

Contamination of Soil due to Leakages of Polychlorinated Biphenyls (PCBs) at a Vandalized Electrical Transformer Site

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Abstract— Worldwide and including in South Africa, the use of polychlorinated biphenyls (PCBs) has been banned as these have been implicated in the destruction of the ozone layer. The lack of the protective ozone layer has been widely blamed for increase in global warming. Here we report on impact of PCBs from a human vandalized electrical transformer on the soil environment at the Rietvlei farm in Louis Trichardt. The particle analysis showed that the soil was sandy followed by loam and then clay. The soil pH was in the range 6.79 to 10.15. The soil moisture content was on average below 6.8%. The analysis of Mg, Al, Ca and K for Cation Exchange Capacity (CEC) was carried out to determine the fertility of the soil. The average CEC of the soil sample was 7.48 meq/g and therefore the soil was fertile and but lacked organic nutrients. However at this site where the transformer oil was spilled it was observed that no grass was growing. The analysis of samples by the GC-MS and GC-ECD at Waterlab and SABS showed that there were ultra-traces of PCBs in the soil samples. Probably the absence of grass growing at the contaminated site was due to presence of the ultra-trace levels of PCBs. Thus there is a need to improve plant growth at the contaminated site in order to prevent easy water infiltration that might contaminate groundwater supplies. Makhado local municipality draws some of its water supplies from borehole just 1 m from the contaminated site.

Keywords—Polychlorinated biphenyls; water contamination; climate change; human vandalism; drinking water supplies.

I. INTRODUCTION

Polychlorinated Biphenyls (PCBs) are persistent organic pollutants with significant bioaccumulation potentials in Environmental systems [1-2]. These compounds are frequently detected in a wide variety of environmental compartment, such as sediments, soil, biota, water and air. The production of PCBs has ceased even though they are still used in other regions of the world and still found in the environment. The production of PCBs has been banned due to their toxicity and their chronic effects on both human beings and the environment [3]. Their wide industrial application started in 1930 because of their chemical stability, non-

flammability and heat resistance properties [4].

As a result, oil spillage by transformer vandalism has some of its detrimental effects on the environment, this also include the aquatic environment, and can therefore take a long time before such problems of oil spillage are reported. Therefore, large quantities of PCB-containing Oil can be spilled onto the land and most of it can soak into the underground were it will drastically affects the chemistry, pH, soil moisture, and the drainage of the soil.

PCBs do not break down easily once they are in the natural environment; they stay attached to the soil particles or sediments [5]. Artificial or natural processes that influences the movement of sediments or soil particles also moves the attached PCBs along. PCBs tend to evaporate (if available in large quantities) from the surface to the air or the atmosphere if the weather is very hot. Microorganisms play a major role of breaking down PCBs that are in the soil particles or sediments, these depends on the number of factors which includes the type of microorganism's present, number of chlorine atoms, concentration of PCB, available nutrient and the temperature. The process of breaking down PCBs by microorganism is very slow and can take whether or not oxygen is available in the soil and sediments, and can also occur in some extent in water [5].

Although PCBs can be broken down it still poses a threat to plant species in the particular area, it therefore changes the way in which they grow. Plants that grow in PCB-amended soil accumulate these compounds in their aerial parts [6]. The main entry of PCBs in plants is through the roots.

PCBs can also be transported into aquatic environments when dry soil with PCBs attached is blown to the streams, lakes, and dams. During rainfall some of PCBs can be washed into the streams with the soil in the process of soil erosion. The soil tends to accumulate at the bottom of the river for longer periods of time. PCB-contaminated river sediments are carried by river water up over the river bank and onto the floodplain during floods and heavy rains [7]. PCBs do not only threaten the natural environment but also threatens the health of human beings via consumption of PCB-contaminated animals such as fish, turtles and frog from contaminated rivers and other wildlife animals that feed on contaminated plants and also drink contaminated water, by also touching soil which is contaminated by PCB, and a work place exposure [8].

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The study aims to contribute to the determination of the levels of PCB-containing oil spilled on the environment and which may be a threat on the health of animals and human beings. The specific objectives were: to determine the physical characteristics of the affected soils at the study site; to determine the levels of PCBs in the soil at different soil depth profiles and to determine the levels of PCBs in grass that was growing on the contaminated soils.

