

ASSESSMENT OF THE LEVELS AND DISTRIBUTION OF
POLYCHLORINATED BIPHENYLS IN SOILS IN THE VICINITY OF
ELECTRIC TRANSFORMERS IN THE CENTRAL REGION OF
GHANA

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CHEMISTRY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is a result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

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Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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Polychlorinated biphenyls (PCBs) in surface soil samples from the Central Region of Ghana were analyzed to assess their distribution, levels and health effects. The soil characteristics were analyzed. Soils samples were digested with a mixture HNO_3 and HClO_4 and the metals analyzed using Varian 235 AAS. The PCBs were extracted with (1:1) hexane:acetone mixture, cleanup with H_2SO_4 , 5% KMnO_4 and copper, and then eluted from a silica gel column with hexane:dichloromethane (97:3% v/v). The PCBs were analyzed using a gas chromatograph equipped with ^{63}Ni electron capture detector (GC – ECD) model CP 3800. The PCBs were dominated by penta and tetra PCBs homologous. The concentration of PCBs for the region was $7.99 \pm 0.38 \mu\text{g/kg}$. The levels for the vertical distribution were $9.15 \pm 0.52 \mu\text{g/kg}$ for (0-10 cm), $7.55 \pm 0.56 \mu\text{g/kg}$ and $7.82 \pm 0.55 \mu\text{g/kg}$ for the 10-20 cm and 20-30 cm sub-surface soils. The pH, clay, silts and sand content of the soils correlated positively with the PCB congeners. The effective cation exchange capacity and moisture showed negative correlation. There were no significant correlations between organic matter, exchangeable base, metals and the PCB congeners or ΣPCB at the 0.05 level. The levels of PCBs were below the soil contact value of 25 mg/kg. The toxicity equivalents of PCB- 118 were all very low. Most of the soils in residential areas had hazard Index greater than one. The estimated lifetime cancer risk to a Reasonable Maximum Exposure (RME) individual via the complete exposure (skin contact) was very low, and ranged between $3.0\text{E}-11$ and $3.0\text{E}-10$ for adult resident and $5.4\text{E}-10$ to $5.3\text{E}-09$ for children resident, implying that the levels of exposure to soil PCBs are acceptable.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADE: Average daily exposure

ANOVA: Analysis of variance

CA: cluster analysis

CB: -Chloro biphenyl

CP Coplanar

CV: Coefficient of variation

DL: Dioxin like

ECEC: Effective cation exchange capacity

EF: Exposure factor

EROD: Ethoxyresorufin-O-deethylase

ex A= Exchangeable acidity

ex B = exchangeable bases

GC: Gas chromatography

HI: Hazard Index

I-TEQ: International Toxicity Equivalent

IUPAC: International Union of Pure and Applied Chemistry

LOD: Limit of detection

nd: Not detected

Nd: Not detected

P: Significance level

PCA: Principal component analysis

PCB: Polychlorinated biphenyl

PCB#: Polychlorinated biphenyl congener number

POPs: Persistence Organic Pollutants

r: Correlation coefficient

RME: Reasonable Maximum Exposure

RPD: Relative percent difference

Σ PCB: Sum of concentration of PCB congeners

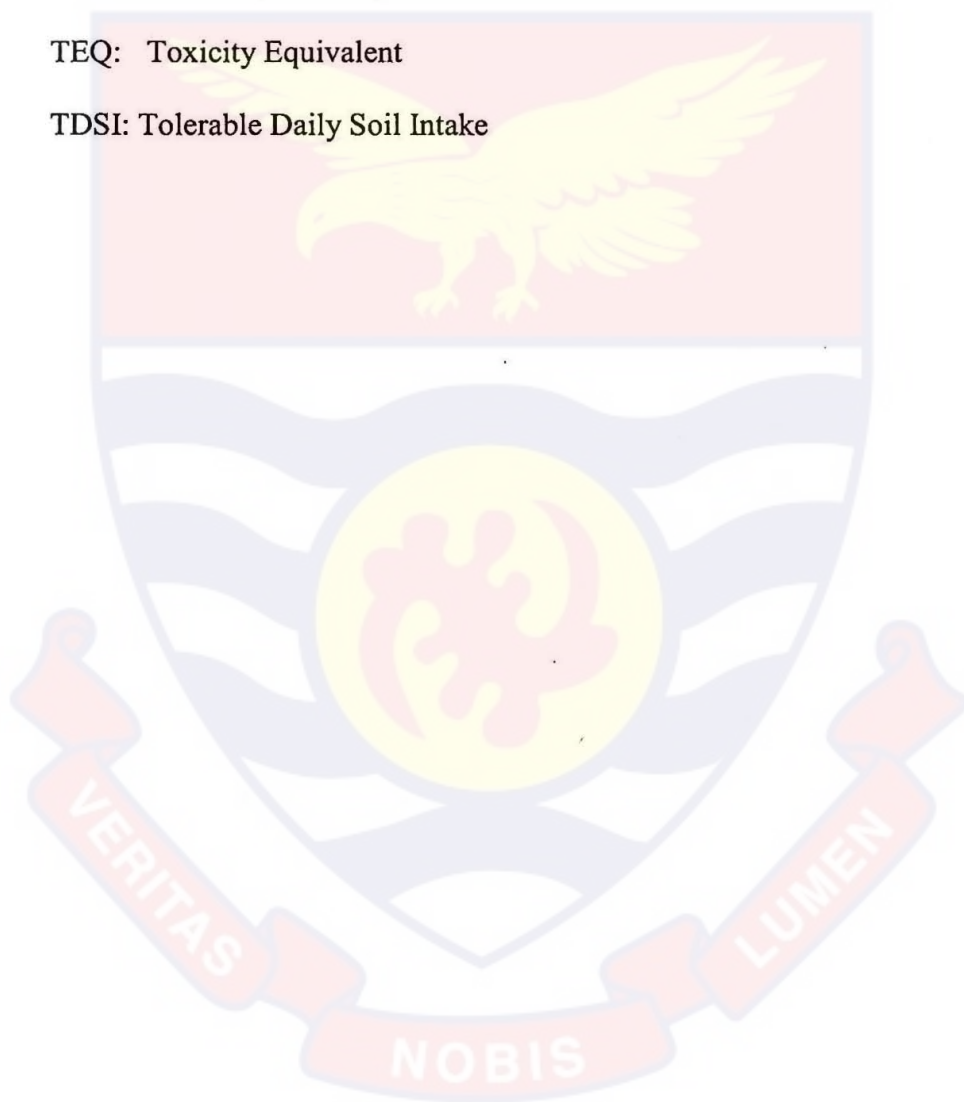
Σ PCB₇: Sum of concentration of seven PCB congeners

TEC: Threshold effect concentration

TEF: Toxic Equivalency Factors

TEQ: Toxicity Equivalent

TDSI: Tolerable Daily Soil Intake



CHAPTER ONE

INTRODUCTION

Background

Polychlorinated Biphenyls, PCBs, are organic compounds that were first produced in the 1930s. PCBs are resistant to heat and are chemically stable. They were used worldwide in transformer and electric capacitor oils, hydraulic and heat exchange fluids, circuit breakers, lubrication and cutting oils, plasticizers, adhesives and inks (Erikson, 1986; Montague, 1993; IPCS, 1993, 2003 & Philips, 1986). About 209 possible PCB congeners exist but 130 of these are used in commercial products. The PCBs are persistent in the environment with a half-life of 3 weeks to 2 years in air. In soils, they persist for more than six years. They have been found to be insidious and toxic to mammals and are carcinogenic to animals and probably human (Barbalance, 1993; Chow and Connor, 1993 & Tryphonas, 1995). Current research findings have attributed some behavioral deficits in children to the associations of exposures of the developing nervous system to PCBs (University of California - Davis - Health System, 2009).

Among its effects on the environment are: bioaccumulation by marine organisms which can result in 200-70,000 times the level of PCB in the open ocean and bioaccumulation in human milk. Phytoplankton (the primary marine food source) and fishes have shown to be particularly susceptible to the toxic effects of PCBs in laboratory tests (Jensen, 1966; Reijnders, 1986 & Johansen *et al.*, 1994). The health human hazards caused by PCBs include: headaches, dizziness, depression, fatigue, impaired immune response, impaired liver function, loss of body weight, and cause a skin condition

called "chloracne". It also affects neurological development in children (Francis 1994; Loomes, 1997 & Ribus-Fito, *et al.*, 2001)

According to Agency for Toxic Substances and Disease Registry, ATSDR, (2008), recent findings indicate that susceptible populations (e.g, sport anglers, the elderly, pregnant women, children, fetuses, and nursing infants) continue to be exposed to PCBs via fish and wildlife consumption. Human health studies discussed in this summary indicate that; reproductive function may be disrupted by exposure to PCBs; neurobehavioral and developmental deficits occur in newborns and continue through school-aged children who had in utero exposure to PCBs; other systemic effects (e.g., self-reported liver disease and diabetes, and effects on the thyroid and immune systems) are associated with elevated serum levels of PCBs; and increased cancer risks, e.g., non-Hodgkin's lymphoma, are associated with PCB exposures.

The Governing Council of the United Nations Environment Programme (UNEP) recognizing the increasing threats that Persistence Organic Pollutants (POPs) pose to human health and the environment, in May 1995 requested in its decision 18/32 that an international assessment process be undertaken on twelve organic pesticides which were considered as pollutants and persistent in the environment. These persistent organic pollutants (POPs) were aldrin, chlordane, dieldrin, dichlorodiphenyltrichloroethane (DDT), dioxins, hexachlorobenzene, heptachlor, endrin, furans, mirex, PCBs and toxaphene.

The Intergovernmental Forum on Chemical Safety (IFCS) was requested by the UNEP to develop an International action for consideration by

Stockholm Convention on POPs. In March 2004, at the National Association of Teachers Hall in Accra the draft NIP was reviewed (Environmental Protection Agency [EPA], 2004). Facts available indicate that there has been no production of POPs in Ghana.

However, locations in Ghana where POPs have been found included Electric Utilities (including distribution network) industrial facilities, residential (figure 1) and commercial buildings. The main potential PCB – containing applications at target location are transformers and capacitors. The Electricity Corporation of Ghana (ECG) as well as the Volta River Authority (VRA) and their clients (individual customers and industry) are the major custodian of PCB containing equipment in Ghana. Although it is on record that the importation of PCB containing transformers and capacitors for use in Ghana ceased in 1972. Recent investigations have shown that some of this equipment imported after 1990 contain PCB oils.

There is evidence that some workers in some industries have been exposed to PCBs because of bad practices, such as the use of empty transformer oil drums as water reservoirs. In addition, some of the dirty oil finds its way into small-scale industries and are used in mechanical garages, for production of pomade, as lubricant for sowing machine and also sold on the local market (EPA, 2004).

Problems Statement

The distributions of polychlorinated biphenyls (PCBs) in the environment have not been studied systematically in Ghana in spite of their negative effect on human health. There are evidences that some of the PCB containing transformers imported into Ghana before 1972 have been

retrofitted and filled with new dielectric fluids, the type of fluid and the procedure for filling were not properly documented. In addition, some transformers have been topped up with some form of PCB oil. An investigation of the contents of some representative samples of transformer oil, by subjecting them to its density test, indicated that they might contain PCB of about 100 ppm or more.

Some PCB containing capacitors have been found at the Achimota and Tema power station with some leaking in a pool of a network of high-tension cables. PCB – containing waste have been found at the Accra central station G, where broken down transformers from all over the country are repaired as well as VRA material stores at Tema. The presence of PCB – containing materials and equipment, and the detection of PCBs in some soils and lagoon in Ghana (Octhere, 2005; Centeno, 2010) are indications of some forms of contamination and exposure to some form of hazards, but the extent of pollution is unknown. Soils, the most common open systems have to be investigated. Any investigation that aims at establishing the presence and the levels of PCBs in the environment will augment the efforts of the EPA (the local point of information and exchange of information on POPs) and the country as a whole in an effort to monitor the POPs and their alternatives.

Objectives

The main objective of this study was to assess the levels, distribution and impacts of PCBs in soils in the neighborhoods of VRA/ECG transformer in some residential and commercial areas in Central Region of Ghana.

The specific objectives were:

1. To determine the concentrations of polychlorinated biphenyls (PCB # 28, 52, 101, 110, 118, 138, 153 and 180) in surface soils (0-30 cm) around ECG/VRA transformer in some selected areas in the Central Region and to compare with the recommended limits;
2. To determine the vertical distribution of PCBs in the contaminated soils;
3. To determine the Toxicity Equivalent of PCB 118 (PCB 118-TEQ) of the soils;
4. To determine the hazard index, and cancer risks to human health;
- 5 To determine the relationships between the soil PCBs and selected soil characteristics; pH, moisture, organic carbon, effective cation exchange capacity, sand, silt, clay and some metals (Ag, Al, Pb, Cu, Fe and Zn);
- 7 To provide database to complement monitoring of PCBs by EPA Ghana.

Importance of Study

The result of this study will indicate the degree of polychlorinated biphenyl contamination of soils in neighborhoods of some VRA and ECG transformers, contaminated sites, as well as the potential of the contaminated soils to cause harm. It will also contribute to the global inventory and pave way for adequate risk assessment where necessary.

Scope and Delimitation

In this work we have used PCB congener residue analysis approach to investigate the levels of polychlorinated biphenyls in soils. The soil properties and their relations with the extracted PCBs have been investigated with the

aim of determining whether the soil properties have any effect on the availability of the soil PCBs. The hazards and cancer risk associated with the levels of the soil PCBs have been estimated. Even though there are different methodologies for PCB residue analysis, our investigations were carried out using Gas chromatography equipped with electron capture detector (GC-ECD) and PCB# 28, 52, 110, 118, 138, 153 and 180 used as pollution indicator.

Research Hypothesis

- H_0 : Soils in the immediate surroundings of Electricity Company of Ghana (ECG) transformers contain polychlorinated biphenyls at levels that may pose health hazards.
- H_1 : Soils in the immediate surroundings of Electricity Company of Ghana (ECG) transformers contain polychlorinated biphenyls at levels that do not pose health hazards.

Structure of the Thesis

The rest of the chapters are organized as follows:

Chapter two will be a review of history of PCBs, some physical and chemical properties, persistence and degradation of PCBs in the environment; and their associated ecological and health impacts. Chapter three describes the sampling procedure, analytical method employed and methods of hazard and risk estimation will be described. In chapter four the results obtained in the previous chapter will be subjected to statistical analysis, compared to recommended limits and discussed. Finally, in chapter five, I will summarize the findings and draw conclusions and make recommendations.

CHAPTER TWO

LITERATURE REVIEW

Persistent Organic Pollutants (POPs)

Persistent Organic pollutants (POPs) are class of chemical agents that includes many organochlorine pesticides such as aldrin, chlordane, dieldrin, dioxins, endrin, DDT (and its main metabolite, DDE), furans, heptachlor, hexachlorobenzene, mirex, polychlorinated biphenyls (PCBs), and toxaphene. Polychlorinated biphenyl (PCBs), dioxins and furans are by products of certain manufacturing processes and waste incineration. POPs are chemicals targeted for international phase out because of their unique physical and chemicals properties. These have spread throughout the global environment and threaten human health, wildlife and damage the ecosystems.

Persistent Organic Pollutants (POPs) have unique characteristics and are also an urgent global environmental health problem because they persist in the environment for many years. POPs concentrate in fatty tissues and bioaccumulate as they move up the food chain. They travel long distances in global air and water currents, generally moving from tropical and temperate regions to concentrate in the northern latitudes; and have been linked with serious health effects in humans and other living organisms, even at very low exposures (Center for Health and Environmental Justice [CHEJ], 2000; Cummin, 1988; Solomon & Weiss, 2000) The available information indicates that Persistent Organic Pollutant residues are present in virtually all categories of foods, including baked foods, fruit, vegetables, meat, poultry, and dairy products (Schafer & Kegley, 2000). Once released to air, water, and soil, these chemicals do not break down readily by natural processes. Some have half-life

measured in decades, and they remain in water and soil where they accumulate in plants and animals that ultimately provide food for humans. It is no surprise; therefore, that POPs are pervasive in store bought food as well as in fish and wildlife.

In just a few decades, POPs have spread throughout the global environment to threaten human health and damage land and water ecosystems. All living organisms on earth now carry measurable amounts of POPs in their tissues. POPs have been found in sea mammals at levels high enough to qualify their bodies as hazardous waste under US law, an evidence of POPs contamination in human blood and breast milk has been documented worldwide. There is a strong evidence that exposure to even miniscule amounts of POPs at critical periods of development, particularly in the uterus, can cause irreversible damage. The effects of such exposures may take years to develop, sometimes appearing first in the offspring of exposed parents.

Despite their hazardous nature, these chemicals continue to be produced, used, and stored in many countries. Even where national bans or other controls exist, these restrictions are often poorly enforced, and the citizens cannot be protected from exposure to POPs that have migrated from other regions where these chemicals are still in use. Even though most POPs have already been banned in many countries, their persistence, combined with the fact that production and release into the global environment still occur in some countries, ensures that they make their way into the world's food supply (CHEJ, 2000; Cummin, 1988; Solomon & Weiss, 2000).

History of Polychlorinated biphenyls (PCBs)

In 1929, Swann Corporation, which later became part of Monsanto, began manufacturing polychlorinated biphenyls (PCBs) for commercial use. PCBs are oily liquids that conduct heat but not electricity. As such, they could be used as an insulating fluid in electrical appliances and were widely applied in everything from hydraulic equipment to degreasing agents for nuclear submarines. PCB mixtures were used for a variety of applications, including dielectric fluids for capacitors and transformers, heat transfer fluids, hydraulic fluids, lubricating and cutting oils, and as additives in pesticides, paints, carbonless copy paper, adhesives, sealants, plastics, reactive flame retardants, and as a fixative for microscopy. They were used in surgical implants (Brown, 1949). The commercial utility was based largely on their chemical stability, including low flammability, and desirable physical properties, including electrical insulating properties.

In effect, either Monsanto has produced or granted production licenses for all but a very small fraction of the world's PCBs, and is responsible for the release of a massive 1.2 million tons of the deadly chemicals worldwide. Although the company, Monsanto, was aware of adverse health effects in workers exposed to PCBs as early as the late 1930s, Monsanto continued to mass-produce them for decades until a highly-publicized PCB health scare 30 years later alerted policy-makers to the hazardous nature of the chemicals (Montague, 1989, 1992, 1993). In 1968, 1,300 residents of Kyushu, Japan, fell ill after eating PCB-contaminated rice. Many of the affected women later gave birth to children with severe defects.

In 1969, the New Scientist published a report revealing the capacity of

PCBs to "bioaccumulate along the food chain" (Jensen, 1966). The chemicals, which take many years to biodegrade, pass easily through the lipid portions of cell membranes and are readily absorbed into mammalian fat tissue. Animals at the top of the food chain, like whales, polar bears, dolphins and humans, can store PCBs at highly concentrated levels. The result has been a terrifying array of adverse reactions. In 1995, it was revealed that a woman who had eaten fish from the contaminated waters of the Great Lakes, Canada, gave birth to children with an unusually high susceptibility to bacterial infection. PCBs damage nerves in the brains of developing mammalian fetuses, leading to behavioral and learning defects (Tryphonas, 1995). PCB poisoning has been found to cause cancers, particularly malignant melanomas. In Ontario, State compensation was provided for the toxins' malignant effects. In addition, PCB-pollution resulted in immune defense deficiencies, hypertension and strokes (Loomis *et al.*, 1997).

Initially, it was assumed that PCB-accumulation was greatest nearest the sources of pollution. However, in 1988, the journal *Environmental Pollution* published an article revealing the extent of contamination borne in particular by marine mammals (Tanabe, 1988). Dolphins, whales and porpoises all contained levels of PCBs that far exceeded that of their terrestrial counterparts. Mediterranean blue-white dolphins, for example, were found to have PCBs at levels nearly 17 times the level requiring goods to be labeled and handled as toxic waste. Marine mammals were also found to have a genetically predetermined sensitivity to PCB-induced reproductive impairment; a sensitivity that only one in ten humans of European origin share. The chemicals, which mimic mammalian hormones, thus pose a real

threat of extinction to these animals (Reijnders, 1986; Subramanian *et al.*, 1987; Subramanian *et al.*, 1988).

Despite active research spanning five decades, extensive regulatory actions, and an effective ban on their production since the 1970s, PCBs still persist in the environment and remain a focus of attention. The available information indicates that POP residues are present in virtually all categories of foods, fruit, vegetables, meat, poultry, and dairy products. The only North American producer, Monsanto, marketed PCBs under the trade name Aroclor from 1930 to 1977. These were sold under trade names followed by a 4- digit number. The first two digits generally refer to the number of carbon atoms in the biphenyl skeleton (for PCBs this is 12), the second two numbers indicate the percentage of chlorine by mass in the mixture. Thus, Aroclor 1260 has 12 carbon atoms and contains 60% chlorine by mass. An exception is Aroclor 1016, which also has 12 carbon atoms, but has 42% chlorine by mass.

Different Aroclors were used at different times and for different applications. In electrical equipment manufacturing in the USA, Aroclor 1260 and Aroclor 1254 were the main mixtures used before 1950, Aroclor 1242 was the main mixture used in the 1950s and 1960s until it was phased out in 1971 and replaced by Aroclor 1016 (UNEP, 1997). Manufacturing peaked in the 1960s, by which time the electrical industry had lobbied the U.S. Congress to make them mandatory safety equipment, knowing all the while that they were extremely toxic. In 1966, a Swedish chemist, Dr. Soren Jensen determined them to be environmental contaminant, according to a 1994 article in Sierra, who named them. Previously, they had simply been called "phenols" or referred to by various trade names, such as Aroclor, Kennechlor, Pyrenol,

Chlorinol and others. Arochlors (chlorinated biphenyls) were known toxins in 1947. Robert Brown reminded chemists in 1947 that Arochlors were "objectionably toxic. Thus, the maximum permissible concentration for an 8-hr. day is 1 mg. per cubic meter of air. They also produce a serious and disfiguring dermatitis. Their chemical and physical stability has also been responsible for their continuing persistence in the environment, and the lingering interest decades after regulations were imposed to control environmental contamination.

In 1972, PCB production plants existed in Austria, then Federal Republic of Germany, France, Great Britain, Italy, Japan, Spain, USSR, and USA. From 1973 the use of PCBs was banned in "open" or "dissipative" sources, such as: plasticizers in paints and cements; casting agents; fire retardant fabric treatments and heat stabilizing additives for PVC electrical insulation; adhesives; paints and water-proofing railway sleepers.

However, they continued to be allowed in "totally enclosed uses" such as in transformers and capacitors, which, however, tended to explode on a regular basis. Ward B. Stone of the New York State Department of Environmental Conservation was the first to publish his findings in the early 1970s that PCBs were leaking from transformers and had contaminated the soil at the bottom of utility poles. Concern over the toxicity and persistence (chemical stability) of PCBs in the environment led the United States Congress to ban their domestic production in 1977, although some use continues in closed systems such as capacitors and transformers. PCBs used in "closed" systems include capacitors, insulating fluids in transformers, vacuum pump fluids; hydraulic fluid. Closed uses of PCBs were also banned

in the UK from 1981, when nearly all UK PCB synthesis ceased.

In Japan, PCBs were first produced by Kanegafuchi Chemical Co. Ltd. (Kaneka) in 1954 and production continued until 1972 when the Japanese government banned the production, use, and import of PCBs. Estimates have put the total global production of PCBs on the order of 1.5 million tons. The United States was the single largest producer with over 600,000 tons produced between 1930 and 1977. The European region follows with nearly 450,000 tons through 1984. According to Treger and Rozanov (2000), there is about 30,000 tons of PCB in Russia (20,000 tons in transformers and 10,000 tons in condensers).

It is unlikely that a full inventory of global PCB production will ever be accurately tallied, as there were factories in Poland, East Germany, and Austria that produced unknown amounts of PCBs (Breivik *et al.*, 2002). The United Nations Environment Program committee concluded a 3-years process of international treaty negotiations between 120 nations on a global legally-binding ban on 12 persistent organic pollutants (called POPs), including PCBs, Dioxins and Furans. The POPs Treaty was signed in Stockholm on 22-23 May 2001. Ratification by at least 50 countries was required before the treaty enters into force, a process that took 3-4 years (Breivik *et al.*, 2002)

Manufacture and Distribution of PCB

The first PCB-like chemical was discovered in 1865, as a by-product of coal tar, and in 1881 the first PCB was synthesized (Montague, 1981). By 1914, enough PCBs had already escaped into the environment to leave measurable amounts in the feathers of birds held in museums. In 1927, PCBs were first manufactured commercially by the Anniston Ordnance Company in

Anniston, Alabama. The company's name changed to the Swann Chemical Company (Riseborough & Brodine, 1971). In 1935 by the Monsanto Industrial Chemical Company of St. Louis, Missouri purchased Swann. Monsanto produced PCBs at plants in Sauget, Illinois and Anniston- Alabama until 1977. Monsanto then licensed others to make PCBs and the product took off. PCB's have been produced in other countries including Italy (Caffaro), France (Protolec), Japan (Kanegafuchi Chemical Co.), Germany (Bayer), and they may still be produced in Russia (Beiles, 2000). Davila *et al.*, (1993), estimated the cumulative world production of PCBs, from 1929 to 1980, to be 2.4 billion pounds.

Polychlorinated Biphenyls were first produced in 1929 for a wide variety of uses that ranged from being an extender in insecticide production to being used as an insulator in transformer production. PCBs have a number of useful physical properties that can be amplified by mixing different PCB congeners. Their unique physical properties made them attractive compounds for industries. As more uses were found for PCBs, their production increased exponentially from 1,000,000 kg in the 1930's (Neely, 1994). Estimates have put the total global production of PCBs approximately 1.5 million tons. The United States was the single largest producer with over 600,000 tons produced between 1930 and 1977. The European region follows with nearly 450,000 tons through 1984. It is unlikely that a full inventory of global PCB production will ever be accurately tallied, as there were factories in Poland, East Germany, and Austria produced unknown amounts of PCBs (UNEP, 1997; Karlyn *et al.*, 2006).

In the 1970s details for some of the commercial procedures for

demethylated using boron tribromide to yield the chlorinated dihydroxybiphenyls

The first indication that PCB's may be damaging to human health occurred four decades after introduction into the environment. Preliminary studies suggested that PCB's may pose a serious health threat to humans, and at the same time there were indications of widespread distribution and longevity throughout the environment. As more attention was turned towards PCB's, it became clearer that PCB's were having a negative impact on many biological systems; and as the extent of PCB contamination became more of a public issue, pressure was mounted to ban their production and importation. Major producers such as Monsanto Co. voluntarily stopped production of open system PCB's (insecticides, coatings) but continued with the production of closed system PCBs (transformers, capacitors) until government legislation eventually banned all production and importation of polychlorinated biphenyls.

While it is believed that the total amount of PCBs produced annually has declined since the 1970s, this does not necessarily imply that the toxicological threat posed by these compounds has also decreased. Few safe disposal options exist for PCBs. In Germany, for example, PCBs were buried in the shafts of salt mines. In such disposal facilities, residues will eventually find their way to watercourses and to the sea. This implies that ecotoxicological problems created by PCB contamination will be evident for many years to come, despite the restrictions on PCB utilization.

The investigations of Tanabe and co-workers have been instrumental in defining the non-ortho coplanar PCBs as those isomers of greatest

toxicological threat. Studies have also shown that the non-ortho coplanar PCBs are very persistent in aquatic environments. Significant levels of these PCBs may therefore bioconcentrate in exposed organisms. It is also probable that such compounds are transferred through the food web. Such transfer results in biomagnification of PCB concentration as one move up the food chain (Phillips, 1986). PCBs are widespread contaminants in the environment primarily in soil and freshwater systems. Their persistence in the environment has been a growing concern due to their low degradability, toxicity, mutagenicity and because of their tendency to bioaccumulate. These compounds have been shown to undergo biodegradation under a variety of conditions in the laboratory and in the field. Polychlorinated biphenyls (PCBs) are a group of industrial chemicals that share a common structure.

PCBs were commercially produced as complex mixtures beginning in 1929 and are not known to occur naturally in the environment. Monsanto Corporation was a major producer of PCBs and marketed them under the trade name Aroclor from 1930-1977. Principal uses of PCBs such as Aroclor include uses in transformers, capacitors, printing inks, paints, dedusting agents, pesticides, plasticizers, lubricant inks, paint additives etc., and they were marketed for these uses. It is because of PCBs chemical and physical stability as well as their electrical insulating properties that make them so commercially attractive.

PCBs occur as liquids or solids, and they are clear to light yellow in colour. They have no odour or taste. Because of their thermal stability they do not easily burn, hence their past popularity as coolants, insulating materials and their wide use for electrical applications. PCBs are difficult to oxidize and

reduce. They have very low water solubility and therefore are highly lipophilic. PCBs also have high electrical resistivity or low electrical conductance. Commercial PCB mixtures were synthesized by chlorination of biphenyl with chlorine gas. The average degree of chlorination was controlled by the reaction conditions in order to produce the desired chemical and physical properties. Today, the productions of PCBs have ceased in North America with the exception of small quantities manufactured strictly for research purposes.

PCBs are an environmental hazard due to their inability to degrade in the environment. They are highly lipophilic leading to their profound persistence and ability to bioaccumulate. These 'foreign' compounds are not readily metabolized by most living organisms and despite the cessation of their production remain a widely distributed health, ecological and environmental concern (Bedard & Habel, 1990; Erickson, 1986; Phillips, 1986).

Uses of PCBs

Polychlorinated biphenyls were commercially produced as complex mixtures containing multiple isomers at different degrees of chlorination. In the United States, Monsanto took over commercial production of PCBs in 1929 from Swann Chemical Company. Manufacturing levels increased in response to the electrical industry's need for a "safer" cooling and insulating fluid for industrial transformers and capacitors. PCBs were also commonly used as stabilizing additives in the manufacture of flexible PVC coatings for electrical wiring and electronic components to enhance the heat and fire resistance of the PVC. Principal uses of PCBs such as Aroclor include uses in

transformers, capacitors, printing inks, paints, dedusting agents, cutting oils, flame retardants, hydraulic fluids, sealants, pesticides, plasticizers, lubricant inks, paint, additives and in carbonless copy paper; and they were marketed for these uses. It is because of PCBs chemical and physical stability as well as their electrical insulating properties that make them so commercially attractive (Karlyn *et al.*, 2006; UNEP, 1997).

Structure and Nomenclature of PCBs

Polychlorinated biphenyls (PCBs) are the chlorinated derivatives of a class of aromatic organic compounds called biphenyls. Polychlorinated biphenyls are composed of two benzene rings each containing six carbon atoms and between 1 and 10 chlorine atoms attached to the biphenyl which are manufactured by the direct chlorination of the biphenyl ring system (Sittig, 1981). Theoretically, there are 209 possible PCB congeners (chlorobiphenyls) that differ in the number and position of the chlorine on the biphenyl structure (Bedard *et al.*, 1987; Mousa *et al.*, 1996; Quensen III *et al.*, 1990; Waid, 1986). The degree of chlorination of any Aroclor may vary between 19 and 71% (Crine, 1988). The chemical formula for all PCBs is: $C_{12}H_{10-x}Cl_x$. Chemical structures of PCBs. Fig.1 shows the possible positions of chlorine atoms (denoted by numbers) on the benzene rings; the coplanar and non-planar geometry, and the structures of dibenzo-P-dioxins (PCDDs) dibenzofuran (PCBFs)

The nomenclature of 209 PCB-homologues are based on procedure adopted by IUPAC and Ballschmiter and Zell (1980). Biphenyl is not technically a PCB congener due to its lack of chlorine substituents, is still typically included in the literature. Commercial PCB mixtures were marketed

as *Clophen* by Bayer in Germany, *Aroclor* by Monsanto in USA, *Kanechlor* by Kanegafuchi in Japan, *Santotherm* by Mitsubishi in Japan, and *Phenoclor* and *Pyralene* by Prodolec in France. In (West-) Germany Bayer AG produced PCBs under the trade name 'Clophen'.

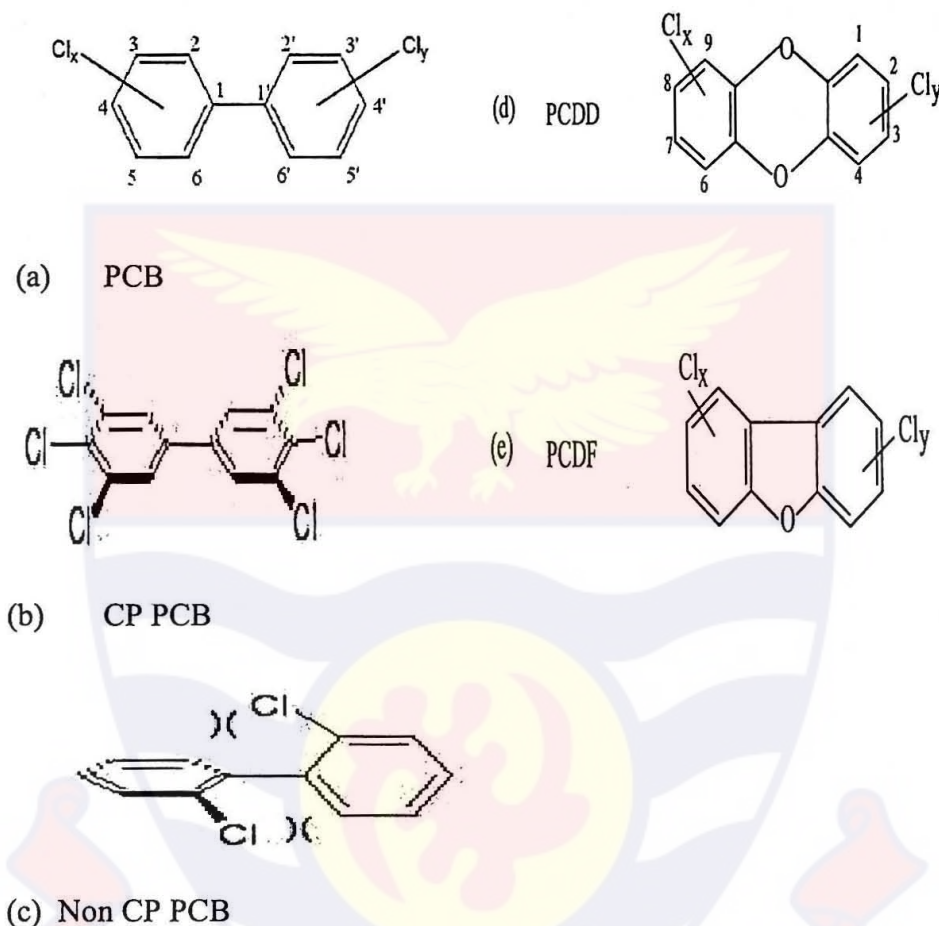


Figure 1: Structures of (a) PCBs (b) coplanar PCBs (CP PCB) (c) non-planer PCBs (d) dibenzo-P-dioxins (PCDDs) (e) dibenzofuran (PCBFs).

PCBs consist of a biphenyl (two benzene rings with a carbon to carbon bond between carbon 1 on one ring and carbon 1' on the second ring) with a varying number of chlorines. Chlorines can be attached to any of the carbons by removing the hydrogen from that carbon and substituting the chlorine in its place. The nomenclature used for identifying the positions of chlorine atoms

substitution at only one of the ortho positions and is referred to as CP1 or mono-ortho congeners.

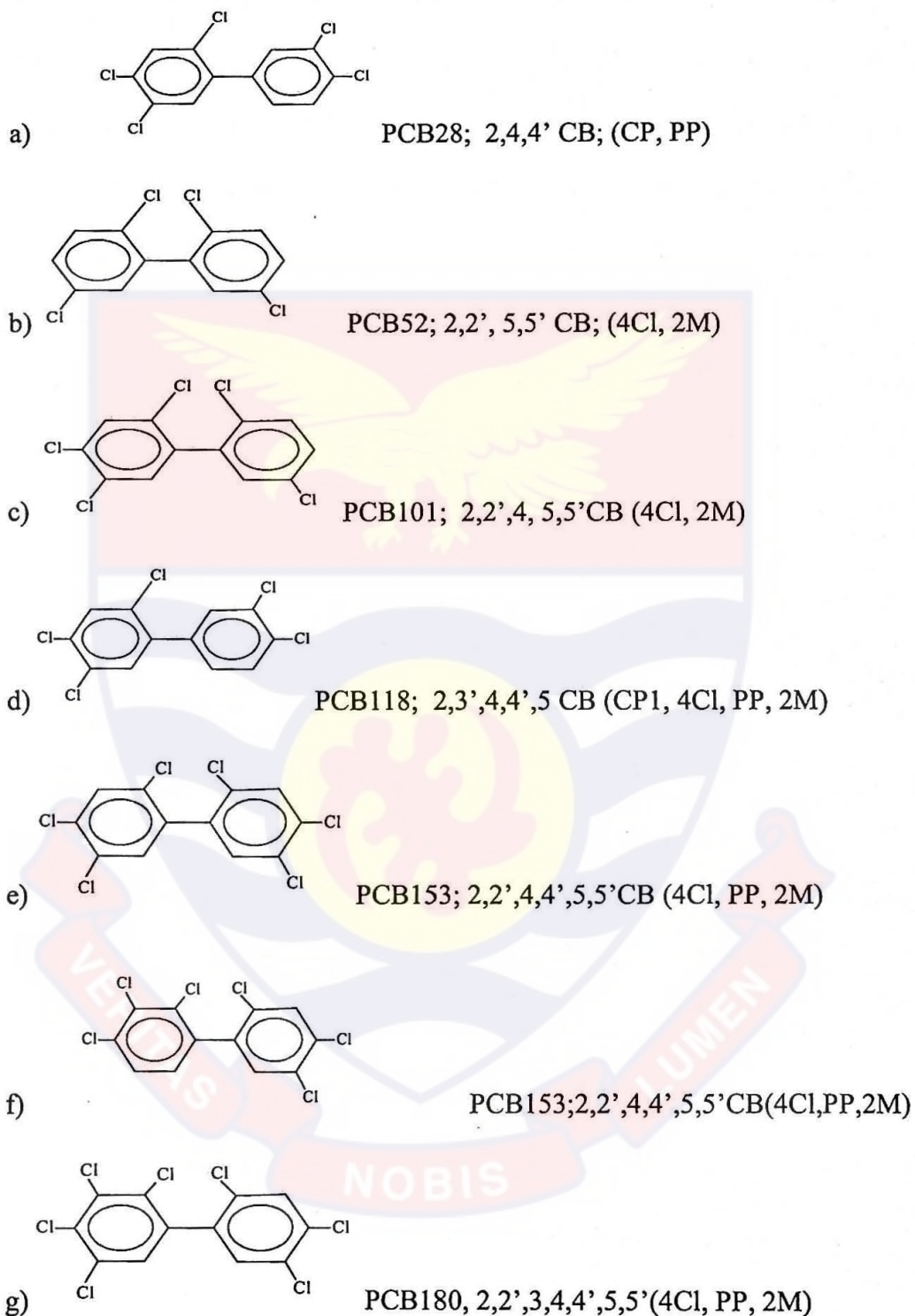


Fig 2: Structures of some PCBs

Congeners that have a total of four or more chlorine substituents, regardless of position are said to be 4Cl; 169 congeners are described as 4Cl. PP; these (54 congeners) have both para positions chlorinated. The 140 congeners that have two or more of the meta- positions chlorinated are described with the notation 2M. Only twelve out of the 209 congeners display all four of the descriptors, and are referred to as being "dioxin-like", referring both to their toxicity and structural features which make them similar to 2,3,7,8 -tetrachloro- dibenzo-p-dioxin (2378-TCDD) The structures and congener descriptors of some congeners (figure 2) are: 2,4,4' tetrachlorobiphenyl - CP1, PP; 2,2',5,5' tetrachlorobiphenyl- 4Cl, 2M; 2,2',4,5,5' pentachlorobiphenyl- 4Cl, 2M; 2,3',4,4',5 pentachlorobiphenyl-CP1, 4Cl, PP, 2M; 2,2,3,4,4',5' hexachlorobiphenyls- 4Cl, PP and 2M; 2,2',4,4',5,5' hexachlorobiphenyl-4Cl, PP and 2M -; 2,2',3,4,4',5,5' heptachlorobiphenyl- 4Cl,PP,2M.

The molecular formula, name, number of isomers, IUPAC number, molecular mass, percentage of chlorine and number of isomers or homologous of PCBs are listed in Table 1. The number of possible isomers within the same degree of chlorination varies. Some of the properties of polychlorinated biphenyls are dependent upon the number of chlorine atoms attached to the biphenyl ring. Properties such as, solubility in water, density, vapour pressure and volatile nature, biodegradation and rate of degradation are affected by the number of chlorines and their position on the biphenyl ring.

Table 1: Molecular formula, name, number of isomers, IUPAC number, molecular mass, percentage of chlorine and number of isomers identified (Heidelore, 2009)

Molecular Formula	Name CB	Number of Isomers	IUPAC No	Molecular Mass	% of Chlorine	Isomers Identified
$C_{12}H_9Cl$	Mono	3	1-3	188.65	18.79	3
$C_{12}H_8Cl_2$	Di	12	4-5	233.10	31.77	12
$C_{12}H_7Cl_3$	Tri	24	16-39	257.54	41.30	23
$C_{12}H_6Cl_4$	Tetra	42	40-81	291.99	48.65	41
$C_{12}H_5Cl_5$	Penta	46	82-127	326.43	54.30	39
$C_{12}H_4Cl_6$	Hexa	42	128-169	360.88	58.93	31
$C_{12}H_3Cl_7$	Hepta	24	170-193	395.32	63.77	18
$C_{12}H_2Cl_8$	Octa	12	194-205	429.77	65.89	11
$C_{12}HCl_9$	Nano	3	206-208	464.21	68.73	3
$C_{12}Cl_{10}$	Deca	1	209	498.66	71.10	1

Physical Properties of PCBs

PCB congeners are odorless, tasteless, clear to pale-yellow viscous liquids. They are formed by electrophilic chlorination of biphenyl with chlorine gas. There are theoretically 209 different PCB congeners; although only about 130 of these were used in commercial PCBs. Commercial PCBs are mixtures of 50 or more PCB congeners. Commercial PCB mixtures are clear to pale-yellow, viscous liquids (the more highly chlorinated mixtures are

more viscous and more yellow, for example, Aroclor 1260 is a sticky yellowish resin). They have high dielectric constants, very high thermal conductivity, and high flash points (170-380°C). The density varies from 1.182 to 1.566 kg/L. Other physical and chemical properties vary widely across the class. As the degree of chlorination increases, melting point and lipophilicity increase, but vapour pressure and water solubility decrease (Australian and New Zealand Environment and Conservation Council [ANZECC], 1997; Boate *et al.*, 2004; Karlyn *et al.*, 2006; UNEP, 1999).

Chemical Properties of PCBs

Chemical properties of PCBs include a high dielectric constant, high solubility in hydrocarbons and virtual insolubility in water. PCBs have low water solubilities — 0.0027-0.42 ng/L for Aroclors, and low vapor pressures at 25°C (10^{-12} - 10^{-4}), but they have high solubilities in most organic solvents, oils, and fats. (i.e. high lipophilicity). They are nonvolatile, chemically inert and do not undergo oxidation, reduction, addition, elimination or electrophillic substitution reactions except under extreme conditions (Sittig, *et al.*, 1980). Most PCBs are oily liquids whose colour darkens and viscosity increases with rising chlorine content.

Studies have been conducted on the solubility of PCBs in water and it was determined that there was an inverse correlation between PCB solubility and degree of chlorination. The solubility of Aroclor is less than 0.1 mg/L in fresh water and 0.04 mg/L in marine water (Sittig, *et al.*, 1981). The octanol-water partition coefficient for tri, tetra and pentachlorobiphenyls is in the range of 10,000 to 20,000. Soil or sediment characteristics that affect the mobility of the PCBs include soil density, particle size distribution, moisture

content, and permeability. In general soil sorption is more likely to occur in the more heavily chlorinated PCB congeners. PCBs readily penetrate skin, PVC (polyvinyl chloride), and latex (natural rubber); organic solvents such as kerosene increase the rate of skin absorption. PCB-resistant materials include Viton, polyethylene, polyvinyl acetate (PVA), polytetrafluoroethylene (PTFE), butyl rubber, nitrile rubber, and Neoprene.

