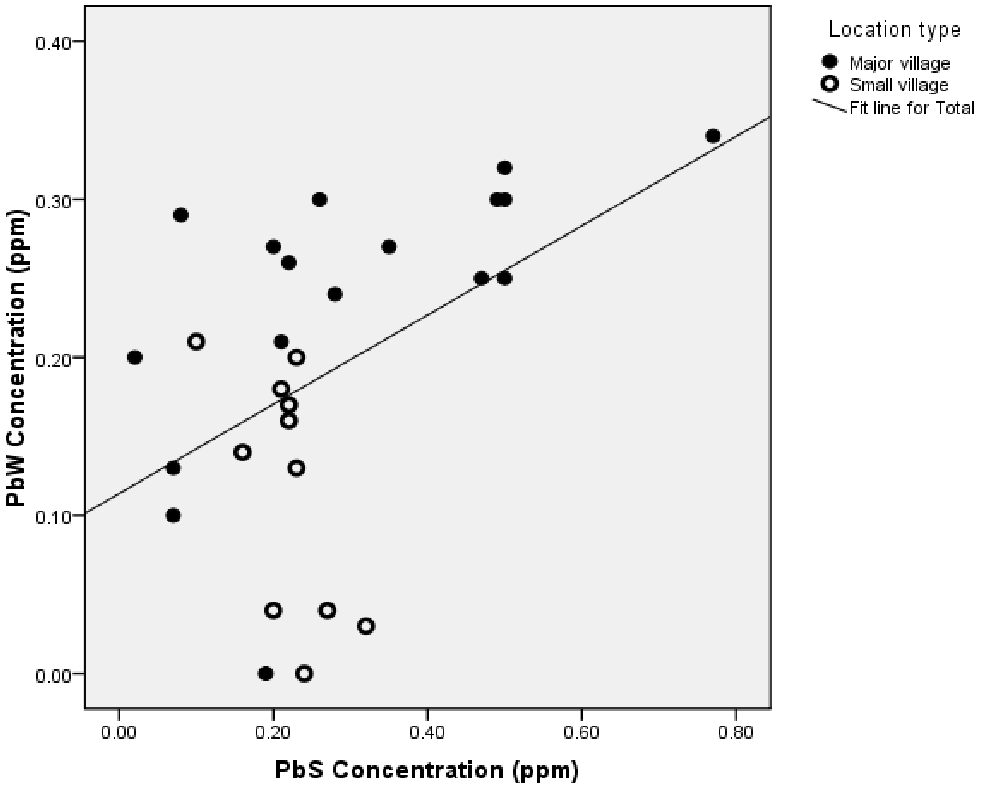

Figure 4.4 Relationship between the soil lead levels and water lead levels

Table 4.6 shows the results of analysis of covariance to establish a relationship between lead levels and location (major village vs small village). The strongest relationship was observed in PbW and PbS between Palapye, a major village and Maunatlala /Lerala (small village). No relationship was observed between Serowe and Maunatlala/Lerala (p>0.05) in terms of PbW. However, a significant relationship was observed between PbS in Serowe and Maunatlala/Lerala.

Table 4.6: Correlation coefficients of major and small villages

	Maunatlala/Lerala (Small Village	Maunatlala/Lerala (Small Village)
Palapye (Major village)		
	-0.24982(S)*	
	-0.19182(W)**	
Serowe (Major village)		
		-0.01848(S)
		-0.08848(W)*