II. MATERIALS AND METHODS

A. Location of the Study Area

The study area of this thesis is situated at Rietvlei Farm owned by Makhado Local Municipality in Limpopo Province (Figure 1).



Fig 1: The location of the damaged transformer in Rietvlei Farm, close to Louis Trichardt, GPS coordinates are: 23° 3'50.14''S; 29° 52'46.89''E

B. Sample Collection and Sample Storage

A total of seven samples were collected from the study area. Sample 1 top (S1 Top) was collected from the point where spillage had occurred, it was collected from 0-9cm below the surface, Sample 1 bottom (S1 Bottom) was collected from the same point but the soil was from 29 cm below the surface. Sample 2 (S2) was collected near sample 1 but only the top soil was collected. Sample 3 (S3) was collected not far from sample 2, only the top soil was also collected here. Sample 4 top (S4 Top) was collected from 160 cm away from the first sample, 0-9 cm top soil was collected and Sample 4 bot (S4 Bottom) was collected from 27 cm below the surface. Sample 5 (S5 control) was collected from 560 cm away from where the samples were collected, this is a sample of clean and not contaminated soil. An instrument known as the auger was used to dig the soil, the soil samples were collected using brown soil sampling bags. Plastics may not be used as primary container for PCB samples because PCBs will absorb in most plastics and can contaminate samples with plasticizers. After collection the samples were stored at 4°C.

C. Determination of the Physical Characteristics of the Affected Soils at the Study Site

The physical characteristics were determined by first determining the soil properties in the area. The soil type influences the movement of oil. Soil properties that influence

the movement of petroleum hydrocarbons include porosity and permeability. For example clay soil tends to slow down the penetration of PCBs into the land. To do that 150 g of soil from each sample were sieved using Retsch AS200 at amplitude of 60 for 20 minutes to determine the soil particles size and also the soil type at the study area in all seven samples. pH in the soil samples was measured using the Crison MM40 pH meter. pH in each sample was measured three times and the average from the three measurements/readings from each sample was the pH recorded.

Moisture content determination was carried out on the same day the samples were collected, 2g of soil from each sample was weighed, and Watch glasses were used. After being weighed the samples were dried in the EcoTherm oven from LABOTEC at 105 °C for five days. After a period of five days was over the samples were removed from the oven and taken to the Desiccator for a period of one day. A desiccator is an instrument used to dry samples and also prevent them from being affected by moisture once they have been dried. After a day, they were removed from the desiccator and measured again. The differences obtained are the amount of moisture that was evaporated in the oven.

D. Determination of Soil Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) is a measure of the soil's ability to hold positively charged ions. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilizers and other ameliorants [9](Hazelton and Murphy, 2007). The CEC was determined by the BaCl₂ compulsive exchange method [10-11].

In a 30-ml centrifuge tube, 2.00 g of air dried soil was added and then mixed with 20 ml of 0.1 M BaCl₂ solution. This was shaken on flash shaker for 2 h. Then the mixture was centrifuged at 10,000 rpm on centrifuge for 20 minutes. The solution was then carefully decanted and taken for metal analysis with flame atomic spectrometer. The samples were then analysed for metals: Potassium (K), Aluminum (Al), Calcium (Ca) and Magnesium (Mg).

E. Determination of PCBs in the Soil at Different Soil Depth Profiles

The extraction process adopted was Method 3540 Soxhlet Extraction [12] which was formally used by Chen et al. [13]. Air dried soil was sieved to obtain 2 mm soil particles, 5 g of sieved soil was extracted using Soxhlet apparatus for 4 hours at 4-6 cycles per hour with 150 ml mixture of hexane-acetone (1:1 v/v), after which the extracted solution was concentrated to 2 ml in a rotary evaporator (Buchi Rotavapor™ Japan model R200 with heating bath B-490 and heating intensity of 20-180 °C). USEPA Method 3630B: Silica gel cleanup was used as this method has been shown to specifically address Aroclor [12, 14,15]. The extracts from Soxhlet extraction was diluted with hexane to a volume of 10 ml and passed from a glass chromatographic column (i.d 20 mm and 400 mm

height) parked with layers of silica gel and anhydrous sodium sulphate and the eluted with 100 ml of hexane [16]. The eluent was finally concentrated with rotary evaporator for the second time to about 1 ml and the PCBs were analyzed using GC-MS at WaterLab (Pty) Ltd and using GC-ECD at SABS.