PCBs are very stable compounds and do not degrade readily. They may be destroyed by chemical, thermal, and biochemical processes, though it is extremely difficult to achieve full destruction, and there is the risk of creating extremely toxic dibenzodioxins and dibenzofurans through partial oxidation. Because of the high thermodynamic stability of PCBs, all degradation mechanisms are difficult to sustain. Intentional degradation as a treatment of unwanted PCBs generally requires high heat or catalysis. Environmental and metabolic degradation generally proceeds quite slowly relative to most other compounds. In terms of toxicity the most toxic congeners are the ones in which there is a coplanar conformation with chlorine substituents on the meta and para positions of the phenyl rings (Sittig, 1981; Boate *et al.*, 2004; Karlyn *et al.*, 2006).

PCBs exhibit a wide range of toxic effects. These effects may vary depending on the specific PCB. Similar to dioxin, the toxicity of coplanar PCBs and mono-ortho-PCBs are thought to be primarily mediated via binding to aryl hydrocarbon receptor (AhR) (Safe, 1984; Safe, 1985). Because AhR is a transcription factor, abnormal activation may disrupt cell function by altering the transcription of genes. The AhR also has physiological roles regulating vascular development, immune function, and cell growth,

suggesting a role in human disease (Aluru, *et al.*, 2011; Besselink, *et al.*, 1998; Wirgin, *et al.*, 2011). The concept of toxic equivalency factors (TEF) is based on the ability of a PCB to activate aryl hydrocarbon.

However, not all effects may be mediated by the AhR. For example, di-ortho-substituted non-coplanar PCBs interfere with intracellular signal transduction dependent on calcium; this may lead to neurotoxicity. Ortho-PCBs may disrupt thyroid hormone transport by binding to transthyretin (Chauhan, 2000; Simon *et al.*, 2007).

Toxicity and Hazards of PCBs

Many studies have shown that PCBs have influence in different human diseases such as cancer, neuro-behavioural effects, abnormal thyroid and immune function in children and low birth weight (Kimbrough, 1995; Kimbrough & Krouskas, 2003). The toxicity of a PCB is dependent not only upon the number of chlorines present on the biphenyl structures, but the positions of the chlorines. For instance congeners with chlorines in both para positions (4 and 4') and at least 2 chlorines at the meta positions (3, 5, 3', 5') are considered to be "dioxin like" and are particularly toxic. When there is just one or no substitution in the ortho position, the atoms of the congener are able to line up in a single plane (sometimes referred to as coplanar). The planar or "flat configuration, referred to as 'dioxin-like', is particularly toxic (Barbalace, 2003).

The toxicity of PCBs to animals was first noticed in the 1970s when emaciated seabird corpses with very high PCB body burdens were washed up on beaches. The sources of the PCBs were unknown though, because seabirds may die at sea and be washed ashore from a very wide area. Where they were

found was no reliable indicator of where they had died. The toxicity of PCBs varies considerably among congeners. The coplanar PCBs, known as non-ortho PCBs because they are not substituted at the ring positions ortho to (next to) the other ring, (i.e. PCBs 77, 118, 126, 169, etc), tend to have dioxin-like properties, and generally are among the most toxic congeners.

Since PCBs are almost invariably found in complex mixtures, the concept of toxic equivalency factors (TEFs) has been developed to facilitate risk assessment and regulatory control, where more toxic PCB congeners are assigned higher TEF values. One of the most toxic compounds known, 2,3,7,8-tetrachlorodibenzo-p-dioxin, is assigned a TEF of 1 (Barbalace, 2003). Chronic exposure to sub-lethal concentrations combined with high lipid solubility and resistance to metabolism can result in PCB accumulation and a toxic response (Exner, 1982).

Safety Guidelines for Exposure to PCBs

Safe standards recommended by various institutions and organizations in the United States (Table 2), such as the Environmental Protection Agency

Table 2: Safety guidelines for exposure to PCBs

Agency	Source	Sample	Recommended limits
U.S. EPA	EPA, 2006a, 2006b	Drinking water is	0.5 ppb.
		Water from lakes or streams	0.17 ppt.
		fish or shellfish	0.17 ppt
U.S. FDA	ATSDR, 2000	Infant and junior foods	0.2 ppm
		Eggs	0.3 ppm

Table 2 continued

U.S. FDA	ATSDR, 1990	Milk and other dairy product	1.5 ppm fat basis
	ATSDR, 2000	Fish and shellfish (edible port)	2 ppm
		Poultry and red meat	3 ppm fat basis
OSHA	ATSDR, 1990,	Air (42% chlorine PCBs)	1 mg/m ³
	ATSDR, 2000	inhalation limit over a period of 8 hours for 5 days per week.	(1 ppb)
		Air (54% chlorine PCBs) inhalation limit over a period of 8 hours for 5 days per week.	0.5 mg/m ³ (0.5 ppb)
NIOSH	ATSDR, 1990	Air (42% and 54% chlorine PCBs) inhalation limit for 10 hours workday for 40 workweek.	1 µg/m ³ (1 ppt)
	ATSDR, 2000		
CCME	CCME, 1999)	Agricultural land	0.5 mg/kg
		Residential lands and parks	1.3 mg/kg
		Commercial and industrial lands	33 mg/kg
USEPA	ATSDR, 1990	Residential lands and parks	1.0 mg/kg
	ATSDR, 2000	Commercial and industrial lands	25 mg/kg

(EPA); Food and Drug Administration (FDA); Atlanta: Agency for Toxic Substances and Disease Registry (ATSDR ATSDR, 1990, 2000, 2006; CDC,

2005), and the National Institute for Occupational Safety and Health (NIOSH), and Occupational Safety and Health Administration (OSHA) EPA, (2006a, 2006b).

Signs and Symptoms of PCB Hazards

The most commonly observed health effects in people exposed to PCBs are skin conditions such as chloracne and rashes (Plate 1), but these were known symptoms of systemic poisoning dating back to the 1920s. Studies in workers exposed to PCBs have shown changes in blood and urine that may indicate liver damage.



Plate 1: Chloracne, a skin conditions caused by contact with clothes contaminated with PCBs (Schroeder, 1991)

In 1968 in Japan, PCB contamination in rice bran oil caused a mass poisoning known as Yushō Disease in over 14000 people. Common symptoms

included dermal and ocular lesions, irregular menstrual cycles and low immune response vision impairment. Other symptoms included fatigue, headache, cough, and unusual skin sores. Additionally, in children, there were reports of poor cognitive development. There have also been studies of the health effects of PCBs in the general population and in children of mothers who were exposed to PCBs. A few studies of workers indicate that PCBs were associated with specific kinds of cancer in humans, such as cancer of the liver and biliary tract.

Women who were exposed to relatively high levels of PCBs in the workplace or ate large amounts of fish contaminated with PCBs had babies that weighed slightly less than babies from women who did not have these exposures. Babies born to women who ate PCB-contaminated fish also showed abnormal responses in tests of infant behavior. Some of these behaviors, such as problems with motor skills and a decrease in short-term memory, lasted for several years. Other studies suggest that the immune system in children born to and nursed by mothers exposed to increased levels of PCBs were affected. The most likely way infants are exposed to PCBs is from breast milk. Transplacental transfers of PCBs have also been reported.

Studies have shown that PCBs alter estrogen levels in the body and contribute to reproduction problems. In the womb, males can be feminized or the baby may be intersex, neither a male nor a female. In addition, both sexes of reproductive organs may develop. More instances of this are being reported. Biological magnification of PCBs has also led to polar bears and whales that have both male and female sex organs and males that cannot reproduce. This effect is also known as endocrine disruption. Endocrine Disrupting Chemicals

(EDC's) pose a serious threat to reproduction in top-level predators (Drinker, 1937; Lincoln, 1999; Loomis *et al.*, 1997; Tilso, 1990).

Animals that eat PCB-contaminated food even for short periods get liver damage and may die. In 1968 in Japan, 400,000 birds died after eating poultry feed that was contaminated with PCBs. Animals that eat smaller amounts of PCBs in food over several weeks or months develop various kinds of health effects, including anemia; acne-like skin conditions (chloracne); and liver, stomach, and thyroid gland injuries (including hepatocarcinoma).

Other effects of PCBs in animals include changes in the immune system, behavioral alterations, and impaired reproduction. PCBs cause birth defects in humans, although those that have dioxin-like activity are known to cause a variety of teratogenic effects in animals. Rats that ate food containing high levels of PCBs for two years developed liver cancer (Robert.1973; Tryphonas, 1995). Humphrey *et al.*, (1983) found a 10% prevalence of unspecified joint problems among families who lived on farms and who consumed dairy products and beef contaminated with PCBs.

Some 30 years after the toxic chemicals were banned in the United States, researchers were unable to explain the associations between exposure to PCBs and its effect on developing nervous system. According to Isaac N. Pessah, professor of molecular biosciences, director of the UC Davis Center for Children's Environmental Health and co-author of all these studies on how PCBs may alter in utero, neonatal brain development, ."We've never really understood the mechanism by which PCBs produce neurobehavioral problems in children; we believe other PCB-like compounds in use today are also capable of changing the structure of protein targets that are contributing to

neurobiological problems in humans". However, current findings could explain at last, the associations between exposure of the developing nervous system to PCBs and behavioral deficits in children (University of California - Davis - Health System, 2009).

Recent studies have implicated oxidative stress as a possible causative mechanism for the non-target toxicity of organochlorine compounds and PCBs. PCBs are also well known as increasing oxidative stress in several biological systems (Coteur *et al.*, 2001; Mariussen *et al.*, 2002; Ruiz-Leal & George, 2004; Voie & Fonnum, 2000). PCBs possibly exert their toxic effects in some bacteria, by accumulating in the cytoplasmic membrane and disrupting its function. In this case, the degradation ability of biphenyl is important not only for energy acquisition but also for detoxification of biphenyl (Delawary *et al.*, 2003).

Route and Type of Exposure

The main routes of exposure are ingestion and inhalation, but exposure may be due to the following; - eating contaminated food. PCBs especially accumulate in fish and marine mammals such as seals and whales. Drinking contaminated well water; leaks from or fires in transformers, capacitors, or other PCB-containing products; breathing indoor air in buildings that have electrical devices containing PCBs.

Toxic Equivalents (TEQ) and Risk Assessment

Commercial mixtures, as well as the individual PCB congeners, elicit a broad spectrum of biochemical and toxic responses, some of which are similar to those caused by 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. Dioxin-like compounds normally exist in environmental and biological samples as

complex mixtures of congeners; therefore, the concept of toxic equivalent (TEQ), have been developed to simplify risk assessment and regulatory control. In applying this concept, relative toxicities of dioxin-like compounds in relation to the reference compound (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) were determined on the basis of *in vivo* and *in vitro* studies (Tab. 3).

Table 3: TEF for mono and di-ortho-substituted PCBs (Ahlborg *et al.*, 1994) ¹ and TEF for humans, mammals, fish, and birds proposed by WHO (WHO, 1997)

PCB Congener	Substitution	IUPA No.	ITEF ¹ (1994)	WHO- TEF(1997) Han	Fish	Birds
Non-ortho	3,3',4,4'-TetraCB	77	0.0005	0.0001	5.0E-5	0.1
substituted:	3,4,4',5-TetraCB	81		0.0001	0.0001	<0.05
	3,3',4,4',5-PentaCB	126	0.1	0.1	0.005	0.1
Mono-ortho	3,3',4,4',5,5'HexaC	169	0.01	0.01	5.0E-5	0.001
	2,3,3',4,4'-PentaCB	105	0.0001	0.0001	<5.0E-6	0.0001
substituted:	2,3,4,4',5-PentaCB	114	0.0005	0.0005	<5.0E-6	0.0001
	2,3',4,4',5-PentaCB	118	0.0001	0.0001	<5.0E-6	1.0E-5
	2',3,4,4',5-PentaCB	123	0.0001	0.0001	<5.0E-6	1.0E-5
	2,3,3',4,4',5HexaCB	156	0.0005	0.0005	<5.0E-6	0.0001
	2,3,3',4,4',5'HexaCB	157	0.0005	0.0005	<5.0E-6	0.0001
	2,3',4,4',5,5'-HexaCB	167	1.0E-5	1.0E-5	<5.0E-6	1.0E-5
	2,3,3',4,4',5,5'HeptaCB	189	0.0001	0.0001	<5.0E-6	1.0E-5
Di-ortho	2,2',3,3',4,4',5HepaCB	170	0.0001	1.0E-5	0	0
substituted:	2,2',3,4,4',5,5'HeptaCB	180	0	0	0	0

Three coplanar PCBs, namely 3,3',4,4'-tetrachlorobiphenyl, 3,3',4,4',5-pentachlorobiphenyl, and 3,3',4,4',5,5'-hexachlorobiphenyl, exhibit dioxin-like effects, such as *Ah*-receptor agonist activity (Safe 1990 and 1994; Ahlborg *et al.* 1992 and 1994). PCB 170 and PCB 180 are included because they are active as inducers of EROD (ethoxyresorufin-*O*-deethylase) activity and are present in significant amounts in environmental samples. In 1997, new TEFs were proposed based on new information (WHO, 1997).

Transport of PCBs within the Environment

PCB contamination in the environment has come exclusively from human activities. According to Wong and Poon (2003) and China SEPA (2003), PCBs polluted the environment during their manufacture and use. Thus, high PCB concentration areas tend to be around industrialized areas, like the Great Lakes. PCBs enter the general environment mainly by leakage of supposedly closed systems, from landfill sites, incineration of waste, agricultural lands, industrial discharges and sewage effluents.

Leakage of small amounts is common in older equipment containing PCBs (Plate 2 & 3) accidental spills and leaks during the transport of chemicals; Illegal or improper dumping of PCB wastes, i.e. old transformer fluids, leaks or releases from electrical transformers containing PCBs; Disposal of PCB-containing consumer products into landfills not designed to handle hazardous waste and burning of PCB-containing wastes in municipal and industrial incinerators (ATSDR, 2000, 2006; CDC, 2005; U. S. EPA, 2006)

PCBs are also widely dispersed in the atmosphere where they are transported by winds and fall to the surface in precipitation. Approximately

98% of the PCBs entering the ocean are currently deposited from the atmosphere. Factors such as air temperature, wind speed, storm frequency,



Plate 2: Immediate environ of a transformer in Accra contaminated by leakage (Centeno, 2010)

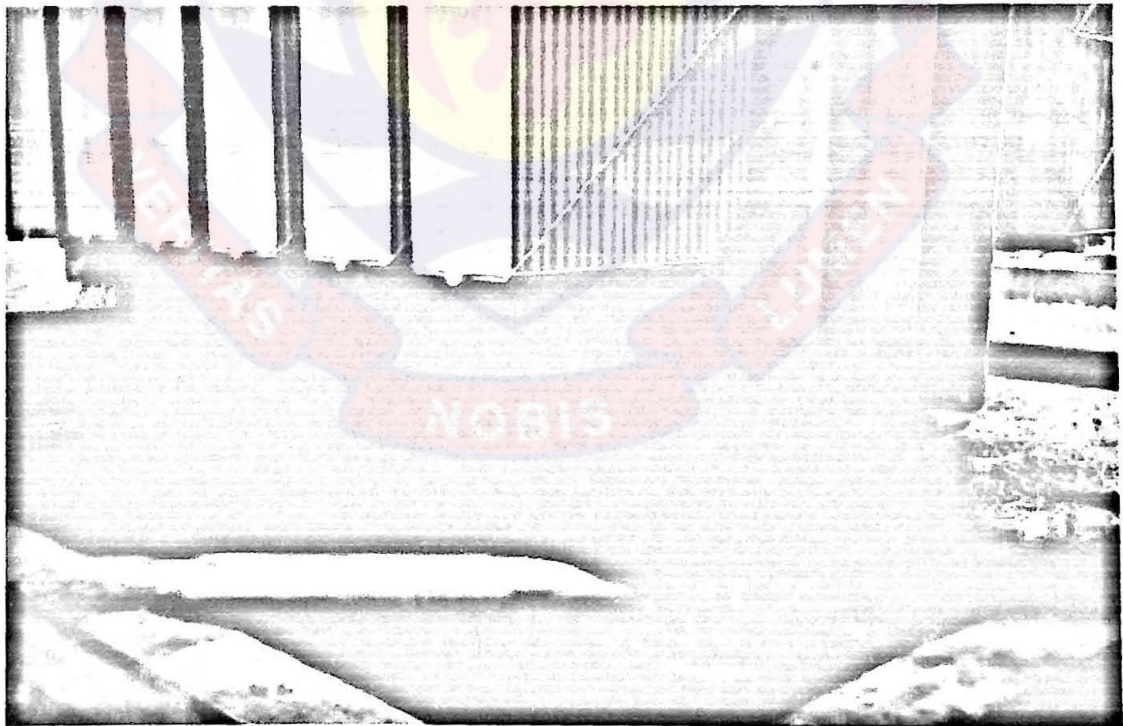


Plate 3: Transformer Oil spillages at transformer base at Oshogbo in Nigeria (Federal Ministry of Environment, 2009)

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rainfall rates and the volatility of individual PCB isomers influence the pattern and rates of PCB movement in the atmosphere. The principal transport route for PCBs through aquatic systems is from waste streams into receiving waters, and re-adsorption onto particles as well as by the movement of sediments. This leaves the marine environment as one of the final sinks for PCBs.

Transport of PCBs within Aquatic Systems

Polychlorinated biphenyls are found in higher concentrations in the sediments of aquatic systems due to their chemical and physical properties which cause high sorption reactions. Sorption increases with chlorine content, surface area and with the organic content of the sorbent. Therefore, PCBs sorb onto falling sediments that eventually end up as bottom sediments. PCBs are associated particularly with suspended sediments of a diameter less than 0.15 mm.

The release of PCBs from sediments to overlying waters can occur by slow desorption, especially when PCB concentrations are high or when sudden hydrographic activity like flooding or dredging causes sediments to be re-suspended and redistributed. Translocation can also occur through biological activity (Halter and Johnson, 1977). Desorption of PCBs from particulate is more likely to occur from lower chlorinated, more water-soluble PCB congeners (Wood *et al.*, 1987).

Transport of PCBs within Air Systems

Airborne contamination has been recognized as a significant source of PCB contamination in the Great Lakes Basin since the mid - 1980's. This is especially true for Lake Superior which is still largely isolated from

industrial and municipal sources estimate that 90% of the PCBs in Lake Superior come from that source (Hileman, 1988; Strachan & Eisenreich, 1988). Many of the sources of airborne PCBs to the Great Lakes Basin, especially those with unusually high concentrations, tend to originate from the southern U.S., Mexico, and Latin America (Atmospheric Environment Service, 1992). Vapour loss of PCBs from soil surfaces appears to be an important fate mechanism, with the rate of volatilization decreasing with increasing chlorination. Although the volatilization rate may be low, the total loss by volatilization over time may be significant because of the persistence and stability of PCBs. Lighter PCBs may also be emitted to air as a result of recycling contamination from previously polluted soils (Coleman, *et al.*, 1997; Defra, 2002, 2006a). PCB emissions are estimated to have fallen by 78 per cent between 1990 and 2001, and the release of total PCBs to air in 2004 was estimated at 1,330 kg (Defra, 2006b).

It has been proposed that the environmental recycling of lighter PCBs from existing soil contamination is the most important contributor to the current atmospheric burden in the UK (Coleman *et al.*, 1997; Defra, 2002, 2006a). However, recent studies have suggested that levels in indoor air from paints and sealants may be a major source of PCBs in ambient air within large towns and cities (Harrad *et al.*, 2006; Jamshidi *et al.*, 2007; Jartun *et al.*, 2009). Enrichment of the low-chlorine PCBs occurs in the vapour phase relative to the original Aroclor; the residue is enriched in the PCBs containing high chlorine content. The dominant atmospheric transformation process is probably the vapour phase reaction with hydroxyl radicals, which

have estimated half-lives ranging from 12.9 days for monochlorobiphenyl to 1.3 years for heptachlorobiphenyl (Leigh, *et al.*, 2006).

Solubility and Transport of Polychlorinated Biphenyls in Soil

Aqueous solubility of polychlorinated biphenyls (PCBs) are low, ranging from 2.7 ppb for Aroclor 1260 to 3500 ppb for Aroclor 1221. Water-soluble PCBs are richer in lower chlorinated isomers than were the original PCB fluids. Earth materials sorb PCBs strongly. There is a very high direct correlation between the total organic carbon content of the soil and the amount sorbed. The number of chlorine atoms in the molecule influences the sorption and retention of PCBs by soils and soil constituents; the more highly chlorinated derivatives are more held tenaciously.

It has been observed that there is a linear regression relation for sorption of PCBs expressed on a unit carbon basis as a function of water solubility. PCBs are not readily mobile in soils when leached with aqueous solutions such as water or sanitary landfill leachates but are highly mobile when leached with organic solvents. Mobility of PCBs is proportional to their solubility in the leaching solvent and to the soil organic matter content (Lubor Halu *et al.*, 1995; Yanjun Chang *et al.*, 2010).

According to Backe and other workers (2004), a study of the relationship between PCB concentrations in soil and different soil parameters showed a large variation between sampling-areas with median concentrations ranging between 2.3 and 332 ng/g. The highest concentrations were found at two sites with sandy soils, one with extremely high organic carbon content. Soils with similar soil textures (i.e. sandy silt moraine) did not show any significant difference in PCB concentrations. Sorption reactions also affect

transport in soils. PCBs that are sorbed by soils, especially highly chlorinated ones, remain significantly immobile against leaching. They are also unlikely to be taken up by plants and therefore are not readily mobile in soil systems. However, because PCBs have a moderate vapour pressure, vapour phase transport may allow for redistribution or migration through the saturated soil pores.

If released into soil, PCBs experience tight adsorption with adsorption generally increasing with the degree of chlorination of the PCB. They generally do not leach significantly in aqueous soil systems; the higher chlorinated congeners have a lower tendency to leach than the lower chlorinated congeners. In the presence of organic solvents, PCBs may leach quite rapidly through soil (Leigh *et al.*, 2006). Affinity to soil and persistence of PCBs have been shown to increase with increasing soil organic carbon (SOC) content, PCB chlorination, and PCB coplanarity. Also the soil matrix can reduce the absolute bioavailability of PCB118 and PCB52 (Xinzhu, *et al.*, 1995).

Fate and Persistence of PCBs Compounds in the Environment

According to Chow and Connor (1993), Vast quantities of PCBs have been dumped, spilled or have leaked into the environment; these have accumulated in the air, water, and land, and pose health hazards to many animals, and perhaps some plants. The dominant mechanism by which PCB's enter the Great Lakes and most other bodies of water is by atmospheric deposition. PCBs have a tendency not to stay dissolved in water and therefore volatilize back into the atmosphere. Because of this, large quantities of PCBs volatilize out of lakes as well as being deposited into them

from the large reservoir of synthesized organic compounds moving in regional and global air masses.

PCBs in water directly and indirectly are the main source of the toxic effects for animal life. PCBs in water or sediments may be filtered through fish, crustaceans, or mollusks via their gills and because they are lipophilic they make their way to the fatty tissues of these animals. These animals are in turn eaten by birds; or mammals like humans or bears. In these animals again, the PCBs accumulate in fatty tissues, and their concentration again becomes greater due to biomagnifications. Birds' eggs often have the highest concentrations of PCBs that is easily testable because they are at the end of the food chain and their yolk is rich in fatty materials. In the Great Lakes gull eggs are often collected for chemical analysis because toxic chemicals will be detectable in them long before their levels in the open water are measurable. Analysis of eggs at different sites allows us to compare the extent of contamination between different areas.

PCBs accumulate in humans too, especially if their diet contains fish or animals that eat fish from polluted areas. A study done in Norway on breast milk and it was found that the milk contained approximately 372 ng/g milk fat of PCBs with PCB-126 being the main contributor (Johansen et al., 1994). According to Report of the Atmospheric Deposition Monitoring Task Force (1987), simply being born to a mother that has high levels of PCB's in her body may contribute to a decrease in birth weight, head circumference, short-term memory, and some cognitive skills.

Degradation of PCBs

PCBs are synthetic compounds that are not readily degraded, as a result of their very stable properties. The degradation of these compounds entails difficult mechanisms of chemical, biochemical or thermal destruction (Abramowicz, 1995; Erickson, 1986). Biodegradation, that is, the degradation of compounds by bacteria or other microorganisms, is a slow yet possible method for destroying PCBs in both aerobic and anaerobic environments. It is the only process known to degrade PCBs in soil systems or aquatic environments.

The specific processes involved are aerobic oxidative dechlorination or hydrolytic dehalogenation and anaerobic reductive dechlorination. Theoretically, the biological degradation of PCBs should result to give CO₂, chlorine and water. This process involves the removal of chlorine from the biphenyl ring followed by cleavage and oxidation of the resulting compound. Persistence of PCBs in the environment increases with the degree of chlorination of the congener. Those compounds with a high degree of chlorination such as 1248 1254 and 1260 are resistant to biodegradation and degrade slowly in the environment (Boyle *et al.*, 1992).

According to Fiedler and other workers (1994), biodegradation by microorganisms may occur via three different mechanisms. These mechanisms are:

1. Aerobic respiration in the presence of oxygen, involving reaction with mono- and dioxygenases; in a final step H₂O will be incorporated;

2. Anaerobic respiration under exclusion of oxygen; inorganic substances such as nitrate, sulfate, and carbon monoxide act as electron acceptors;
3. Fermentation under exclusion of oxygen- the organic compound to be degraded acts as electron acceptor.

Aerobic Oxidative Dechlorination

In general, bacteria cannot use chlorinated aromatic hydrocarbons as substrate. Present knowledge assumes that bacteria growing on non-chlorinated biphenyl are capable to cause chemical reactions on the chlorinated ring system as well. However, some microorganisms are capable to use lower chlorinated PCBs as C-source. Thus, *Acinetobacter* sp. P6, *Achromobacter* sp. B 218, and *Bacillus brevis* B 257 can grow on 4-chlorobiphenyl as the only carbon source. The main degradation product is 4-chlorobenzoic acid. In general, formation of chlorinated benzoic acids is the major degradation pathway for PCBs.

Further microorganisms capable of the biodegradation of PCBs belong to the class of *Acetobacter*, *Alcaligenes*, and *Pseudomonas*. Aerobic Oxidative Dehalogenation involves the oxidation of PCBs by aerobic microbes, especially by bacteria of the genus *Pseudomonas*. This involves the addition of oxygen to the biphenyl ring (Boyle, et al., 1992). Further research by Bevinakatti and Ninnekar (1992), proposed the degradation of biphenyls also by the *Micrococcus* sp. The metabolic pathway used by this family of bacteria (Figure 3) resembles that described for the *Pseudomonas* sp. By way of 1,2- dioxygenative ring cleavage, benzoate results as a common by-product of biphenyl degradation. Although different bacterial

species seem to produce benzoate through PCB metabolism, further breakdown of benzoate seems to differ among the different microbes. Nevertheless, the by-products produced are less toxic compounds to people and the environment. Since PCBs are more persistent with increasing chlorination of the congener, aerobic biodegradation involving biphenyl ring

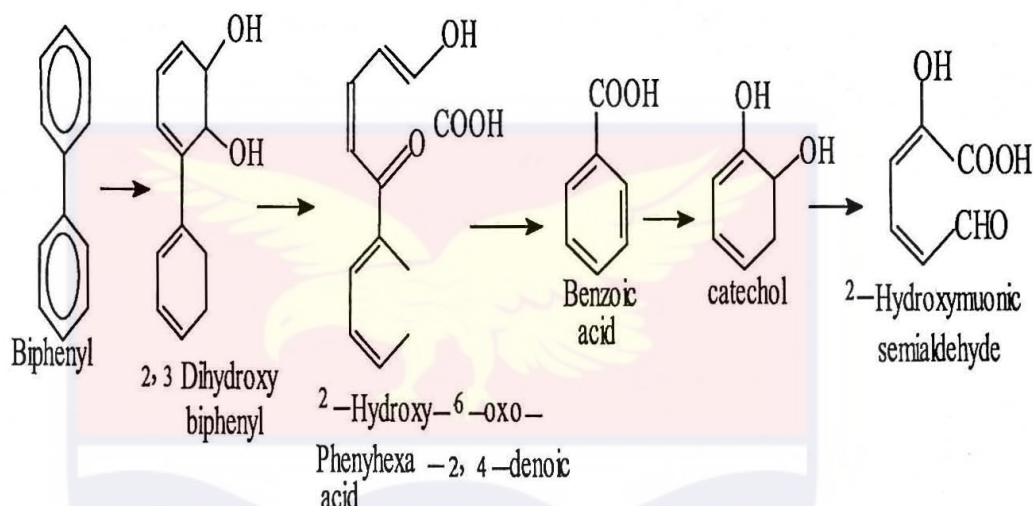


Figure 3: A possible pathway for the aerobic oxidative dehalogenation of PCBs (Bevinakatti and Ninnekar, 1992)

cleavage, is restricted to the lightly chlorinated congeners (DHHS, 1992; Rochkind *et al.*, 1986). Some general conclusions that can be drawn from aerobic biodegradation are as follows (Bedard *et al.*, 1987; Furukawa *et al.*, 1978 & Rochkind *et al.*, 1986).

1. Increasing number of chlorine substituents decreases biodegradation of PCBs;
2. Congeners with two *ortho* chlorines are extremely resistant to biodegradation. Two chlorines in *ortho*-position at the same or on different aromatic rings of the biphenyl molecule significantly inhibit

biodegradation (exception: 2,4,6-trichlorobiphenyl which is readily biodegradable by *Acinetobacter*);

3. If there are chlorine substituents on both rings, the ring with less chlorine atoms will be hydroxylated first;
4. Biphenyls that have chlorine substituents only on one ring system are metabolised more rapidly than a chlorobiphenyl with the same number of chlorine atoms but on both rings; thus, 3,4-dichlorobiphenyl will be better metabolised than 3',4'-dichlorobiphenyl;
5. PCB metabolism is facilitated when a carbon atom with a chlorine substituent is between two unsubstituted carbon atoms;
6. Higher chlorinated congeners having a 2,3,4-trichlorophenyl group, are resistant towards biological degradation;
7. PCBs containing an unsubstituted ring are generally degraded more rapidly than isomers that are chlorinated on both rings. Thus ring cleavage occurs preferentially in the unsubstituted ring;
8. PCB containing chlorines at positions 2 and 3, e.g. 2,2',3,3'-tetrachlorobiphenyl, 2,2',3,5'-tetrachlorobiphenyl, and 2,2',3',4,5-pentachlorobiphenyl are more readily biodegraded than other tetra- and penta-chlorinated biphenyls.

Anaerobic Degradation

Polychlorinated biphenyls are extremely resistant to conventional aerobic transformation, but they will undergo anaerobic reductive dechlorination. Studies of PCB contamination in Hudson River sediment demonstrated that anaerobic environments yield markedly lower levels of tri-

tetra-, and pentachlorobiphenyls and higher levels of mono- and dichlorobiphenyls. Many of the less chlorinated PCBs then are aerobically biodegradable because generally less toxic than highly chlorinated PCBs. For PCBs, the degradation rate is inversely related to the degree of chlorination; thus, highly chlorinated congeners are more readily dechlorinated than lower chlorinated congeners.

There is evidence that not only the number of chlorine substituents determines degradation rates, but also their position. Reductive dechlorination predominantly reduces chlorine in *meta*- and *para*-positions, resulting in accumulation of the *ortho*-chlorinated congeners (Abramowicz *et al.*, 1989; Brown *et al.*, 1984; Brown *et al.*, 1987; Fiedler *et al.*, 1994; Quensen *et al.*, 1990). Anaerobic reductive dechlorination involves the replacement of chlorine with a hydrogen atom on the biphenyl ring. This type of degradation transforms the more highly chlorinated congeners to less chlorinated ones. Specifically, the monochlorobiphenyls and *ortho*-substituted dichlorobiphenyls are degraded in this manner. Byproducts of this process, illustrated below (Figure 4), are less toxic and can usually be degraded by the aerobic microbes, (Ye, *et al.*, 1992).

According to Alder *et al.*, (1993), the different pathways of dechlorination observed may explain by the different microbial populations that exist in the environment. However, a similarity between degradation patterns exists. The *para*- and *meta*-substituted congeners are more commonly degraded than *ortho*-substituted congeners. Only a few *ortho*-substituted congeners have been reported to degrade.

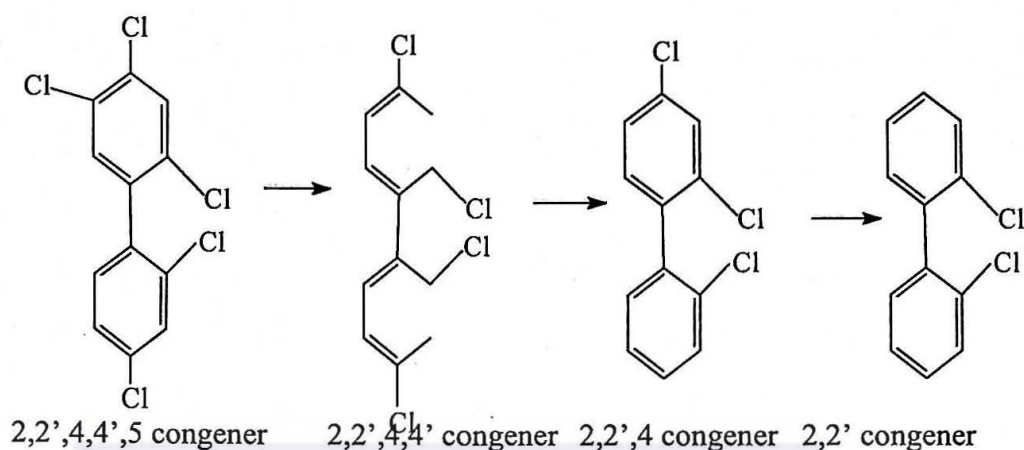


Figure 4: Potential pathway for anaerobic degradation of a highly chlorinated congener to a less chlorinated one (Fish and Principe, 1994).

Moreover, anaerobic degradation has most commonly been observed under methanogenic conditions. This may lead one to conclude that anaerobic reductive dechlorination occurs under methanogenic conditions, if not inhibited by sulfate-reducing conditions. Sulfates have a higher affinity for electrons than the chloroaromatics (Alder *et al.*, 1993; Fish and Principe, 1994). Many environmental factors can affect the degradation of biphenyls, both aerobically and anaerobically. These factors may include; degree of chlorination, concentration of the congener, type of microbial population, temperature, pH and available nutrients.

More highly chlorinated congeners are less readily degraded than the less chlorinated congeners. The position of chlorine atoms on the rings also affects the rate of biodegradation. Not only are PCBs with para- and meta-substituted rings more easily degraded than the ortho-substituted compounds, but PCBs containing all chlorines on one ring are biodegraded faster than those which contain chlorines throughout both rings. It has been

suggested that both aerobic and anaerobic conditions are affected with the addition of certain nutrients. It is also interesting to note that biodegradation rates decrease with high levels of organic carbon present (DHHS, 1992).

According to Woods & Trobaugh (1999), while microbes work well in laboratory conditions, there is often a problem in transferring a successful laboratory strain to a natural system. This is because the microbes can access other sources of carbon, which they decompose in preference to PCBs. PCBs undergo reductive dechlorination under anaerobic conditions, leading to the formation of less-chlorinated congeners. Lower chlorinated congeners and biphenyl are resistant to further degradation in anoxic environments. Anaerobic reductive dechlorination is an important step toward the bioremediation of PCBs since it reduces the chlorine content of PCB mixtures thereby reducing their bioaccumulation potential and, in some respects, toxicity (Rhee *et al.*, 1993). Dechlorination of PCBs in anaerobic environments is generally considered to be slow, with major change occurring over period of months or years. Anaerobic reductive dechlorination of PCBs involves replacement of a chlorine atom with a hydrogen atom (Mousa *et al.*, 1996; Nies and Vogel, 1990). The mechanism of reductive dehalogenation can be represented by the reaction:



Where R represents: an organic molecule, X a halogen, and [H] an electron plus a proton. The reduction potential of PCBs increases with increasing chlorine number (Nies and Vogel, 1990; Rusling and Miaw, 1989). However, the positions of the chlorine substituents also influence ease of reductive dechlorination. Generally, chlorines in the *meta* and *para* position

are most readily removed (Abramowicz, 1990; Abramowicz and Olson, 1995; Boyle *et al.*, 1992; Mousa *et al.*, 1996; Nies and Vogel, 1990). Chlorines substituted in *ortho* position are generally recalcitrant to anaerobic dechlorination (Yadav *et al.*, 1995). However, reductive *ortho* dechlorination of PCBs has also been shown (Berkaw *et al.*, (1996).

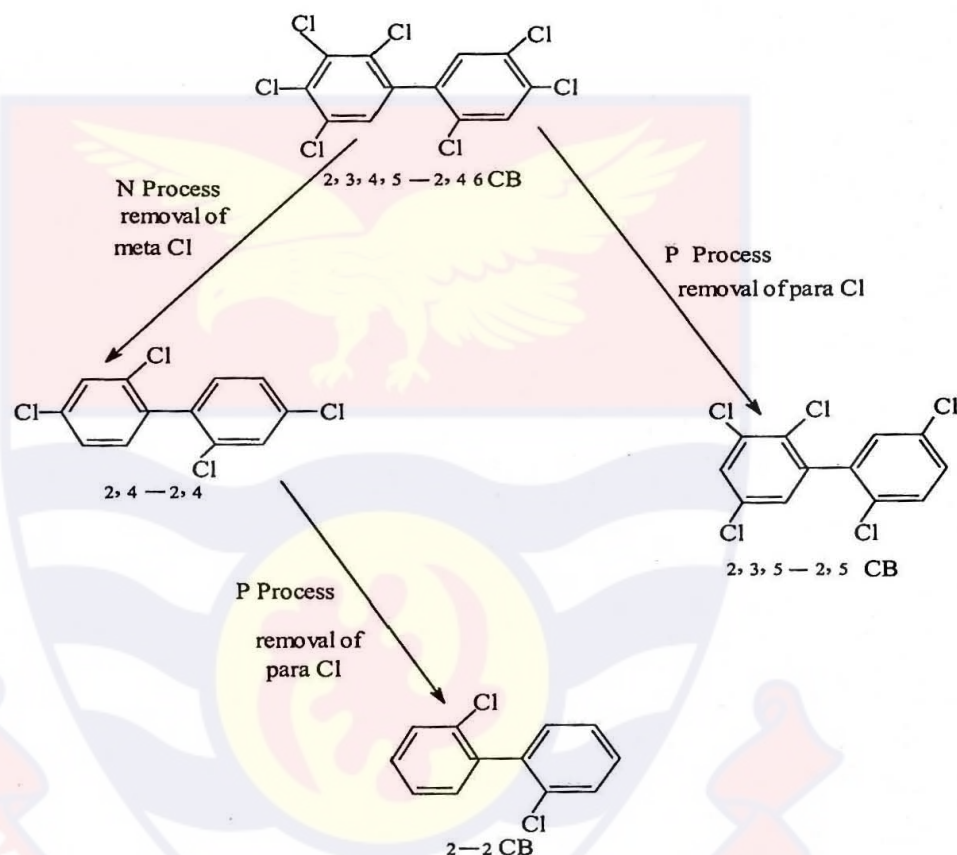


Figure 5: Dechlorination of major compounds of arochlor 1260 in Hudson River (Bedard *et al.*, 1998)

Anaerobic dechlorination could potentially be used as the first step in a remediation process. The decrease in highly chlorinated congeners resulting from anaerobic reductive dechlorination would decrease the Cl content of a given congener resulting in a PCB congener much more susceptible to degradation by aerobes possessing oxygenases. All lightly

chlorinated congeners that are products of reductive dechlorination are biodegraded by aerobic PCB-degrading microorganisms (Bedard *et al.*, 1986). Thus, aerobic degradation could be used as the second step in a bioremediation process (Nies and Vogel, 1990). A sequential anaerobic-aerobic system has an additional advantage, and the potential to mineralize PCBs. Degradation of PCBs based on pathways described by Boyle *et al.*, (1993); Quensen, *et al.* (1990); Rhee *et al.*, (1993); William, (1994); Wu *et al.*, (1997) and other workers are shown in figures 5 and 6.

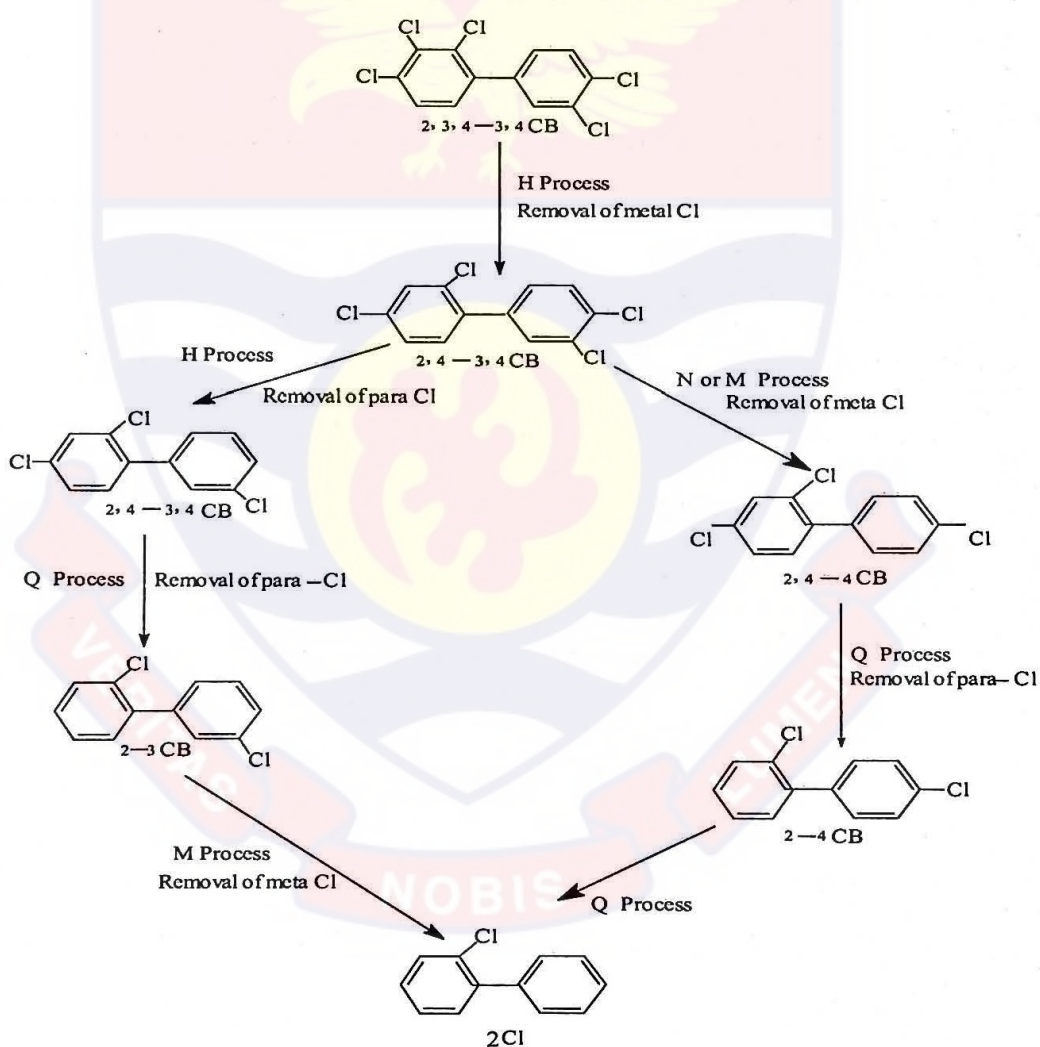


Figure 6: Some dechlorination pathways for PCBs

Phytostimulation Degradation of PCBs

A greenhouse study conducted by Smith *et al.*, (2007), found that PCB degradation was greatest in soils treated with an organic amendment (straw) and in plants with low transpiration rates. The low transpiration rates provided the proper reducing conditions, while the amendment provided a labile carbon source which initiated dechlorination. They found *Carex aquatica* (sedge) and *Spartina pectinata* (prairie cordgrass) to be the most promising plant species for PCB degradation.

An *in situ* examination of PCB degradation at a contaminated site found significantly higher PCB-degrading microorganisms in the rhizosphere of *Pinus nigra* (Austrian pine) and *Salix caprea* (goat willow) compared to the rhizosphere of other plants or the bulk soil (Leigh *et al.*, 2006). They theorize that these plants, which naturally produce compounds (terpenoids, phenols, and tannins) similar to the structure of PCBs, stimulate the proper microorganisms to degrade PCBs. Magee *et al.* (2007), have observed increased dechlorination of PCBs in the presence of nitrate reductase. This was magnified when the enzyme's cofactor, molybdenum, was also added. (Rezek *et al.* 2007), found that plant cells can metabolize PCBs and do not exude the degradation products into the soil. The metabolites maintained the same level of chlorination.