***p<0.05; **p<0.001**
S= Soil
W=Water

4.5 Discussion

4.5.1 Lead in soils and clay:

Soil lead levels were detected in trace amounts and were well below the set soil standard limits of 140ppm.[56] These low Pb levels may be attributed to the soil types in the study area, particularly in Serowe and Paplapye which are generally of a sandy nature and therefore moderately to well drained as reflected in Table 3. There is evidence that atmospheric lead enters the soil as lead sulphate or is converted rapidly to lead sulphate at the soil surface. EPA (2006) estimates that soils with a pH of ≥ 5 and with at least 5% organic matter atmospheric lead is retained in the upper 2-5 cm of undisturbed soil.[66] The movement of lead from soil by leaching is also observed to be slow under natural conditions therefore making lead persistent in the soils. The soil characteristics of Serowe Palapye fit this description with a pH greater than 5 and an organic content of approximately 10% except around the coal mining area where the soils are only 3% clay.[53] These types of soils may facilitate the removal of lead from surface soils by leaching and by run-off. Some of the conditions which could induce leaching are the presence of lead that either approach or exceed the sorption capacity of the soil, the presence in the soil of materials that are capable of forming soluble chelates with lead, and therefore a decrease in pH of the leaching solution such as acid rain[67]. Zhai *et al.* (2009) also observed Pb levels lower than the set standards (1.00-35ppm) in bedrock samples from Palapye.[52] He further reported low Pb levels in the range of 19.4-21.9ppm; 81.6—101.4ppm and 16.2-19.2ppm in bottom ash, inlet fly ash and coal respectively[52]. Our values are generally lower (0.04-0.77ppm) than those of the study by Zhai et al (2009).[52] This however can be expected due to the variability of the distribution of lead in soils. Chaney (1984) examined soil lead concentrations in urban Baltimore gardens and found that soil Pb concentrations varied more than 10 fold within a single garden.[68] On the other hand, we are exercising some caution in comparing these results because of the sampling design, chemical extractions and analytical techniques used to measure lead levels in the two studies. Our study focussed on residential areas without particular attention to areas of intense pollution, whereas the study by Zhai et al. (2009) focussed on Palapye and the coal mining area. Our results are however comparable to those of Okonkwo and Maribe (2004) who measured lead levels in soils in Thohoyandou, a remote area in South Africa. Their mean Pb concentrations mean (±SD) ranged from 0.205±0.09 – 0.312±0.08.[69]

While Zhai *et al.* (2009) results did not find significant differences on Pb concentrations in the mine plant soils, intermediate soils and rural soils,[52] our study found a significant difference in concentrations between rural soils and soils from major villages. Palapye soil Pb concentrations were three to fourfold higher than rural small village soils (even though all levels were near detection limit values). The low lead levels in the small villages are consistent with studies elsewhere which have shown low Pb levels in soils from rural areas compared to urban areas[70,71]. To further strengthen this finding, a further comparison of older settlements versus new settlements in all locations showed a significant difference with older settlements having higher soil lead levels. The difference could be attributed to activities such as waste disposal, auto workshops and gas stations etc, which are less prevalent in newer settlements and in smaller villages. In the case of Palapye, which is near a major highway and a railroad line, these could be contributing factors. Zhai et al. 2009, found Pb concentrations near the highway significantly higher than concentrations in other locations further away from the highway suggesting automobile related pollution (Zhai, 2009).[52]

Environmental heavy metal contamination, especially by lead in soil (including clays) and sediments, has become increasingly recognised as a significant problem in public health. As a result of this recognition, the developed world has come up with comprehensive and complex environmental legislation and associated guidelines,[72] to safeguard public health. There is a strong positive correlation between exposure to lead contaminated soils and blood lead levels. CDC (1991) reports a 3-7µg/dl for every 1000ppm increase in soil or dust lead concentrations[73]. Although the PbS levels in this study are extremely low, soil impact as an exposure source for pregnant women cannot be ruled out for several reasons;1) Studies have found that human absorption and retention of Pb as a function of both particle size and chemical species.[74] The smaller the particle, the more easily it will be absorbed by the digestive system. This observation is derived from studies that have observed that almost half exhaust particles emitted from petrol was less than 0.25µm in size with most of the remaining emissions between 10 and 20µm[66]; 2) High dose source does not always mean greater risk.[19] The bioavailable fraction of lead in soil or dust is generally defined as that fraction that can be absorbed into the blood stream.[72] Although there is a general notion that lead based-paint poses the greatest risk because it is a high dose lead source, Mielke and others(1998) argues that paint has larger particle size (from 200-300µm) to the visible range, hence they are less easily absorbed and therefore less bioavailable[19,72]; 3) There is evidence of non-uniformity of lead distribution in soils from the same location[68]. It is therefore possible that some areas may have soil lead levels greater than the current levels; 4) The low lead in soils, particularly for pregnant women who ingest soil will add to the lead load from other sources.[57,66]

In terms of cosmetic clays, the current levels may add up to the lead load in pregnant women through skin absorption.[33-36]