F. Data Analysis

The data was obtained from GC-MS and GC-ECD instrument was used as is. The CEC formula (cmolc/kg soil) = $[Ca/20 + Mg/12 + K/39 + Al/9]$ was used [17]. Microsoft excel was used to record the data and to produce tables and graphs for better understanding of the results.

III. RESULTS AND DISCUSSION

A. Physical Characteristics of the Soil

The soil type of the study area was found to be sandy because the sandy particles were 65 – 82% in the samples, loamy particles were about 9 – 22% in the soil samples and clay was about 4 – 17% in the soil samples (Figure 2). Therefore the soil of the study area was sandy since larger quantities of particles are sandy.

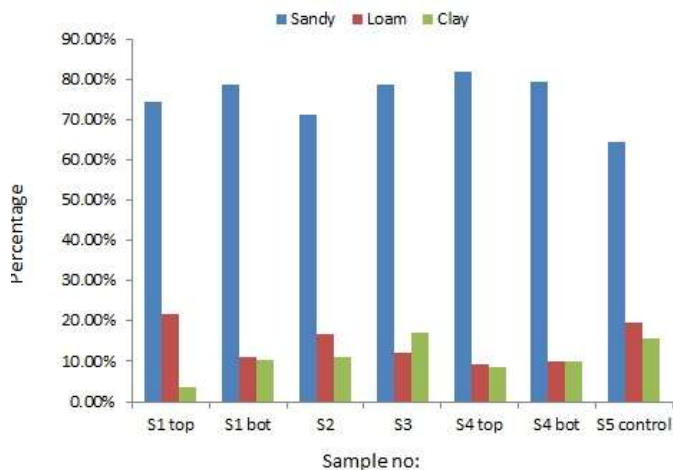


Fig 2: Particle size graph showing the amount of sandy, loamy and clay soil in the study site.

B. Soil pH

The pH of the samples varied from sample to sample, pH ranged from 6.79 to 10.15 (Figure 3).

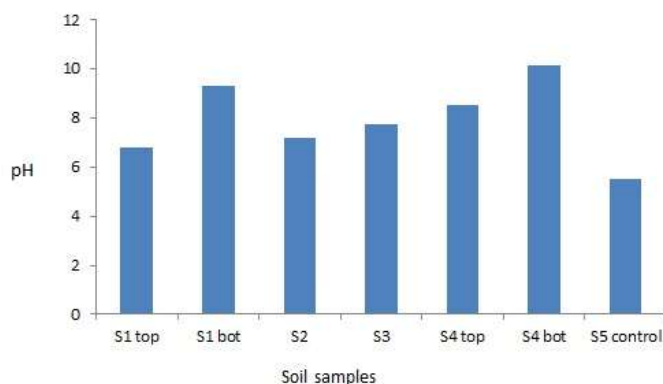


Fig 3: Soil pH. This is the pH of each sample from S1 Top to S5 Control.

Therefore the amount of moisture in the soil was very low

and it includes very low amount of PCBs (Table 1).

TABLE 1:
THE MOISTURE CONTENT OF SOIL SAMPLES FROM THE STUDY AREA

	S1 top	S1 bottom	S2	S3	S4 top	S4 bottom	S5 control
Moisture content %	6.8	5.8	6.4	6.2	5.8	4.6	1.2

C. Cation Exchange Capacity (CEC)

CEC is the term used to describe the holding capacity of particular soil for positively charged elements (cations) [18]. The CEC is part of the soil test which is calculated from the levels of potassium, magnesium, calcium, and aluminum these cations are the ones of greatest concentration in most soil [9]. In this study only four elements were analyzed by the AA (Table 2).

TABLE 2
ELEMENTS ANALYSED BY THE AA FOR CEC DETERMINATION IN MG/L

SAMPLES	Al	K	Ca	Mg
S1 Top	1.2	27.1	170.4	4.2
S1 Bottom	1.2	27	150.5	4.9
S2	1.1	20.5	111.6	3.3
S3	1.5	32.3	126.6	2.4
S4 Top	0.7	17.6	114.4	3.2
S4 Bottom	1.1	8.2	51.27	3.3
S5 Control	1.3	27.2	175.6	6.4

In this study CEC was calculated using the Base cations that are shown on the Table 2. According to [17], a good direct measure of CEC can be obtained by measuring Ca, Mg, K and Al by ICP or AA. For ICP or AA results in mg/L: $CEC = [Ca/20 + Mg/12 + K/39 + Al/9]$ [17]. The main ions associated with CEC in the soil are exchangeable cations calcium, magnesium, aluminum, potassium and sodium [19], and are generally referred to as base cations. In most cases, summing the analyzed base cations gives an adequate measure of CEC by the bases.