Mohammadi *et al.* (2007), found that a transgenic *Nicotian tabacum* (tobacco) plant with introduced bacterial (*Burkholderia xenovorans*) genes can produce the necessary enzymes to initiate degradation of PCBs. This has the potential to allow plants to begin the remediation process while stimulating the proper microorganisms to complete degradation. Zeeb *et al.*,

(2006), conducted a greenhouse experiment using soil collected from sites contaminated with PCBs to study the fate of PCBs in the presence of plants.

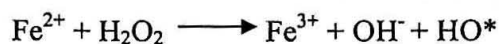
They found that *Cucurbita pepo* (pumpkin) extracted PCBs from the soil through root uptake, followed by translocation to shoots. Although the PCB levels in the soil did not significantly decrease, these results suggest that, in a field setting, pumpkins may be used to extract PCBs from contaminated sites. A field experiment conducted by Aslund *et al.*, (2007), examined the potential for plants to accumulate PCBs in aboveground tissues. This experiment showed that PCBs do accumulate in the aboveground tissues of *Cucurbita pepo* (pumpkin), *Carex normalis* (sedge), and *Festuca arundinacea* (tall fescue). Further experimentation is needed to determine the uptake pathways and the possible wide-scale application of this strategy

Physical and Chemical Degradation of PCBs

Some other methods of PCB destruction are being used, developed and investigated. More popular is incineration and photolysis. Incineration involves exposing the PCB congeners to extremely high temperatures (1200 °C), a mixing /agitation process as well as a long residence time (>2 sec). Photolysis on the other hand is the most popular means of chemical degradation of PCBs. This process uses the free radicals produced from sunlight to remove the chlorine atoms from the biphenyl ring. This method however, is limited to PCBs found in the air and water (Alder *et al.*, 1993 & Erickson, 1986).

PCBs can be chemically degraded by Fenton's reaction. Fenton's reaction is an advanced oxidation process for destruction of toxic organic

compounds in water. In Fenton's reaction, H_2O_2 is combined with Fe^{3+} in the presence or absence of light to generate hydroxyl radicals (HO^*):



The HO^* initially adds to the aromatic ring to give a substituted hydroxycyclohexadienyl radical which may further react by acid catalyzed elimination. Chen and Pignatello (1997), proposed the catalytic role of quinone intermediates in Fenton's oxidation of aromatic compound. In this reaction quinone intermediates shuttle electrons from HO^* radical adduct of the starting aromatic compound to Fe^{3+} , thus facilitating the degradation of the starting aromatic compound. The presence of co-oxidants like oxygen and quinones play a crucial role in steering oxidation into the desired pathways.

Volatilization and Evaporation

Vapour loss of PCBs from soil surfaces appears to be an important fate mechanism, with the rate of volatilization decreasing with increasing chlorination. Although the volatilization rate may be low, the total loss by volatilization over time may be significant because of the persistence and stability of PCBs. Enrichment of the low-chlorine PCBs occurs in the vapour phase relative to the original Aroclor; the residue is enriched in the PCBs containing high chlorine content. The dominant atmospheric transformation process is probably the vapour phase reaction with hydroxyl radicals, which have estimated half-lives ranging from 12.9 days for mono-chlorobiphenyl to 1.31 years for hepta-chlorobiphenyl.

Effects of Soil Organic Matter on Sorption of Organic Pollutants

Organic pollutants can undergo a number of processes such as degradation, volatilization, leaching, bioaccumulation and sorption in soil (Kim and Osako, 2003; Semple *et al.*, 2003; Ahangar, A. G., 2011), which has been identified as a one of the most important repositories for fluxes of organic compounds between soil and air and soil processes can have a large bearing on their future distribution patterns (Meijer *et al.*, 2003, Sweetman *et al.* 2005, Lohmann *et al.*, 2007). According to Karickhoff *et al.*, (1979)); Ren *et al.*, (2007); Koblickova *et al.*, (2008); Scheringer, (2009), the contribution of the organic matter of soils or sediments to the sorption of nonpolar compounds have been found to be much more relevant than the contribution of other components.

The varied composition and structure of the organic matter; consisting of heterogeneous mix of organic materials often classified as an amorphous, gel-like "soft carbon" matrix or domain and a condensed, glasslike "hard carbon" matrix or domain including altered and relatively unaltered aliphatic polymers, polysaccharides, lignin and lignin degradation products, fats, proteins, pectines (Schumann 2006), and the different fractions such as humic and fulvic acids, lipids, and humins; can give a variation in the sorptivity of organic compounds (Weber *et al.*, 1992; Allen-King *et al.*, 2002; Schmidt *et al.*, 2002; Accardi-Dey and Gschwend, 2003). Components of organic matter found in soils, for example carbonaceous black carbon that acts like activated carbon, may have affinities for nonionic organic compounds and pollutants which cannot simply be explained by their

aquifer materials, and soil strongly depends upon the nature and concentration of the inorganic cations in solution, but virtually independent of solution pH. Sorption of low polarity organic compounds depends very little on the soil pH (Karickhoff 1984; Delle Site 2001).

Organic matter makes a substantial contribution of the cation exchange capacity (CEC) of the whole soil and hence to the retention of exchangeable cations. This is because humification, the formation of humus (complex organic polymers) from raw organic materials such as fulvic acids, humic acids or humin) from organic matter; produces organic colloids of high specific surface area., The organic matter content of the soil increases with increasing decomposition up to the limit set by temperature. (Franz Meier *et al.*, 1985)

A number of studies have reported that soil minerals have an indirect effect on the sorption affinity of soil organic matter. The chemical nature, pore size distribution and pore shape, and especially on the microporous structures of the soils and intraparticle mass transfer have been observed to play a significant role in the adsorption of volatile organic compounds on soils. It has been demonstrated that various organic compounds may be firmly bound to natural sorbents with sufficient exposure time, because they are entrapped in soil micropores so that they are difficult to extract (Njoroge *et al.*, 1998; Bonin & Simpson, 2007).

PCBs in Tropical Media

According to Spongberg & Witter (2009), for the past ten years only 33 papers out of the published 177 papers on PCBs in sediments and biota were from samples obtained in tropical areas. Sediments from the tropics

contained relatively low concentrations of total PCBs. The most polluted tropical site was found in India, which had sediment concentrations up to 2330 mg/g dw attributed to industrialization and pollution. Sediment from pristine areas was unquantifiable at levels below the detection limits. Biota samples covered a range of species from a range of locations. Biotas from pristine tropical areas were below the detection limits. Higher taxa from more developed sites had relatively higher concentrations when compared to other tropical biota, but were still low compared to samples from temperate climates. These researchers indicated that correlation of PCB concentrations detected in the tropics with other factors was problematic due to lack of data from the tropics.

Guzzela *et al.*, (2005), studied surface sediments from the highly developed areas of West Bengal, India. Their Total PCB concentrations from ten sites averaged 750 ng/g dw, with the maximum detection of 2330 ng/g dw attributed to proximity to the source. PCBs were dominated by congeners with four to six chlorines. Wurl and Obbard (2005), found a wide variation in total PCBs from sediments around Singapore, ranging from 1.4 to 329.6 ng/g dw (average = 73.9 ng/g dw). Batterman *et al.* (2000), observed that as at 2005 information regarding polychlorinated biphenyls (PCBs) in environmental media in Africa was limited. They found that the total airborne concentrations of PCBs in KwaZulu-Natal, South Africa, averaged $128 \pm 47 \text{ pg m}^{-3}$, and levels were highest in winter; with the tri- through hexa-congeners predominated, The tetra- through hexa-chlorinated congeners had levels comparable to those at urban sites in the northern hemisphere, but hepta- through deca-congeners resembled levels at

background sites. Soils at three rural sites showed high PCB concentrations, and milk from a local dairy showed PCB concentrations comparable to USA levels in year 2000.

Also polychlorinated biphenyls have been detected in African lake ecosystems. I. Hartbeespoort Dam, Transvaal and Voëlvlei Dam, Cape Province, in the Republic of South Africa (Greichus *et al.*, 1997). Bacci and other workers found PCB residues in plant foliage from West Africa (Bacci *et al.*, 1988), Osibanjo (2006), & Osibanjo and Bamgbose (1990), revealed the presence of PCBs in the Nigerian environment.

According to the Republic of Nigeria Federal Ministry of Environment (Federal Ministry of Environment, 2009), transformer oil spillages at transformer base in Oshogbo and oil drums stored in open air (Plate 4), and extensive spillage in Sapele Power Plant Storage area for transformer turbine oils (Plate 5), are potential sources of PCBs in the Nigerian environment. Polychlorinated biphenyl (PCB) concentrations in air and soil, measured by various research groups from around the world, were compiled and analyzed; The average soil concentrations (pg/g dry weight) for Sigma PCB at background sites were 7500 (47-97 000) for Europe, 4300 (110-25 000) for North America, 1400 (61-9 500) for South America, 580 (120-2 900) for Asia, 390 (94-620) for Africa, and 280 (140-540) for Australia (Li *et al.*, 2010).

A team aboard the German research vessel *Polarstern*, led by researcher Rosalinda Gioia at Lancaster University (United Kingdom), has shown that high concentrations of PCBs are found in some countries in West Africa, such as the Gambia and Ivory Coast, and all along this coast.



Plate 4: Transformer Oil spillages at transformer base in Oshogbo, Nigeria, and oil drums stored in open (Federal Ministry of Environment, 2009)



Plate 5: Storage area for transformer/turbine oils with extensive spillage in Sapele Power Plant in Nigeria (Federal Ministry of Environment, 2009).

They also gathered samples from land-based stations (Gambia, Sierra Leone, Ivory Coast and Ghana), and used particle dispersion models to seek the possible sources of the contamination. The shipboard $\Sigma_{29}\text{PCB}$ concentrations off West Africa ranged from 10 to 360 pg m^{-3} and from 6 to 99 pg m^{-3} in Cape Verde; the highest land-based concentrations were observed in Ivory Coast and the Gambia (up to 300 pg m^{-3}) and the lowest was observed in Ghana (9 pg m^{-3}).



Plate 6: A huge ships' graveyard in Mauritania off the West African coast. (*JS Callahan/tropicalpix/Alamy*)

The likely sources of the pollution is the illegal dumping of waste containing these compounds, old electrical waste such as capacitors and other PCB-containing products. Developing countries take large amounts of waste from Western nations and break them down or dispose of them, often with little regard for safety or pollution. High levels of PCBs are released through volatilization, as well as the storage and scrapping of old ships. Another probable source of the PCBs is one of the world's largest ships' graveyards (Plate 6), just south of Nouadhibou in Mauritania, where hundreds of wrecks have been grounded in shallow water where they are scavenged or simply left to decay. This break-up probably releases PCBs (Gioia *et al.*, 2011).

PCBs in the Ghanaian Environment

The sources of PCBs are transformers and capacitors. Evidence available indicates that the Electricity Company of Ghana as well as the Volta River Authority ceased importing PCB-containing transformers and capacitors for use in Ghana since 1972. However, it has been established that 455 pre-1972 possible PCB-containing transformers could be found countrywide. The emission levels of dioxins and furans from known sources to air, land and water and residue have been estimated using the UNEP Toolkit to be 386 g I-TEQ of PCDDs/PCDFs in 2002. The sector of uncontrolled combustion processes released a total of 372 g I-TEQ to air. Within this sector emission to air due to indiscriminate burning of forest, savannah grassland and waste dumps were 218.8g and 129.4g and 24.6 g respectively. Additionally, a total of 278.6 g I-TEQ of PCDDs/PCDFs was released to land from uncontrolled combustion processes in 2002

(Environment Youth Action Network [EYAN] & Integrated Community Care [ICC], 2006).

Surrounding areas of the pre-1972 transformers country wide, Electrical Company of Ghana- Accra Central Station G, and Municipal wastes dumps have been identified as PCB contaminated sites in Ghana (Centeno, 2010). Some contaminated sites and transformers identified to contain PCBs are shown (Plate 7-10). Persistent Organic Pollutants including polychlorinated biphenyls have been detected in environmental samples and in some food and breast milk samples in Ghana. Since the analysis of PCBs began in 2007, they have been found at levels typical for urban areas. In human milk, WHO-PCB-TEQ was found to be 2.88 pg/g (Adu-Kumi & Osae, 2009).



Plate 7: Waste PBC oil storage tank at the ECG transformer servicing center in Accra (Centeno, 2010)



Plate 8: Potential contaminated sites identified at ECG transformer servicing center in Accra (Centeno, 2010)

Significant levels of polychlorinated biphenyls have been found in soils and borehole (Plate 9), underground water, in the compound of the transformer servicing center of the Electricity Company of Ghana (ECG) in Accra. The total PCB concentrations found in soils at ten different sites of the ECG compound ranged between 0.357 and 20.721 mg/kg. Investigation of the soil profile at the ECG office in Accra revealed very high levels of PCBs, 82.3 mg/kg and 129.96 mg/kg at some areas. Analysis of two boreholes (Plate 8) drilled at the site indicated that the levels of PCBs in underground water were 0.059 mg/L and 0.071 mg/L, which were much higher than the recommended level of 0.0094 mg/L (Centeno, 2010).

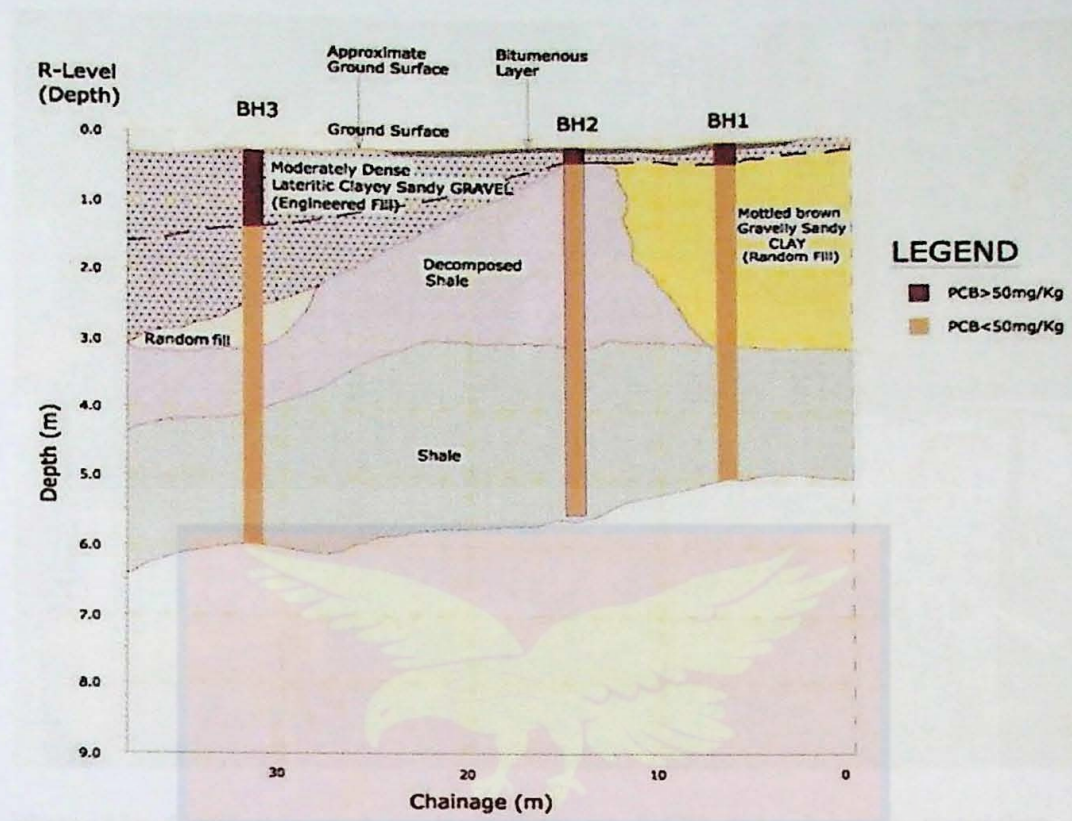


Plate 9: Soil profile of ECG transformer servicing center at Mokola, Accra (Centeno, 2010)

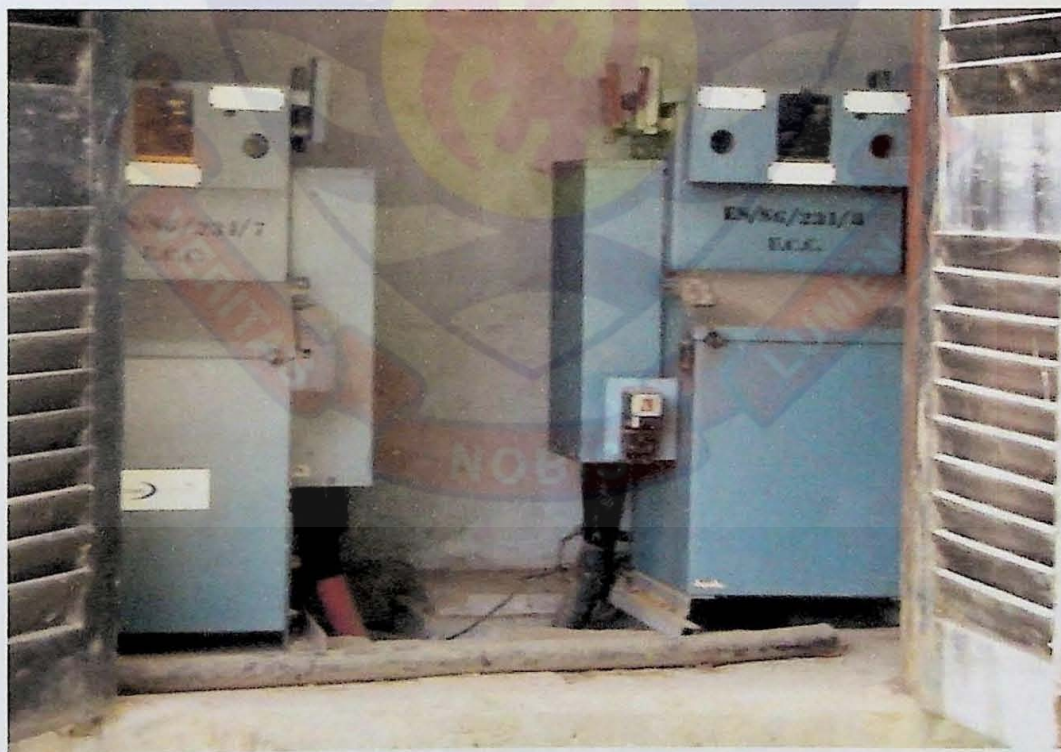


Plate 10: Transformer at UCC C.D.S - Cape coast (manufactured in 1967)

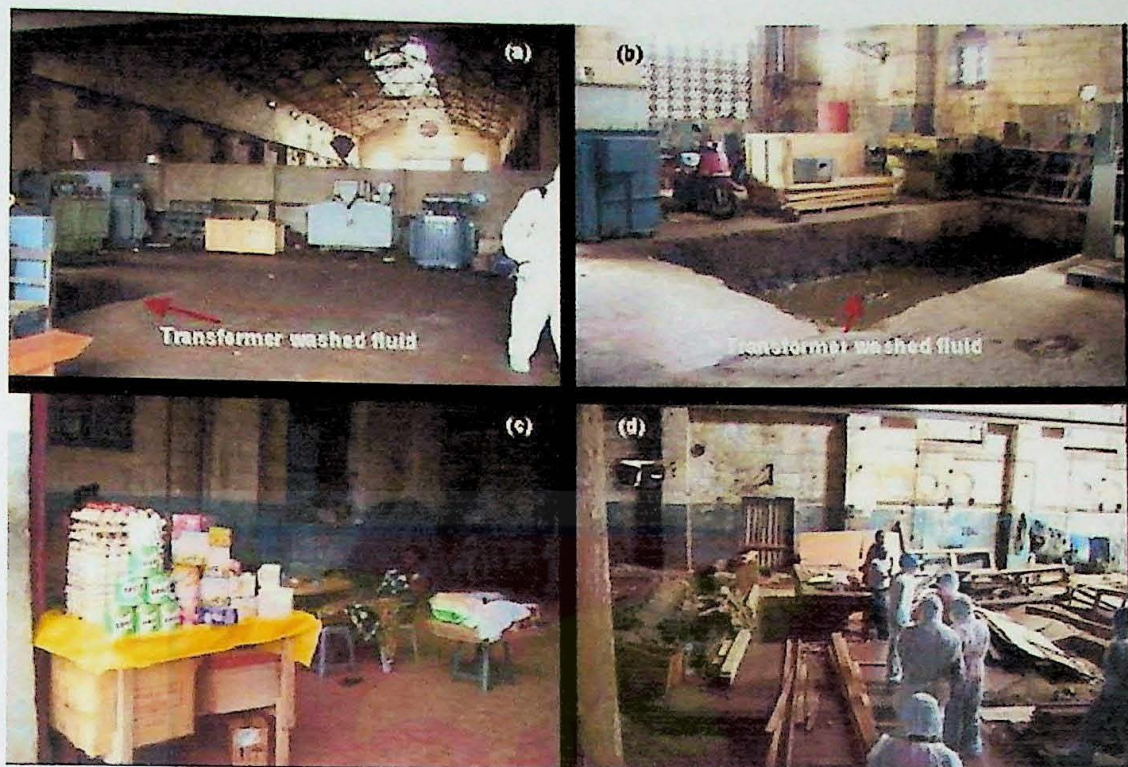


Plate 11: Contaminated waste water at ECG transformer servicing center in Accra (Mokola) identified as potential source of surface water contamination (Centeno, 2010))

Human exposure to polychlorinated biphenyls (PCBs) and brominated flame retardants (BFRs) such as polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecanes (HBCDs) evaluated in Ghana using breast milk samples collected in 2004 and 2009. The mean levels and ranges of PBDEs and PCBs respectively were (4.5; 0.86-18 w ng/g lw) and (62; 15-160 ng/g lw). The estimated hazard quotient (HQ) for PCBs revealed that all the mothers had HQ values exceeding the threshold of 1, indicating potential health risk for their children (Asante *et al.*, 2011). Otchere (2005), found the level of PCBs in samples of bivalves, *Anadara (Senilia) senilis* from lagoons in Ghana to be 0.10 $\mu\text{g/g dw}$ or 2.2 $\mu\text{g/g lw}$ (median values).

This contamination was attributed to indirect sources since neither Aroclor known 1254 or 1260 which is to be present in Ghana was detected.

However the dominant congeners in all cases were homologues 52 and 28, which have four and three chlorine atoms each, respectively. In general, however, the correlations were confounded by many factors, including the amount and source of food, lipid content, and season. Contaminated waste water at ECG transformer servicing center in Accra (Plate 11), has been identified as potential source of PCBs for surface and underground water contamination (Centeno, 2010)

Behavior of Polychlorinated Biphenyl in Residue Methodology

Methodology for PCB analysis includes several steps: sample collection and storage, extraction, cleanup, and determination (EPA 1995c, 1999k; Hess *et al.*, 1995). Interest has continued to grow in analytical aspects of PCBs. Emphasis on identification and measurement of the residue themselves has surpassed the original concern of prevention their interferences in pesticide residue analysis. Experimental investigation has led to elucidation of composition of several Aroclor reference materials.

The specific congeners in some Aroclors have been listed in Table 4. The number appearing after the Aroclor name refers to the amount of chlorine (the percent by weight) present in the product, not the specific PCB congener composition. For instance, in any two manufacturing batches of Aroclor 1254, the amount of chlorine present in each batch is the same, but the mixture of PCB congeners making up those batches may be different. So each Aroclor product, designated by a specific number, represents a mixture of PCB congeners inconsistent between different manufacturing batches of that Aroclor product. The use of Aroclors as reference materials for the quantitation of PCB residue involves inherent problems because the residue

Table 4: Specific PCB congeners that are major components in common

Aroclor (USEPA, 2007)

Congener	No	Aroclor						
		1016	1221	1232	1242	1248	1254	1260
Biphenyl			*					
2-CB		*	*	*	*			
23-Di CB		*	*	*	*	*		
34- Di CB		*		*	*	*		
244'- Tri CB (PCB28)				*	*	*	*	*
22'35' –Tetra CB				*	*	*	*	*
23'44' –Tetra CB'						*	*	*
22'55' –Tetra CB' (PCB52)			*				*	
233'4'6-Penta CB							*	*
22'44'5'-Penta CB (PCB101)								*
23'44'5'-Penta CB (PCB118)								*
22'44'55'-Hexa CB (PCB153)								*
22'344'5'-Hexa CB (PCB138)								*
22'344'55'-Hepta CB (PCB180)								*
22'334'55'-Hepta CB								*
22'33'44'5'-Hepta CB								*

(CB= chloro Biphenyl) Source: USEPA, 2007

is most often altered in composition from the original Aroclor. Alteration can occur in several ways; e.g., weathering and /or metabolism, variation in recovery of components through the methodology and variation in the amount of loss through volatilization of the different components. The

accuracy of the quantitative result decreases with the increasing alteration of the PCB residue from the pattern of the Aroclor reference. The disproportionate response of the electron capture detector (ECD) to the more highly chlorinated components aggravates the problem of quantitation of altered residue. The analyst should be aware of these limitations, and if possible quantitate altered residues using one of the halogen specific detectors and reference Aroclor(s) whose pattern matches that of the residue most closely.

Methods of Extraction of PCBs from Soil

For solid samples, finely-divided sample (prepared using a mortar and pestle when necessary) is used. The Polychlorinated biphenyls in the solid samples extracted with solvent using the Soxhlet extractors or the Microwave Assisted Process for soil and sediment samples. Soil samples are extracted with toluene, acetone – hexane (1:1), methylene chloride, methylene chloride – acetone (1:1) or water- methanol – hexane (1:4:5). The addition of 10% (v/v) polar solvent such as acetone is recommended for samples which have not been thoroughly dried. Such extracts contain many single component organochlorine and organophosphoate chemicals; chlorinated benzene, chlorinated naphthalenes and other chlorinated organic compounds (or pesticides). The use of hexane acetone generally reduces the amount of interferences that are extracted and improves signal-to-noise. When PCBs are to be determined as Aroclors decachlorophenyl is used as a surrogate, and is added to each sample prior to extraction.

Field contaminated samples or spiked samples should be used to verify the applicability of the selected extraction technique to each new

sample type. Such samples should contain or be spiked with the compound of interest in order to determine the present recovery and limit of detection. When the presence of specific Aroclor is not expected, the 1016/1260 mixture or 1242/1254/1260 mixture may be an appropriate choice of spiking (Scott, 2002; Van Hoof & Hsieh, 1996).

Clean-up of Solid Samples

It is recommended that all sample extracts be subjected to some form of cleanup before the GC-ECD analysis. Depending on the complexity of the sample matrix, one or two of the following techniques can be applied to clean extract: sulphuric acid, Potassium Permanganate, modified silica column, copper, alumina column, florisil column and disposable Sep-Pak column. If no surrogate is added to correct for the possible loss of PCBs during sample workup, cleanup steps should be minimized (Brian, & Morrison, 2007).

Extracts for PCBs analysis may be subjected to sulfuric clean up. It is suitable for the rigorous cleanup of samples extract and it should be used whenever elevated baseline or overly complex chromatograms prevent accurate quantization of PCBs. Thus clean up technique will destroy or remove many single component organochlorine or organophosphorus pesticides and chemical including pesticides Aldrin, Dieldrin, Endrin Endosulfan and Endesulfan sulphates. Acid cleaning is an effective way to remove some method interferences without alteration of the target PCBs.

However, the cleanup will not destroy chlorinated benzene, chlorinated naphthalenes. To acid clean the samples, the hexane (or organic) layer is separated from the hexane layer; sulphuric acid (1+1) was added and

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agitated vigorously for one minute. If a clean phase is achieved (with the hexane layer not coloured) then the organic layer could be analyzed for PCB.

The permanganate cleanup is employed when the sulphuric acid cleanup has not removed the entire colour from an extract. For permanganate clean 5 ML of five percent (5%) aqueous potassium permanganate solution is added to the acid cleared extract and agitated. It is then allowed to stand for phase separation if the organic layer is still coloured the cleaning is repeated.

Some sediment extracts may contain high levels of elemental sulphur which cause significant interference on the ECD. For such extracts freshly treated copper (approximately 0.5 g) is added to a 5-mL aliquot of the sample extract in a small Erlenmeyer flask. Swirl the flask and allowed the extract to stand for approximately 10 minutes. The addition of 0.5 g of copper is repeated until no further reactions (copper turns black) are observed. The sample extract is then transferred through a filter paper or glass wool to remove the copper.

Basic alumina (or anhydrous silica gel) column is prepared by adding of hexane to a column. When the hexane has drained just to the top of the sodium sulphate layer, a 250-mL boiling flask is placed under the column for sample collection. Using a Pasteur pipet, the sample extract is transferred onto the column following with 30 mL of hexane. When this solvent has drained to the top of sodium sulphate layer, freshly prepared 5% dichloromethane is added.

External Standard and Internal Standard Calibration Technique

The calibration of GC may be done using either the external standard or the internal standard techniques. External standard calibration involves the

comparison of the instrument responses from the sample to the responses from the target compounds in the calibration standards. Sample peak areas are compared to peak areas of the standards. The ratio of the detector response to the amount (mass) of analyte in the calibration standard is defined as the calibration factor (CF).

$$CF = \frac{\text{Peak areas (or peak heights) of the compound in the standard}}{\text{Mass of compound injected (in nanogram)}} \quad (1)$$

Internal standard calibration involves the comparison of the instrument responses from the target compounds in the sample to the responses of a specific standard added to the sample or sample extract prior to injection. The ratio of the peak areas (or peak heights) of the target compounds in the sample or sample extract to the peak areas (or peak heights) of the Internal standard in the sample or sample extract is termed the response factor (RF), and may be known as the relative response factor (RRF) (Erikson, 1986).

For each of the internal calibration standards, the response factor (RF) for each target compound relative to the internal standard is calculated as:

$$RF = \frac{A_s / C_s}{A_{is} / C_{is}} = \frac{A_s \times C_{is}}{A_{is} \times C_s} \quad (2)$$

Where:

- A_s = Peak area (or height) of analyte or surrogate
- A_{is} = Peak area (or height) of internal standard
- C_s = Concentration of the analyte or surrogate
- C_{is} = Concentration of the internal standard.

The initial calibration consists of the analysis of a minimum of five calibration solutions, each at different concentrations that span the expected concentration range of the sample. These standards include the analyte of interest as well as the appropriate surrogate (SS) and internal standard (IS). The range of concentrations of these standards is 1.0-100 ng/mL, the concentrations of the IS and SS should be the same in all calibration solutions and in the same concentration range as they are spiked in the samples, typically at a concentration 2 to 5 times below the highest calibration standard (Erikson, 1986; Montague, 1993; Scott, 2002; Van Hoof & Hsieh, 1996).

Calibration for Analysis of Aroclors

A multilevel calibration is employed when samples are to be quantified for multi-component mixtures such as Aroclors, or toxaphene. A standard containing mixture of Aroclor 1016 and Aroclor 1260 will include many of the peaks represented in the other five Aroclor mixtures. As a result, a multi-point initial calibration employing a mixture of Aroclors at five concentrations should be sufficient to demonstrate the linearity of the detector response without the necessity of performing initial calibration for each of the seven Aroclors namely 1016, 1221, 1232, 1242, 1248, 1254, 1260. Such a mixture can be used to demonstrate that a sample does not contain peaks that represent any of the seven Aroclors. The mixture can also be used to determine the concentrations of either Aroclor 1016 or Aroclor 1260 if they are present in a sample.

relative retention times, relative to the internal standard (Brian, & Morrison, 2007)..

Quantitation of PCBs

Quantitation of PCBs is performed by the external standard method. The peak area or height of a representative peak in the sample is compared to the peak area or height of the same peak in the PCB standard analysed closest in time to the sample. The concentration of the injected extract is determined by direct ratio with the standard. The final concentration is corrected for sample size.

$$\text{Conc. } \mu\text{g/g} = \frac{\text{std, conc } (\mu\text{g/mL}) \times \text{sample's peak height} \times 1\text{mL} \times \text{dil.}}{\text{Standard peak height} \times (\text{net weight of sample in gram})} \quad (3)$$

The quantitation of PCB congeners is accomplished by the comparison of the sample chromatogram to those of the PCB congeners standards. The quantitation of PCB residues as Aroclors is accomplished by comparing the sample chromatogram to that of the most similar Aroclor standard. The amount of Aroclor is calculated using the individual calibration factors for each of the 3 to 5 characteristics peaks chosen (Shifrin & Toole, 1998).

Any peaks that are not identifiable as PCBs on the basis of retention time should be subtracted from the total area. When determining PCB congeners by internal standard procedure, the response factor (RF) for each congener in the calibration standards relative to internal standard is calculated using equation (2). The calibration factor for each analyte calculated from calibration verification standard (CF) must not exceed a

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difference of more than ± 15 percent when compared to the mean calibration
from the initial calibration curve.

When determining PCBs as Aroclor by the external standard technique the calibration factor for each characteristic Aroclor Peak in each of the initial calibration standard is calculated using the equation below:

$$CF = \frac{\text{Peak Area (or height) in standard}}{\text{Total Mass of Standard Injected (ng)}} \quad (4)$$

Five set of calibration factors will be generated for the Aroclors 1016/1260 mixture, each set consisting of the calibration factors for each of the five (or more) peaks chosen for the mixture. A minimum of three peaks must be chosen for each Aroclor and preferably 5 peaks. The peaks must be characteristic of the Aroclor no question. Peaks in the Aroclor standard that are at least 25% of the height of the largest peak is chosen.

Other Methods for Analysis of PCBs

The many regulations applicable to PCBs (polychlorinated biphenyls) have greatly increased the number of samples requiring analysis. Electric utilities, industrial concerns, and governmental agencies are all required to do massive amount of PCB analysis. Anyone who owns or operates electrical transformers at some time will need to analyze for PCBs. Although excellent techniques for PCB testing utilizing gas chromatography have been practiced for many years, the high cost of these methods has spurred the growth of alternative procedures.

These include direct determination of the chlorine, X-Ray fluorescence, micro coulometry, colorimetric test and electrochemical

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methods. These methods are based on the measurement of the total chlorine contained in a sample containing Aroclors.

PCB/Chloride Analyzer System

Analysis of PCB using the Dexsil L 2000 PCB/Chloride Analyzer System is a field instrument designed to quantify PCB concentration in soils, dielectric fluids and surface wipes. Field analysis for PCBs using the Dexsil system involves a series of chemical reactions which extract organic chloride from the soil and fixes the chloride as an inorganic salt. Inorganic chloride and water are removed from the extract by passing it through a Florisil cartridge. The extract is mixed with a reaction solution and metallic sodium, which dechlorinate the PCB molecules. The free chloride released into the reaction solution is measured with an ion-specific electrode. Only chloride which was part of any organic molecule contributes to the signal. Inorganic chloride originally present in the sample does not interfere. The output of the chloride- specific electrode is electronically converted to the surficial PCB concentration.

The Dexsil instrument provides a direct readout, in parts per million (ppm), of total chloride. A selector on the instrument provides a direct readout of total chloride as equivalent PCB. The instrument has four different settings; Aroclor 1242, Aroclor 1260 Askarel (60% Aroclor 1260/40% trichlorobenzene) setting and total chloride. The “1242” setting is used when Aroclor 1242 is suspected in the sample. This is the most conservative setting in that it may result in inaccurate high readings for samples containing Aroclor 1260. The “1260” setting is used when a sample is suspected to contain Aroclor 1260. The Askarel setting on the analyzer

assumes a ratio of Aroclor 1260 to trichlorobenzene of 60:40. The last setting is for the measurement of total chloride. The instrument does not measure Aroclor 1254, and Aroclor identification cannot be made because the measurement cannot distinguish among the PCB congeners. Hence, the user needs to use site history of previous data to set the analyzer to convert the chloride concentration to the PCB congener.

The different settings provide direct readout as equivalent PCB in ppm based on the total chloride measured. Aroclor 1242 contains 42% chloride and Aroclor 1260 contains 60% chloride. Therefore, the relative amounts of chloride in 1242 sample would be higher than 1260 sample. For example, for a 10 gram sample, if the total chloride concentration is 10 ppm, the PCB concentration as equivalent Aroclor 1260 will be $10 / 0.60$ or 16.7 ppm and the equivalent Aroclor 1242 concentration will be $10 / 0.40$ or 23.8 ppm. By knowing the relationship between the chloride and the various PCBs, it is possible to calculate the Aroclor 1254 or PCB concentration based on the readout for the total chloride. The analyzer is simple to operate, gives immediate results, but detect PCB in soil if the concentration is 5 ppm or more (Finch, 1990).

X-Ray Fluorescence

Various methods of total chlorine analysis are in use for testing transformer oil. The most widely techniques are X-ray fluorescence, microcoulometry, colorimetric methods and electrochemical methods. X-ray fluorescence is the only one method that is non-destructive. For this analysis a sample is placed in a cup which is transparent to X-rays. The sample is irradiated with a particular wavelength and if chlorine is present, radiation of

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a different but specific wavelength is radiated back to a detector, which can quantify the amount of chlorine present.

This chlorine level can then be translated back into parts per million of PCB. The sample must be homogenous as the instrument is only sensing the chlorine in a very thin layer at the bottom of the cup- this is generally not a problem with transformer oils. X-Ray Fluorescence analyzers are expensive and require trained personnel to operate but can become quite economical when large number of samples are processed on daily basis.

Microcoulometry

Microcoulometry is a method whereby a sample is completely combusted at high temperature and then passed into titration cell where the resulting chloride is titrated electrically with a silver electrode. By totaling the amount of silver that must be generated to neutralize the chloride, the total amount of chloride can easily be calculated. From this result, the original PCB concentration in the sample is found. In addition to transformer oil sample this technique can also be used for soil samples and waste oils. Detection limits are in the low ppm range and only a very small sample is required for analysis.

Colorimetric Method

Colorimetric methods are the simplest and least expensive of the chloride detection techniques. The sample is first reacted with a sodium compound that breaks the PCBs down into fragmented hydrocarbons and chlorine. The resulting chloride is then extracted into aqueous phase where it can be detected by a colorimetric reagent. The most prevalent method involves adding a fixed amount of mercuric nitrate which complexes with the

chloride in a ratio of 1:2. Diphenyl carbazone, an indicator very sensitive to free mercuric ions is then added to the solution. If free mercuric ions are present, a deep purple color develops.

If however, all the mercury is complexed with the chloride, then no color appears. By adding a precise amount of mercuric nitrate to the sample, the test can be engineered to generate a specific end point at any chosen action level. For PCB, this level is usually 50 ppm. The advantages to the colorimetric method are speed, portability and ease of use. The main disadvantage is that the technique provides a quantitative result at the chosen end point. Pre-packaged kits cost about \$10.0 per test.

Electrochemical Methods

The electrochemical method is similar to the colorimetric method in that it requires an initial reaction with sodium based compound to remove the chloride from the PCB backbone. After this has been completed, instead of adding a colorimetric reagent, an ion-specific electrode is used to quantitatively measure the concentration of chloride ions that is in the sample. The instrument used to make the measurement can then translate the concentration of chloride that it sense directly into parts per million PCB. This is a quantitative method with a limit of detection of about 2 ppm. It is just as fast as colorimetric techniques but requires line voltage to operate and involves an initial investment of several thousands of dollars.

It requires little training by the operator and can be used outside, but does use reagents that cost about 5 dollars per test. Extensive studies have shown this method to be comparable to gas chromatography for both soil and oil samples when test at levels between 2 and 2,000 ppm.

Some laboratories may wish to express residue in terms of ppm DCB (decachloro biphenyl) in order to establish a uniformity in their reporting. However, when the procedure is used for quantitative confirmation, DCB is expressed in terms of a specific Aroclor by using a factor for mathematical conversion. Calculations for measuring PCB residue by GLC based on DCB derivative formed are:

DCB in sample injected (ng) =

$$(6) \quad \frac{(\text{DCB}) \text{ peak height of sample} \times \text{ng of standard injected}}{\text{Peak height of DCB standard}}$$

$$(\text{ng DCB in sample injected}) \times (\text{factor for specific Aroclor [X]}) = \text{ng Aroclor in sample injected}$$

$$\text{ppm Aroclor in sample} = \frac{\text{ng Aroclor in sample injected}}{\text{Weight of sample injected (mg)}} \quad (7)$$

$$\text{Where } X = \frac{\text{molecular weight of Aroclor}}{\text{molecular weight of DCB(499)}} \quad (8)$$

Choice of Method for Analysis of PCBs

Specific technique such as gas chromatography is most appropriate when the sample is suspected to be contaminated with sources of chlorine other than PCBs. For instance, if a motor oil sample contaminated with large amounts of chlorinated paraffins was tested for PCBs with non-specific chlorine test, a large number of false positives would result as the non-specific test cannot distinguish between PCBs and chlorinated paraffins. A properly equipped gas chromatography however, would easily separate the PCBs from the other chlorinated organics.

On the hand, with samples such as transformer oil which seldom contain chlorinated compounds, it is much more economical to use non-specific method which is able to find the PCBs much more quickly and right in the field. Specific methods, such as gas chromatography can provide widely varying results on the same sample so a second test may be used to confirm the results. (Finch, 1990).