4.5.2 Lead in water

Pb levels in water exceeded the WHO permissible concentrations of 0.01ppm.[57] Our overall PbW mean concentration (±SEM) was 0.19±0.019ppm (190±19µg/l) which is nineteen times higher than the permissible concentrations safe for human consumption in drinking water. Compared to PbW levels in rural South Africa, the levels are approximately 10 times higher.[69] These levels are comparable to levels in the developed world in the 1990s prior to restrictions on plumbing materials containing[75]. This finding is a course for concern and presents a potential risk for lead exposure to pregnant women and other vulnerable groups such as children. Mathew (1981) has estimated that water lead level of 50µg l^{-1} would yield average intake of lead from water alone for an average adult at about 60 µg dayl^{-1}[76] While this estimate may be small for adults, the relative intake of lead from water is estimated to be seven and half times for children who are bottle-fed and dependent on tap water compared to that of adults.[76]

Palapye, had significantly higher PbW levels compared to other locations. One assumption for the higher PbW is the soil setting of the study area, which is mainly aeolian, derived from the weathering of the Ntane Sandstone Formation.[58] These are moderately to high vulnerability and additionally they do not contain any significant clayey material (or organic material) likely to prevent the downward migration of contaminants.[53] This situation has contributed to a number of boreholes in the Palapye area being closed down due to high nitrate levels as a result of soil pollution.[53] Palapye underground water sources are therefore prone to industrial pollution as it is a moderately industrial village compared to the other study villages. In support of this, our results showed a relationship between PbS and PbW concentrations, particularly in Palapye which had the highest PbS and PbW levels. That is, an increase in PbS concentrations resulted with an increase in PbW concentrations. Additionally, Palapye is in the vicinity of Morupule coal mine and power station. There is therefore a highly likely possibility of Pb lechachates from ash disposal ponds into underground water.[50] It should also be noted that the water in Palapye is slightly more acidic than the water in Serowe and this could be the result of some materials in the soils capable of forming chelates with lead and therefore decrease the pH of the water.[67] A pH of <7 would also cause more corrosion in plumbing systems. It is desirable to have pH levels of 8-9 to reduce corrosion from plumbing systems.[77,78] All of the samples collected from Palapye were from indoor household taps.

Other than the soil types and pH, several reasons may help explain the generally high concentrations of PbW in the Serowe Palapye villages. Currently, all drinking water is from boreholes and is stored in steel tanks and then distributed to public standpipes and households through polyvinyl chloride (PVC) pipes which then connect with interior plumbing. At household level, interior plumbing is mostly copper pipes with lead solder in joints between copper pipes. At public standpipes the standpipe material is mostly steel. The presence of lead in water is generally a result of its dissolution from natural sources but primarily from plumbing systems within residences which including brass fittings and lead solder[79]. Soldered connections in recently built homes fitted with copper piping have been reported to release enough lead to cause intoxication (210-390µg/l) that may cause intoxication in children.[80] It is also reported that PVC pipes contain lead compounds that can be leached from them resulting with high lead concentrations in drinking water[57].The amount of Pb dissolved from plumbing is however influenced by factors such as the presence of chloride and dissolved oxygen, pH, temperature, water softness and standing time of water. Soft and acidic water is reported to be the most plumbosolvent.[81,82] Research also points elevated PbW levels in drinking water to certain types of faucets and certain types of water meters[78]. Our study analysed the first flush water from communal and residential tap water for practical reasons that people would not normally flush their system before they collect their drinking water. Our results are comparable with those of Gulson (1997). In his study he compared variations in lead concentrations for water samples collected at hourly intervals from the kitchen tap in one house. Lead concentrations of the first flush were 119µg/l compared to a fully flushed tap which had PbW of 1.7µg/L).[64] In his conclusion Gulson (1997) observed that a pregnant woman who consumes 0.5 L of water a day of first flush water could be at a greater risk of exposure than one who consumes water from a fully flushed system.[64] He further observes that if more than 0.5 l of water was consumed in drinks and formulae using first flush water, then the blood lead levels could exceed the recommended CDC action blood lead level of 10µg/dL.[64,83] A Boston men normative aging study concluded that ingestion of first morning tap water contaminated with Pb was an important predictor of elevated bone lead levels(Vijayalakshmi et al. 1999). Men who lived in households with ≥ 50ugPb/L of first morning tap water (water that has been standing overnight in the plumbing), who ingested ≥ 1glass /day had progressively higher patella lead levels than did those with low water consumption (< 1 glass per day).[84] This finding is important for women of reproductive age who have exposure to Pb levels in water as this would not only contribute to elevated Pb levels later in life, but would have Pb released from bone during pregnancy and thus result with undesirable birth outcomes.[85]