TABLE III:
THE CEC-MEASURED PER SAMPLE

Samples	CEC (meq/g)
S1 Top	9.70
S1 Bottom	8.76
S2	6.50
S3	7.52
S4 Top	6.52
S4 Bottom	3.17
S5 Control	10.16

Since the CEC in each sample was below 11 meq/g it is a clear indication that the soil has a high sand content with low clay content (Table 3). Therefore the amount of CEC in each sample varies according to the clay percentage, clay type, soil pH and organic matter [20]. Therefore overall soil CEC of the entire study area is 7.48 meq/g. Productive crops and pastures can be grown on low CEC soil [21]. The soil in the study area is fertile and has sufficient nutrient for plant growth.

D. Analysis of PCBs in Contaminated Soils

The samples were collected from the site where the transformer contents were leaked to the ground after when the transformer was damaged by thieves (Figure 4). The results showed that there were ultra-trace levels of PCBs which were less than 0.01 mg/kg. The absence of PCBs at the surface may be because they have migrated downwards.



Fig 4: (A) The vandalized transfer that was damaged by the thieves, (B) the contents of transformer were thrown into the ground, (C) collecting of samples from the contaminated site and (D) notice there is no grass growing at the contaminated site

During the sampling process at 20 cm we encountered hard bed rock such that we were unable to penetrate beyond this point. A group of first samples were taken to SABS in Pretoria and were analysed there and the results that were found were less than 0.01 mg/kg. A second group of samples were taken to Waterlab in Pretoria and the results found showed that the amounts of PCBs in all samples were less than 0.01 mg/kg or below the limit of quantitation in all Arochlor (Table 4).

TABLE IV:
THE LEVEL OF PCBs (PPM) IN SOIL SAMPLES

Poly Chlorinated Biphenyls	S1 bot	S2	S3	S4 bot	S1 top	S4 top	S5 control
Arochlor 1242	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arochlor 1254	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arochlor 1260	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

At the contaminated site there was no grass that was growing and this may be due to the ultra-trace levels of PCBs that may have inhibited their growth (Figure 4D). The study of Streck et al. [22] has shown that the presence of PCBs in the soil can interfere with the growth of plants when they are applied at higher concentration. Streck and Weber [23] noted

an important or significant decrease in plant height, fresh top weight and inhibition of cumulative water use in soybeans and beetroot on application of 1000µg/g Arochlor 1254. At the control site, the grass was growing, as the growth conditions were acidic, sandy loam with high clay content and CEC 10.16 meq/g.

IV. CONCLUSION

In this study the PCB distribution profile around the study area indicated very low contamination of soil by PCBs. The average total concentration of PCBs in the study area was less than the Limit Of Quantitation (LOQ) which was 0.02 mg/kg. The absence of PCBs at the surface may be because they have migrated downwards. During the sampling process at 20 cm we encountered hard bed rock such that we were unable to penetrate beyond this point. The receiving soil was sandy and with low organic content, the PCB could migrate downward until it reaches a confining layer such as clay or a bed rock. Some Arochlors could migrate to greater depth because the viscosity of the mixture is much lower than the pure PCB. The soil of the study area was classified as sandy soil and has a low water holding capacity which also resulted in poor holding of the PCBs by the soil. The average moisture content of the all the sample was 5.8%. The low levels of PCBs imply a very low carcinogenic burden, contamination of plants and very poor movement to the underground water table. The average CEC of the sample was 7.48 meq/g and therefore the soil was fertile and would promote the growth of plants including grass. However at this site where the transformer oil was spilled it was observed that no grass was growing. Probably the absence of grass at the contaminated site was due to presence of the ultra-trace levels of PCBs. It is therefore recommended that more studies should be conducted on the PCB-containing oil that has spilled on the ground from the damaged transformers. Also are studies should be carried to introduce grass that is able to grow in the contaminated soil.

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