CHAPTER THREE

MATERIALS AND METHODS

Sampling and Treatment of Samples

The Soil samples were collected from the immediate surroundings of Electricity Corporation Ghana (ECG) transformer sites in five districts in the Central Region of Ghana (Table 5). A total of seventy eight (78) composite

Table 5: Names of Metropolis, Districts and sampling towns

Metropolis/District	Sampling Town/Location	Sample
Cape Coast	UCC Science Library	UCL
	UCC Science Auditorium	UAD
	UCC CDS	CDS
	Nurses Flat	NF
	Pedu	PDU
	Mfantshipim Sec. Sch.	MSS
	Ashanti road	ARD
	Brofoyedur	BRO
	Elmina Market	ELM
	Elmina Clinic	ECL
Komenda-Edna-Abrem-	Elmin SSNIT Flat	ESF
Aguaful (KEEA)	Anomabo	ANO
Mfantsiman	Salt Pond Aahamadyah	SAH
	Salt Pond ECG Office	SEC
	Mankesim	MAN
	Mankesim ECG Office	MEC

Table 5 continued

Awutu-Efutu Senya	Apam Manfam	AMF
	Apam Sec. Sch.	ASS
	Winneba NVTI	NVT
	Winneba Baal Ltd.	WBL
	Winneba Police Dep.	WPD
	Winneba Basic Chemicals	BCH
Agona	Sweedru ECG Offic	ASE
	Swedru Sakora Park	ASP
	Nsaba Post Office	ANP
	Kwanyako GWCL	KGW

soil samples were collected from twenty six different locations in the five districts from the 17 -18th September, 2008. At each site three (3) composite samples were collected with a garden hand towel, at depth of 0 - 10 cm, 10 - 20 cm and 20-30 cm, in order to assess the vertical distribution of the PCBs. Each composite sample weighed between 880 - 950 g, and consisted of ten core samples which were collected randomly from each site, thoroughly mixed and sub sampled to obtain the composite. The samples were placed in labeled polythene bags and sent to the laboratory. They were air dried, and each sample was sieved using 250 μ m mesh sieve. Sub samples were taken in duplicates and stored in a refrigerator for analysis. A map of the sampling sites (Plate 12) One of the selected sites at Brofoyedur, in Cape Coast are shown (Plate 13) are shown

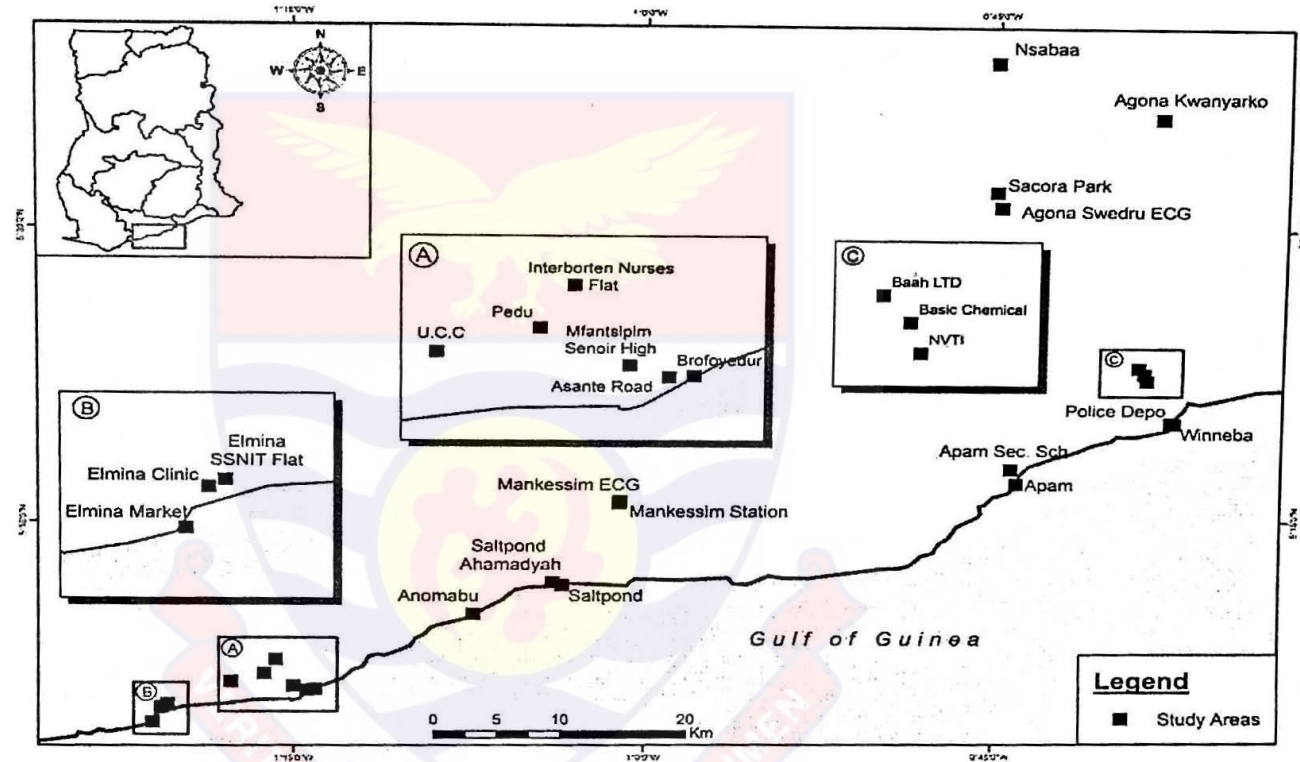


Plate 12: Map showing sampling sites in the Central Region

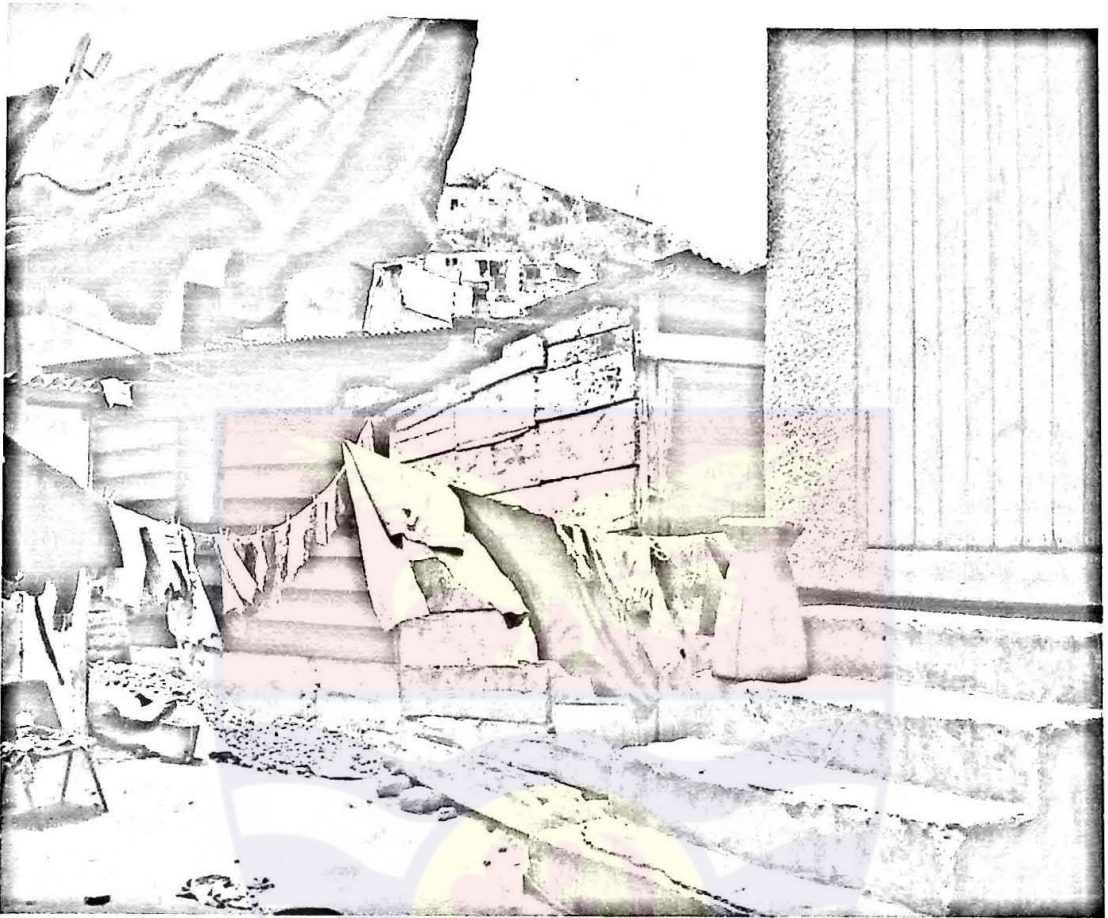


Plate 12: Potential contaminated sampling site around transformer house at Brofoyedur- Cape Coast (Transformer manufactured in 1970 and installed in 1971)

Determination of Moisture Content

Ten grams of air - dried soil were weighed in a previously weighed silica dish, dried in an oven at 110 °C for 24 hours, and then cooled in a desiccator to room temperature. After cooling the soil was re-weighed. The process was repeated to ensure a constant weight was obtained after reweighing. The moisture content of the air-dry was obtained by difference.

The average moisture content was calculated and expressed as g/100 of air-dry soil or percentage moisture (David, 1994).

$$\% \text{ moisture} = \frac{\text{air dry weight} - \text{oven dried weight}}{\text{air dry weight (mg)}} \times 100 \quad (9)$$

Measurement of Soil pH

Twenty grams of air dried soil sample was weighed, placed in a 100 ml beaker and 20 ml of double distilled water added, and stirred several times for 20 minutes. HANNA 211 microprocessor pH meter was calibrated and used for the measurement of pH. The pH reading was allowed to stabilize and the pH read, and recorded as the soil pH (Rowell, 1994).

Determination of Soil Textures

The pipette method was employed in the determination of the clay, sand and silt contents of the soils (Kilmer and Alexander, 1949). Five ml of 5% sodium hexametaphosphate (SHMP) (NaPO_3)₆ solution was placed in a previously weighed porcelain dish. It was evaporated to dryness in an oven, cooled in a desiccator and then weighed. The weight of the salt was found by difference. A 10.2 g of 2mm sieved soil was placed in a 250 ml beaker. 10 ml of 5% sodium hexametaphosphate solution was added followed by 100 ml of distilled water. The mixture was then stirred thoroughly for 10 minutes using a magnetic stirrer. The suspension was quantitatively transferred into 500 ml measuring cylinder and more distilled water was added to make the total volume 400 ml. The suspension was stirred for 1 minute with a rod and placed in a water bath, kept at 25°C. The suspension was allowed to stand for 3 hours 27 minutes 40 seconds.

After this period 5 ml aliquot was collected at a depth of 5 cm using a

pipette into a previously weighed porcelain dish. This was used to determine the amount of clay. The suspension was evaporated to dryness on a steam bath and then in an electric oven at 105 – 110 °C for 34 hours. It was cooled in a desecrator and then weighed. The remaining suspension was transferred into a 63 µm mesh sieve. The sand was transferred into an evaporating dish and dried in the oven. It was cooled in desiccators and then sieved again to ensure that all silt particles had been removed (Kilmar and Alexander, 1949; Black, 1965). The clay, sand and silt were expressed as percentage as follows:

$$\% \text{ Clay} = \frac{V_s(W_c - W) \times 100}{V_p W_o} \quad (10)$$

$$\% \text{ Sand} = \frac{W_1 \times 100}{W_o} \quad (11)$$

$$\% \text{ Silt} = 100 - (\% \text{ Sand} + \% \text{ Clay})$$

(12) Where: W_o = weight of soil (10g)

W_1 = weight of sand

W_c = weight of clay residue in pipette

W = weight of salt in sample (0.005 g)

V_p = volume of pipette (5 cm³)

V_s = volume of suspension

Determination of Soil Organic Matter

The method described by Baker (1976) & Jackson (1995)) was used for the organic carbon (organic matter) determination. Three grams of soil was sieved with 212 µm mesh sieve and ground to a fine powder with pestle, and then sieved again with 63µm mesh sieve. To 1.0 g of the fine soil in 250 ml conical flask, 10 ml of 1.0 M potassium dichromate ($K_2Cr_2O_7$) solution was

added followed by 5.0 ml of 5 g AgNO₃ in 500 ml of concentrated H₂SO₄. The flask was swirled for 30 seconds and then heated on a steam bath for 2 minutes. After cooling under tap it was allowed to stand for 30 minutes, 1.0 ml of concentrated orthophosphoric acid (H₃PO₄) was added and the mixture diluted with 100 ml of double distilled water. Three drops of barium diphenylamine indicator was added and titrated with 0.5 M ammonium ferrous sulphate solution. At the end point the colour changed from dark brown through purple to green. The same procedure was repeated and the average titre value calculated. A same procedure was followed for the blank. The percentage organic carbon was calculated using the relation:

$$\% C_t = \frac{(V_s - V_o) \times (M_{Fe}) \times 12 \times 100 \times 1.30}{W \times 4000} \quad (13)$$

where:

V_o = ml of Fe²⁺ solution used to titrate blank

V_s = ml of Fe²⁺ solution used to titrate sample

W = weight of soil sample in gram

M_{Fe} = Concentration of Fe²⁺ solution used to titrate

12/4000 = milliequivalent weight of C in g.

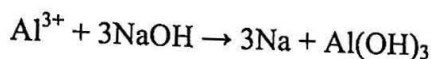
Determination of Effective Cation Exchange Capacity (ECEC)

The method described by David (1994) was used for the determination of the Effective Cation Exchange Capacity (ECEC).

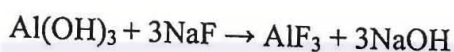
Determination of Exchange Acidity

Ten grams of soil was placed in a 100 ml beaker and 30 ml of 1.0 M potassium chloride solution added, stirred and allowed to stand overnight. The suspension was filtered through a 110 mm diameter Whattman filter paper into 100 ml volumetric flask. The soil was thoroughly washed with successive 10

ml volume of KCl solution into the flask; two drops of phenolphthalein indicator was added and titrated with 0.01 M sodium hydroxide to pink colour. Two drops of 4% sodium fluoride solution was added to the pink solution and titrated with 0.01M HCl to colorless end point. The first end point measured the exchangeable acidity (Al^{3+} and H^+).



The reaction after the addition of NaF was



The released NaOH was then titrated with the 0.01 M HCl. The titre volume measured the exchangeable Al^{3+} . The exchange capacity in $\text{cmol}_c\text{kg}^{-1}$ was calculated using the formulae below.

$$\text{Ex} (\text{Al}^{3+} + \text{H}^+) = \frac{0.2y \times 10}{\text{Soil mass (g)}} \quad (14)$$

Where y is respectively the volumes of NaOH used. The exchangeable H^+ was calculated as

$$\text{Ex} (\text{H}^+) = \text{ex} (\text{Al}^{3+} + \text{H}^+) - (\text{exAl}^{3+}) \quad (15)$$

Determination of Exchangeable Bases

Ten grams of air dried soil was placed in a 100 ml beaker and 20 ml of 1.0 M ammonium acetate solution added. It was then stirred for 30 seconds and left to stand overnight. The suspension was filtered into a 250 ml volumetric flask. The beaker was washed thoroughly with the ammonium acetate solution into the funnel, and the soil in the funnel washed with successive 25 ml volumes of the acetate solution. The funnel was allowed to drain between each addition till 250 ml of filtrate had been collected.

The absorbance of sodium, potassium standards (0-10 ppm) and

calcium (0 - 30 ppm) were determined with SHERWOOD Model 420 Flame Photometer, and a calibration curve prepared from the standards. The absorbance of sodium and potassium for each of the soil extract was measured with this flame photometer; Magnesium and calcium were measured by AAS Varian 240FS model, and the corresponding concentrations calculated. The exchangeable cations were calculated using the relations:

$$\text{cmol}_c \text{ kg}^{-1} (\text{air dry soil}) = \frac{0.2174 \times G \times 5}{\text{Soil mass (g)}} \quad (16)$$

Where G is the concentration of Na^+ in ppm found from sodium calibration curve.

The exchangeable potassium was calculated as follows:

$$\text{cmol}_c \text{ kg}^{-1} (\text{air dry soil}) = \frac{0.1283 \times Z \times 5}{\text{Soil mass (g)}} \quad (17)$$

Where Z is the concentration of K^+ in ppm

Calculation of Exchangeable Ca and Mg

The exchangeable Ca and Mg were calculated using the relation:

$$\text{cmol}_c \text{ kg}^{-1} = (\text{ppm Ca} \div 200) + (\text{ppm Mg} \div 120) \quad (18)$$

For results expressed in ppm or mg/dm^3 , the exchangeable bases are calculated by summing up of the exchangeable K^+ , Na^+ and $(\text{Ca}^{+2} + \text{Mg}^{+2})$.

The effective cation exchange capacity (ECEC) was calculated as follows:

$\text{ECEC (cmol}_c \text{ kg}^{-1}) = \text{exchangeable acidity} + \text{exchangeable bases}$

$$= \text{ex}(\text{Al}^{+3} + \text{H}^+) + \text{ex}(\text{Ca}^{+2} + \text{Mg}^{+2} + \text{K}^+ + \text{Na}^+) \quad (19)$$

Analysis of Heavy Metals in Soils

The soil samples were air-dried at 100 °C for 48 hours in the oven. The dried samples were passed through a 2 mm standard screen to remove large particles. For the digestion of the soil sample, one gram of dried and homogenized soil was weighed and placed in an acid washed Teflon vessel.

The digestion was performed with a mixture HNO_3 and HClO_4 acid. The digested samples were analyzed for Cu, Zn, Pb, Ag, Fe and Al metals by Varian 235 AAS (US EPA, 1999). The analytical precision and accuracy of the method was accomplished by analyzing a blank and duplicate spike samples. The metal analysis was done with Varian 235 AAS at the Ghana Atomic Energy Commission.

Analysis of Polychlorinated Biphenyls (PCBs)

A modified analytical procedure of Van Hoof and Hsieh (1996); USEPA method 3665A & 8000B (1996); Scott Clifford *et al.*, (2002) and Screening Analysis of Polychlorinated Biphenyls (2006) were employed for the PCBs analysis.

Performance Validation and Reproducibility

Two recovery studies were conducted for the performance validation (to assess the ability to achieved acceptable recovery) as well as the reproducibility of the GC/ECD analysis. The first recovery study involved random spiking of the soil samples with 0.02 ppm PCB mix standards (surrogate), containing PCB# 28, 52, 101, 118 .138, 153 and 180, before extraction. The samples were extracted and cleaned; the extracted samples were analyzed and the recoveries calculated. The second recovery study involved the use of PCBs certified reference materials from the National Institute of Standards and Technology (NIST, USA). Recoveries were calculated from the differences in peak areas (concentrations) of spike samples (or certified standard) and the peak areas (concentrations) obtained after analysis using GC/ECD. For the reproducibility, 0.02 ppm PCB mix standards containing PCB# 28, 52, 101, 118 .138, 153 and 180 was used and the

Relative Percent Difference (RPD) between duplicates calculated based on the peak areas of congeners with identical retention times. The RPD was also estimated by analyzing duplicate of unspiked samples.

Calculation of Recovery and Precision Estimation

The percentage recovery of spiked sample was calculated according to the following formula:

$$\text{Recovery (\%R)} = \frac{C_s - C_u}{C_n} \quad (20)$$

where

C_s = Measured concentration (peak area) of spiked sample aliquot

C_u = Measured concentration (peak area) of unspiked sample aliquot

C_n = Nominal concentration (peak area) of standard or spike

The precision was estimated from the relative percent difference (RPD) of the concentration (peak areas) measured for spike duplicate pairs.

The RPD was

calculated according to the following formula:

$$\text{RPD} = \frac{[C_1 - C_2] \times 100}{\frac{1}{2} [C_1 + C_2]} \quad (21)$$

Where

C_1 = Measured concentration (peak area) of the first sample aliquot

C_2 = Measured concentration (peak area) of the second sample aliquot

Extraction of PCBs

Ten grams of air dried soil was put into a cellulose timble and covered with a layer of glass wool. This was placed in an automated soxhlet apparatus and extracted with 100 ml of hexane-acetone mixture (1:1 v/v) for 16 hours. When the extraction was completed, the inner surface of the condenser was

rinsed 3 times with acetone-hexane and allowed to cool. The extract was evaporated and concentrated to 10 ml by rotary vacuum evaporator at 40 °C; 50 ml of hexane was added and concentrated to remove the acetone. This was then drained through a funnel containing hexane - rinsed sodium sulphate and glass wool to dry the extract. The transfer was completed by rinsing the vessel containing the extract followed by sodium sulphate with 5 ml portions of hexane. This was evaporated and concentrated to 5 ml before clean up.

Clean up with sulphuric acid

In order to remove co-extractive, organochlorines and other organic compounds, sulphuric acid cleanup was carried out, as the PCB is not affected by the acid. 10 ml of concentrated extract was transferred, with three 5 ml hexane rinses of the flask into a 125 ml separatory funnel. 20 ml of concentrated sulphuric acid (1+1) was added and shaken vigorously for two minutes; gas built up was carefully discharged, and the mixture was allowed to stand for 20-30 minutes for the phase to separate. When the sample had partitioned into the discrete layers the acid layer (lower layer) was drained and discarded. The organic layer was rinsed with two 5 ml of double distilled water which was drained out and discharged (Brian, & Morrison, 2007).

Clean up with KMnO_4

Five millimeters of 5% (w/v) aqueous potassium permanganate was added to a separator containing the acid cleaned extract, this was shaken vigorously and allowed to stand for phase separation. Permanganate layer was drained and discarded. The organic layer was washed with two 10 ml deionized water and the aqueous layer discarded. The sample was passed

through sodium sulphate in a funnel to dry the extract before the copper clean up (Brian, & Morrison, 2007).

Clean up with Copper Granules

The copper clean up was necessary to remove any sulphur present which might significantly interfere with the GC/ECD analysis. Copper granules were rinsed with sulphuric acid, washed with water and then with the extraction solvent (hexane -acetone). Approximately 0.5 g of the freshly treated copper was added to 10 ml extract, agitated and allowed to stand for 10 minutes and the extract quantitatively transferred through a funnel plugged with a glass wool to remove the copper. The process was repeated and the extract obtained concentrated by the rotary evaporator to 5ml. The extract was further cleaned with silica gel (Brian, & Morrison, 2007; Screening Analysis of Polychlorinated Biphenyls, 2006).

Silica gel Clean up

The column (0.75 m, 16 mm ID) was plugged with glass wool, filled with silica gel and 2 g Na_2SO_4 placed on top. The column was pre washed with 30 ml of 3% dichloromethane in hexane (v/v). 250 ml flask was placed under the column and the solvent was drained to reach the top of sodium sulphate layer. The concentrated extract was transferred using a pipette onto the column followed by three 5 ml rinses of the sample flask using the pipette each time. The solvent was drained to the top of the sodium sulphate and the column eluted with 100 ml of hexane: dichloromethane (97:3). The eluate was concentrated to about 1 ml. The final clean up extract was transferred into a pre cleaned 2 ml vial with acetate ethyl resins and added to the vial to make

the total volume 2 ml. This was stored in a refrigerator below 10 °C until GC - ECD analysis.

Gas Chromatography - Electron Capture Detector (GC-ECD) Analysis

The final extract of 2.0 ml was analyzed for PCBs, at the Ghana Standard Authority, using a gas chromatograph equipped with ^{63}Ni electron capture detector GC - ECD model CP 3800. The capillary column used was VF 5ms 30 m $\times$ 0.25 mm id $\times$ 0.25 μm film thickness. The GC conditions were as follows: injection point temperature: 270°C; oven temperature programme: 70 °C (hold 2 min) to 180 °C at a rate of 25 °C/min (hold 1min) to 300 °C at a rate of 5 °C/min. Temperature of detector was 300 °C; carrier gas-nitrogen at flow rate: 1.0 ml/min; make-up gas flow rate - 29.0 ml/min. The total runtime was 31.368 min. The retention time for the PCBs standard were PCB 28, 12.54 min; PCB 52, 14.161; PCB 101, 17.341 min; PCB 153, 20.14 min; PCB 138, 21.027 min; and PCB 180 23.272 min.

The identification of PCBs congeners in the sample was conducted by comparing the retention times of the PCBs congeners in sample to that of the PCB standards. The concentrations of the individual PCBs congeners in mg/kg were calculated on dry weight basis, and the total PCBs concentration (ΣPCB) calculated by summing up the concentrations of individual PCB congeners.

Hazard Assessment

In order to assess the likely hazard or impact of the levels of the PCBs on the ecology and health the Toxicity Equivalent (TEQ), Hazard Index (HI) and the dermal and carcinogenic risk were determined.

Calculation of Toxicity Equivalent (TEQ)

PCB congener 118 has been assigned a Toxicity Equivalent Factor (TEF) of 0.0001 by the World Health Organization (Van den Berg *et al.*, 1998). The concentration of the dioxin-like PCB, PCB 118, was multiplied by its TEF to obtain the PCB-TEQ.

Calculation of Hazard Index (HI)

The Hazard Index approach described by Environment Agency (2009b, 2009c and 2009d) and Iann and Stutt (2009), was adopted for the calculation of HI. For congener PCB 118, the average daily exposure from soil (ADE) was calculated using the relation:

$$ADE = C \times EF \times TEF \quad (22)$$

Where

ADE: Average daily exposure of PCB118 from soil, pg WHO-TEQ kg⁻¹bw day⁻¹

C: Soil concentration, ng kg⁻¹dw

TEF: Toxic equivalency factor for dioxin-like PCB 118 = 0.0001pg WHO-TEQ pg⁻¹

EF: Exposure factor = 1.29E-02 and 5.57E-04 pg kg⁻¹ BW day⁻¹ per ng kg⁻¹dw respectively for residential and commercial land use scenario

The Hazard Index (HI), which is the ratio of the total soil exposure (ADE) to the oral Tolerable Daily Soil Intake (TDSI), was calculated using the relation:

$$HI = ADE / TDSI \quad (23)$$

Where

HI: Hazard Index

ADE: Average daily exposure from soil (pg WHO-TEQ kg⁻¹ BW day⁻¹)

¹for residential and commercial land use scenario, respectively.

Estimation of Carcinogenic Risk

Some soil contaminants may be absorbed across the skin into the bloodstream. Absorption will depend upon the amount of soil in contact with the skin, the concentration of chemicals in soil, the skin surface area exposed, and the potential for the chemical to be absorbed across the skin. The potential for carcinogenic risk level (EPA, 1986a, b) is evaluated using the relations:

$$\text{High cancer Risk} = 1 - \exp(-\text{CDI} \times \text{SF}) \quad (24)$$

$$\text{Low cancer Risk} = \text{CDI} \times \text{SF} \quad (25)$$

where

Risk = a unitless probability (e.g., 2×10^{-5}) of an individual developing cancer;

CDI = chronic daily intake averaged over 70 years (mg/kg-day);

SF = slope factor, expressed in (mg/kg-day)⁻¹ and

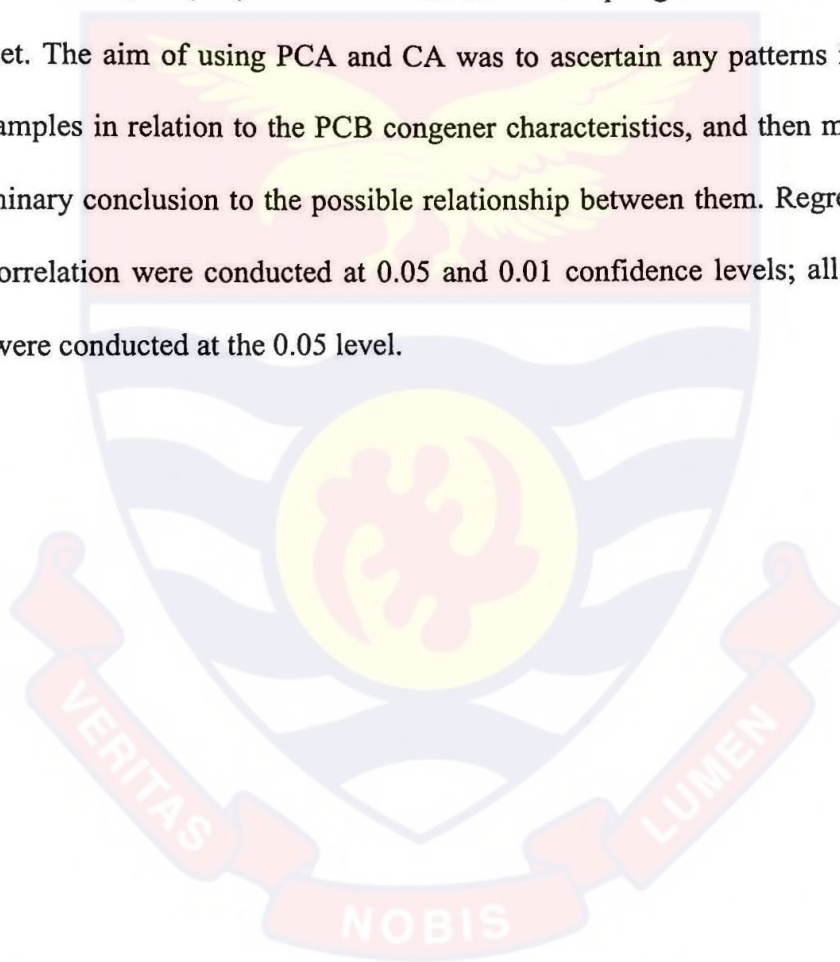
exp = the exponential

In this study the cancer risk assessment was based on the estimated lifetime cancer risk to a Reasonable Maximum Exposure (RME) individual via the complete dermal exposure (skin contact). Human health evaluation computerized software- RISC 4.02 (USEPA 1989) was used in the evaluation of the cancer risk assessment. The estimated life time used was 70 years, the body weight and exposure duration was 15 kg and 2 years for children, and 70 kg and 9 years for adult.

Statistical Analysis

Statistical analysis were performed using SPSS 16.0 and Microsoft

excel 2010. Assessment of the normal distribution of the PCB data was carried out through Kolmogorov-Smirnov test and Shapiro-Wilk test. Both Pearson's and Spearman Rho methods of regression and correlation were used to identify the relationship among PCBs and other soil parameters. Multivariate analysis of variance (MANOVA) with Post Hock test was used to demonstrate the significant differences of PCB concentrations in the surface and subsurface soils. Principal component analysis (PCA), based on the correlation matrix, and cluster analysis (CA) were conducted for the sampling sites and soil PCB data set. The aim of using PCA and CA was to ascertain any patterns in the soil samples in relation to the PCB congener characteristics, and then make a preliminary conclusion to the possible relationship between them. Regression and correlation were conducted at 0.05 and 0.01 confidence levels; all other tests were conducted at the 0.05 level.



CHAPTER FOUR

RESULTS AND DISCUSSIONS

Precision and Reproducibility of Analysis

The results of the recovery and precision analysis are presented in Appendix B. The mean recovery of 0.2 ppm mix PCB standards from the spiked duplicate soil samples indicated 89% recovery, which was within the 75 -125% (or $\pm 25\%$) acceptable criteria. The precision of the analysis calculated as the relative percent difference (%RPD) was 8% and was within the acceptable range of $\pm 15\%$ (Appendix B). The mean percentage recovery of PCBs from the standard reference material was 79%. The Polychlorinated biphenyl congeners were qualitatively identified by their respective retention time indicated on the chromatogram (Fig. 7).

The retention times in minutes for the seven polychlorinated biphenyls congeners; 28, 52, 101, 118, 153, 138 and 180 were respectively 13.725, 14.938, 17.754, 19.688, 20.443, 21.332 and 23.555.

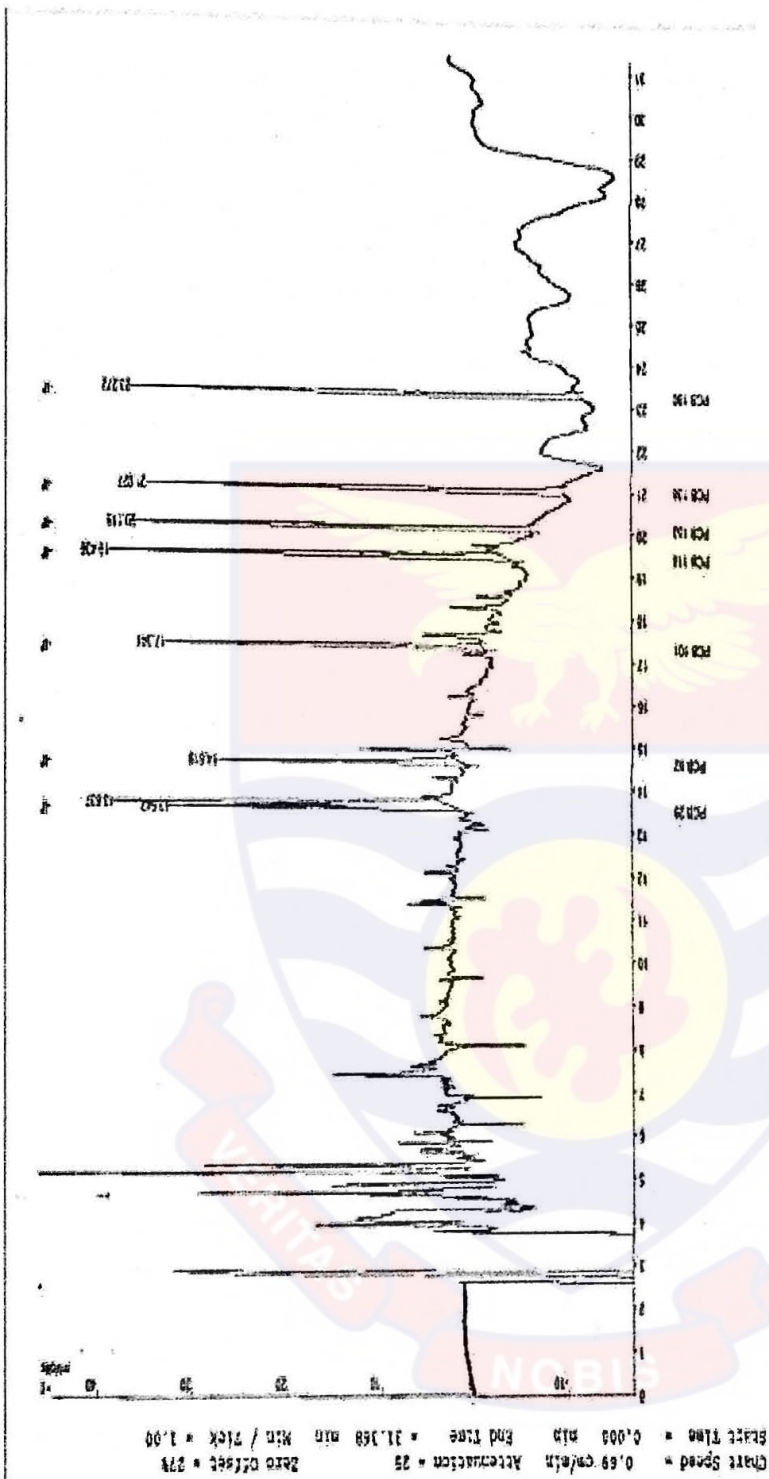


Figure 7: Chromatogram of PCB mix standards

The results of the analyses of soil samples collected around transformers in the Central Region are shown (Appendices G). The concentration of the sum of the seven key PCBs, (IUPAC No. PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153 and PCB 180) for 78 samples of soils from 26 sites are also shown in Table 6. The concentration (mean $\pm$ CV) of PCBs in soils was $7.99 \pm 38 \mu\text{g/kg}$ and ranged from 1.32 - $12.94 \mu\text{g/kg}$. The highest concentrations of PCBs were found at two sites, Winneba (WPD) $12.72 \mu\text{g/kg}$ and Saltpond (SAH), $12.94 \mu\text{g/kg}$ (Figure 8); with soils from SAH being sandy loams with higher organic carbon 0.39% and the other WPD being sandy soils, with lower organic carbon content 0.15% . The observation is similar to those found in soils in the west coast of southern Sweden (Backe *et al*, 2004), where the highest concentrations were found at two sites with sandy soils, one with extremely high organic carbon content.

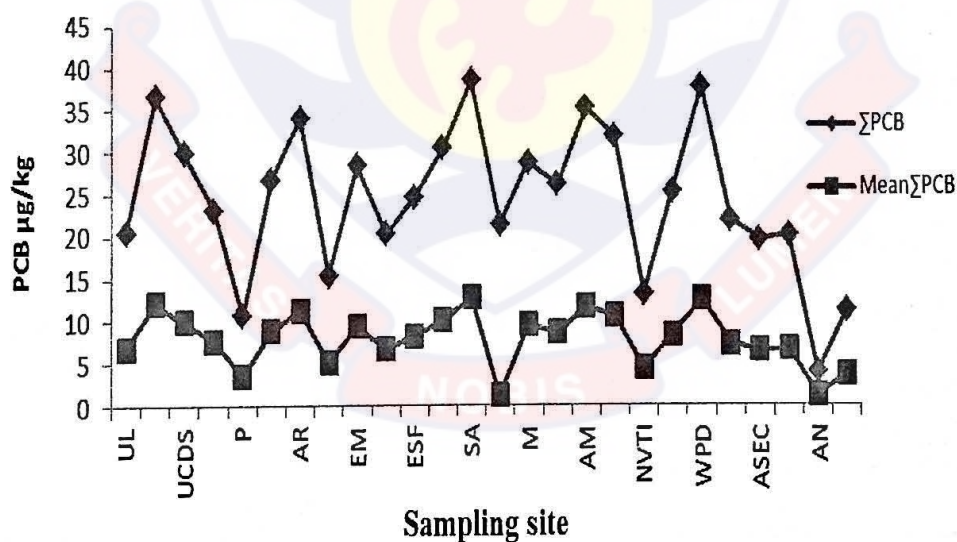


Figure 8: Total and mean concentrations of PCBs at the sampling sites

Table 6: Concentration of PCBs in soil from the Central Region

Sampling Site	Σ PCB ($\mu\text{g/kg}$)	Sampling Site	Σ PCB ($\mu\text{g/kg}$)
UCL	6.86	SEC	7.19
AUD	12.21	MAN	9.65
CDS	9.99	MEC	8.79
NSF	9.76	AMF	11.86
PDU	3.53	ASS	10.73
MSS	8.96	NVT	4.46
ARD	11.39	WBL	8.53
BRO	5.17	WPD	12.72
ELM	9.50	BCH	7.39
ELC	6.81	ASE	6.61
ESF	8.29	ASP	6.79
ANO	3.22	ANP	1.32
SAH	12.94	KGW	3.77

Source: Laboratory analyses of soil samples, 2009

The levels of PCBs contamination in the soils studied were low; they were much lower (more than thousand times lower) than the recommended limits of 25 mg/kg and 33 mg/kg set by the Canadian Soil guide (CCME, 1999) and the US EPA, respectively. The range of polychlorinated biphenyl concentrations compares with those found in soils in Wales, which ranged from < 0.2 to 12.2 $\mu\text{g/kg}$ (Jones, 1989). The levels were comparable to levels detected in soils in Linfen city, China (Fu *et al.*, 2008); but lower than those found in soils elsewhere in Bahrain, 0.2-72.2 $\mu\text{g/g}$ (Al-Haddad *et al.* 1993); in

Greenwich, with a PCB level of 53 mg/kg (Chamoff, 2011); in Soils from Vietnam with PCB concentrations ranged from 0.61 ng/g to 9960.00 ng/g (Thao *et al.*, 2009), in Burgos (Spain), where PCB levels were between 0.824 and 1.240 µg/g (Gonzalez *et al.*, 1991); Moscow region (Wolfgang *et al.*, 2006); Switzerland (Zennegg *et al.* 2004); Belarus (Kukharchyk *et al.*, 2007); New York, (Herrick *et al.* 2007); India, Guzzela *et al.* (2005) and in Ghana, which were between 0.357 mg/kg and 20.721 mg/kg (Centeno, 2010); but higher than those found in Poland by Lulek *et al.* (1999). Even though the soils examined were contaminated with PCBs, they were not polluted and can be classified as clean. However, the presences of these toxic compounds in the environment raises concerns because of their potential to bio-accumulate.

Regression analysis among the seven congeners revealed that only PCB 138 and 153 correlated significantly at the 5% level of significance. However, the correlation was weak, $r = 0.30$. The positive correlation is an indication that these PCBs were from the same sources, probably Aroclor 1260, which contain PCB 138,153 and 180 (Syracuse, 2000). Even though the three PCB congeners are suspected to be from the same source, no significant correlation was observed between PCB 180 and any of the other two. This could be due to the degradation of PCB180 (2,2',3,4,4',5,5' heptachlorobiphenyl) via T-process, a degradation process which removes meta-chlorine from single chlorobiphenyl group to give either PCB138 (2,2',3,4,4',5' hexachlorobiphenyl) or PCB153 (2,2',4,4',5,5' hexachlorobiphenyl) as noted by Wu *et al.* (1997). These two congeners have the 4Cl, PP, 2M structure.

Distribution of PCB Congener in the Study Areas

The mean of the congeners in $\mu\text{g/kg}$ were PCB 28, 2.26 ± 81 > PCB 52, 2.22 ± 133 > PCB 101, 2.03 ± 83 > PCB 180, 1.23 ± 65 > PCB 153, 1.10 ± 63 > PCB 138, 0.95 ± 71 > PCB 118, 0.79 ± 79 (Appendix F). The highest concentrations of PCB 28, 153 and 180 were also found in the Awutu-Eufutu-Senya district (AES) (Figure 13). PCB 110, 118 and 138 were found highest at Elmina in the Komenda-Edna- Eguaful -Abrem district; and PCB 52 found highest at Anomabo, Salt Pond and Mankesim sampling areas in the Mfantseman district (ASM). There were variation in the levels of the congeners, and PCB congener 52 showed the greatest variation and PCB-153 the least. The variation, as revealed by the coefficient of variation (Table 6), increase in the order: PCB-153, PCB-180, PCB-138, PCB-118, PCB-28, PCB-110, and PCB- 52.

The trend in the distribution of the PCB congeners in the vicinity on transformers in the metropolis and districts of the central region were as follows (Figure 9): for Cape Coast PCB 28 > PCB 153 = 138 > PCB 52 > PCB 180 > PCB > PCB 101 > PCB 118; for the Awutu Efutu Senya district; PCB 28 = PCB 138 = PCB 153 > PCB 118 = 180 > PCB 101 = 52. For the Mfantseman district; PCB 28 > PCB 52 = PCB 138 > PCB 101 = PCB 118 = PCB 180 > PCB 53. The trend in the Agona district was PCB 28 > 101 = 153 > PCB 52 > PCB 118 = 138 > PCB 180; and in the KEEA, PCB 28 > PCB 101 = PCB 153 > PCB 52 = PCB 138 > PCB 118 > PCB 180.

In general PCB 28 was found to be most prevalent in all the districts and PCB 180 the least. Within the region the trend of PCB distribution was PCB 28 > PCB 153 > PCB 138 > PCB 52 > PCB 101 > PCB 180 > PCB 118.

However, PCB # 101, 118 and 180 did not differ much. The dominance of PCB 28 is not strange as Otchere (2005), found PCB 28 and 52 as dominant congeners in mussels from some lagoons in Ghana.

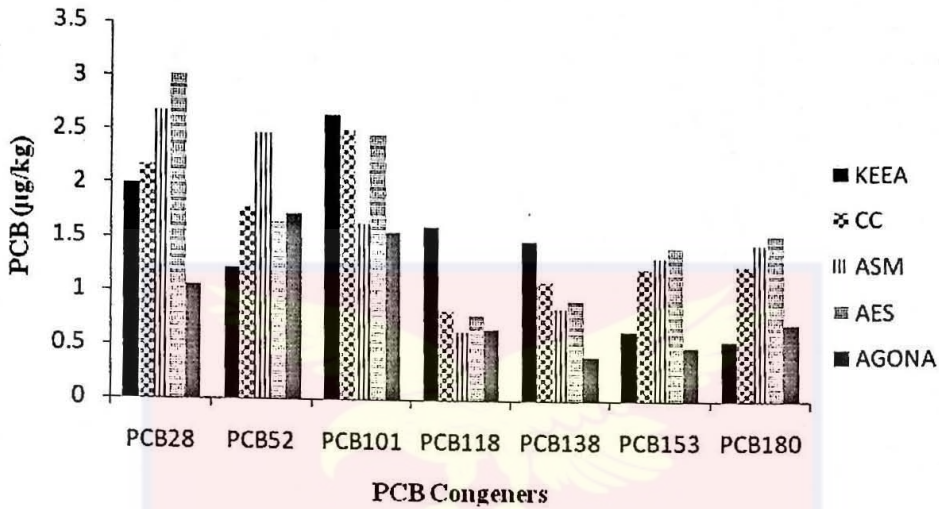


Figure 9: Mean concentration of PBC congeners in the soils

A total of 126 PCB congeners were detected in soils from eight sampling sites out of the eighteen transformer sites identified in Cape Coast. The 126 congeners comprised of twenty four PCB 28; nineteen PCB 52; twelve PCB101; eleven PCB 118; twenty two PCB 138; twenty two PCB 153 and sixteen PCB 180. All the three (3) sites identified in the KEEA district were selected, and the total number of congeners identified was 48. In the Awutu-Efutu-Senya district six out of eleven sites were examined and a total of 79 PCBs were detected. For Agona and Mfantseman districts, four and five sites each out of six and seven sites respectively were examined and the total numbers of PCBs identified were respectively 58 and 88. The numbers of PCB congeners detected in soils from the study areas are shown in Figure 10.

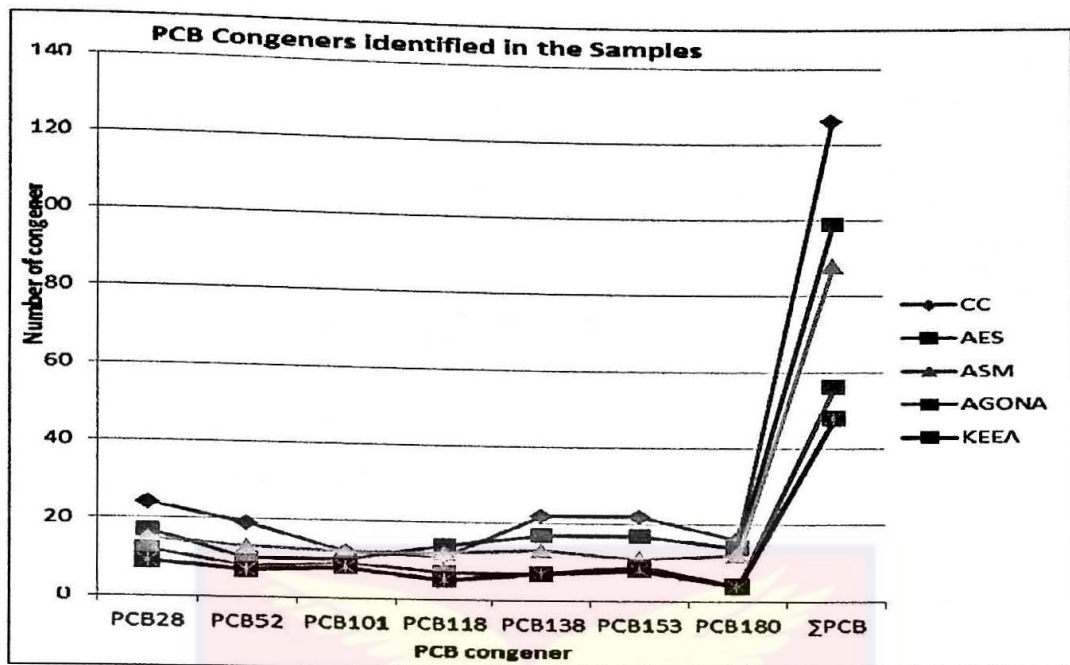


Figure 10: Total number of PCBs identified in the study areas.