Social factors are also reported by studies to affect lead levels in water and some of these factors include spending time away from home by being at work during the day thereby creating lead to leach from the tap and thereby increasing the lead load.[64]

Most households would generally use more water in the morning before going to work and in the evening when they come back from work and school. In the case of households using public standpipe the same situation can apply. In this study 60% and 40% of tap water was from indoor and outdoor taps respectively. The mean temperature of the water at the time of collection was above 30^{o}C. Levin (1990) has attributed day-time leachability of lead to exceed that of overnight because plumbosolvency is temperature dependent.[37] It is also important to note cultural factors in the context of developing countries. It is generally accepted that storing water in clay pots will keep the water cooler in the rural areas where most people do not own refrigerators. This, depending on the water acidity and whether the clay pot is made out of material that contains lead or not may contribute an additional lead load to water at the household level. In one study, clay pot water storage was correlated to elevated blood lead levels.[86] Even though the authors related this to be an indicator for lower socio economic status, rather than a risk factor itself, it cannot be entirely ruled out that clay pots used for storage of water may be a source of lead exposure depending on the water pH, as well as whether the pot itself was made up of clay that is contaminated with lead.

Elwood, in his critical review of sources of lead in blood,[46] concludes that while water may be considered a relatively minor source in people exposed to high levels from other sources, it should be of greater importance and should generate greater attention if other sources are low. He further notes that as higher PbW levels are likely to be associated with older housing in inner city areas with dust and air lead levels, the potential for bias in the event of ignoring water may turn out to be considerable. In our study we observed no significant differences between PbW in older and newer settlements. This is explained by the fact that unlike soil, variations in the types of materials used in lead pipes are not dependent on how old the residence.[87] It is also an indication of possible contamination of the water from the source water tanks or from soil leaching.

4.6 Limitations:

The number of clay samples was extremely small to be included in the analysis. The limitation was a result of non- availability of *letsoku* at the time of sampling in the study areas. Only 3 samples were bought in the market. Despite this limitation, it could be confirmed that *letsoku* may pose a potential exposure source for women who apply it on their skin as well as ingest it. Additionally, due to limited resources we restricted our sample size to 28, for both water and soils. A larger sample size would be beneficial in future to compare these results. The limited resources also deviated us from collecting water from a city, which does not use borehole water. This therefore limited our capacity to be able to apply the findings of this study nationally. The results of the study however create an opportunity for further research on drinking water quality.

4.7 Conclusions:

While soil Pb levels were at trace levels and lower than the set maximum Pb limits, Pb levels in water were in excess of the set drinking water-quality standards. It is important to highlight that even though the soil Pb levels are low the combined influences of other environmental sources of exposure to lead in pregnant women have to be taken into consideration. In assessing the risk of exposure for pregnant women in the Serowe Palapye it is necessary to look at other factors which may be economic, social as well as lead levels from air, dust, water, food, paint, cosmetics and others. This is particularly so for pregnant women who are geophagic and may be using traditional clay cosmetics to apply on their skins. Irrespective of the low lead levels, pregnant women need to be sensitized on geophagy and the use of traditional clay for cosmetic and pharmaceutical purposes.

To determine the public health impact of environmental lead contamination, a biomarker should be available and one of the most commonly recommended biomarkers in any population is the measurement of blood lead levels (PbB). The need to measure PbB of pregnant women and other vulnerable groups such as children in the Central and other districts is recommended to assess if there is a relationship in blood lead levels and water lead levels. In doing so, other potential confounders will need to be taken into consideration such as the behaviours and other practices of pregnant women during pregnancy. Such behaviours will include but not limited to geophagia, lifestyle behaviours such as alcohol and tobacco use, and the use of traditional and other cosmetic products.

There is need to assess the types of plumbing materials used in household and communal drinking water taps as well educating the public and in particular women of reproductive age on the importance of flushing the first draw of water in the mornings as well as later in the evening if the tap was not used frequently during the day.

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