In general the prevalence of the PCBs was found in the order: Cape Coast > Efutu Awuto Senya > Mfantisman (AES) > Agona > KEEA. Regression analysis indicated a strong linear correlation between the independent variable (number of site) and the number of PCB congeners detected, with a Coefficient of Determination $R^2 = 0.86$ ($p < 0.05$). Also logarithmic and exponential relation indicated strong correlation, with the values of R^2 being respectively 0.79 and 0.87 at 5 % confidence level (Figure 11). These observations suggest that soils in areas with large numbers of PCB containing transformers are likely to be exposed to greater amounts of PCBs.

The composition of PCB homologous in the soils were dominated by hexa-PCBs (Fig. 12), and followed the order hexa-PCBs (31.89 %) > penta-PCBs (23.98 %) > tri-PCBs (18.47 %) > tetra-PCBs (13.67 %) > hepta-PCBs (11.99 %). Zhang *et al.* (2007), found the Tetra-, penta-, and hexa-chlorinated biphenyls as dominant species in some agricultural soils from Southern Jiangsu, China.

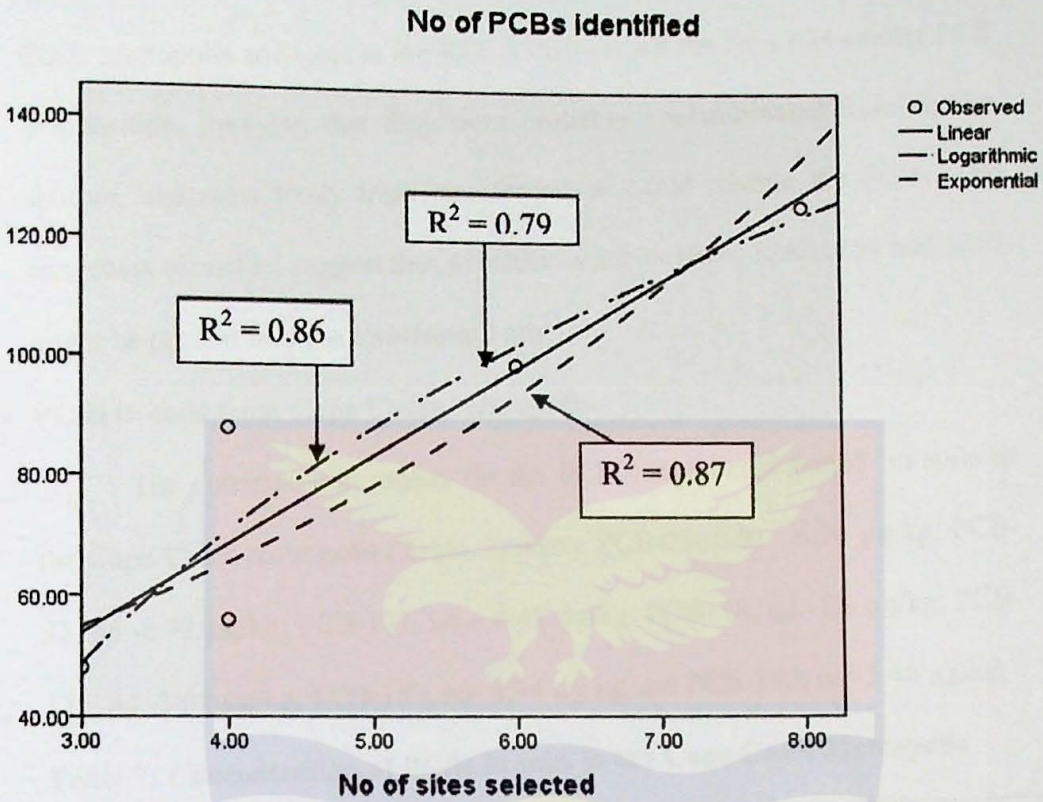


Figure 11: Correlation of number of transformer sites with corresponding number of PCBs identified

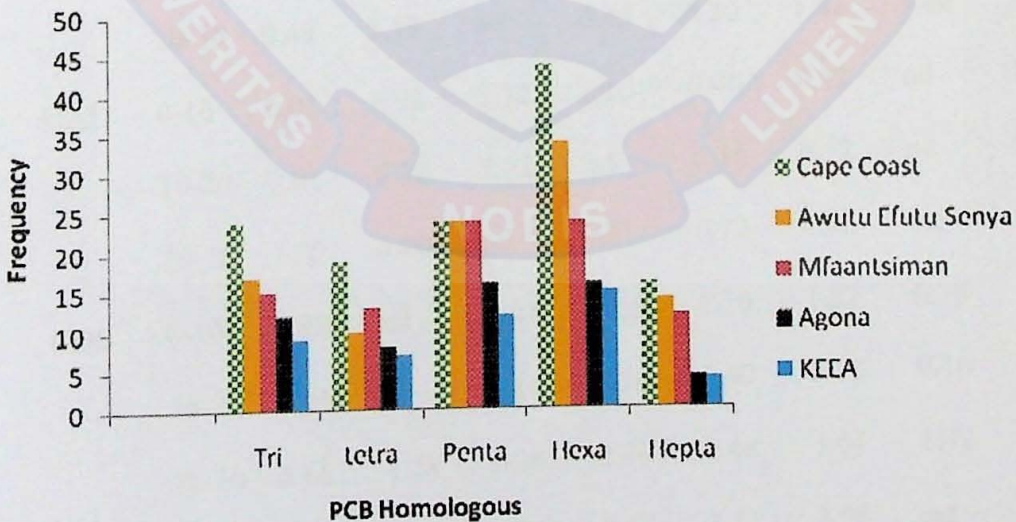


Figure 12: PCB homologous detected in soils at the study areas

PCB Homologous

Generally, all these PCB homologous were found highest in the Cape Coast metropolis and least in the KEEA district. All the sites had similar PCB composition, implying that they were probably contaminated from similar sources, and most likely from transformer oils that contain the PCBs. The congeners identified suggest that Arochlors such as 1016, 1242, 1254 and 1260 might be present in those transformer oils.

PCBs in soils from Cape Coast Metropolis

The concentration ranges for the PCB congeners detected in soils in the Cape Coast metropolis (Table 7) were: PCB-28, 0.01– 6.76 $\mu\text{g/kg}$; PCB-52, nd -6.92 $\mu\text{g/kg}$; PCB-101, nd – 6.42 $\mu\text{g/kg}$; PCB118, nd -1.1 $\mu\text{g/kg}$; PCB-138, nd -3.04 $\mu\text{g/kg}$; PCB-153, nd- 4.94 $\mu\text{g/kg}$ and PCB-180, nd -5.46 $\mu\text{g/kg}$.

Table 7: Concentration of PCBs in soils in the Cape Coast Metropolis

Site	Depth (cm)	PCB Congener ($\mu\text{g/kg}$)							
		28	52	101	118	138	153	180	ΣPCB
UCL	0-10	0.52	3.66	nd	0.58	1.48	0.20	1.50	7.94
	10-20	2.10	0.18	nd	nd	1.06	2.16	nd	5.50
	20-30	0.49	3.17	nd	0.45	0.20	1.43	1.40	7.14
UAD	0-10	0.01	6.92	3.32	nd	0.40	0.12	nd	10.77
	10-20	0.01	6.32	2.92	nd	0.34	0.12	nd	9.712
	20-30	7.00	0.80	nd	nd	0.72	4.98	1.64	16.14
CDS	0-10	4.88	nd	0.44	1.10	1.16	1.22	0.78	9.58
	10-20	1.04	nd	0.16	0.26	0.40	0.18	0.16	2.20
	20-30	6.68	1.28	6.28	0.70	0.48	1.04	1.72	18.18
NFL	0-10	0.02	0.68	0.67	0.67	1.11	2.08	nd	5.23

Table 7 continued

	10-20	0.02	0.98	0.74	0.72	1.94	2.58	nd	6.98
	20-30	2.48	nd	6.02	nd	1.98	nd	0.58	11.06
PDU	0-10	0.80	0.64	nd	0.12	0.12	nd	nd	1.68
	10-20	1.06	0.78	nd	nd	1.44	0.50	nd	3.78
	20-30	1.30	nd	0.01	3.60	nd	0.26	0.12	5.29
MSS	0-10	0.01	5.52	nd	0.68	1.12	1.66	nd	8.99
	10-20	0.26	nd	nd	nd	3.04	0.92	2.04	6.26
	20-30	2.60	0.18	2.80	0.24	nd	0.34	5.46	11.62
ARD	0-10	6.76	0.34	nd	nd	2.08	1.37	1.18	11.73
	10-20	6.16	0.24	nd	nd	1.88	1.48	1.38	11.14
	20-30	6.76	0.14	nd	nd	1.31	1.68	1.41	11.30
BRO	0-10	0.62	0.32	nd	nd	1.30	0.5	0.28	3.02
	10-20	0.16	1.32	0.62	nd	0.50	0.18	0.16	2.94
	20-30	0.20	0.46	6.42	nd	0.36	1.66	0.44	9.54

Source: Laboratory analyses of soil samples, 2010

The mean concentration ($\pm$ rsd) of the individual congeners, PCB # 28, 52, 101, 118, 138, 153 and 180 in all the soils from Cape Coast were 2.16 ± 1.21 $\mu\text{g/kg}$, 1.14 ± 1.48 $\mu\text{g/kg}$, 1.27 ± 1.71 $\mu\text{g/kg}$, 0.38 ± 2.00 $\mu\text{g/kg}$, 1.12 ± 0.75 $\mu\text{g/kg}$, 1.22 ± 1.02 $\mu\text{g/kg}$ and 0.84 ± 1.42 $\mu\text{g/kg}$ respectively. There were variations in the levels of the congeners as revealed by the relative standard deviation, with PCB 118 showing the greatest variation and PCB 138 the least. The total PCB concentration of the seven congeners, ΣPCB , of the samples ranged between 1.6 -18.18 $\mu\text{g/kg}$. The highest concentration of PCB, 18.18 $\mu\text{g/kg}$, was found

in the soil sample in the vicinity of a transformer in the University of Cape Coast (CDS) and the least, 1.68 $\mu\text{g/kg}$, found in soil from the Pedu (PDU).

The profile of PCBs in 0-30 cm soils from the Cape Coast metropolis is shown in Figure 13. The mean of ΣPCB in the 0-30 cm layer of soil ranged from 3.58 to 12.21 $\mu\text{g/kg}$, with the soils samples from around the University of Cape Coast auditorium (UAD) showing the highest concentration and sample from Brofoyedur (BRO) the least amount of PCBs. The total PCBs concentrations ΣPCB in the top surface (0-10 cm) and sub-surface soils, 10-20 cm and 20 -30 cm, ranged between 1.68 -11.73 $\mu\text{g/kg}$, 2.20 -11.14 $\mu\text{g/kg}$ and 5.29 – 18.18 $\mu\text{g/kg}$ respectively (Table 6). There were significant variations in the levels of individual PCB congeners. PCB118 showed the highest variation with the relative standard deviation (rsd) of 2.00, and PCB 138 showed the least variation with the rsd of 0.75. PCB-28 had the highest concentration of 2.16 ± 01.21 $\mu\text{g/kg}$ and PCB 118 the least 0.38 ± 2.00 . Generally, the levels of PCBs in the Cape Coast Metropolis were higher than those of the other districts (Fig.13 & 14).

In the Cape Coast Metropolis, the highest levels of PCBs were found in the 20 -30 cm sub-surface soils. The levels in the 10-20 cm layer were generally lower than those in the surface soils. Some PCB congeners were below their detection limits. PCB 101 was not detected in any of the samples taken from sites close to the UCC library (UCL) and Ashante Road (ARD). Similarly PCB 118 was not found in any of the samples from a site in the vicinity of the UCC auditorium (UAD), Ashante Road (ARD) and Brofoyedur (BRO).

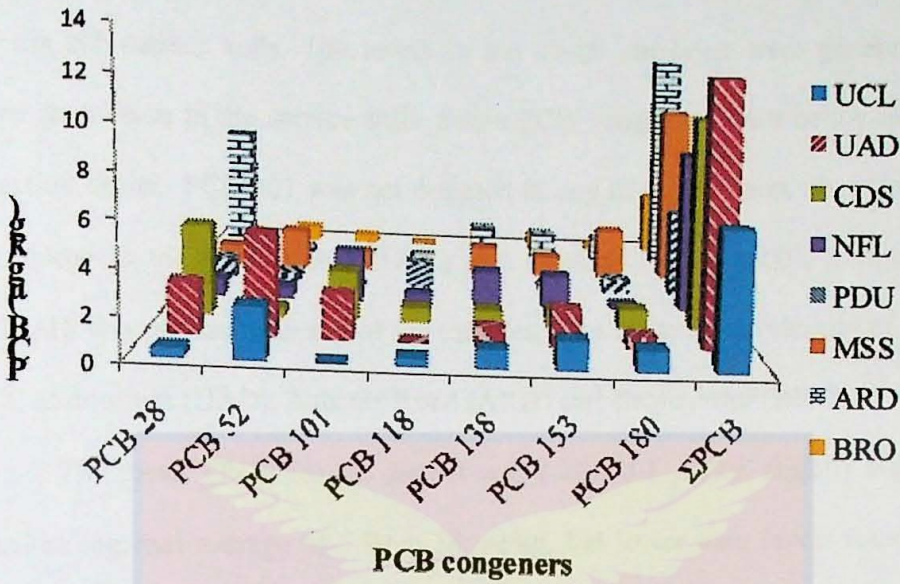


Figure 13: PCBs congener profile in soils from Cape Coast metropolis

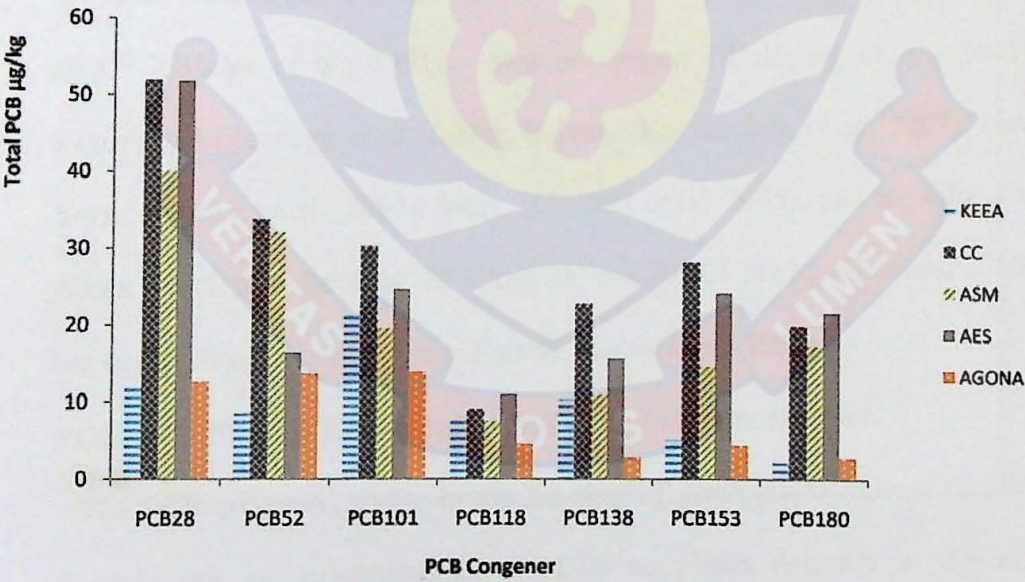


Figure 14: Total concentration of PCB congeners in 0-30 cm soil samples from the districts and metropolis

In the Cape Coast Metropolis, the highest levels of PCBs were found in the 20-30 cm sub-surface soils. The levels in the 10-20 cm layer were generally lower than those in the surface soils. Some PCB congeners were below their detection limits. PCB 101 was not detected in any of the samples taken from sites close to the UCC library (UCL) and Ashante Road (ARD). Similarly PCB 118 was not found in any of the samples from a site in the vicinity of the UCC auditorium (UAD), Ashante Road (ARD) and Brofoyedur (BRO).

The mean Σ PCB for the district was $8.24 \pm 0.01 \mu\text{g/kg}$, slightly higher than the regional average of $7.99 \pm 38 \mu\text{g/kg}$, but lower than levels found in soils in Linfen city, China (Fu *et al.*, 2008); but lower than those found in soils elsewhere in Bahrain, 0.2-72.2 $\mu\text{g/g}$ (Al-Haddad *et al.*, 1993); in Greenwich, with a PCB level of 53 mg/kg (Chamoff, 2011); in soils from Vietnam with PCB concentrations ranged from 0.61 ng/g to 9960.00 ng/g (Thao *et al.*, 2009), in Burgos (Spain), where PCB levels were between 0.824 and 1.240 $\mu\text{g/g}$ (Gonzalez *et al.*, 1991); Moscow region (Wolfgang *et al.*, 2006); Switzerland (Zennegg *et al.*, 2004); Belarus (Kukharchyk *et al.*, 2007); New York, (Herrick *et al.*, 2007); India, (Guzzela *et al.* 2005); and in Ghana in Accra, which were between 0.357 mg/kg and 20.721 mg/kg (Centeno, 2010); but higher than those found in Poland (Lulek *et al.*, 1999).

PCBs in Soils from Komenda/Edina/Eguafo/Abirem District

The PCB congener profile in the Komenda/Edina/Eguafo/Abirem (KEEA) districts and the concentrations of PCBs congeners detected in the soils collected from the KEEA district are listed in Table 8. The levels of PCB#101, 138 and 180 were higher than the regional averages of 2.02 $\mu\text{g/kg}$, 0.95 $\mu\text{g/kg}$

and 1.23 $\mu\text{g/kg}$ respectively. The mean concentration of PCB# 28, 52, 101, 118, 138, 153 and 180 were respectively 1.99 ± 0.25 , 0.94 ± 0.17 , 2.38 ± 0.06 , 0.90 ± 0.17 , 1.16 ± 0.15 , 0.57 ± 0.96 , and 0.56 ± 0.004 $\mu\text{g/kg}$. The mean concentrations of the congeners decreased in the order PCB 101 > PCB 28 > PCB 138 > PCB 52 > PCB 118 > PCB 153 > PCB 180; and the variability was in the order PCB 153 > PCB 28 > PCB 52 = PCB 118 > PCB 138 > PCB 101 > PCB 180 the other congeners had lower levels.

Table 8: Concentration of PCBs in soils in the KEEA District

Site	Depth	PCB Congener ($\mu\text{g/kg}$)							ΣPCB
		28	52	101	118	138	153	180	
ELM	0-10	2.70	0.44	0.38	2.78	0.14	1.92	nd	8.36
	10-20	2.80	3.44	1.84	2.66	nd	0.64	nd	11.38
	20-30	1.90	3.01	1.34	2.06	nd	0.45	nd	8.76
ECL	0-10	2.38	0.44	nd	nd	0.82	0.6	nd	4.24
	10-20	0.74	nd	4.36	nd	4.96	nd	nd	10.06
	20-30	2.18	0.60	0.014	nd	2.8	0.18	0.36	6.13
ESF	0-10	2.98	0.28	0.18	nd	0.12	0.76	0.2	4.52
	10-20	0.94	nd	8.18	0.44	0.62	0.32	0.86	11.36
	20-30	1.30	0.3	5.12	0.16	1.00	0.28	0.82	8.98

Source: Laboratory analysis of soil samples, 2010

The mean of ΣPCB (total concentration of the seven congeners) in three levels of the soils (0-30 cm) at sites ELM, ECL and ESF were 9.5 $\mu\text{g/kg}$, 6.811 $\mu\text{g/kg}$ and 8.286 $\mu\text{g/kg}$ respectively (Fig 15). The concentration of PCBs in the top surface soils (0-10 cm) ranged from 4.52 to 8.98 $\mu\text{g/kg}$; for the sub-surface soils 10 -20 cm and 20-30 cm, the

ranges were respectively 4.24 -11.38 $\mu\text{g/kg}$ and 6.234 -8.98 $\mu\text{g/kg}$.

Higher levels were found in the 10 -20 cm sub-surface soils.

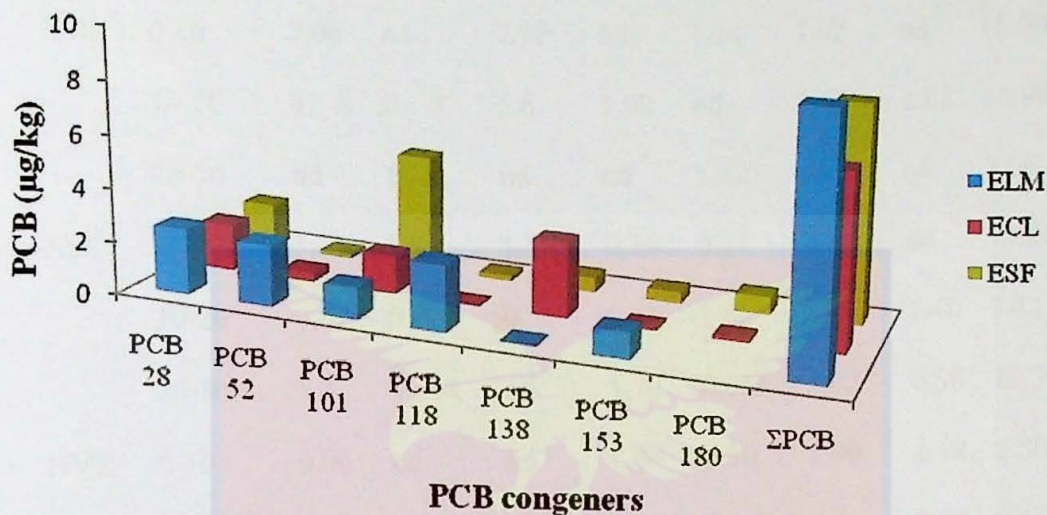


Figure 15: PCB congener profile in soils from KEEA District

The profiles of PCB congeners in soil samples from the KEEA district are shown in Figure 15. Some PCB congeners were below their detection limits. PCB 118 and 180 were not detected in ECL and ELM respectively. The mean ΣPCB for the district was $8.20 \pm 0.04 \mu\text{g/kg}$, which is higher than the regional average of $7.99 \pm 38 \mu\text{g/kg}$.

PCB in Soils from Awutu/Efutu/Senya District

Polychlorinated biphenyls detected in soils in the Awutu/Efutu/Senya district are shown in Table 9. The mean (and ranges) of the congeners were PCB-28, $2.88 \pm 1.07 \mu\text{g/kg}$ (nd -9.26); PCB-52, $0.92 \pm 1.74 \mu\text{g/kg}$ (nd - 5.8); PCB-101, $1.39 \pm 1.75 \mu\text{g/kg}$ (nd -7.37); PCB-118, $0.62 \pm 0.84 \mu\text{g/kg}$ (nd-1.7); PCB-138, $0.88 \pm 0.87 \mu\text{g/kg}$, (nd - 2.62); PCB-153, $1.36 \pm 0.83 \mu\text{g/kg}$, (nd - 4.44) and PCB-180, $1.22 \pm 0.98 \mu\text{g/kg}$ (nd -4.20). The levels of these congeners were in the order PCB-

28> PCB-101 > PCB-52 > PCB-153 > PCB-180 > PCB-118. It was observed that generally the surface soils had the highest levels of Σ PCB and the 20 -30 cm sub soils the least. PCB-52 was not detected in sample NVT.

The mean of the total PCBs concentration of the seven congeners (mean Σ PCB) in soils in the Awutu /Efutu /Senya district ranged between 4.45 and 12.72 $\mu\text{g/kg}$. Soil samples from the vicinity of a transformer at the Winneba Police Depot (WPD) had the highest mean Σ PCB 12.72 $\mu\text{g/kg}$ and sample from around transformer at the National Vocational Technical Institute (NVT) had the least mean Σ PCB of 4.46 $\mu\text{g/kg}$. Figure 16 shows the trend in the levels of Σ PCB in the soils (0-30 cm).

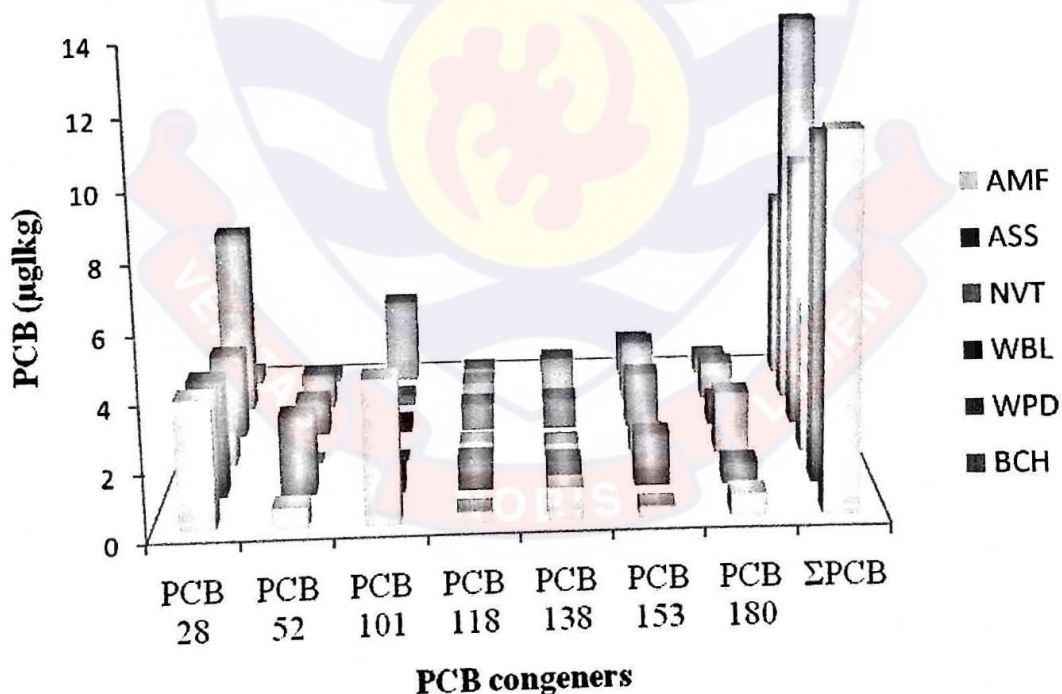


Figure 16: PCB congener profile of soils from Awutu Efutu Senya

District

The highest level of Σ PCB, 18.0 $\mu\text{g/kg}$, was detected in the soil sample from Apam Manfam (AMF) and the smallest, 2.56 $\mu\text{g/kg}$, found in sample taken from transformer site at the National Vocational and Technical Institute (NVT). The mean Σ PCB for the district was $9.28 \pm 0.53 \mu\text{g/kg}$; higher than the regional average of $7.99 \pm 0.38 \mu\text{g/kg}$ but lower than levels in soils in Linfen city, China (Fu *et al.*, 2008); but lower than those found in soils elsewhere in Bahrain, 0.2-72.2 $\mu\text{g/g}$ (Al-Haddad *et al.*, 1993); in Greenwich, with a PCB level of 53 mg/kg (Lisa Chamoff, 2011); in Soils from Vietnam with PCB concentrations ranged from 0.61 ng/g to 9960.00 ng/g (Thao *et al.*, 2009), in Burgos (Spain), where PCB levels were between 0.824 and 1.240 $\mu\text{g/g}$ (Gonzalez *et al.*, 1991); Moscow region (Wolfgang *et al.*, 2006); Switzerland (Zennegg *et al.*, 2004); Belarus (Kukharchyk *et al.*, 2007); New York, (Herrick *et al.* 2007); India, (Guzzela *et al.*, 2005) and in Ghana in Accra, which were between 0.357 mg/kg and 20.721 mg/kg (Centeno, 2010); but higher than those found in in Poland Lulek *et al.*, 1999).

PCBs in Soils from Mfantseman District

The mean levels of PCBs (Σ PCB) in soils from the Mfantseman district were between 8.48 and 15.98 $\mu\text{g/kg}$ (Table 10) For the 10-20 cm and 20-30 cm sub- surface soils, the PCB concentrations ranged respectively from 5.41 to 16.13 $\mu\text{g/kg}$ and 3.72 -10.84 $\mu\text{g/kg}$. The mean of Σ PCB for the soils (0 -30 cm) at the various sampling sites ranged from 7.193 to 12.931 $\mu\text{g/kg}$. The mean concentrations (and ranges) of the individual PCB congeners in $\mu\text{g/kg}$ in the soils were as follows: PCB-28, 2.68 ± 0.96 (0.42 -9.62); PCB-52, 2.15 ± 1.29 (nd – 7.8); PCB-101, 1.32 ± 1.49 (nd -6.42); PCB-118, 0.51 ± 1.78 (nd -3.7);

PCB-138, 0.74 ± 1.13 (nd - 2.82); PCB-153, 0.99 ± 1.41 (nd - 4.32) and PCB-180, 1.17 ± 1.12 (nd - 3.64).

Table 10: Concentration of PCBs in soils in the Mfantsiman District

Site	Depth	PCB Congener (μ g/kg)							Σ PCB
		28	52	101	118	138	153	180	
ANO	0-10	3.16	2.98	1.58	0.24	0.40	0.12	nd	8.48
	10-20	1.64	0.50	4.80	0.60	nd	0.38	2.50	10.42
	20-30	1.04	0.50	2.90	0.55	0.38	nd	3.50	8.87
SAH	0-10	6.34	2.32	0.34	0.58	0.34	1.92	nd	11.84
	10-20	0.011	7.80	0.52	0.10	2.82	2.42	2.46	16.13
	-30	0.42	0.46	6 42	0.22	2.2	0.82	0.30	10.84
SEC	0-10	5.16	3.85	0.34	0.16	0.12	nd	1.06	10.69
	10-20	0.54	0.26	0.01	0.48	nd	0.48	3.64	5.41
	20-30	1.42	nd	0.01	3.70	0.34	nd	0.01	5.48
MAN	0-10	9.62	0.014	0.36	0.26	0.80	nd	0.12	11.17
	10-20	2.76	0.42	1.94	0.36	0.26	0.32	1.00	7.06
	20-30	2.26	5.54	0.56	nd	0.18	0.10	2.08	10.72
MEC	0-10	2.92	7.48	nd	0.38	0.56	4.32	0.32	15.98
	10-20	1.14	0.16	nd	nd	1.26	3.50	0.62	6.68
	20-30	1.80	nd	nd	nd	1.46	0.46	nd	3.72

Source: Laboratory analysis of soil samples, 2010

The variability in the levels of the PCB congeners follow the order: PCB-28 < PCB-180 < PCB-138 < < PCB-52 PCB-101 < PCB-153 < PCB-118. The PCB congener profile in soils from the Mfantsiman district is depicted in Figure 17. The highest concentration of PBCs (PCB52) was found in soils

(MAN) at Mankesim (Fig 17) and the lowest found in soils at Mankesim Electricity Company yard (MEC). PCB-28 was detected in all the fifteen samples whilst PCB 153 was found in eleven samples

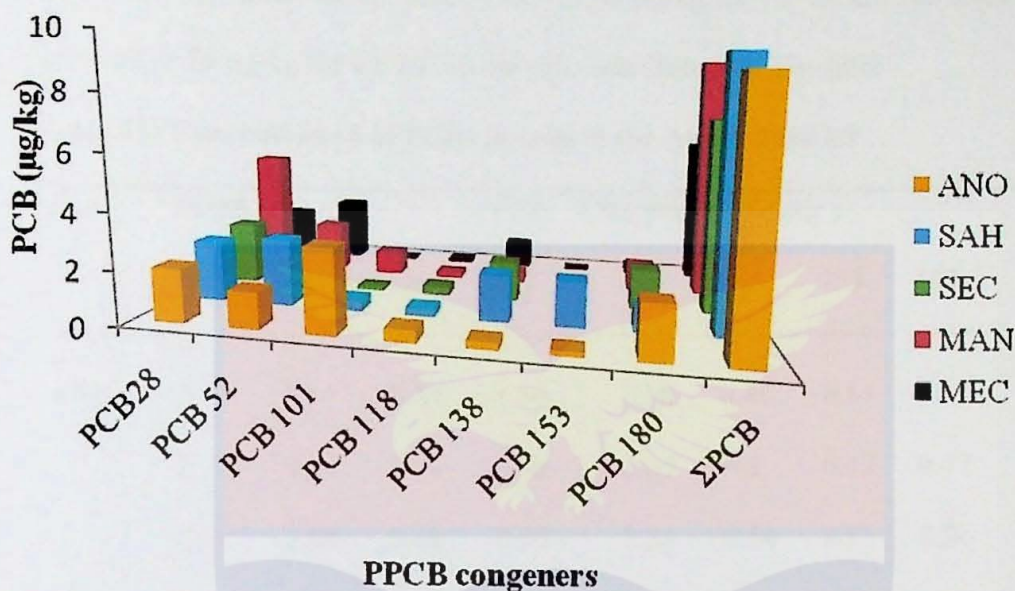


Figure 17: PCB congener profile in soils from Mfantseman District

The mean Σ PCB for the district was $9.56 \pm 0.38 \mu\text{g/kg}$, this was higher than the regional average of $7.99 \pm 0.38 \mu\text{g/kg}$, but lower than levels found in soils in Linfen city, China (Fu *et al.*, 2008); but lower than those found in soils elsewhere in Bahrain, 0.2-72.2 $\mu\text{g/g}$ (Al-Haddad *et al.*, 1993); in Greenwich, with a PCB level of 53 mg/kg (Chamoff, 2011); in Soils from Vietnam with PCB concentrations ranged from 0.61 ng/g to 9960.00 ng/g (Thao *et al.*, 2009), in Burgos (Spain), where PCB levels were between 0.824 and 1.240 $\mu\text{g/g}$ (Gonzalez *et al.*, 1991); Moscow region (Wolfgang *et al.*, 2006); Switzerland (Zennegg *et al.*, 2004); in Belarus (Kukharchyk *et al.*, 2007); New York, (Herrick *et al.* 2007); India, (Guzzela *et al.*, 2005) and in Ghana

in Accra, which were between 0.357 mg/kg and 20.721 mg/kg (Centeno, 2010); but higher than those found in in Poland (Lulek, *et al.*, 1999).

PCBs in soils from Agona District

The concentration of PCBs in soils of Agona district ranged between 1.5 –15.88 µg/kg for surface soils, 1.24 -12.88 µg/kg for 10 -20 cm sub soils and 1.22 -5.16 µg/kg for the 20 -30 cm sub soils (Tab. 11). The total

Table 11: Concentration of PCBs in soils in the Agona District

Site	Depth (cm)	PCB Congener (µg/kg)							ΣPCB
		28	52	101	118	138	153	180	
ASE	A	1.64	8.34	1.56	2.78	0.40	0.54	nd	15.26
	B	0.40	0.44	0.70	0.25	Nd	0.12	0.47	2.38
	C	0.36	0.40	0.50	0.24	0.14	nd	0.56	2.20
ASP	A	0.56	1.76	nd	nd	Nd	nd	nd	2.32
	B	1.20	0.22	8.60	0.8	Nd	1.66	0.40	2.88
	C	0.90	0.96	0.24	0.32	1.0	0.24	1.44	5.16
ANP	A	0.80	nd	nd	0.10	0.50	0.10	nd	1.50
	B	0.70	nd	0.24	nd	0.30	Nd	nd	1.24
	C	0.36	nd	0.36	nd	nd	0.50	nd	1.22
KGW	A	4.04	0.48	1.52	nd	0.12	0.34	nd	6.50
	B	0.44	nd	Nd	0.16	Nd	0.88	nd	1.48
	C	1.32	1.18	0.36	nd	0.36	0.12	nd	3.34

Source: Analysis of soil samples, 2009

concentration, ΣPCB, of the seven congeners in the soils (0-30 cm) at the four sites ranged from 1.32 -7.768 µg/kg. The mean and ranges (in µg/kg) of the individual PCB congeners detected in soils at the four sampling sites were;

PCB-28, 1.06 ± 0.97 (0.36 -4.04); PCB 52, 1.72 ± 2.03 (nd - 8.34); PCB 101, 1.56 ± 2.04 (nd -8.6); PCB118, 0.66 ± 2.03 (nd -2.78); PCB 138, 0.41 ± 1.32 (nd - 1.06); PCB-153, 0.50 ± 1.3 (nd - 1.66) and PCB 180, 0.72 ± 1.82 (nd -1.44).

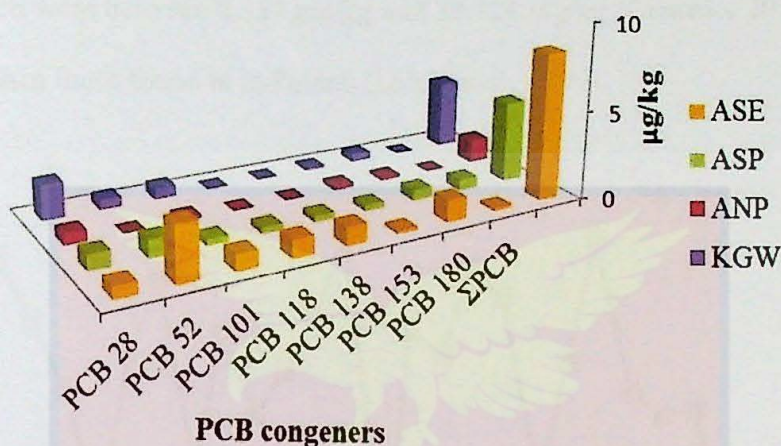


Figure 18: PCB congener profile of soils from in Agona Districts

The variation in the concentrations of the congeners decreased in the order PCB-110 > PCB-52 = PCB-118 > PCB-180 > PCB-138 > PCB-153 > PCB-28. PCB-52 was not detected in any of the samples from site AN. Similarly PCB-180 was not detected in soils taken from sites AN (Agona Nsaba) and KGW (Kwanyako Ghana Water Company Limited). The profile of the PCB congeners in the soils (Fig. 18) shows soils from sites AN (Agona Nsaba) had the lowest PCB concentration of 1.32 µg/kg, and sample ASE from Agona Swedru ECG had the highest, 6.61 µg/kg.

The mean Σ PCB for the district was 4.62 ± 1.02 µg/kg, and lower than the regional average of 7.99 ± 0.38 µg/kg, and also levels found in soils in the Linfen city, China (Fu *et al.*, 2008); but lower than those found in soils elsewhere in Bahrain, 0.2-72.2 ug/g (Al-Haddad *et al.* 1993); in Greenwich, with a PCB level of 53 mg/kg (Lisa Chamoff, 2011); in Soils from Vietnam

with PCB concentrations ranged from 0.61 ng/g to 9960.00 ng/g (Thao *et al.*, 2009), in Burgos (Spain), where PCB levels were between 0.824 and 1.240 µg/g (Gonzalez *et al.*, 1991); Moscow region (Wolfgang *et al.*, 2006); Switzerland (Zennegg *et al.* 2004); Belarus (Kukharchyk *et al.*, 2007); New York, (Herrick *et al.* 2007); India, (Guzzela *et al.*, 2005) and in Ghana in Accra, which were between 0.357 mg/kg and 20.721 mg/kg (Centeno, 2010); but higher than those found in in Poland (Lulek *et al.*, 1999).

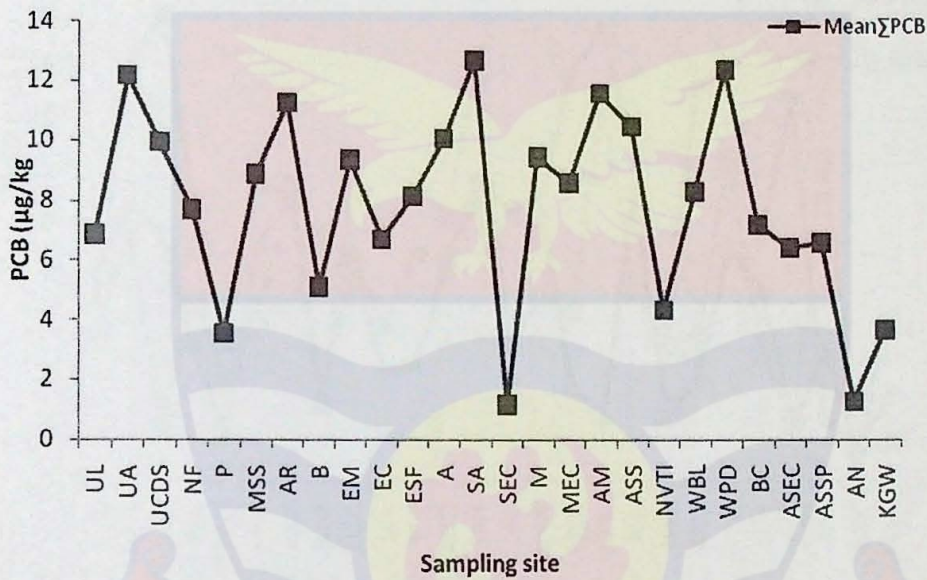


Figure 19: Mean concentrations of PCBs at the sampling site

The mean Σ PCB for the distributions of PCBs at the sampling sites are shown (Figure 19). For the metropolis and districts, the mean Σ PCB follow the order: Agona (4.62 ± 0.06 µg/kg) < KEEA (8.20 ± 0.04 µg/kg) < Cape Coast (8.24 ± 0.06 µg/kg) < Awutu-Efutu Senya (9.28 ± 0.53 µg/kg) < Mfantsiman (9.56 ± 0.38 µg/kg). This means the soils in the vicinity of transformers in the Mfantsiman district is most contaminated with PCBs and that of the Agona district least contaminated.

Vertical Distribution of PCBs in the Soils

In general the surface soils, 0 -10 cm, had the highest levels of PCBs (Σ PCB), and the 10-20 cm subsurface soils the least. Figure 20 show the levels and the distributions of PCBs in the different depth of the soils at the sampling sites.

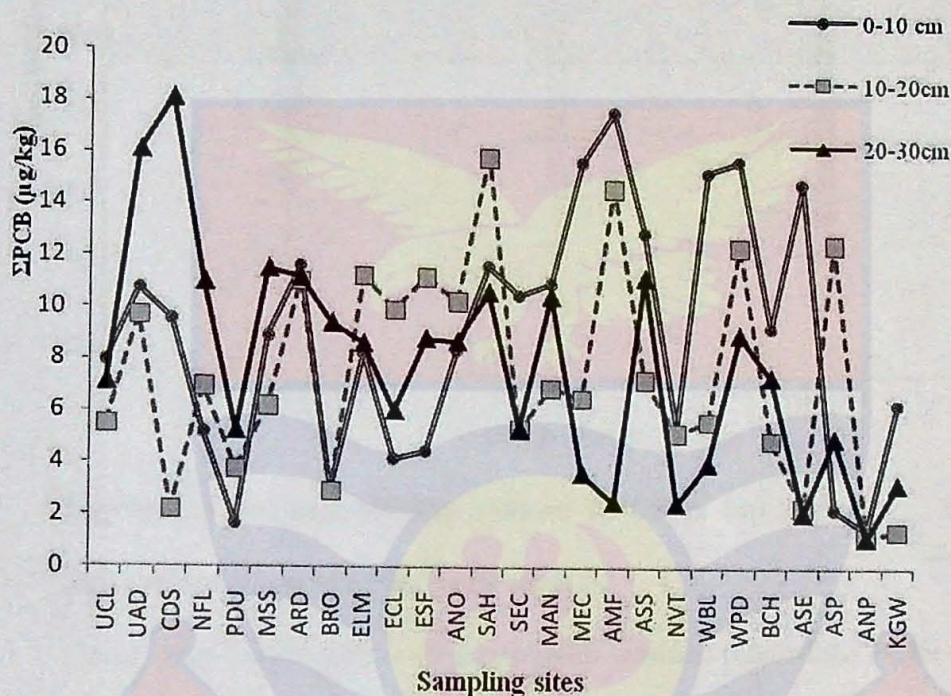


Figure 20: Profiles of PCBs in different depth of soils

A box or box-and-whisker plots of total PCBs (Σ PCB) in the top and sub-surface soils from all sampling sites examined are shown (Fig. 21). The box plots for the PCBs relate to the levels of PCB contamination of the soils. The plot indicates that the underlying distribution is skewed toward relatively high concentration of PCBs. The mean levels of Σ PCBs in the top and sub-surface soils (based on dry weight) in the whole area of study (in the metropolis/districts) was $9.15 \pm 0.53 \mu\text{g/kg}$ for the top surface soils and $7.55 \pm$

0.56 $\mu\text{g/kg}$ and 7.82 ± 0.55 $\mu\text{g/kg}$ for the 10-20 cm and 20-30 cm subsurface soils respectively.

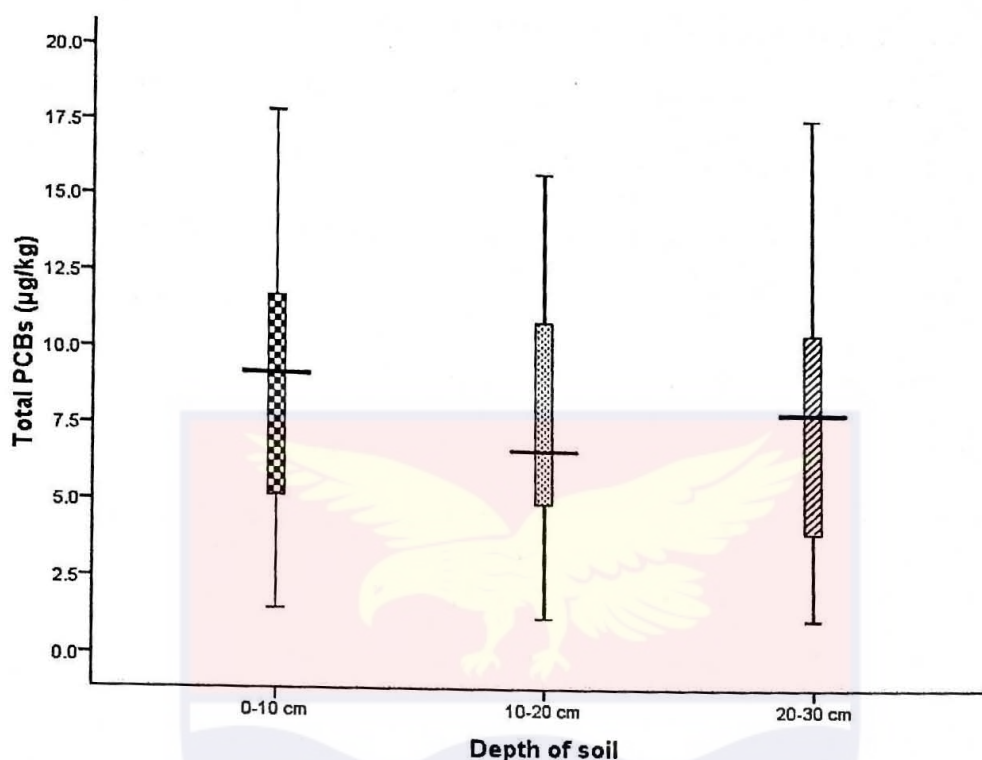


Figure 21: Box-and-whisker plots of ΣPCB in top surface and subsurface soils in the study areas

In general, the top surface (0-10 cm) soils retained most of the PCBs that enter the soils probably because generally PCBs are adsorbed strongly onto surface soils and are not easily desorbed to enable them percolate through the soil. The higher levels of PCBs in the 20-30 cm layer compared to the 10-20 cm layers might be due to factors, such as the porosity of soil, soil air space, age of spill, and the volume of spilled oil containing PCBs that enable the oil spilled to move through the soils to a depth of 20-30 cm or below. PCB concentrations in the soils showed a large variation between sampling-areas. The highest concentrations were found at three sites; Winneba Police Depot (WPD), Apam Manfam (AMF) and the University of Cape Coast (AUD) with

sandy soils and WPD with low level of organic carbon. The high levels of PCBs found in the sandy soils agree with the observation made by Backe *et al.*, (2004). Differences in PCB profiles were observed among districts, probably due to the combined effects of environmental conditions, and magnitude and age of the contamination, which determines the time available for volatilization and degradation, and differences in climatic conditions, which influence volatilization and deposition.

This observation is not strange as Carmela Centeno (2010), observed both increasing and decreasing concentrations of PCBs with depth of soil at different sites in an assessment of Persistence Organic Pollutants (POPs) contamination sites in the transformer servicing center of the Electricity Company of Ghana in Accra. The levels of PCBs (Σ PCB) in the study areas in the Central Region were all about one-thousandth of the levels found by Centeno (2010), in soils in the transformer servicing center of the Electricity Company of Ghana in Accra, which were between 0.357 mg/kg and 20.721 mg/kg.

Kolmogorov-Smirnov test and Shapiro-Wilk test of normality data at 0.05 significance level showed that the three sets of PCB data were normally distributed and may come from the same population. The F-statistic of the Analysis of variance (ANOVA) results showed that there were significant differences between the three sets of soil PCB data at the 0.05 level ($F=0.975$, $df=2$, $p\text{-value}=0.382$). Multiple comparisons among the three sets (Post Hoc test) performed in order to assess whether the variation as revealed by ANOVA was significantly high, showed that the mean Σ PCBs ($9.15 \pm 0.53 \mu\text{g/kg}$) was the highest for the 0-10 cm top surface soils, This is probably

because sorption or adsorption of organic compounds onto soils increases with surface area (Kuhnt and Muntau, 1994), and since the surface soils have larger surface areas PCBs were strongly adsorbed onto surface soils than the sub surface soils.

Patterns in Soil PCB Congeners

Multivariate analysis, principal component analysis (PCA) and cluster analysis (CA) and correlation matrix were used in the study to provide a better insight and understanding of the the dynamics of the PCBs in the top and sub- surface soils, and source identification. When the PCA was applied on the logarithmic form of investigated PCB congeners data and Varimax with Kaiser Normalization rotation method used to maximize the sum of the variance of the factor coefficient, highly correlated variables or factors, (with sum of squared loadings > 0.3) were grouped into one component. The number of components indicates the total number of possible sources of variation in the data.

For the cluster analysis hierarchical agglomerative clustering by the Ward's method was selected for sample classification because it possesses a small space distorting effect, uses more information on cluster contents than other methods, and has been proved to be an extremely powerful grouping mechanism (Willet, 1987). The method was applied to normalized data using squared Euclidean distances as a measure of similarity (Massart and Kaufman, 1983). The results of the principal component analysis are shown in Tables 12-14. PCBs that showed moderate to high factor loading, greater than 0.5, are marked with single asteric, and very high loading greater than 0.8 marked with double asteric, while negative factor loadings have been

Three (3) principal components (PCs) with eigenvalues greater than one (1) were extracted. Three components were identified (Table 12) for the surface soil, 0-10 cm. Three (3), and four (4) components were extracted for the 10 -20 cm and 20-30 cm subsurface soils respectively. Thus, the initial dimension of the three sets of data are reduced to three (3), three (3) and four (4), which cumulatively accounted for 72.81, 64.99 and 78.82 % of the total variability in the original PCB data of the study area respectively.

Table 12: Component matrix showing Factor loadings for PCB congeners in 0-10 cm top surface soils

	Component		
	A1	A2	A3
PCB 28	0.726	0.253	-0.461
PCB 52	-0.774	-0.145	-0.443
PCB 101	-0.029	0.759	0.206
PCB 118	-0.401	-0.031	0.68
PCB 138	0.691	0.14	0.341
PCB 153	0.226	-0.696	0.527
PCB 180	-0.283	0.799	0.295

significant correlations with factor loadings > 0.3 have been made bold (Source: PCA analysis of soil PCBs, 2010)

Among them, three groups A1, A2 and A3 were identified in the top soils. The three groups were loaded with PCBs 28*,52*, 118 and 138* respectively, (A1: accounting for 25.76 % of variance); PCBs 101*, 180* and

153* into the second group (A2: accounting for 24.945 % variance) and PCBs 118*, 153*, 138, 28* and 52 into the third group (A3: 22.11% of variance). Comparing the PCB congeners in the components (Table 12) to specific components of Aroclors (Table 4) suggest that the sources of the PCB congeners in components A1, A2 and A3 may be Arochlor 1254, 1260 and 1248 respectively.

Table 13: Component matrix showing Factor loadings for PCB congeners in 10-20 cm sub-surface soils

	Component		
	B1	B2	B3
PCB 28	0.689	0.363	-0.234
PCB 52	0.651	-0.408	0.037
PCB 101	0.239	0.597	0.434
PCB 118	-0.065	-0.711	0.079
PCB 138	0.821	0.023	-0.242
PCB 153	-0.43	0.451	-0.529
PCB 180	0.011	0.163	0.866

significant correlations with factor loadings > 0.3 have been made bold (Source: PCA analysis of soil PCBs, 2010)

The subsurface soils (10 -20 cm), showed three groupings (Table 13) with PCBs 28*, 52*, 138* and 153 into the first component B1, which account for 24.776 % of variance; PCBs 28*, 153*, 101*, 52 and 118* into the

second group B2, accounting for 20.673% of variance; and PCBs 101*, 180** and 153* grouped into a third component B3: accounting for 19.537% of variance. The possible sources of PCB congeners in components B1, B2 and B3 are respectively Arochlor 1260 and 1248, 1260 and 1254 and 1260

**Table 14: Component matrix showing Factor loadings
for PCB congeners in 20-30 cm sub-surface soils**

	Component			
	C1	C2	C3	C4
PCB 28	0.365	0.836	0.209	-0.034
PCB 52	-0.099	0.248	0.905	-0.203
PCB 101	0.445	-0.524	0.137	0.264
PCB 118	0.276	0.294	-0.055	0.828
PCB 138	0.808	0.302	-0.081	-0.173
PCB 153	0.621	-0.179	0.235	-0.485
PCB 180	-0.613	0.428	0.477	-0.142

(Source: PCA analysis of soil PCBs, 2010) significant .

correlations with factor loadings > 0.3 have been made bold

The subsurface soils (20-30 cm) had four components (Table 14), (C1: 26.165 % of variance) containing PCBs 28, 101, 138**, 153* and 180*; (C2: 20.397 % of variance) containing 28**, 138, 180 and 101*; (C3: 16.768 % variance) and (C4: 15.489 % variance) are respectively characterized by PCBs 180* and 52**, and PCBs 118** and 153*. The sources of PCB congeners in components C1, C2, C3 and C4 could be re The sources of the PCB congeners detected in the soils could be attributed to Aroclor 1260 1254, and 1248. These aroclors have been found to be contained in some

transformer oils and soils from Ghana (Asamoah, 2005; Otchere, 2005).
spectively Arochlor 1254 and 1260, 1260 and 1254, 1248 and 1260 and 1260.

Based on the information obtained from the PCA, hierarchical cluster analysis (CA) was performed on the PCB congeners with Ward's method and the squared euclidean distance as similarity measured (Fig.22-24). Factors having strong correlation form cluster. The same number of groupings, three (3), three (3) and four (4), which were obtained for the PCA, were obtained for the top surface (0-10 cm), 10 -20 cm, and 20-30 cm subsurface soils respectively by cluster analysis. For the 0-10 cm soils cluster 1 included PCB# 101,118,138,153 and 180; cluster 2 contained PCB# 52 and cluster 3 contained PCB 28 (Fig.22).

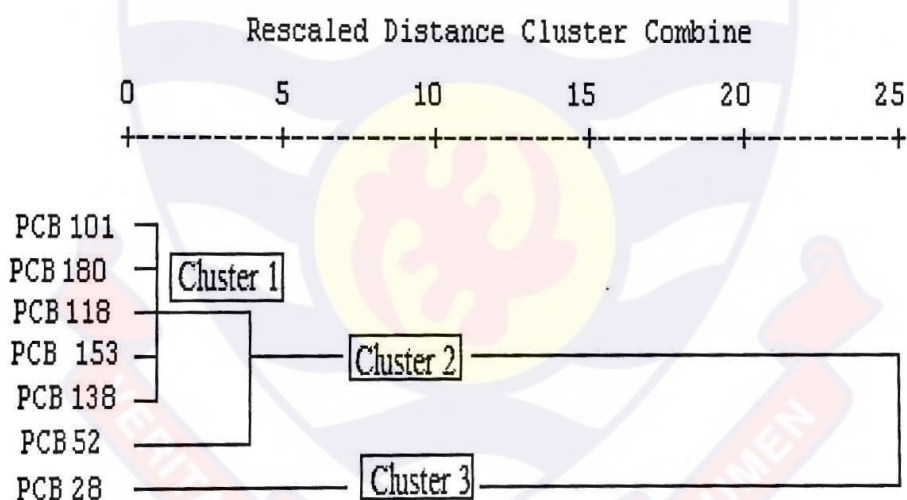


Figure 22: A dendrogram obtained by hierachical clustering analysis for PCB congeners in surface soils (0-10 cm).

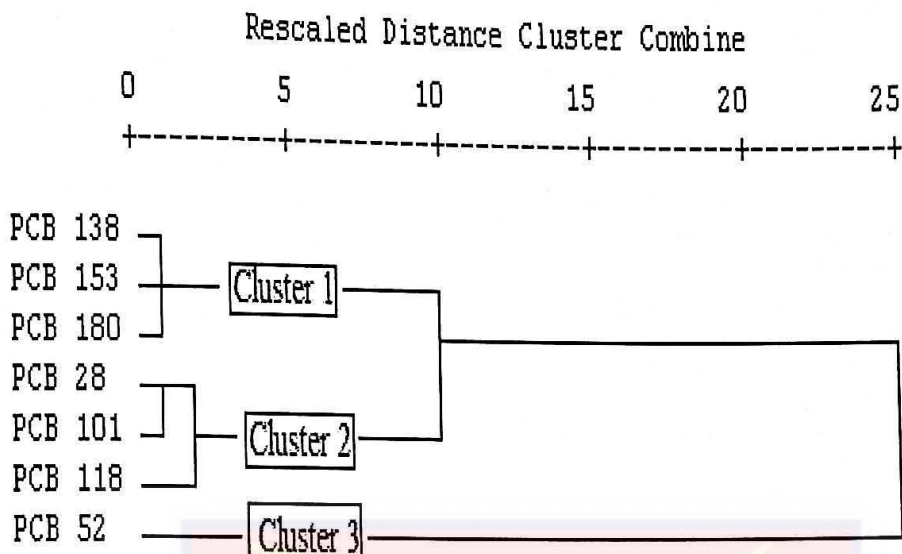


Figure 23: A dendrogram obtained by hierarchical clustering analysis for PCB congeners in sub-surface soils (10-20 cm)

The subsurface soils (10-20 cm) is characterized by PCB# 138,153 and 180 in cluster 1; PCB# 28,101 and 118 in cluster 2 and PCB 52 in cluster 3 (Fig.23). The first cluster of PCBs in the subsurface soils (20-30 cm) included PCB# 52,118,138 and 153; the second, contained PCB180; the third and fourth were characterized by PCB# 28 and 101 respectively (Fig.23 & 24).

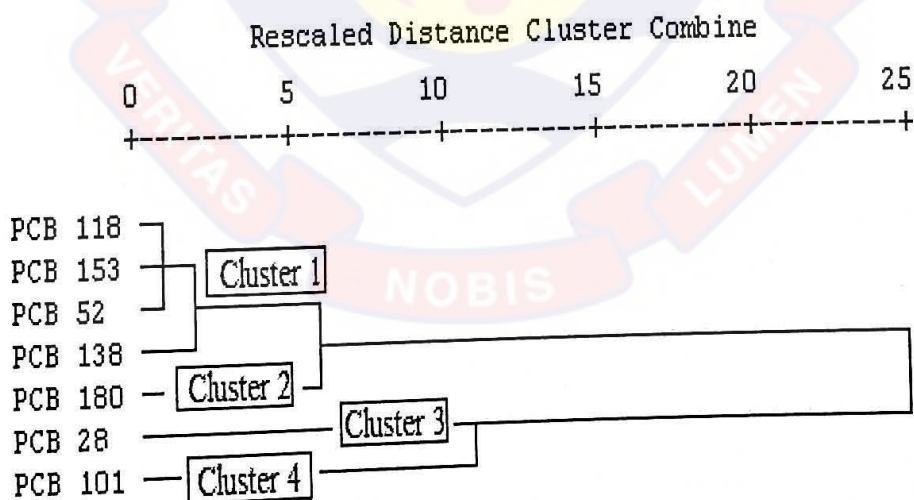


Figure 24: A dendrogram obtained by hierarchical clustering analysis for PCB congeners in sub-surface soils (20-30 cm)

The sampling sites were also analyzed by clustering methods and organized in the dendrogram, by the Ward's method (Fig.25-27), to identify similar sites. Sites in the same cluster have similarities in their PCB congener composition. The dendrograms of sampling sites showed two (2), three (3) and two (2) well differentiated clusters for the top (0-10 cm) surface soils, 10-20 cm and 20-30 cm subsurface soils respectively. Also in the PCA classification method, the same numbers of components were obtained (Table 14). The first cluster of the top surface soil (Fig. 25), comprised of fifteen sampling sites and the second cluster, eleven.

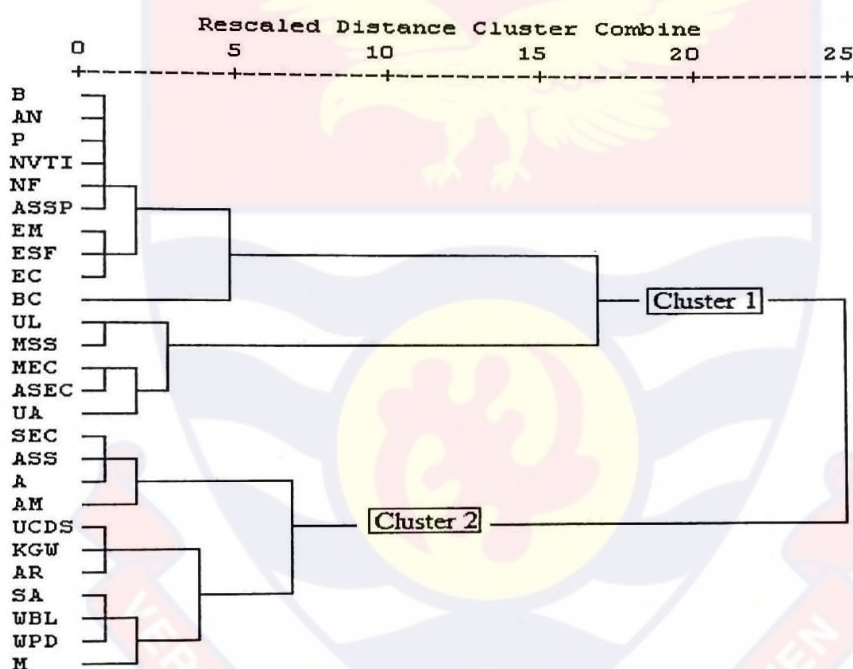


Figure 25: A dendrogram showing clustering of sampling sites for 0-10 cm surface soils

Also in the PCA classification method, two components were obtained. The number of members (sites) in the first, second and third cluster of the 10-20 cm sub-surface soils were 20, 3 and 3 respectively (Fig. 26).

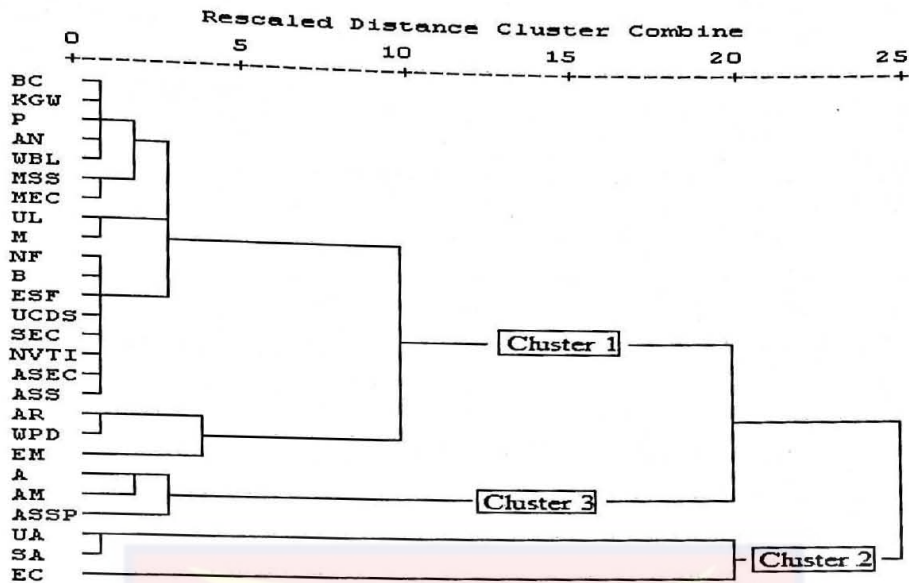


Figure 26: A dendrogram showing clustering of sampling sites for 10-20 cm sub- surface soils.

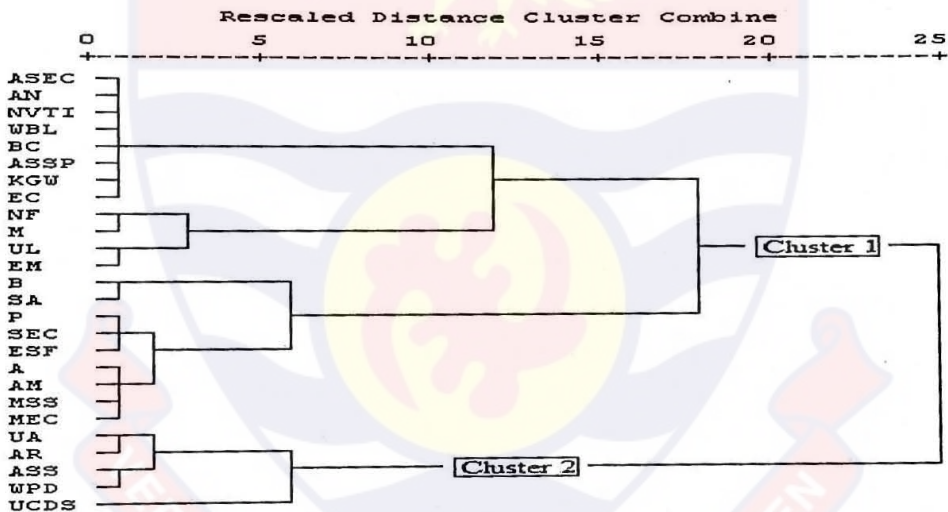


Figure 27: A dendrogram showing clustering of sampling sites for 20-30 cm sub-surface soils.

Three components were classified by the PCA (Table 15). Twenty one (21) and five (5) sites were included in cluster 1 and 2 respectively for the 20-30 cm subsurface soils (Fig. 27); the same number of components, two, were classified at this level of the soil by the PCA. In the PCA classification method, two components were obtained.

Table 15: Extracted components at different depth by Principal

Component Analysis

Site	0-10 cm		10-20 cm			20-30 cm	
	1	2	1	2	3	1	2
UCL	-0.808	1.604	0.938	0.029	-0.091	-1.264	-0.913
UAD	-2.809	2.011	-2.088	0.178	-2.109	0.078	3.345
CDS	2.342	-0.503	0.265	-0.327	0.032	2.292	1.949
NF	-0.377	0.033	-0.302	0.262	-0.101	-1.906	-1.103
PDU	0.261	0.242	-0.040	-0.062	0.395	1.817	-0.084
MSS	-0.601	2.455	0.241	1.190	0.181	1.228	0.786
ARD	3.362	-0.763	1.808	-1.692	0.717	0.185	3.528
BRO	0.114	-0.099	-0.402	0.009	-0.365	3.174	-1.518
ELM	1.321	-0.067	-0.501	-0.414	0.098	-0.811	-0.253
ECL	1.065	-0.158	-1.287	2.917	2.135	-0.415	1.041
ESF	1.587	-0.066	-0.179	-0.323	-0.173	2.485	-0.533
ANO	0.558	0.661	1.338	0.921	-1.184	1.236	-0.241
SAH	2.957	0.775	-3.314	-0.771	-1.694	3.160	-1.392
SEC	-0.322	1.621	0.001	-0.147	0.190	1.862	-0.039
MAN	5.419	-0.571	1.015	-0.494	-0.345	-2.422	-0.738

Table 15 continued|

MEC	-0.322	3.583	0.282	0.668	1.121	0.441	0.539
AMF	1.697	2.754	2.285	0.077	-1.070	0.681	-0.327
ASS	1.184	2.169	0.052	0.340	0.230	-0.117	2.154
NVT	0.120	-0.179	0.295	0.255	-0.233	0.007	0.553
WBL	3.154	1.012	-0.369	0.601	0.552	-0.056	-0.477
WPD	4.422	0.939	1.214	-1.780	0.483	0.235	1.718
BCH	-2.084	-2.835	0.007	0.368	0.450	0.764	-0.168
ASE	-1.658	3.521	0.066	0.058	-0.165	0.056	-0.046
ASP	-0.873	-0.217	2.236	2.391	-2.211	-0.377	0.131
ANP	0.273	-0.221	0.066	0.046	0.454	0.074	-0.032
KGW	1.712	-0.647	0.150	0.399	0.386	-0.444	0.269

Source: PCA analysis of soil PCB data, 2010

Twenty one (21) and five (5) sites were included in cluster 1 and 2 respectively for the 20-30 cm subsurface soils (Fig. 27); the same number of components, two, were classified at this level of the soil by the PCA. In the PCA classification method, two components were obtained. The number of members (sites) in the first, second and third clusters of the 10-20 cm subsurface soils were 20, 3 and 3 respectively. Also three components were classified by the PCA. Twenty one (21) and five (5) sites were included in cluster 1 and 2 respectively for the 20-30 cm subsurface soils; the same

number of components, two, were classified at this dept of the soil by the principal component analysis.

Dioxin-like Pentachlorobiphenyl

The *mono-ortho*substitute PCBs identified were 2, 4, 4 - Tetrachlorobiphenyl (PCB 28) and 2, 3', 4, 4', 5 - pentachlorobiphenyl (PCB118). These are co-planar, however, only PBC 118 is "dioxin like" (DL). It has toxicity similar to dioxin, and is more toxic than di-ortho (2 2' substituted (PCB 180) which is non-coplanar. The total number of PCB 28 in the soil follows the order Cape Coast (28) > Awuto Efutu Senya (17) > Mfantseman (15) > Agona (12) > KEEA (9). For PCB 118 the trend was Awutu-Efutu-Senya (14) > Mfantseman (12) > Cape Coast (11) > Agona (7) > KEEA (5). The number of PCB 118 identified in the five districts were Awutu-Efutu-Senya (14) > Mfantseman (12) > Cape Coast (11) > Agona (7) > KEEA (5). Generally, a positive linear correlation ($R^2 = 0.93$), exponential ($R^2 = 0.89$) and logarithm ($R^2 = 0.93$) ($p < 0.05$) existed between the mono- ortho PCB 28 in the soils and the number of sampling sites(Fig. 28).

The mean concentration of all DL PCB 118, in soils from the five districts and Metropolis were; $0.71 \pm 0.82 \mu\text{g/kg}$ for (0-10 cm) surface soil; $0.69 \pm 0.60 \mu\text{g/kg}$ and $1.13 \pm 1.18 \mu\text{g/kg}$ for the subsurface soils 10-20 cm and 20-30 cm respectively, and $0.83 \pm 0.89 \mu\text{g/kg}$ for the 0-30 cm layer. The relatively smaller concentrations of PCB 118 in the soils indicates that small amounts of the "dioxin-like" PCBs, namely the coplanar (*non-ortho* substituted) and *mono-ortho* substituted congeners, are present in the commercial mixtures (Aroclor), used for the formulation of transformer oils, as observed by Mackay *et al.* (1992

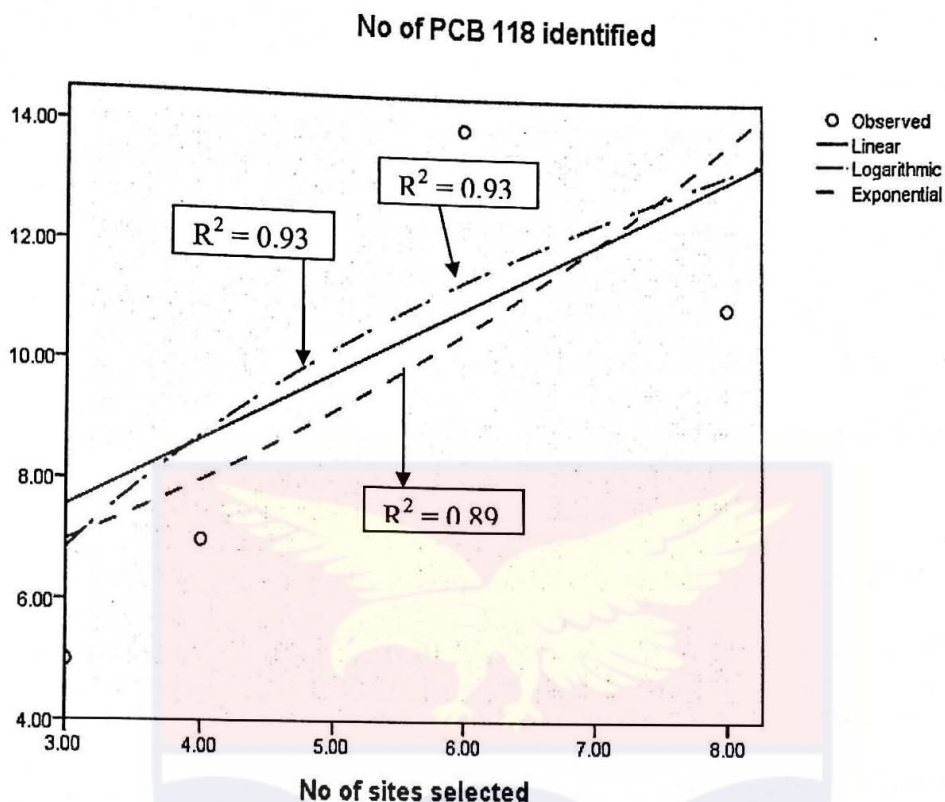


Figure 28: Correlation of number of site with corresponding PCB 118 identified

In this study PCB 118 was 9.89% of the total number PCBs congeners. However, Zhang and others found PCB 118 as dominant species in some agricultural soils from Southern Jiangsu, China, where PCB118 was the most abundant congener in all the samples, and was about 20% of sigma PCBs (Zhang *et al.*, (2007). There was a positive correlation between PCB 118 and number of sampling sites.

The concept of toxic equivalency factors (TEF) is based on the ability of a PCB to activate or bind to aryl hydrocarbon receptor (AhR), which is a transcription factor. Abnormal activation may disrupt cell function by altering the transcription of genes. Using WHO's TEF scheme (Van den Berg *et al.*,

1998), the contribution of PCB 118 to Toxicity Equivalent (PCB -WHO-TEQ) in the soils sampled were calculated (Table 16). The contribution of PCB 118 to the Toxicity Equivalent (WHO PCB 118-TEQ) for the soils follow the order: KEEA (90 pg/kg dw) > Awutu-Efutu-Senya (62.33 pg/kg dw) > Agona (37.00 pg/kg dw) > Cape Coast (36 pg/kg dw) > Mfantseman (28.00 pg/kg dw). Thus toxicity of the soils due to PCB 118 is greatest for soils from KEEA and least for soils from Mfantseman. Toxicity Equivalent has been proven to be a significant indicator in risk assessment for human and wildlife (Behnisch et al., 2001; Qiao et al., 2006).

This observation thus indicates that soils in areas with higher levels of dioxin like PCBs (higher TEQ) are likely to be more toxic, and may cause cancer, hormone and reproduction problems, skin disease and disturbances of the immune system. They decompose very slowly, pollute the environment permanently and are enriched in the food chain. PCB# 28, 52, 101, 138, 153 and 180 on the other hand, show high bioaccumulation and chronic toxicities. Soils in children's playgrounds, residential areas and industrial areas, respectively containing more than 100 ng I-TEQ, 1,000 ng I-TEQ, and 10,000 ng I-TEQ are considered hazardous and remediation of such contaminated soil are required. However, none of the soils had PCB 118-TEQ levels equal to or greater than 1.0 ng/kg I-TEQ, as the largest level of PCB 118 TEQ obtained for the soils was 90 pg/kg dw (0.009 ng/kg).

Table 16: TEQ of PCBs in soil from different districts of the Central Region of Ghana

Metropolis /District	samples	mean	PCB118	PCB 118 -
		PCB 118	TEQ	TEQ
		ng/kg	pg/kgdw	pg/kg dw
KEEA	EM	2500	250	
	EC	< LOD	0	90
Cape Coast	ESF	200	20	
	UL	340	34	
	UA	< LOD	0	
	UCDS	670	67	
Mfantseman	NF	460	46	37.75
	P	1240	124	
	MSS	310	31	
	AR	< LOD	0	
	B	< LOD	0	
	A	460	46	
	SA	300	30	
	SEC	340	34	28.00
	M	210	21	
	MEC	130	13	
Awutu/Efutu/Senya	AM	360	36	
	ASS	940	94	

Table 16 continued

	NVTI	530	53	62.33
	WBL	870	87	
	WPD	700	70	
	BC	340	34	
Agona	ASEC	1030	103	
	ASSP	370	37	
	AN	30	3	37
	KGW	50	5	

Source: Soil PCB data, 2010 PCB118, I-TEF = WHO-TEF = 0.0001

Impacts on Ecological and Health Implications

According to CCME (1999), Soil PCBs of concentration of 0.014 mg/kg (14.0 µg/kg) have been found to reduce nitrification rate. This means the nitrification rates in about 9% of the sampling sites in the whole study area is likely to be adversely affected. The PCBs may possibly exert their toxic effects on some microorganisms by accumulating in their cytoplasmic membrane and disrupting their function as observed by Delawary *et al.*, (2003). The levels of ΣPCB in these soils were: for sub-surface soils 20-30 cm, AUD (16.14 µg/kg) and CDS (18.18 µg/kg); for the 10-20 cm layers, SAH µg/kg (16.13 µg/kg); and for the top surface soil, MEC (15.98 µg/kg), ASE (15.260 µg/kg), WBL (15.65 µg/kg) and WPD (16.16 µg/kg). The levels of ΣPCB in all the soils were below the soil contact value or threshold effect concentration (TEC) of 25 mg/kg and 33 mg/kg (or 25,000 and 33,000 µg/kg) recommended by US EPA and the CCME (1999) respectively, for all land

individual via the complete exposure (skin contact) relating to PCBs in this study ranged between 3.0×10^{-11} and 3.0×10^{-10} for adult resident, and 5.4×10^{-10} to 5.3×10^{-09} for children resident.

This means that the probability of developing cancer through soil contact ranged between 3 out of 100,000,000,000 and 3 out of 10,000,000,000 adult residents, and between 5 out of 10,000,000,000 and 5 out of 1,000,000,000 children residents are at risk of getting cancer. For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an incremental upper bound lifetime cancer risk to an RME individual of between 10^{-4} (1 in 10,000) and 10^{-6} (1 in 1,000,000) (USEPA 1990a,1999). This implies that the probability of an individual developing cancer as a result of exposure to PCBs through skin contact with soils in the study area is negligible, and that the levels of exposure to soil PCBs are acceptable. The negligible levels of exposure (very low cancer risk) could be due to the very low levels of the dioxin-like PCB 118 in the soils.

Hazard Index

The hazard indices of the soil PCBs are presented (Table 17). The hazard Index calculated indicated that most of the soils in residential areas where electric transformer are situated had $HI > 1.0$, implying those soils have some potential to cause harm if ingested. Soils in six locations out of twenty six had $HI < 1.0$; the HI range between 0.387 and 32.25. For commercial purposes, only soil from Elmina market (EM) had $HI > 1$, implying the level of PCBs in that soil could pose some hazard if ingested by persons who are in contact with the soil regularly.

Table 17: Hazard Index (HI) of dioxin-like PCB 118 in soils in some residential and commercial areas in five districts of the Central Region of Ghana

Metropolis /District	Samples	Mean PCB ng/kg	Hazard Index	
			Residential	Commercial
KEEA	EM	2500	32.25	1.07
	EC	< LOD		
	ESF	200	2.58	0.09
Cape Coast	UL	340	4.39	0.15
	UA	< LOD		
	UCDS	670	8.64	0.29
	NF	460	5.93	0.20
	P	1240	15.99	0.53
	MSS	310	3.99	0.13
	AR	< LOD		
	B	< LOD		
	A	460	5.93	0.20
	SA	300	3.87	0.13
Mfantsiman	SEC	340	4.39	0.15
	M	210	2.71	0.09
	MEC	130	1.68	0.06
Awutu/Efutu/Senya	AM	360	4.64	0.15
	ASS	940	12.13	0.40
	NVTI	530	6.84	0.23
	WBL	870	11.22	0.37

Table 17 continued

Agona	WPD	700	9.03	0.30
	BC	340	4.39	0.15
	ASEC	1030	13.29	0.44
	ASSP	370	4.77	0.16
	AN	30	0.39	0.01
	KGW	50	0.65	0.02

(Source: Analysis of soil PCBs data, 2010

TEF=0.00003

Soil characteristics

The soils studied in the Central region were slightly acidic to slightly basic, with a mean of 7.04 ± 0.07 (Appendix F). The descriptive statistics is shown in Table 18. The soils from Brofoyedur (BRO) had the lowest pH of 4.04 and the soils from the Ashanti Road (ARD) had the highest pH of 7.83. Almost all the soils had pH that fall within representative soil series of Ghana (Yawson *et al*, 2011), which ranged between 3.7 and 7.8. The pH was comparable to those of soils in Kumasi with mean pH and median of 6.895 and 7.250 respectively (Asamoah, 2005). The soils studied were also characterized by low moisture and organic carbon (organic matter). The mean organic carbon was 0.33%, and ranged between 0.15 and 0.77%. These levels were lower than those found by Yawson *et al*, 2011; which were between 0.90 - 4.3%; and lower than levels found in some soils in Kumasi which had a mean of 1.221% and a median of 1.198% (Asamoah, 2005).

Table 18: Mean results of soil characteristics in the Central Region of Ghana

	pH	Moisture (%)	Exchangeable ions (cmolc/kg)			Particle size (%)			OC (%)
			Acidity	Babe	ECEC	Sand	Silt	Clay	
Mean	7.04	2.06	0.33	1,91	7.50	68.17	22.82	9.28	0.33
sdv	0.47	1.60	0.12	1.42	3.85	12.29	20.44	4.86	0.15
CV	7	78	35	74	51	19	46	52	46
Max	7.83	7.06	0.65	7.71	19.46	94.00	46.82	24.00	0.77
Min	6.04	0.31	0.23	0.78	3.24	29.72	2.78	3.20	0.15

Source: Statistical analysis of soil data, 2009

The mean percentages of sand, silt and clay contents of the soils were all within the levels found for the representative soil series of Ghana; the soil particle sizes were sand, 71%; silt, 4.28% and clay 11.0 - 47%. Also, the soil particle distribution compares with those found in the Upper East Region of Ghana (Dawidson and Nilsson, 2000). Both the exchangeable acidity and the effective cation exchange capacity (ECEC) were within the levels found for soil series of Ghana, which ranged respectively from 0.01 - 3.34 cmol_ckg⁻¹ and 3.26 - 35.96 cmol_ckg⁻¹.

There were large variations in the levels of each of the soil properties, which were between 7 and 78% (Table 18), and follow the order; moisture, 78% > exchangeable bases, 74% > ECEC, 52% > clay, 51% > organic carbon = silt 46% > exchangeable acidity 35% > sand, 19% > pH, 7%. These imply

that the effect of the soil properties on the persistence and availability of PCBs in the soils at the different sites may vary.

Physical and Chemical Properties of Surface and Sub Surface Soil

The soil properties were measured in order to relate them to the PCBs to establish how the properties affect the available PCBs. The results of analysis of the physical and chemical characteristics measured, namely, moisture content, particle size distribution (amounts of sand, silt and clay) and texture, soil pH, organic matter (OM), exchangeable hydrogen, exchangeable aluminum, exchangeable bases and the effective cation exchange capacities (ECEC) of the surface soils 0-10 cm, and sub-surface soils 10-20 cm and 20-30 cm are shown (Tab. 18-23)

Soil Particle Size Distribution

The results of particle size distribution and texture of the soils are presented in Tables 19-21. The mean and ranges of the percentages of soil particles of the top surface soils were; sand, $70.58 \pm 13.86\%$ (33.09 -95.82); silt, $21.12 \pm 12.08\%$ (2.18 – 48.08); and clay, $9.01 \pm 6.67\%$ (1.60 – 20.0). For the 10-20 cm sub-surface soils (Table 19), the mean and ranges of the amount of sand were $70.26 \pm 14.78\%$ (20.74-91.35); silt, $22.69 \pm 12.25\%$ (4.65 – 58.46) and clay $7.077 \pm 5.25\%$ (1.60 – 23.20) respectively. For the 20 – 30 cm layer (Table 20), the sand content was $63.67 \pm 14.00\%$ (35.32-94.48); silt, $24.66 \pm 11.5\%$ (1.51 – 48.64) and clay $11.66 \pm 5.18\%$ (3.6 – 18.40).

Table 19: Mean moisture content (%) and texture of 0-10 cm surface soils

Sample	Moisture	Sand	Silt	Clay	Texture
UCL	0.79 ± 0.27	55.73 ± 0.3	38.67 ± 0.01	5.96 ± 0.02	SL
AUD	0.42 ± 0.11	80.4 ± 0.01	10.80 ± 0.01	8.80 ± 0.01	LS
CDS	0.98 ± 0.03	62.92 ± 0.3	34.67 ± 0.01	2.40 ± 0.03	SL
NFL	0.98 ± 0.03	69.33 ± 0.01	23.46 ± 0.02	7.22 ± 0.04	SL
PDU	0.30 ± 0.85	76.37 ± 0.02	7.62 ± 0.03	16.0 ± 0.03	SL
MSS	1.0 ± 0.00	74.0 ± 0.00	19.10 ± 0.71	6.40 ± 0.01	SL
ARD	1.20 ± 0.13	68.53 ± 0.03	25.07 ± 0.04	6.39 ± 0.01	SL
BRO	1.19 ± 0.4	78.26 ± 0.20	12.16 ± 0.03	9.60 ± 0.01	SL
ELM	0.43 ± 0.1	71.08 ± 0.04	26.52 ± 0.03	2.40 ± 0.04	LS
ECL	1.30 ± 0.14	41.52 ± 0.02	48.08 ± 0.03	10.37 ± 0.0	L
ESF	2.72 ± 0.96	63.95 ± 0.03	34.45 ± 0.04	16.0 ± 0.00	SL
ANO	3.69 ± 0.00	81.42 ± 0.04	25.75 ± 0.06	16.0 ± 0.03	SL
SAH	1.44 ± 0.03	80.4 ± 0.01	10.80 ± 0.01	18.8 ± 0.04	LS
SEC	1.44 ± 0.03	66.74 ± 0.03	26.86 ± 0.4	6.40 ± 0.03	SL
MAN	0.78 ± 0.00	81.59 ± 0.03	14.42 ± 0.01	4.0 ± 0.01	LS
MEC	1.51 ± 0.38	62.19 ± 0.05	26.62 ± 0.01	11.20 ± 0.03	SL
AMF	4.76 ± 0.04	62.92 ± 0.03	31.47 ± 0.01	5.60 ± 0.03	SL
ASS	7.11 ± 0.31	33.10 ± 0.07	39.71 ± 0.01	27.20 ± 0.04	CL
NVT	3.82 ± 0.11	59.22 ± 0.04	20.79 ± 0.01	20.0 ± 0.03	SCL
WBL	2.50 ± 0.11	76.37 ± 0.04	18.82 ± 0.01	14.8 ± 0.03	LS
WPD	0.10 ± 0.03	95.81 ± 0.01	21.80 ± 0.00	1.99 ± 0.01	S
BCH	0.86 ± 0.06	86.94 ± 0.01	8.28 ± 0.04	4.80 ± 0.06	LS

Table 19 continued

AEC	1.03 ± 0.10	92.01 ± 0.01	5.99 ± 0.01	2.0 ± 0.00	S
ASP	4.19 ± 0.18	74.64 ± 0.01	21.36 ± 0.00	4.0 ± 0.01	LS
ANP	4.29 ± 0.04	69.39 ± 0.01	13.81 ± 0.06	16.79 ± 0.04	SL
KGW	6.14 ± 0.18	70.18 ± 0.01	24.21 ± 0.03	5.6 ± 0.03	SL

Source: Laboratory analysis of soil samples, 2009

Table 20: Mean moisture content and texture of 10-20 cm sub-surface soils

Samle	Mean ± sd (%)				
	Moisture	Sand	Silt	Clay	Texture
UCL	1.00 ± 0.28	64.78 ± 0.02	28.81 ± 0.02	6.4 ± 0.00	SL
AUD	0.20 ± 0.00	80.44 ± 0.04	16.35 ± 0.02	3.20 ± 0.01	LS
CDS	1.00 ± 0.00	66.44 ± 0.01	31.16 ± 0.02	2.40 ± 0.01	SL
NFL	1.80 ± 0.17	61.40 ± 0.00	18.60 ± 0.01	20.0 ± 0.01	SL
PDU	0.20 ± 0.01	78.13 ± 0.03	19.47 ± 0.03	2.40 ± 0.01	LS
MSS	1.30 ± 0.14	71.58 ± 0.01	22.02 ± 0.00	6.40 ± 0.00	SL
ARD	1.30 ± 0.14	63.69 ± 0.01	31.51 ± 0.02	4.81 ± 0.01	SL
BRO	0.60 ± 0.28	76.34 ± 0.01	19.50 ± 0.00	4.01 ± 0.01	LS
ELM	1.30 ± 0.42	86.76 ± 0.01	6.84 ± 0.01	6.40 ± 0.01	LS
ECL	2.80 ± 0.00	43.09 ± 0.01	46.51 ± 0.02	10.40 ± 0.01	L
ESF	1.60 ± 0.00	69.57 ± 0.00	20.83 ± 0.02	5.60 ± 0.01	SL
ANO	3.90 ± 0.14	72.85 ± 0.00	3.95 ± 0.03	23.19 ± 0.01	SCL
SAH	0.20 ± 0.00	80.60 ± 0.01	17.79 ± 0.01	1.60 ± 0.03	LS
SEC	0.80 ± 0.00	69.85 ± 0.01	18.15 ± 0.01	11.56 ± 0.08	SL

Table 20 continued

MAN	0.70 ± 0.14	65.44 ± 0.03	29.76 ± 0.04	4.80 ± 0.04	SL
MEC	0.30 ± 0.14	89.76 ± 0.01	62.35 ± 0.01	4.01 ± 0.01	S
AMF	4.40 ± 0.00	61.45 ± 0.01	33.74 ± 0.04	4.80 ± 0.02	SL
ASS	9.05 ± 0.42	20.74 ± 0.02	58.46 ± 0.01	2.08 ± 0.01	SIL
NVT	3.00 ± 0.00	61.55 ± 0.04	21.64 ± 0.01	16.80 ± 0.0	SL
WBL	1.40 ± 0.18	82.97 ± 0.01	15.43 ± 0.00	1.60 ± 0.01	LS
WPD	1.50 ± 0.56	91.35 ± 0.01	4.65 ± 0.04	4.05 ± 0.01	S
BCH	0.50 ± 0.14	80.40 ± 0.03	15.59 ± 0.01	4.00 ± 0.00	LS
AEC	0.30 ± 0.14	85.21 ± 0.02	18.18 ± 0.01	1.60 ± 0.01	LS
ASP	5.40 ± 0.28	68.54 ± 0.01	28.28 ± 0.01	3.20 ± 0.04	SL
ANP	3.80 ± 0.00	67.85 ± 0.03	27.34 ± 0.02	4.80 ± 0.03	SL
KGW	1.80 ± 0.28	66.01 ± 0.04	29.19 ± 0.02	4.80 ± 0.02	SL

Source: Laboratory analysis of soil samples, 2009

Table 21: Mean moisture content (%) and texture of 20-30 cm sub-surface soils

Sample	Moisture	Sand	Silt	Clay	Texture
UCL	1.80 ± 0.80	62.94 ± 0.01	27.02 ± 0.03	10.40 ± 0.14	SL
AUD	0.03 ± 0.14	77.78 ± 0.01	15.81 ± 0.01	6.40 ± 0.02	LS
CDS	1.60 ± 0.56	58.87 ± 0.01	30.72 ± 0.10	10.40 ± 0.01	SL
NFL	0.80 ± 0.30	62.38 ± 0.01	12.04 ± 0.01	25.61 ± 0.03	SCL
PDU	3.80 ± 0.01	73.45 ± 0.01	19.35 ± 0.00	7.20 ± 0.13	LS
MSS	0.05 ± 0.08	69.36 ± 0.03	21.04 ± 0.03	9.61 ± 0.02	SL
ARD	1.05 ± 0.07	51.66 ± 0.01	35.54 ± 0.01	12.81 ± 0.02	SCL

Table 21 continued

BRO	1.20 ± 0.01	57.60 ± 0.01	28.79 ± 0.01	13.60 ± 0.01	SCL
ELM	2.00 ± 0.28	88.42 ± 0.03	1.98 ± 0.01	9.61 ± 0.01	LS
ECL	1.35 ± 0.07	41.71 ± 0.01	40.69 ± 0.01	17.60 ± 0.01	LS
ESF	1.40 ± 0.03	39.36 ± 0.01	48.64 ± 0.01	12.05 ± 0.14	LS
ANO	2.26 ± 0.76	70.11 ± 0.01	18.68 ± 0.05	11.22 ± 0.01	SL
SAH	1.30 ± 0.14	68.93 ± 0.03	21.46 ± 0.02	9.60 ± 0.01	SL
SEC	0.75 ± 0.07	65.40 ± 0.01	27.40 ± 0.01	7.20 ± 0.00	SL
MAN	0.75 ± 0.07	61.23 ± 0.01	29.96 ± 0.02	8.80 ± 0.01	SL
MEC	1.68 ± 0.42	51.68 ± 0.01	37.12 ± 0.00	11.20 ± 0.01	SL
AMF	3.78 ± 0.31	52.58 ± 0.01	40.22 ± 0.03	7.20 ± 0.04	SL
ASS	5.00 ± 0.80	35.31 ± 0.01	40.68 ± 0.01	24.00 ± 0.01	L
NVT	3.20 ± 0.28	59.22 ± 0.01	23.18 ± 0.01	17.59 ± 0.01	SL
WBL	1.30 ± 0.14	71.09 ± 0.01	18.16 ± 0.02	10.35 ± 0.07	SL
WPD	2.75 ± 0.78	94.83 ± 0.01	15.05 ± 0.02	3.60 ± 0.01	S
BCH	0.80 ± 0.01	80.07 ± 0.01	12.73 ± 0.04	7.20 ± 0.02	LS
AEC	1.14 ± 0.08	61.72 ± 0.01	19.87 ± 0.02	18.40 ± 0.01	LS
ASP	4.40 ± 0.02	59.81 ± 0.01	30.61 ± 0.02	9.61 ± 0.02	SL
ANP	3.60 ± 0.28	61.92 ± 0.02	26.88 ± 0.00	11.14 ± 0.06	SL
KGW	4.10 ± 0.56	77.89 ± 0.13	10.99 ± 0.03	11.15 ± 0.07	SL

Source: Laboratory analysis of soil samples, 2009

SCL-Sandy clay loam; SL-Sandy loam; LS-Loamy sand; L- Loamy; S- Sand

SL-Sandy loam LS-Loamy sand S- Sandy

The order of variation of the amount of sand, silt and clay in the soils were clay > silt > sand. The soils had varied textures mostly sandy loams and

loamy sands. In the surface soils (Table 19) the sandy loams and loamy sand constituted 65 and 27 % respectively of the total sample. Very few were loamy, sandy loam, clay loams and sandy. In the 10-20 cm layer, the soils were again dominated by similar texture which made up 50 and 31% sandy loams and loamy sands respectively. The same two textures were encountered in the 20-30 cm layer consisting of 54 and 27% sandy loams and loamy sands respectively. The low clay content of the soils, between 1.6-27.20%, suggests that the soil particles would have minimal influence on the accumulation of the PCBs.

Soil Moisture

The mean percentage moisture contents in the soils are shown (Tab, 19-21). The concentration (mean $\pm$ rsd) and ranges of the surface soils (0-10 cm) and sub-surface soils (10-20 cm and 20-20 cm) were respectively 2.22 ± 1.93 (0.1 - 7.11), 1.93 ± 2.03 (0.20 - 9.05) and $2.02 \pm 1.35\%$ (0.03-5.0%). The moisture contents were very low between 0.1 and 9.05%. Soils at the sub-surface, 10 - 20 cm had the highest moisture contents and 20 - 30 cm layer, the least. The subsurface soils (10 -20 cm) showed the greatest variation in the amounts of their moisture contents, followed by the top soil (0 – 10 cm) and the 20 -30 cm sub-surface soil had the least variation as revealed by the relative standard deviation. The low moisture content indicates that the solubility of the PCBs would be very minimal and hence mobility and leaching of the compounds would be very low and the top soils are likely to retain or adsorb the greatest amounts of PCBs that enter the soils.

Soil pH

The pH of the soils are shown (Table 22). The soils were slightly acidic to slightly basic. The mean pH of the top 0 - 10 cm surface soil was 7.11 ± 0.87 , and ranged from 4.96 to 8.67. The 10 - 20 cm layer had a mean pH of 6.91 ± 0.44 and ranged from 6.50 to 8.00 and the mean and range pH of the 20-30 cm soils were 6.66 ± 0.34 and 6.5 to 7.8 respectively.

Table 22: pH of soils from selected sites in the Central Region

Site	Sample	pH of soils from different depth		
		0-10 cm	10-20 cm	20 -30 cm
UCC Science Library	UCL	6.36 ± 0.02	7.30 ± 0.07	7.60 ± 0.07
UCC Science Auditorium	AUD	8.30 ± 0.04	6.97 ± 0.28	7.51 ± 0.02
UCC CDS	CDS	6.80 ± 0.07	6.70 ± 0.28	6.50 ± 0.04
Nurses Flat	NF	8.10 ± 0.14	6.63 ± 0.07	6.80 ± 0.14
Pedu	PDU	7.21 ± 0.02	7.23 ± 0.01	7.80 ± 0.14
Mfantshipim Sec. Sch.	MSS	7.53 ± 0.14	7.44 ± 0.07	7.70 ± 0.14
Ashanti road	ARD	7.92 ± 0.07	7.58 ± 0.28	8.00 ± 0.04
Brofoyedur	BRO	4.96 ± 0.04	6.58 ± 0.04	6.60 ± 0.28
Elmina Market	ELM	8.16 ± 0.02	7.54 ± 0.28	6.80 ± 0.04
Elmina Clinic	ECL	5.97 ± 0.14	6.15 ± 0.07	7.60 ± 0.07
Elmin SSNIT Flat	ESF	6.66 ± 0.07	6.75 ± 0.28	6.74 ± 0.01
Anomabo	ANO	7.08 ± 0.14	6.77 ± 0.29	6.86 ± 0.07
Salt Pond Aahamadyah	SAH	7.65 ± 0.14	6.65 ± 0.30	6.66 ± 0.01
Salt Pond ECG Office	SEC	6.83 ± 0.02	6.93 ± 0.31	6.90 ± 0.01
Mankesim	MAN	6.32 ± 0.07	6.00 ± 0.32	6.88 ± 0.02

Table 22 continued

Mankesim ECG Office	MEC	7.51 ± 0.14	7.11 ± 0.33	7.21 ± 0.28
Apam Manfam	AMF	7.12 ± 0.14	6.83 ± 0.34	6.91 ± 0.01
Apam Sec. Sch.	ASS	6.83 ± 0.02	6.50 ± 0.35	6.50 ± 0.01
Winneba NVTI	NVT	7.38 ± 0.04	6.64 ± 0.36	6.71 ± 0.28
Winneba Baal Ltd.	WBL	7.70 ± 0.02	6.84 ± 0.37	6.65 ± 0.07
Winneba Police Dep.	WPD	8.67 ± 0.14	7.66 ± 0.38	7.11 ± 0.28
Winneba Basic Chemicals	BCH	6.94 ± 0.07	6.73 ± 0.39	7.80 ± 0.01
Sweedru ECG Office	ASE	6.86 ± 0.02	6.88 ± 0.40	6.71 ± 0.14
Swedru Sakora Park	ASP	8.05 ± 0.04	7.80 ± 0.41	7.60 ± 0.01
Nsaba Post Office	ANP	6.35 ± 0.01	6.75 ± 0.42	7.70 ± 0.04
Kwanyako GWCL	KGW	5.63 ± 0.02	6.11 ± 0.43	6.70 ± 0.02

Source: Laboratory analysis of soil samples, 2009

The top 0 - 10 cm soils were less acidic and showed the greatest variation in the pH and the 20 - 30 had the least variability. The mean pH for the 0 - 30 cm was 7.04 ± 0.07 and range from 6.04 to 7.82. Acidity in soils comes from H^+ and Al^{3+} ions in the soil solution and sorbed to soil surfaces. Between pH 4 and 6, Al^{3+} reacts with water (H_2O) forming $AlOH^{2+}$, and $Al(OH)_2^+$, releasing extra H^+ ions (Soil survey manual, 1993). The relative neutral nature of the soils means that the exchangeable Al^{+3} precipitate as hydroxide at pH of about 6.5; and the acidity may be due significantly to the exchangeable hydrogen. It is reported that the pH is an essential factor that influences the cation mobility and regulates the solubility of heavy metals in soil. Most of the metals tend to be available in acidic pH. Even though the pH has no direct effect on PCBs, it could lead to high levels of metals in the soil,

which may in turn affect significantly the soil organisms responsible for the degradation of these compounds and subsequently affect the persistence of the PCBs.

Organic Carbon of Soils

The soils are characterized by relatively low Organic carbon (organic matter) contents (Table 23). The means $\pm$ CV and ranges of organic carbon were as follows: top soil $0.32 \pm 65.6\%$ (0.04- 0.75), for the 10 - 20 cm layer $0.33 \pm 47.16\%$ (1.04 -0.16) and for the 20 - 30 cm layer $0.35 \pm 82.6\%$ (0.85 -0.70). The mean percentage for the soils 0 - 30 cm was $0.33 \pm 0.46\%$ (0.13-0.77).

Organic matter has been found to influence heavy metal adsorption in soils due to the high CEC of organic materials. The relatively low organic matter content is not favorable for heavy metal sorption in soils as observed by Kabata-Pendias (2007). The low levels of organic matter also imply that the persistence of PCBs will be minimal since PCB persistence is greater in soil of higher organic matter. The persistence may also decrease with depth of soil as the levels of organic carbon in the soils were found to decrease with depth. However the PCB persistence may depend on the nature and quality of the soil organic matter, the amount of compound sorbed into the soils and the nature of other compounds in the soils (Alexander, 2000; Reid *et al.*, 2000).

Table 23: Organic Carbon content of soils from selected sites in Central Region

Site	Sample	Organic carbon (%)		
		0-10 cm	10-20 cm	20 -30 cm
UCC Science Library	UCL	0.28 ± 0.14	0.44 ± 0.07	1.60 ± 0.01
UCC Science Auditorium	UAD	0.69 ± 0.07	0.54 ± 0.14	0.44 ± 0.12
UCC CDS	CDS	0.66 ± 0.14	0.45 ± 0.01	0.55 ± 0.02
Nurses Flat	NFL	0.13 ± 0.01	0.17 ± 0.07	0.17 ± 0.14
Pedu	PDU	0.55 ± 0.04	0.62 ± 0.14	0.31 ± 0.14
Mfantshipim Sec. Sch.	MSS	0.04 ± 0.07	0.17 ± 0.02	0.44 ± 0.04
Ashanti road	ARD	0.17 ± 0.01	0.16 ± 0.04	0.15 ± 0.14
Brofoyedur	BRO	0.15 ± 0.01	0.39 ± 0.04	0.27 ± 0.01
Elmina Market	ELM	0.09 ± 0.01	0.33 ± 0.04	0.51 ± 0.14
Elmina Clinic	ECL	0.12 ± 0.01	0.22 ± 0.04	0.29 ± 0.04
Elmin SSNIT Flat	ESF	0.34 ± 0.07	0.23 ± 0.04	0.26 ± 0.01
Anomabo	ANO	0.74 ± 0.01	0.23 ± 0.04	0.22 ± 0.01
Salt Pond Aahamadyah	SAH	0.29 ± 0.10	0.47 ± 0.04	0.41 ± 0.14
Salt Pond ECG Office	SEC	0.43 ± 0.01	0.45 ± 0.14	0.33 ± 0.07
Mankesim	MAN	0.29 ± 0.01	0.39 ± 0.01	0.22 ± 0.70
Mankesim ECG Office	MEC	0.35 ± 0.02	0.25 ± 0.28	0.17 ± 0.07
Apam Manfam	AMF	0.75 ± 0.14	0.70 ± 0.14	0.23 ± 0.28
Apam Sec. Sch.	ASS	0.18 ± 0.28	0.34 ± 0.07	0.12 ± 0.04
Winneba NVTI	NVT	0.23 ± 0.28	0.31 ± 0.14	0.40 ± 0.07
Winneba Baal Ltd.	WBL	0.17 ± 0.01	0.13 ± 0.14	0.40 ± 0.03

Winneba Police Dep.	WPD	0.15 ± 0.01	0.17 ± 0.12	0.13 ± 0.14
Winneba Basic Chemicals	BCH	0.19 ± 0.14	0.23 ± 0.14	0.20 ± 0.07
Sweedru ECG Office	ASE	0.19 ± 0.01	0.21 ± 0.28	0.29 ± 0.14
Swedru Sakora Park	ASP	0.23 ± 0.14	0.17 ± 0.14	0.21 ± 0.01
Nsaba Post Office	ANP	0.45 ± 0.28	0.54 ± 0.28	0.55 ± 0.01
Kwonyako GWCL	KGW	0.22 ± 0.14	0.19 ± 0.14	0.22 ± 0.03

Source: Laboratory analysis of soil samples, 2009

Effective Cation Exchange Capacity (ECEC) of Soils

The exchangeable acidity, the exchangeable base and the effective cation exchange capacity (ECEC) of the soils are presented (Table 24). The mean exchangeable acidity (mean ± std) and range in $\text{cmol}_c\text{kg}^{-1}$ of the top surface soils 0 – 10 cm soils were 0.375 ± 0.667 and (0.21 – 1.27), that of the 10- 20 cm subsurface soil were 0.326 ± 0.12 and (0.20 – 0.77) and for the 20 – 30 cm layer 0.295 ± 0.64 and (0.621 – 0.47). The mean and range of the ECEC for the soils 0-30 cm surface was 0.332 ± 0.17 (0.19 – 1.29) respectively. The exchangeable bases (mean ± std) and range in $\text{cmol}_c\text{kg}^{-1}$ of the soils were 6.01 ± 0.09 (2.31 – 13.08) for the topsoil (0 – 10 cm); 7.63 ± 0.14 (1.48 – 21.71) for the 10 – 20 cm soils, and 8.25 ± 0.14 (3.08 – 20.88) for the 20 – 30 cm subsurface soils. The mean and range of ECEC ($\text{cmol}_c\text{kg}^{-1}$) of the top soils (0 – 10 cm) were 6.39 ± 0.09 and (2.56 – 14.37) respectively; for the 10 – 20 cm layer, the mean and range were 7.95 ± 0.09 and (1.73 – 21.91) respectively; and for the 20 – 30 cm layer, 8.55 ± 0.10 and (1.73 – 21.91) respectively.

Table 24: Effective Cation Exchange Capacity of Soils (cmol_ckg⁻¹)

Depth	© University of Cape Coast 0-10 cm			https://ir.ucc.edu.gh/xmlui 10-20 cm			20-30 cm		
	Site	Ex acidity	Ex bases	ECEC	Ex acidity	Ex bases	ECEC	Ex acidity	Ex bases
UCL	0.28	6.13	6.41	0.29	8.98	9.27	0.31	9.72	10.03
UAD	0.23	6.34	6.57	0.37	5.92	6.29	0.34	6.32	6.66
CDS	0.29	6.44	6.73	0.26	4.99	5.26	0.28	5.17	5.45
NFL	0.27	5.79	6.06	0.42	5.02	5.44	0.34	5.44	5.78
PDU	0.37	4.16	4.53	0.41	9.34	9.75	0.36	9.23	9.59
MSS	0.47	3.13	3.60	0.39	3.42	3.81	0.47	3.08	3.55
ARD	0.35	2.62	2.97	0.38	9.20	9.58	0.34	9.41	9.75
BRO	1.29	13.08	14.37	0.2	21.71	21.91	0.22	21.88	22.1
ELM	0.81	6.38	7.19	0.77	6.05	6.82	0.25	6.17	6.42
ECL	0.36	4.83	5.19	0.45	5.03	5.48	0.38	4.66	5.04
ESF	1.07	11.58	12.65	0.51	18.73	19.24	0.37	17.82	18.19
ANO	0.23	2.76	2.99	0.27	4.29	4.56	0.28	6.43	6.71
SAH	0.26	4.97	5.23	0.25	7.31	7.56	0.23	7.28	7.51
SEC	0.32	4.73	5.05	0.25	4.24	4.49	0.27	4.62	4.89
MAN	0.25	6.36	6.61	0.28	19.55	19.83	0.26	9.96	10.22
MEC	0.32	5.36	5.68	0.19	4.43	4.62	0.22	4.29	4.51

AMF	0.26	12.10	12.36	0.23	9.07	9.30	0.32	9.16	9.48
ASS	0.23	8.26	8.49	0.34	7.50	7.84	0.23	7.34	7.57
NVT	0.26	6.10	6.36	0.34	8.05	8.39	0.25	8.01	8.25
WBL	0.21	3.62	3.83	0.33	2.43	2.76	0.32	3.22	3.54
WPD	0.23	3.11	3.34	0.24	2.16	2.40	0.22	3.76	3.98
BCH	0.25	2.31	2.56	0.25	1.48	1.73	0.27	8.86	9.13
ASE	0.3	3.75	4.05	0.27	3.54	3.81	0.32	4.06	4.38
ASP	0.35	8.22	8.57	0.25	12.30	12.55	0.36	5.37	5.73
ANP	0.23	7.12	7.35	0.24	8.29	8.53	0.22	10.74	10.96
KGW	0.25	7.08	7.33	0.25	5.20	5.45	0.23	12.62	12.85



The exchangeable acidity showed greater variations than the bases, with the 10-20 cm sub-surface soils showing the greatest variation. For the exchangeable bases, the topsoil showed the greater variation than the subsurface soils. The variations in the ECEC were almost the same, as indicated by their relative standard deviations. The results imply that most of the soils had low capacity to retain and supply nutrient and other cations. It is expected that soils with higher ECEC would sorb greater amount of the PCBs, and favour their persistence. However the sorption may depend on the amount and type PCB congener

Heavy Metals in Soils

The concentration (mean $\pm$ CV) of Al and heavy metals in the soils (Table 25) were Ag, 0.263 ± 144.01 mg/kg; Al, 0.685 ± 55.33 mg/kg; Cu, 21.63 ± 95.82 mg/kg; Fe, 0.565 ± 59.36 mg/kg; Zn, 94.70 ± 130.80 mg/kg and Pb, 26.67 ± 139.63 mg/kg. The ranges of the metals were Ag, 0.0071-1.084 mg/kg; Al, 0.98-1.72 mg/kg; Cu, 2.36-76.96 mg/kg; Fe, 0.007-0.13 mg/kg; Zn, 11.33-538.97 mg/kg and Pb, 3.19-184.26 mg/kg. The levels of the metals decrease in the order: Zn > Pb > Cu > Al > Fe > Ag. The very low levels and large variation in the levels of silver in addition to the fact that silver was detected in only six samples suggest that the soils do not contain significant amounts of silver, and the source is anthropogenic, probably from spent transformer oils which also contain polychlorinated biphenyls (PCBs). The variations in the levels of the metals are demonstrated by their coefficient variation of (CV), and follow the order Pb (139.63%) > Zn (130.80%) > Ag (144.01%) > Cu (94.82%) > Fe (59.36%) > Al (55.33%).

Table 25: Mean concentration of some metals in the soils

Sample	Concentration of metal in mg/kg					
	Ag	Al	Cu	Fe	Zn	Pb
UCL	nd	0.99±0.05	7.29±0.11	0.05±0.02	27.97±0.11	5.91±0.11
UAD	nd	0.48±0.02	13.11±0.04	0.06±0.00	59.31±0.11	44.21±0.08
CDS	nd	0.61±0.04	23.69±0.06	0.03±0.02	18.33±0.01	6.01±0.10
NFA	nd	0.86±0.02	14.95±0.06	0.09±0.05	33.44±0.09	22.93±0.11
PDU	0.09±0.01	0.23±0.04	8.33±0.06	0.02±0.01	16.50±0.03	11.75±0.10
MSS	nd	0.83±0.01	14.41±0.00	0.05±0.00	60.31±0.10	10.24±0.08
ARD	nd	0.66±0.00	13.88±0.02	0.06±0.01	38.78±0.06	12.66±0.01
BRO	nd	0.76±0.01	23.64±0.09	0.08±0.02	52.02±0.05	8.35±0.02
ELM	0.09±0.01	0.35±0.04	10.64±0.08	0.08±0.01	249.30±0.07	47.76±0.09
ECL	nd	0.69±0.09	32.63±0.00	0.08±0.02	56.40±0.02	11.24±0.01
ESF	nd	0.58±0.06	18.25±0.01	0.04±0.00	102.35±0.00	184.26±0.01
ARD	nd	0.96±0.03	76.96±0.00	0.05±0.06	395.71±0.04	25.79±0.04
SAH	0.11±0.00	0.33±0.01	6.23±0.04	0.03±0.02	31.95±0.02	8.28±0.04
SEC	nd	0.70±0.00	12.06±0.02	0.03±0.01	29.91±0.03	9.89±0.01
MAN	nd	1.19±0.04	2.36±0.01	0.07±0.04	23.50±0.03	8.71±0.01
MEC	0.26±0.00	0.23±0.09	13.85±0.10	0.04±0.02	107.12±0.13	17.01±0.08
AMF	nd	1.08±0.02	39.83±0.06	0.13±0.02	538.97±0.12	40.02±0.08
ASS	nd	1.72±0.02	70.48±0.03	0.13±0.01	140.72±0.12	85.30±0.11
NVT	nd	0.10±0.04	4.56±0.01	0.01±0.02	11.33±0.07	3.19±0.06
WBL	nd	0.53±0.01	7.17±0.06	0.04±0.02	38.55±0.02	5.81±0.02
WPD	nd	0.10±0.01	5.23±0.03	0.01±0.01	22.61±0.01	4.05±0.04
BCH	nd	0.72±0.06	20.82±0.04	0.03±0.01	35.46±0.07	14.30±0.01

Table 25 continued

ASEC	0.01±0.01	0.72±0.01	19.53±0.05	0.04±0.01	69.03±0.06	13.97±0.02
ASP	1.01±0.01	0.63±0.01	69.26±0.05	0.07±0.01	142.69±0.04	46.52±0.01
ANP	nd	1.36±0.04	14.10±0.04	0.13±0.06	129.82±0.04	28.36±0.01
KGW	nd	0.75±0.04	19.19±0.02	0.03±0.02	30.14±0.10	17.01±0.00

Source: Statistical analysis of soil data, 2010

Table 26: Pearson's Correlation matrix for Σ PCB and metals in soils around some transformers in the Central Region of Ghana

	Ag	Al	Cu	Fe	Zn	Pb	PCB
Ag	1	-0.159	0.408*	0.023	0.082	0.085	-0.069
P value		0.438	0.039	0.91	0.69	0.69	0.739
Al		1	0.472*	0.753**	0.304	0.19	-0.082
P value			0.015	0	0.131	0.352	0.691
Cu			1	0.428*	0.575**	0.292	0.082
p value				0.029	0.002	0.148	0.692
Fe				1	0.523**	0.25	0.014
P value					0.006	0.218	0.945
Zn					1	0.261	0.234
p value						0.197	0.25
Pb						1	0.108
p value							0.598
PCB							1

Source: Statistical analysis of soil data, 2010

*Correlation is significant at the 0.05 level **significant at the 0.01 level (2-tailed)

The levels of Pb, Cu, and Al were much lower than those found in some agricultural soils along the Obasandjo Road in Accra, and in some soils in farms in Cape Coast (Bentum *et al.*, 2011); in Bangladesh (Ahmad and Goni, 2009); in Lagos (Akinola, *et al.*, 2008); the levels of Pb, Cu and Zn were lower than those found in top soils in Mexico City (Morton-Bermea *et al.*, 2009). Both the Spearman and Pearson's method of regression and correlation analysis revealed strong positive correlations amongst the metals at 0.05 and 0.01 levels, Significant positive correlations were observed at the 0.05 level between Al and Cu, and also between Fe and Cu, with the Pearson's correlation coefficient being respectively $r = 0.47$ and $r = 0.43$ (Table 26).

At the 0.01 level, the Pearson's correlation coefficient for significant correlations were; Ag and Cu, $r = 0.41$; Al and Fe, $r = 0.75$; Cu and Zn, $r = 0.58$ and Fe and Zn, $r = 0.52$. The Spearman's rho for significant correlations between pairs of metal at the 0.01 level were; for Al and Fe, 0.65; Cu and Zn, 0.6; Cu and Pb, 0.55; Fe and Zn, 0.64; for Fe and Pb, 0.51; and 0.78 for correlation between Zn and Pb. The positive correlations amongst the metals suggest that they were from common sources; probably from the vehicular emissions and also from the transformer oils. The varied distribution of Ag in the soils strongly indicates that it is from transformer oils, which have been found to contain Ag which is a component of the electric transformers These observations imply that these metals may show similar correlations with the concentrations of polychlorinated biphenyl detected in the soils.

Multivariate analysis, principal component analysis (PCA) and cluster analysis (CA) and correlation matrix were used in the study to provide a better insight and understanding of the dynamics of the PCBs and metals in the surface soils. Principal component analysis was used following standard procedure reported in literature (Dragovi *et al.*, 2008; Yu *et al.*, 2008), for evaluation of extent of metal contamination in the study area and source identification, PCA was performed on the logarithmic form of the metal data. Varimax rotation (Jolliffe, 1986) was used to maximize the sum of the variance of the factor coefficients.

This technique clusters variables into groups, such that variables belonging to one group are highly correlated with one another (with sum of squared loadings > 0.3) were grouped into one component. The number of components indicates the total number of possible sources of variation in the data. For the cluster analysis hierarchical agglomerative clustering by the Ward's method was selected for sample classification because it possesses a small space distorting effect, uses more information on cluster contents than other methods, and has been proved to be an extremely powerful grouping mechanism. The method was applied to normalized data using squared euclidean distances as a measure of similarity.

The results of the PCA (Table. 27) and CA (Fig. 30) are shown. Only factor loadings greater than 0.3 are significant. . Three principal components (PCs) with eigenvalues greater than 1 were extracted. PCA leads to a reduction of the initial dimension of the dataset to three components which explain 73.27% of the data variation. Therefore, these three factors play a significant role in explaining PCB and metal contamination in the study area.

Table 27: Component matrix with strong loading in bold face

Parameter	Component		
	PC1	PC2	PC3
Ag	-0.14	0.93	-0.06
Al	0.92	0.09	-0.07
Cu	0.553	0.641	0.26
Fe	0.89	0.06	0.11
Zn	0.54	0.27	0.54
Pb	0.86	0.24	0.4
PCB	-0.15	-0.14	0.9

Source: PCA of field data, 2009

The components one PC1, which had high loadings of Al, Fe and Pb; moderate positive loading of Cu and Zn accounted for 33.68 % of variance, and is the most important component. PC1 could be better explained as anthropogenic and lithogenic sources. The anthropogenic source may have been derived from transformers and vehicular emissions. These metals showed significant correlations among each other (Tab 26).

The second component PC2, which had high positive loadings of Ag and moderate positive loading of Cu, accounted for 20.5% of variance. PC2 can be considered as a anthropogenic and derived from the transformers. Only Cu showed significant correlation with Ag (Tab 26). The third component PC3, is highly loaded with PCBs and moderately loaded with Zn and Pb accounted for 20.1% variance; and indicating a mixed source from both

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 lithogenic and anthropogenic inputs. The PCBs can be considered as an anthropogenic component, from transformers while Zn and Pb were from both lithogenic and anthropogenic sources. No significant correlations were observed amongst the elements in PC3. In general, correlations between metals agreed with the results obtained by PCA.

Based on information assessed from principal component analysis, hierarchical cluster analysis was performed. Two main clusters can be distinguished in the dendrogram (Fig 30), obtained from the CA performed on the analyzed parameters with Ward's method and the squared Euclidean distance as a similarity measure (Fig. 30). Cluster 1 includes elements Ag, Fe, Al, Cu and Pb, which in the previous section were identified as contaminants derived from both lithogenic and anthropogenic sources. Cluster 2, which contains PCB is derived from anthropogenic sources, specifically from transformers.

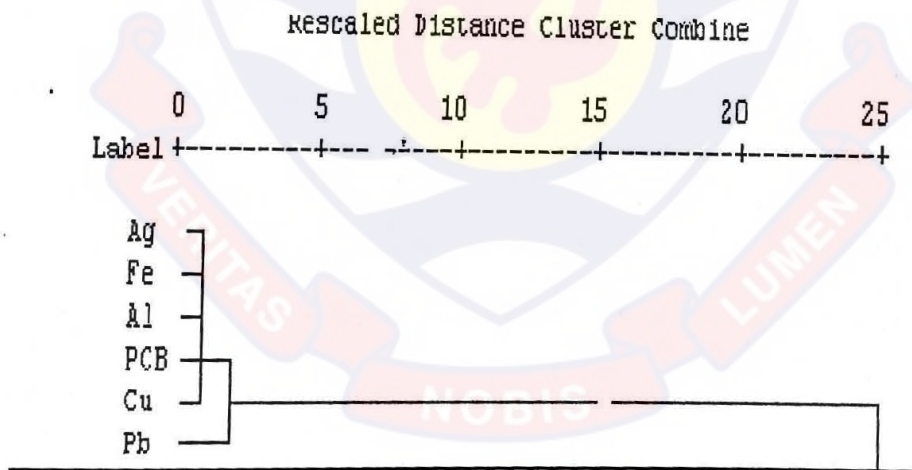


Figure 30: A dendrogram obtained by hierarchical clustering analysis for metals

The relationship of PCBs to different soil parameters was studied. Regression analyses revealed some significant relationships between the soil characteristics and the PCB content of the soils. The pH of the surface soils correlated positively with PCBs content in the 10 -20 cm sub-surface soils with $r = 0.535$ ($p < 0.01$). With moisture content, a significant negative correlation was observed between the moisture and PCBs in the 20-30 cm sub-surface soils at 0.05 level, $r = 0.414$. The soil organic carbon (organic matter) content showed only a weak correlation with the PCBs. However, the correlation was not significant as observed by Zhang *et al.*, (2007). Sorption of organic compounds such as mono-ortho-polychlorinated biphenyls (PCBs) in soils and sediment in the temperate regions has been reported to be higher than could be anticipated based on the compounds' hydrophobicities (Ayris & Harrad, 1999; Ahmad *et al.*, 2001; Allen-King *et al.*, 2002; Jonker & Koelman, 2002).

The observations made in this study indicate that the adsorption of the PCBs onto the soils studied was weak; also the only mono-ortho-polychlorinated biphenyls in the PCB indicator used was PCB118. The weak correlation might be due to decreased in sorption strength of the PCBs onto the soil organic matter with increasing residence time of the compound in soil resulting in desorption of the PCBs. The desorbed PCBs might have been co-evaporated with water increasing the volatilization of PCBs from the soils. The statistically insignificant correlation observed between the PCBs and the soil organic carbon at the study sites might also be due to decreased sorption of the PCB residues and the higher temperature of the prevailing environment

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compared to the temperate region, as studies have shown that temperature is one of the drivers of the observed variability in the distribution of POPs as a result of volatilization and soil-air exchange.

The insignificant correlation between organic matter and PCB concentrations may also imply that absorption of the PCBs by plants did not probable occur, therefore decayed plant material did not contain any significant PCBs. Other soil properties, besides organic carbon (organic matter) might have been responsible for adsorption (Wahid and Sethunathan, 1979), but their role could be masked by that of the organic matter. The Effective Cation Exchange Capacity (ECEC) correlated negatively with PCBs in the surface and sub soils, but significant correlation was observed between the PCBs and the 10-20 cm and 20-30 cm subsurface soils, with respective r values of -0.45 and -0.43 ($p < 0.05$) respectively.

A significant negative correlation was observed between the exchangeable bases and the PCBs in the top surface and 10-20 cm sub-surface soils with respective correlation coefficients $r = -0.394$ and -0.433 ($p < 0.05$). Generally there were no significant relations between the exchangeable acidity and the soil PCBs, only PCB 118 showed significant correlation with the exchangeable acidity with $r = 0.367$ ($p < 0.05$), suggesting that the observed negative correlation between the ECEC and the soil PCBs was mainly due to significant correlation between the soil PCBs and the exchangeable base.

Some congeners also showed significant relationships with pH, base, and acidity and the cation exchange capacity. The PCB# 138 and 180 correlated with pH and exchangeable at the 0.01 confidence levels; and the respective values of r were 0.257 and 0.346. Even though pH does not have

direct effect on the degradation of PCBs, the coefficient of determination or explained variation as a percentage of total variation in the levels of PCB# 138 and 180 in the soils that are accounted for by the variations in the soil pH, determined by squaring the correlation coefficient r and multiplying by 100, were respectively 6.6% and 12.47%. PCB 101 correlated with exchangeable base and the ECEC at the 0.05 level with the corresponding values of $r = 0.299$ and 0.28 respectively.

There was no significant correlation between the metals and $\sum\text{PCB}$ (Tab 25) at the 0.05 and 0.01 levels. However, some significant correlations were observed between the metals and the PCB congeners at the 0.05 level. PCB 101 showed significant positive correlation with Zn, also PCB 153 correlated positively with Ag; the Pearson's correlation coefficients being respectively $r = 0.498$ and $r = 0.880$ ($p < 0.05$).

Using the Spearman's regression and correlation method, the correlation coefficients for significant correlations at the 0.05 level were; between PCB 101 and Cu, $r = 0.584$; and between PCB 153 and Pb, $r = -0.484$. Also, PCB 101 showed very strong negative correlation with Ag, with $r = -1.0$. The significant positive correlations between the PCB congeners 101 and the metals Cu, and Zn suggest that significant amounts of these metals found in the soils were from the transformers oils.

The very strong negative correlation between PCB101 and Ag reflects the depletion of Ag metal in the soils. These observations do not suggest that these metals have significant effect on the persistence of the PCBs in the soils, since there are no available records on the effects of these metals on the degradation of soil PCBs. The non-significant correlation observed between

several of the PCB congeners and the metals could be due to volatilization of the soil PCBs, very low sorption of the PCBs onto the soils, translocation of some the metals into plants, leaching of the metals deep into the soils whiles PCBs are not usually carried deep into the soil with rainwater, or the non-existence of any significant relation between the levels of PCBs in the transformer oils and the levels of metals introduced into the oils through wear and tear as the transformers function.

These observations made suggest that the temporal distribution and levels of PCBs in the soils depends not on any single factor, or on the soil characteristic only; but on the combined effect of the soil characteristics, the soil sorption of the PCB congeners, plant uptake, the presence of other organic compounds and traces of mineral salts and nutrients, and particularly the quantity of oils from the electric transformers that might have significantly affected the degradation rate and amounts of PCBs at the different depths of the soils as observed by Streck and Weber (1982); Fiebiget *et al.*, (1993); WHO, (1993); Lubor Halu ka *et al.*, (1995) and Yanjun Chang, *et al.*, (2010).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The mean concentration of the PCB congeners were; PCB28, 2.27 ± 2.44 ; PCB52, 1.84 ± 2.27 ; PCB101, 2.17 ± 2.52 $\mu\text{g/kg}$; PCB 118, 0.83 ± 0.89 $\mu\text{g/kg}$; PCB138, 0.99 ± 0.91 $\mu\text{g/kg}$; PCB153, 1.18 ± 1.11 $\mu\text{g/kg}$ and PCB180, 1.18 ± 1.19 $\mu\text{g/kg}$. Overall, 23.63% of the results for single congeners were below the limit of quantification. The mean ΣPCB follow the order: Agona (4.62 ± 0.06 $\mu\text{g/kg}$) < KEEA (8.20 ± 0.04 $\mu\text{g/kg}$) < Cape Coast (8.24 ± 0.06 $\mu\text{g/kg}$) < Awutu-Efutu Senya (9.28 ± 0.53 $\mu\text{g/kg}$) < Mfantiman (9.56 ± 0.38 $\mu\text{g/kg}$). The mean levels of ΣPCBs in the top surface and subsurface soils (based on dry weight) in the whole area of study (in the five metropolis/districts) were 9.15 ± 0.52 $\mu\text{g/kg}$ for the surface soils and 7.55 ± 0.56 $\mu\text{g/kg}$ and 7.82 ± 0.55 $\mu\text{g/kg}$ for the 10-20 cm and 20-30 cm sub soils respectively.

The median were respectively 9.266, 6.83 and 8.17 $\mu\text{g/kg}$. PCB concentrations in soil showed a large variation between sampling-areas. The highest concentrations were found at three sites, WPD, and AUD with sandy soils. The soil levels give an indication of long-term accumulation.

In general the prevalence of the PCBs was found in the order Cape Coast > Efutu Awuto Senya > Mfantipim > Agona and KEEA. Soils in areas with higher number of transformers were exposed to greater amounts of PCBs. The PCBs homologous in all the soil samples were dominated by hexa-PCBs and follow the order hexa-PCBs (31.89 %) > penta-PCBs (23.98 %) > tri-PCBs (18.47 %) > tetra-PCBs (13.67%) > hepta-PCBs (11.99 %). The PCB

congener profile in the whole study area was PCB 28 > PCB 153 > PCB 138 > PCB 52 > PCB 101 > PCB 180 > PCB 118.

The Σ PCB-TEQs of the soils were all below limit. The trend in the study area was KEEA (90 pg/kg dw) > Awutu-Efutu-Senya (63.33) pg/kg dw > Cape Coast (292 pg/kg dw) > Agona (148 pg/kg dw) > Mfantsiman (144 pg/kg dw). This observation thus indicates that soils in areas with greater number of transformers are likely to have higher levels of dioxin-like PCBs, The levels of Σ PCB in all the soils were below the soil contact value (or threshold effect concentration, TEC) of 25 mg/kg and 33 mg/kg (or 25,000 and 33000 μ g/kg) recommended by US EPA and the CCME (1999) for all land uses. Most of the soils in residential areas where electric transformer are situated had hazard Index (HI) greater than one (1.0).

The pH, clay, silts and sand correlated positively with the soil PCBs; the CEC and moisture showed negative correlation. No significant correlations were observed for the regression of organic matter, exchangeable base, metals on the Σ PCB, or the PCB congeners at the 0.05 level.

Multivariate analysis (PCA, CA) and correlation matrix used in this study provide important tools for better understanding of the source identification and dynamics of pollutants. The PCA applied on the investigated PCBs identified three (3), three (3) and four (4) components, or possible sources of variations in the data, in the top surface (0-10 cm), 10-20 cm and 20-30 cm sub-surface soils respectively. All of them were positively and negatively loaded with PCBs. The multivariate analysis indicated that the sources of the congeners might be aroclor 1248, 1254 and 1260

The results of the study have revealed the presence of Polychlorinated biphenyl (PCBs) in soils in the vicinity of electric transformers in the Central Region of Ghana. The concentration of the sum of the seven key PCBs (IUPAC No. PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153 and PCB 180) for 78 samples of soils from 26 sites were $7.99 \pm 38 \mu\text{g/kg}$ and ranged from $1.32\text{--}12.94 \mu\text{g/kg}$. The mean concentration ($\mu\text{g/kg}$) of the congeners in the Central Region were PCB 28, 2.26 ± 81 > PCB 52, 2.22 ± 133 > PCB 101, 2.03 ± 83 > PCB 180, 1.23 ± 65 > PCB 153, 1.10 ± 63 > PCB 138, 0.95 ± 71 > PCB 118, 0.79 ± 79

Soils from Agona showed the smallest mean ΣPCB concentration of $4.62 \pm 0.06 \mu\text{g/kg}$ and soils from Mfantseman showed the highest concentration of $9.56 \pm 0.38 \mu\text{g/kg}$. Only Soils from Agona had mean ΣPCB lower than the average, $7.99 \pm 0.38 \mu\text{g/kg}$, for the Central region. This means the soils in the vicinity of transformers in the Mfantseman district was most contaminated with PCBs and that of the Agona district least contaminated. The vertical distribution of PCBs showed a mean concentrations of $9.15 \pm 0.52 \mu\text{g/kg}$ for the surface soils (0-10 cm), $7.55 \pm 0.56 \mu\text{g/kg}$ and $7.82 \pm 0.55 \mu\text{g/kg}$ for the 10-20 cm and 20-30 cm sub-surface soils respectively.

The mean PCB 118-TEQs of the soils were all below limit. The trend in the study area was KEEA (90.0 pg/kg dw) > Awutu-Efutu-Senya (62.33 pg/kg dw) > Cape Coast (37.75 pg/kg dw) > Agona (37.0 pg/kg dw) > Mfantseman (28.0 pg/kg dw). Soils with hazard index greater than one have the potential to cause harm if ingested. The estimated lifetime cancer risk to a Reasonable Maximum Exposure (RME) individual via the complete exposure

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(skin contact) relating to PCBs was low, and thus the probability of an individual developing cancer as a result of exposure to PCBs through skin contact with soils in the study area was negligible, implying that the levels of exposure to soil PCBs are acceptable.

The association of some soil characteristics with PCBs in the area of study indicates retention of PCBs in the soils. Even though the soils are contaminated with PCBs, the levels of the PCBs are relatively low when compared to recommended limits. The presence of these compounds in the soil environment poses some form of risk since bioaccumulation is an important aspect of the environmental fate and behavior of PCBs, and because the compounds have high lipid solubility. Also because of their slow rate of metabolism and elimination they are likely to accumulate in some organisms even at the low levels. Thus, sustained low levels of the PCBs in the soils may result in adverse chronic effects in the biota exposed to them.

The results of this study will contribute significantly to the monitoring of Persistent Organic Pollutants (POPs) including PCBs in the Ghanaian environment by the Environmental Protection Agency (EPA). It will also serve as a data base upon which other (including future) analysis of soil PCBs in our environment would be compared.

Recommendations

The following recommendations have been made for further work:

1. The presence and levels of PCBs in soil organisms in the area of study, where samples were collected, must be assessed.
2. The presence and levels of PCBs in other environmental samples such as food, fish and human samples must be investigated.

3. Since PCBs have high lipid solubility and slow rate of metabolism and elimination, their presence and levels in animals including human, tissues of aquatic biota, crops and foods in the vicinity of the transformers must be investigated.
4. Precautionary measures must be taken to ensure very limited introduction of PCB oils into the surrounding soils during retrofitting of PCB containing transformers.



BIBLIOGRAPHY

- Accardi-Dey, A., & Gschwend, P. M. (2003). Reinterpreting literature sorption data considering both absorption into organic carbon and adsorption onto black carbon. *Environmental Science & Technology*, 37, 99 -106.
- Abramowicz, D. A. (1990). Aerobic and anaerobic biodegradation of PCBs: a review. In G.G. Steward & I. Russell (Eds), *CRC Critical Reviews in Biotechnology*, Boca Raton, FL: CRC Press, 1 10(3), 241-251
- Abramowicz, D. A. (1995). Aerobic and Anaerobic PCB Biodegradation in the Environment. *Environmental Health Perspectives Supplements*, Brogan & Partners, 103(S5), 97-99.
- Adu-Kumi S., Kareš, R., Literák, J., Borůvková, J., Yeboah, P. O., Carboo, D., Akoto, O., Darko, G., Osae, S., & Klánová, J. (2012, July). Levels and seasonal variations of organochlorine pesticides in urban and rural background air of southern Ghana *Environmental science and pollution research international*, 19(6), 1963-70.
- Agency for Toxic Substances and Disease Registry (ATSDR). (1990) *Public health statement for PCBs*. Atlanta, GA: U.S. Department of Health and Human Services
- Agency for Toxic Substances and Disease Registry (2000). *Toxicological Profile for Polychlorinated Biphenyls*. Atlanta: GA: U.S. Department of Health and Human Services, Public Health Service.
- Available at: www.atsdr.cdc.gov/toxprofiles/tp17.html
- Ahlborg U.G., Hanberg, A. & Kenne, K. (1992). Risk Assessment of Polychlorinated Biphenyls (PCBs). *Institute of Environmental*

Retrieved on March 7, 2008, from

http://www.chem.unep.ch/pops/POPs_Inc/proceedings/bangkok/FIEDLER1.html

Ahlborg U.G., Becking, C.G., Birnbaum, L.S., Brouwer, A., Derks, H. J.G.M., Feeley, M., Golor, G., Hanberg, H., Larsen, J.C., Liem, A.K.D., Safe, S.H., Schlatter, C., Waern, F., Younes, M., & Yrjänheikki, E. (1994). Toxic Equivalency Factors for Dioxin-like PCBs - Report on a WHO-ECEH and IPCS Consultation, Dec. 1993. *Chemosphere* 28, 1049-1067

Ahmad, J. U., & Goni, A. (2010). Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh, *Environ Monitoring Assessment*, 166(1-4):347-57.

Ahmad, R., Kookana, R. S., Alston, A. M., & Skjemstad, J. O. (2001). The nature of soil organic matter affects sorption of pesticides: 1. Relationships with carbon chemistry as determined by ¹³C CP/MAS NMR spectroscopy. *Environmental Science & Technology*, 35, 878-884.

Ahmad, J. U., & Goni, A. (2010, July). Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh *Environmental Monitoring and Assessment*, 166(1-4), 347-357

Akinola, M. O., Njoku, K.L., & Ekeifo, B. E. (2008). Determination of lead, cadmium and chromium in the tissue of an economically important plant grown around a textile industry at Ibeshe, Ikorodu Area of Lagos State, Nigeria, *Adv. Environ. Biol.*, 2(1), 25-30.

- Alder, A. C., Haggblom, M. M., Oppenheimer, S. R. & Young, L. Y. (1993). Reductive Dechlorination of Polychlorinated Biphenyls in Anaerobic Sediments, *Environmental. Science Technology*, 27, 530-538
- Alexander M., & Namhyun C. (2002). Effect of soil properties on bioavailability and extractability of phenanthrene and atrazine sequestered in soil *Chemosphere*, 48, 109-115
- Allen-King, R. M., Grathwohl, P., & Ball, W. P. (2002). New modeling paradigms for the sorption of hydrophobic organic chemicals to heterogeneous carbonaceous matter in soils, sediments and rocks. *Advanced Water Resources*, 25, 985-1016.
- Aluru, N., Karchner, S. I., & Hahn, M. E. (2011). Role of DNA methylation of AHR1 and AHR2 promoters in differential sensitivity to PCBs in Atlantic Killifish, *Fundulus heteroclitus*. *Aquat Toxicol.*, 17, 101(1), 288-294.
- Al-Haddad, I., Madany, M. & Farha J. A. (1993). Levels of PCBs and PAHs in Bahrain soil. *Environment International*, 19(3), 277-284
- Ahangar A. G. (2011), Organic pollutant in the soil environment: Emphasis on sorption process: A review. *American Journal of Scientific Research*, 32, 115-127.
- Anonymous (nd). The history of PCB: When were health problems detected. Retrived, August 22, 2007, from [Http://w.w.w.Foxriverwatch.com/monsanot2amPeb-Pebs-html](http://w.w.w.Foxriverwatch.com/monsanot2amPeb-Pebs-html)
- Asamoah, K. A. (2005). Determination of the levels of polychlorinated biphenyl (PCBs) in some environmental samples in the vicinity of selected transformers of the Electricity Company of Ghana (ECG), in

- Asante, K. A., Adu-Kumi, S., Nakahiro, K., Takahashi, S., Isobe, T., Sudaryanto, A., Devanathan G, Clarke E, Ansa-Asare O. D, Dapaah-Siakwan S, Tanabe S. (2011) Human exposure to PCBs, PBDEs and HBCDs in Ghana: Temporal variation, sources of exposure and estimation of daily intakes by infants. *Environment International*, 37(5), 921-928.
- Aslund, M. L. W., & Zeeb, B. A. (2007). In situ phytoextraction of polychlorinated biphenyl - (PCB) contaminated soil. *Science of the Total Environment*, 374(1), 1-12.
- Australian and New Zealand Environment and Conservation Council (ANZECC) (1997). Identifying PCB-containing capacitors, pp.4-5. Retrieved on August 7, 2007.
- Ayris, S. & Harrad, S. (1999). The fate and persistence of polychlorinated biphenyls in soil. *Journal of Environmental Monitoring*, 1, 395-401.
- Bacci, E., Calamari, D., Gaggi, C., Biney, C., Focardi, S., & Morosini, M. (1988). Organochlorine pesticides and PCB residues in plant foliage: (*Magifera indica*) from West Africa. *Chemosphere*, 17(4), 693-702
- Backe, C., Cousins I.T. & Larsson P. (2004, March). PCB in soils and estimated soil-air exchange fluxes of selected PCB congeners in the south of Sweden, *Environmental Pollution*, 128 (1-2), 59-72.
- Ballschmiter, K., & Zell, M. (1980). Analysis of polychlorinated biphenyls by glass capillary gas chromatography. *Fresenius Z. Analytical Chemistry*, 302, 20-31
- Baker, K. T. (1976). The determinations of organic matter in soil using probe colorimeter. *Laboratory practice*, 2592, 82 – 83

- Environmental Chemistry.Com*. Retrived September 2, 2011, from <http://EnvironmentalChemistry.com/yogi/chemistry/pcb.html>
- Batterman, S., Chernyak, S., Gouden, Y., Hayes, J., Robins, T. & Chetty, S. (2009). *Environmental Pollution*, 157(2), 654-663
- Bauer U., Amaro A. R., & Robertson, L. W. (1995) A new strategy for the synthesis of polychlorinated biphenyl metabolites. *Chemical Research in Toxicology*. Jan-Feb; 8(1):92-5
- Bedard, D. L. (1990). Bacterial transformations of polychlorinated biphenyls. In D. Kamely, A. Chakrabarty & G.S' Omenn (Eds), *Biotechnology and Biodegradation, Advances in Applied Technology Series*, Vol 4, The Woodlands, TX: Portfolio Publishing, 369-388.
- Bedard, D. L., Unterman, R. L., Bopp, H., Brennan, M. J., Haberl, M. L., & Johnson, C. (1986). Rapid assay for screening and characterizing microorganisms for the ability to degrade polychlorinated biphenyls. *Applied Enviromental Microbioogy*, 51,761-768.
- Behnisch, P. A., Hosoe, K., & Sakai S. (2001). polychlorinated biphenyls. *Environment Inernational*, 27, 495-519.
- Beiles, N. (2000, Friday, May 12,). What Monsanto Knew: Outraged by PCB Contamination, in Alabama Town Unearths a Company's Past. *The Nation*. <http://www.thenation.com/doc.mhtml?i=20000529&s=beiles>
- Bentum, J. K., Essumang, D. K., Tuffour, J. k. & Agyekum, I. (2011). Analysis of heavy metals in roadside soils and crops along the Obansandjo way in the Accra metropolis. *International Journal of Biological & Chemical Science*, 4(3), 803-808

- © University of Cape Coast <https://ir.ucc.edu.gh/xmlui>
Benvinakatti, B.G., and Ninnekar, H.Z. (1992), Degradation of Biphenyl by a
Micrococcus Species, *Applied Microbiology and Biotechnology*,
38273-275.
- Besselink, H. T., Denison, M. S., Hahn, M. E., Karchner, S. I, Vethaak, A. D.,
& Koeman, J. H. (1998). Low inducibility of CYP1A activity by
polychlorinated biphenyls in flounder (*Platichthys flesus*):
characterization of the Ah receptor and the role of CYP1A inhibition.
Toxicology Science 43(2),161-71.
- Boate, A., Deleersnyder, G., Howarth, J., Mirabelli, A., & Peck, L. (2004).
Chemistry of PCBs. Retrieved November 7, 2007,
- Bonin, J. L., & Simpson, M. J. (2007). Variation in phenanthrene sorption
coefficients with soil organic matter fractionation: the result of
structure or conformation? *Environmental Science & Technology*, 41,
153-159.
- Boyle, A.W., Silvín, C. J., Hassett, J. P., Nakas, J.P., & Tanenbaum, S.W.
(1992). Bacterial PCB Biodegradation, *Biodegradation*, 3, 285-2
- Braida, W. J., Pignatello, J. J., Lu, Y., Ravikovitch, P. I., Neimark, A. V., &
Xing, B., (2003). Sorption hysteresis of benzene in charcoal
particles. *Environmental Science & Technology*, 37, 409-417.
- Breivik K., Sweetman, A., Pacyna, J. M., & Jones, K.C. (2002). Towards a
global historical emission inventory for selected PCB congeners - a
mass balance approach 1. Global production and consumption". *The
Science of the Total Environment*, 290,181-198
- Brian, M., & Morrison, R. D. (2007). Introduction to environmental forensics
(2nd ed.). Academic Press, p. 33

Brown, R. M., (1947). Polychlorinated biphenyls, *Chemist-Analyst*, 36, 33

Canadian Council of Ministers of the Environment. (1999). Canadian soil quality guidelines for the protection of environment and human health: Polychlorinated biphenyls (total) (1999). In: Canadian Environmental Quality guidelines, 1999, Canadian Council of Ministers of Environment, Winnipeg.

Centers for Disease Control and Prevention (CDC). (2005). *Third national report on human exposure to environmental chemicals*. Atlanta: Retrived June 2, 2011, from www.cdc.gov/exposurereport/

Center for Health and Environmental Justice. (2000). *A comprehensive list of studies of human contamination*. Falls Church, VA: Center for Health and Environmental Justice,

Centeno, C. (2010, June). POPs contaminated sites assessment in Ghana using the United Nations Industrial Development Organization (UNIDO) toolkit. contaminated sites conference 2010, Bratislava. UNIDO www.unido.org

Chauhan K. R, Kodavanti, P. R, McKinney, J. D. (2000). Assessing the role of ortho- substitution on polychlorinated biphenyl binding to transthyretin, a thyroxine transport. *Toxicology and Applied Pharmacology*, 162(1), 10-21.

Cheng S. (2007). Heavy metal pollution in China: Origin, pattern and
control a state-of-the-art report with special reference to literature
published in Chinese journals. *Environmental Science & Pollution
Research*, 14,489-48

Chow, W., Connor, K. K. (1993). (editors) Managing Hazardous Air
Pollutants, State of the Ar: Lewis publishers, Boca Ratan Fld. P.221.

Chou, S. F. J., & Griffin, R. A. (1986). Solubility and soil mobility of
polychlorinated biphenyls and the environment. Volume I CRC
Press, Inc., Boca Raton FL. pp101-120,

Coleman, P., Lee, R., Alcock, R. & Jones, K. (1997). Observations on PAH,
PCB, and PCDD/F trends in UK urban air 1991-1995. *Environmental
Science & Technology*, 31, 2120- 2124.

Cousins, I. T., & Larsson, P. (2004). PCB in soils and estimated soil-air
exchange fluxes of selected PCB congeners in the south of Sweden.
Environmental Pollution, 128, (1-2), 59-72

Crine, Jean-Pierre (1988). Hazards, decontamination, and replacement of
PCB.A omprehensive guide. *Environmental Science Research*,Vol.
37. Plenum Press, New York

Cummins, J. E. (1988). Extinction: the PCB threat to marine mammals.
Ecologist 60, 18.

David, R. L., (1994). Soil Science: Methods and Applications, John Willey &
Sons. New York. pp 140-146

- Whitford, K. W. & Saylor, E. S. (1993). Technology alternatives for the remediation of PCB-contaminated soil and sediment. EPA Engineering Issue EPA 540-S-93-506, 26 pp.
- Dawidson, E. & Nilsson C. (2000). Soil organic carbon in Upper East Region, Ghana – Measurements and Modelling. Lunds Universitets Naturgeografiska Institution Seminarieuppsatser Nr. 77, pp 15-16, 24.
- Delawary, M. , Ohtsubo, Y., & Ohta, A. (2003). The dual functions of biphenyl degrading ability of *Pseudomonas* sp KKS102: energy acquisition and substrate detoxification. *Bioscience Biotechnology and Biochemistry* 67, 1970– 1975
- Delle Site, A. (2001). Factors affecting sorption of organic compounds in natural sorbent/water system and sorption coefficients for selected pollutants: A review. *Journal of Physical and Chemical Reference Data*, 30(1), 187-253
- Department for Environment Food and Rural Affairs (2002.). Dioxins and dioxin-like PCBs in the UK Environment.Consultation Document. London: Department for Environment, DEFRA Publications.London p 18- 28
- Department for for Environment, Food and.Rural Affairs (DEFRA), (2006a). *A review of the current source inventories for dioxin and dioxin-like PCBs for air, soil, & water with view to updating emission factors/ estimates and inclusion of new sources.* Report NCEN/ED 48412/R1. London:
- Department for Environment Food and Rural Affairs (DEFRA), (2006b). *National Implementation Plan for the Stockholm Convention on*

© University of Cape Coast <https://ir.ucc.edu.gh/xmlui>
Persistent Organic Pollutants. London: Retrived July 6, 2011, from
<http://www.defra.gov.uk/environment/chemicals/pdf/popnationalplan.pdf>

Department of Health & Human Services (DHHS) (1992). *Toxicological Profile for Selected PCBs (Arochlor-1260, -1254, -1248, -1242, -1232, -1221, and 1016)*. U.S. DHHS

Dorgan, J. F., Brock, J. W., Rothman, N., Needham, L. L., Stephenson, H. E. Jr., & Miller, R. (1999). Serum organochlorine pesticides and PCBs and breast cancer risk: results from a prospective analysis (USA). *Cancer Causes Control*, 10(1), 1-11.

Dragovi, S., Mihailovi, C. B., & Gajic, B. (2008, June). Heavy metals in soils: distribution, relationship with soil characteristics and radionuclides and multivariate assessment of contamination sources. *Chemosphere*, 72 (3), 491-549

Drinker, C. K. (1937). The problem of possible systemic effects from certain chlorinated hydrocarbons, *Journal of Industrial Hygiene and Toxicology*, 19, 283- 311.

Environment, Food and Rural Affairs. (1994, September/October.) *News review- Sierra magazine Westinghouse – covered their toxic trails*
Retrived June 4, 2010 from
<http://www.defra.gov.uk/environment/chemicals/pdf/dioxi>

Environment Agency (2009b). Updated technical background to the CLEA model. Science Report SC050021/SR3. Bristol: Environment Agency.

- Environment Agency (2009c). Human health toxicological assessment of contaminants in soil. Science Report SC050021/SR2. Bristol: Environment Agency.
- Environment Agency, (2009d). Contaminants in soil: updated collation of toxicological data and intake values for humans. Dioxins, furans and dioxin-like PCBs. Science Report SC050021/SR TOX12. Bristol: Environment Agency
- Environmental Protection Agency (EPA). (1986a, September 24). *Guidelines for Carcinogen Risk Assessment*. 51 Federal Register 33992
- Environmental Protection Agency (EPA). (1986b, September 24). *Guidelines for the Health Risk Assessment of Chemical Mixtures*. 51 Federal Register 34014
- Environmental Protection Agency (1999). Executive Summary Human Health Risk Assessment: Upper Hudson River. US, EPA
- Environmental Protection Agency (2004). Draft national implementation plan (NIP) on POPs. Unpublished document, EPA, Ghana
- Environmental Protection Agency (2006). Preliminary inventory of POPs. Unpublished document EPA – Cape Coast, Ghana
- Environment Youth Action Network (EYAN) & Integrated Community Care (ICC), (2006). The international POPs elimination project :Ghana POPs situation report, Ghana Retrieved from <http://www.ipen.org>
- Erickson, M. D. (1986). Analytical Chemistry of PCBs. *Ann Arbor Science*) Butterworth Publishers, Stoneham, MA.
- Exner, J. H. (1982). Detoxification of hazardous waste. *Ann Arbor Science*, Publishes, Ann Arbor, Michigan

Federal Ministry of Environment (2009, April). *National implementation plan for the stockholm convention on persistent organic pollutants (POPS)*

Final Report. Federal Ministry of Environment Abuja, Federal Republic of Nigeria. pp, 113-114

Fiebig, R., Schulze, D., Erlemann, P., Slawinski, M., & Dellweg, H. (1993) Microbial degradation of polychlorinated biphenyls in contaminated soil *Biotechnology Letters*, (1993) 15(1), 93-98.

Fiedler, H., Hoff, H., Tolls, J., Mertens, C., Gruber, A. & Hutzinger, O. (1994). Environmental fate of organochlorines in the aquatic environment. *Organohalogen Compd.* 15, ECO-INFORMA Press, Bayreuth, 199 pp, ISBN 3-928379-11-9

Finch, S. (1990). Available options for the analysis of PCBs. Dexsil corporation. *Generators Journal*, Winter DIR 12-02, www.dexsil.com.

Fish, K.M., & Principe, J. M. (1994). Biotransformations of arochlor 1242 In Hudson river test tube microcosms, *Applied and Environmental Microbiology*, 60(12), 4289-4296

Franzmeier, D. P., Lemme, G. D, & Miles, R. J. (1985). Organic carbon in soils of north central. United States. *Soil Science Society of America Journal*, 49, 702-708

Furukawa, K., Tonomura, K. & Kamibayashi, A. (1978). Effect of chlorine substitution on the biodegradability of polychlorinated biphenyls.

- Fu, S., Cheng, Liu, H., Zhang, L., Yang, Z., Li, K., Xia, X. & Xu, X. (2008) Polychlorinated Biphenyls Residues in soil in Linfen, China. *Bulletin of Environmental Contamination and Toxicology* 81, 594-598
- Gioia, R., Eckhardt, S., Breivik, K., Jaward, F., Prieto, A., Nizzeto L., & Jones, K. C. (2011). Evidence for major emissions of PCBs in the West African Region". *Environmental Science and Technology* 45(4), 1349-1355.
- Gonzalez, M. J., Jimenez, B., Fernandez M. & Hernandez, L. M. (1991). PCBs, PCDDs and PCDFs in soil samples from uncontrolled burning of waste electrical material for metal reclamation. *Toxicological & Environmental Chemistry* 33(3-4), 169-179
- Green Land Environment (2006, June 9). Screening analysis of polychlorinated biphenyls In waste management-PCB analysis . Canada's World Wide Web. Retrieved August 22, 2007 from <http://www.ec.gc.ca/wmddgd/default.asp?lang=En&n=B0EDBA461&offs et=3&toc=show>
- Greichus, Y. A., Greichus, A., Amman, B. D., Call, D. J., Hamman, D.C., & Pott, R. M. (1977). Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. I. Hartbeespoort Dam, Transvaal and Voëlvlei Dam, Cape Province, Republic of South Africa. *Archives of Environmental Contamination and Toxicology*, 6(2-3), 371-383.
- Guzzela, L., Roscioli, C. Vigano, L. Saha, M. Sarkar, S.K. & Bhattacharya, A. (2005). Evaluation of the concentration of HCH, DDT, HCB, PCB

West Bengal, Northeast India. *Environ. Internat.* 31, 523:534

Harrad, S., Hazrati, S., & Ibarra, C. (2006). Concentrations of polychlorinated biphenyls in indoor air and polybrominated diphenyl ethers in indoor air and dust in Birmingham, United Kingdom: implications for human exposure. *Environmental Science and Technology*, 40, 4633-4638

Harnly, M. E., Petreas, M. X., Flattery, J., & Goldman, L. R. (2000). Polychlorinated dibenzo-pdioxin and polychlorinated dibenzofuran contamination in soil and home-produced chicken eggs near pentachlorophenol sources. *Environmental Science and Technology*, 34, 1143-1149.

Heidelore, F. (2009). Polychlorinated biphenyls (PCBs): Uses and environmental releases. Retrived 2010, March, 5 from http://www.chem.unep.ch/pops/POPs_Inc/proceedings/bangkok/FIEDLER1.html

Hemminger, T., & Mason, B. J. (1994). In D C. Adriano *et al*, (Eds.), Contaminated groundwaters: Northwood, UK. *Science Reviews*, 16, 477-519

Herrick, R. F., Lefkowitz, D. J., & Weymouth, G. A. (2007, February). Soil contamination from PCB-containing buildings. *Environ Health Perspect*, 115(2), 173-175.

Hileman, B., (1988). The Great Lakes Cleanup Effort. *Chemistry and Engineering*, pp. 22-39.

Humphrey H. E. B. (1983). Population studies of PCBs in Michigan residents.

In: F.M. D'Itri, M. Kamrin (Eds.), *PCBs: Human and environmental*

- Hutzinger, O., Safe, S., & Zitko, V. (1971). Polychlorinated biphenyls: Synthesis of some individual chlorobiphenyls *Bulletin of Environmental Contamination and Toxicology* May, 6 (3), 209-219
- Ian, M., & Stutt, E. (2009). Soil guideline values for dioxins, furans and dioxin-like PCBs in soil Science Report SC050021 / Dioxins SGV. Environment Agency, pp 18-23.
- International Programme on Chemical Safety (IPCS), (1993). Polychlorinated biphenyls and terphenyls. Environmental Health Criteria No.140 (2nd edn.). Geneva: World Health Organization /International Programme on Chemical Safety. Retrived July 7, 2009, from <http://www.inchem.org/documents/ehc/ehc/ehc140.htm>
- International Programme on Chemical Safety (IPCS), (2003). Polychlorinated biphenyls: human health aspects. Concise International Chemical Assessment Document (CICAD) No. 55. Geneva: World Health Organization/International Programme on Chemical Safety. Retrived June, 2009, from <http://www.inchem.org/documents/cicads/cicads/cicad55htm>
- Jackson, M. L. (1995). Soil chemical Analysis. Constable and CO. Ltd. London pp.
- Jamshidi, A., Hunter, S., Hazrati, S. and Harrad, S. (2007). Concentrations and chiral signatures of polychlorinated biphenyls in outdoor and indoor air and soil in a major UK conurbation. *Environmental Science and Technology*, 41, 2153-2158

- Jartun, M., Ottesen, R.T., Steinnes, E., & Volden, T., (2009). Painted surfaces – important sources of polychlorinated biphenyls (PCBs) contamination to the urban and marine environment. *Environmental Pollution*, 157, 295- 302.
- Jensen S. (1966). Report on a new Chemical Hazard. *New Scientist* 32, 612
- Johansen, R., Becher, G. & Polder A. (1994). Congener-specific determination of polychlorinated biphenyls and organochlorine pesticides in human milk. from Norwegian mothers living in Oslo. *Journal of Toxicology and Environmental Health*, 42, 157-171
- Jolliffe, T. (1986). *Principal Component Analysis*, Springer, New York,
- Jonker, M. T. O., & Koelman, A. A. (2002). Sorption of polycyclic aromatic hydrocarbons and polychlorinated biphenyls to soot and soot-like materials in the aqueous environment: Mechanistic considerations. *Environmental Science & Technology*, 36, 3725-3734.
- Jones, K. C. (1989). polychlorinated biphenyls. *Chemosphere* 18 (7-8), 1665-72
- Kabata-Pendias A. (2007). Trace elements in soils and plants (3rd ed)..CRC Press; Boca Raton, FL, USA.
- Kania-Korwel I., Parkin S., Robertson L. W., & Lehmler, H. J. (2004 Aug) Synthesis of polychlorinated biphenyls and their metabolites with a modified Suzuki-coupling. *Chemosphere*. 56(8):735-44
- Karlyn, B. K., Carlisle, J., Siegel, D. & Salinas, J. (2006, October). Health concerns and environmental issues with PVC-containing building materials in Green Buildings. Integrated Waste Management Board,

California Environmental Protection Agency, USA, p.11. Retrieved on 08-08.2007

Karickhoff, S.W., Brown, D. S., & Scott, T. A. (1979). Sorption of hydrophobic pollutants on natural sediments. *Water Research*, 13, 241-248.

Karickhoff, S. W. (1984). Organic pollutant sorption in aqueous system. *Journal of Hydraulic Engineering*, 110, 707-735.

Kilmer, V. J. & Alexander, L.T. (1949). Methods of making mechanical analysis of soils. *Soil Science*, 68, 15-24.

Kim, Y. J. & Osako, M. (2003). Leaching characteristics of polycyclic aromatic hydrocarbons (PAHs) from spiked sandy soil. *Chemosphere*, 51, 387-395.

Kimbrough R. D., (1995). Polychlorinated biphenyls (PCBs) and human health: an update. *Critical Reviews in Toxicology*, 25,133–63.

Kimbrough R, D, & Krouskas, C. A. (2003). Human exposure to polychlorinated biphenyls and health effects: a critical synopsis. *Toxicological Reviews*, 22, 217– 233.

Klasson, K. T., Barton, J. W., & Evans, B. S. (1996). Reductive Microbial Dechlorination of Indigenous Polychlorinated Biphenyls in Soil Using a Sediment-Free Inoculum; *Biotechnology Progress* 12, 310-315

Koblickova, M., Ruzickova, P., Cupr, P., Komprda, J., Holoubek, I., & Klanova, J. (2008). Soil burdens of persistent organic pollutants: Their levels, fate, and risks. Part IV. Quantification of volatilization fluxes of organochlorine pesticides and polychlorinated biphenyls from

- contaminated soil surfaces. *Environmental Science & Technology*, 43, 3588-3595.
- Kuhnt G., & Muntau, H. editors, (1994) *Euro-soils: Identification, Collection, Treatment, Characterization* JRC Ispra, European Commission Special Pub. No. 1.94.60
- Kukharchyk T. I., Kakareka, S. V., Khomich, V. S., Kurman, P. V. & Voropai, E. N. (2007). Polychlorinated biphenyls in soils of Belarus: Sources, contamination levels, and problems of study 2007, *Pochvovedenie*, No. 5, pp. 532-540
- Leigh, M. B., & Prouzova, P. (2006). Polychlorinated biphenyl (PCB)-degrading bacteria associated with trees in a PCB-contaminated site. *Applied and Environmental Microbiology*, 72(4), 2331-2342.
- Li, Y. F., Harner T., Liu, L., Zhang, Z., Ren, N.Q., Jia H, Ma, J., & Sverko, E. (2010). Polychlorinated biphenyls in global air and surface soil: distributions, air-soil exchange, and fractionation effect *Environmental Science Technology*, 44(8), 2784-2790.
- Lisa Chamoff, (2011, August 12, Friday). PCBs detected in soil at GHS fields *Greenwich Times*.
- Lincoln D., (1999, February 19). History of PCB pollution problems *Greenlite*. Retrived from <http://hometown.aol.com/davelinc/index.html>
- Lohmann, R., Breivik, K., Dachs, J., & Muir, D. (2007). Global fate of POPs: Current and future research directions. *Environmental pollution*, 150, 150-165.
- Loomes, D., Browning, S., Schenk, A., Gregory, E., & Svitz, D. (1997). Cancer morality among electric unity workers exposed to

- polychlorinated biphenyls. *Occupational Environmental Medicine* 54, 720-728.
- Lubor H. (Dec. 1995) Degradation of PCB in different soils by inoculated *Alcaligenes xylosoxidans*. *Science of The Total Environment*, 175 (3, 15), 275-285
- Lulek, J., Szafran, B., & Lasecka. E. (1999). Levels of polychlorinated biphenyls in soil samples from some former soviet army bases in Poland in R.L. Lipnick (Eds.) Persistent, bioaccumulative, toxic chemicals; Symposia papers presented before the division of environmental chemistry. *American Chemical Society*, pp. 160-162 in Preprints of Extended Abstracts, Vol. 39 No. 1) Anaheim, CA March 21-25.
- Mackay, D., Shiu, W.Y., & Ma, K. C. (1992). *Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals. Volume I & II*. Lewis Publishers Inc., Boca Raton, FL, USA
- Magee, K. D., Michael, A. (2008). Dechlorination of PCB in the presence of plant nitrate reductase, Elsevier Science Bv.
- Mariussen, E., Myhre, O., Reistad, T., & Fonnum, F. (2002). The polychlorinated biphenyl mixture Aroclor 1254 induces death of rat cerebellar granule cells: the involvement of the N-methyl-d-aspartate receptor and reactive oxygen species. *Toxicology and Applied Pharmacology*, 179, 137- 144.
- Massart, D. L. & Kaufman, L. (1983). The interpretation of analytical chemical data by the use of cluster analysis. New York: Wiley,

- Meijer, S. N., Ockenden, W. A., Sweetman, A., Breivik, K., Grimalt, J. O., & Jones, K. C. (2003). Global distribution and budget of PCBs and HCB in background surface soils: implications for sources and environmental processes. *Environmental Science & Technology*, 37, 667-672
- Michigan Department of Environmental Quality (2005). Soil direct contact risk-based screening levels. Technical Support Document - Attachment 6, part 201, Soil direct contact criteria part 213 tier I. Remediation & Redevelopment Division Operational Memorandum No.1
- Mohammadi, M., & Chalavi, V. (2007). Expression of bacterial biphenyl-chlorobiphenyl dioxygenase genes in tobacco plants. *Biotechnology and Bioengineering* 97(3), 496-505.
- Montague, P.P. (1993). The History of Chlorinated Diphenyls (PCBs) Part 1 *Hazardous Waste News*, No.327.
- Montague, P. (1993). How we got here - Part 2. *Hazardous Waste News*. No. 329,
- Montague, R. (1989). Thanks to Monsanto. *Hazardous Waste News*, No. 144,
- Morton-Bermea, Hernández-Álvarez E., González-Hernández, G., & Romero, F. (2009). Assessment of heavy metal pollution in urban topsoils from the metropolitan area of Mexico City. *Journal of Geochemical Exploration* 101, 218-224
- Mousa, M. A., Quensen III, J. F., Chou, K., & Boyd, S. A. (1996). Microbial dechlorination alleviates inhibitory effects of PCBs on mouse gamete

- fertilization in vitro. *Environmental Science & Technology*, 30, 2087-2092
- Mullin, M. D., Pochini, C. M., & McCrindle, S. (1984). High Resolution PCB Analysis: Synthesis and Chromatographic Properties of all 209 PCB Congeners. *Environmental Science & Technology*, 18, 468-476.
- Nies, L., & Vogel, T. M. (1990). Effects of organic substrates on dechlorination of Aroclor 1242 in anaerobic sediments. *Applied and Environmental Microbiology*, 56, 2612-2617
- Njoroge, k. B. N., Ball, W. P., & Cherry, R. S. (1998). Sorption of 1, 2, 4-trichlorobenzene and tetrachloroethene within an authigenic soil profile: Changes in Koc with soil depth. *Journal of Contaminant Hydrology*, 29, 347-377.
- Osibanjo O. (2006). Global and national POPs situation-effort and challenges. A commissioned paper presented at NES-IPEP Awareness Raising Workshop, Lagos. www.ipen.org p 69.
- Osibanjo, O., & Bamgbose, O. (1990). Chlorinated hydrocarbons in marine fish and shellfish of Nigeria. *Marine Pollution Bulletin*, 21, 581-6.
- Otchere, Fred A. (2005). Organochlorines (PCBs and pesticides) in the bivalves *Anadara (Senilis) senilis*, *crassostrea tulipa* and *Perna perna* from the lagoons of Ghana. *Science of the Total Environment*, 348, 102- 114
- Philips, D. J. H. (1986). *PCBs and the environment*. Vol.2 CRC Pronn, the UNA pp. 191
- Pless-Mullooli, T., Schilling, B., Paepke, O., Griffiths, N., & Edwards, R. (2001). Transfer of PCDD/F and heavy metals from incinerator ash

- on footpaths in allotments into soil and eggs. *Organohalogen Compounds*, 51, 48-52.
- Pu X., Lee L. S, Galinsky R. E, & Carlson, G. P. (2006, January 5) Bioavailability of 2,3',4,4',5-pentachlorobiphenyl (PCB118) and 2,2',5,5'-tetrachlorobiphenyl (PCB 52) from soils using a rat model and a physiologically based extraction test. *Toxicology*, 217(1), 14-21.
- Qin, S. W., Gu, Y. C., & Zhu, Z. L. (1998). A preliminary report on long-term stationary experiment on fertility evolution of fluvo-aquic soil and the effect of fertilization. *Acta Pedologica Sinica* (in Chinese). 35, 367-375.
- Qiao, M., Chen, Y.Y., Zhang, Q. H., Huang, S. B., Ma, M., Wang, C. X., & Wang, ZJ. (2006). Identification of Ah receptor agonists in sediment of Meiliang Bay, Taihu, China. *Environmental Science & Technology*, 40, 1415-1419.
- Quensen III, J. F. Boyd, S. A., & Tiedje, J. M. (1990). Dechlorination of four commercial polychlorinated biphenyl mixtures (Aroclors) by anaerobic microorganisms from sediments. *Applied and Environmental Microbiology*. 56, 2360-2369
- Reijnders. P. (1986). Reproduction failures in common seals feeding on fish from Polluted coastal waters. *Nature*, 324, 456-457.
- Ren, N. M. Que, Li, Y. F., Liu, U., Wan, X., Xu, D., Sverko, E., & Ma, J. (2007). Polychlorinated Biphenyls in Chinese Surface Soils *Environmental Science & Technology*, 41: 3871-3876.
- Rezek, J., Macek, T. (2007). Plant metabolites of polychlorinated biphenyls in hairy root culture of black nightshade *Solanum nigrum* SNC-90

Chemosphere, 69 (8), 1221-1227.

Rhee, G-Yull Sokol, R. C., Bush, B. & Bethoney, C. M. (1993). Long-term study of the anaerobic dechlorination of aroclor 1254 with and without biphenyl enrichment. *Environmental Science & Technology*, 27, 714-719

Ribus-Fito 'N, Sala M., & Koge vinas M. (2001). Polychrominated byphenyls (PCBs) and neurological development in children. A systemic review *Journal of Epidermology & community Health*, 55, 537-546.

Riseborough, R. & Brodine, V. (1971). More letters in the wind. In S. Novick & D. Cottrell (Eds.), *Our World in Peril: An Environment Review* Greenwich, Conn.: Fawcett, pp. 243-255.

Rousk, J., Philip, C. Brookes, and Erland, B. (2009, March.) Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied Environmental Microbiology*. 75(6), 1589-1596

Ruiz-Lea, l M., & George S. (2004). An in vitro procedure for evaluation of early stage oxidative stress in an established fish cell line applied to investigation of PHAH and pesticide toxicity. *Marine Environmental Research*; 58:631- 5.

Rusling, J. F., & Miaw, C. L. (1989). Kinetic estimation of standard reduction potentials of polyhalogenated biphenyls. *Environmental Science & Technology*, 23, 476-479

Schafer, K. S., & Kegle, y, S. E. (2002). Toxic chemicals in the US food supply. *Journal of Epidemiology and Community Health*; 56:813-817.

- Scheringer, M. (2009). Long-range transport of organic chemicals in the environment. *Environmental Toxicology & Chemistry*, 28, 677-690.
- Schmidt, M. W. I., Skjemstad, J. O., & Jaeger, C. (2002). Carbon isotope geochemistry and nanomorphology of soil black carbon: Black chernozemic soils in central Europe originate from ancient biomass burning. *Global Biogeochemical Cycles*, 16, 1123-1131.
- Schroeder M. (1991, August 12). Did westinghouse keep mum on PCBs? *Business Week*, pp. 68-77
- Scott C., Van Langenhove, A. & Maxfield, R. (2002). Standard operating procedure for polychlorinated biphenyls (PCBS). Field testing for soils and sediment samples. Office of Environment Management and Evaluation, EPA Region, New England. pp 1-15.
- Sample, K. T., Morriss, A. W. J., & Paton, G. I. (2003). Bioavailability of hydrophobic organic contaminants in soils: fundamental concepts and techniques for analysis. *European Journal of Soil Science*, 54: 809-818.
- Simon, T., Britt, J. K., & James, R. C. (2007, July). Development of a neurotoxic equivalence scheme of relative potency for assessing the risk of PCB mixtures. *Regulatory toxicology and pharmacology*, RTP 48 (2), 148-70.
- Sittig, M. (1981). *Handbook of toxic and hazardous chemicals*, Noyes Publications, New Jersey NJ: 729 pp.
- Smith, K. E., & Schwab, A. R. (2007). Phytoremediation of polychlorinated biphenyl (PCB)-contaminated sediment: A greenhouse feasibility study. *Journal of Environmental Quality*, 36(1), 239-244.

- Soil survey manual (1993). Selected chemical properties. Soil Conservation Service. U.S. Department of Agriculture Handbook 18. Chapter 3.
- Solomon, G, & Weiss, P. (2002). Environmental contaminants in breastmilk. San Francisco: Time trends and regional variability. *Environmental Health Perspective*, 110, A339-A347
- Spongberg A. L. & Witter J. D. (2009). A review of PCB concentrations in tropical media, 1996-2007. *Rev. Biol. Trop.*, 56 (Suppl. 4), 1-9
- Strek, H. J., & Weber, J. B. (1982). Behaviour of polychlorinated biphenyls (PCBs) in soils and plants. *Environmetal Pollution*, (Series A) 28, 291-312
- Subramanian, A., Tanabe, S., & Tarsukaaura, R.. (1988). Use of Organochlorines as chemical tracers in determining reproductive parameters in dalls' porpoises. *Marine Pollution*, 1988
- Subramanian, A., Tanabe, S., Tatsukaura, R., Sairo, N. & Miyanznki, N., (1987). "Reduction in the testosterone levels by PCBs and DDE in Dalls' porpoises. *Marine Pollution Bulletin*, 18, 643-646.
- Sweetman, A. J., Valle, M. D., Prevedouros, K., & Jones, K. C. (2005). The role of soil organic carbon in the global cycling of persistent organic pollutants (POPs): interpreting and modelling field data. *Chemosphere*, 60: 959-972.
- Tanabe, S. (1988). PCB problems in the future. *Environmental Pollution*. 50, 5-28.
- Thao, Vu Duc, Toan, Vu Duc and Kawano, Masahide (2009) Temporal Variation of Persistent Organochlorine Residues in Soils from Vietnam. In Y. Obayashi, T. Isobe, A. Subramanian, S. Suzuki and S.

- Tanabe (Eds.), *Interdisciplinary Studies on Environmental Chemistry*
— *Environmental Research in Asia*, pp. 73–82.
- Treger, Y. A. & Rozanov, V. N. (2000). Production and consumption of polychlorinated biphenyls in Moscow, Russia, *Polychlorinated Biphenyls*, 5, 64–70.
- Tryphones, H. (1995). Immunotoxicity of PCBs in relation to the Great Lakes
Environment Health Perspectives 103, Supp. 19, pp.35-46.
- United Nations Environment Programme (2001). The Stockholm Convention. UNEP. Retrieved from <http://www.chem.unep.ch/sc/>
- United Nations Environment Programme (UNEP). (1997). Proceedings of the Subregional Awareness Raising Workshop on Persistent Organic Pollutants (POPs), Bangkok, Thailand November 25-28th, Retrieved December 11, 2007
- United Nations Environment Programme (UNEP) Chemicals, (1999).
Guidelines for the Identification of PCBs and Materials Containing PCBs. United Nations Environment Programme, p.2. Retrieved on 2007-11-07
- United Nations Environment Programme (UNEP), (1999). Inventory of Information Sources on Chemicals – Persistent Organic Pollutants, UNEP
- UNEP Chemicals and UNEP Environmental Law and Institutions. (1995).
Guidance on Chemicals Legislation – An Overview, Prepared by – Programme Activity Center, UNEP
- University of California - Davis - Health System (2009, April 14). How PCBs May Alter In Utero, Neonatal Brain Development. *Science Daily*.

Retrieved April 12, 2011, from <http://www.sciencedaily.com-/releases/2009/04/090413204546.htm>

U.S. Environmental Protection Agency. (August 1990). *Guidance on remedial Actions for superfund sites with PC contamination*. EPA/540/G 90/007, p33.

US Environmental Protection Agency (1989). Risk assessment guidance for superfund (RAGS), vol 1, Human Health Evaluation Manual (Part A).OWSER Directive 92857-01A USA EPA-540/1-89-002.

US Environmental Protection Agency (1996). *Reference Methodology*, 3665A, 8000B, p 41, US EPA, Washington, DC.

US Environmental Protection Agency Reference Methodology, (1999).

Standard opening procedure for the digestion of soil/sediment sample using a hot plate/beaker digestion technique, Chicago, IL. SW-846.US EPA, Washington, DC.

US Environmental Protection Agency (2007). Polychlorinated biphenyls (pcbs) by Gas Chromatography *US EPA Method 8082A* Revision 1, p37.

Van den Berg, M., Birnbaum, L., Bosveld, A.T.C., Brunström, B., Cook, P., Feeley, M.*et al.* (1998). Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. *Environ. Health Perspect*, 106,775-792

Van Hoof & Hsieh, (1996). Analysis of Polychlorinated Biphenyls and Chlorinated Pesticides by Gas Chromatography with Electron Capture Detection; National Oceanic and Atmospheric Administration,

- Commonwealth Boulevard, Standard Operation Procedures GLERL-M-501-02, version 2. Pp. 337- 347
- Van Leeuwen, F. X. L., & Younes, M. (1998). WHO Tolerable Daily Intake (TDI) for dioxins. *Organohalogen Compounds*, 44, 421-424.
- Voie, O. A. & Fonnum, F. (2000). Effect of polychlorinated biphenyls on production of reactive oxygen species (ROS) in rat synaptosomes. *Archives of Toxicology* 73:588- 93.
- Waegeneers, N., De steur, H., Detemmerman, L., Van Steenwinkel, S., Gellynck, X. & Viaene, J., (2009). Transfer of soil contaminants to home-produced eggs and preventive measures to reduce contamination. *Science of the Total Environment*, 407, 4438-4446
- Wahid, P. A., & Sethunathan, N., (1979). *Journal of Agric. Food Chem.* 27, 1050
- Weber, W. J. Jr., McGinley, P. M., & Katz, L. E. (1992). A distributed reactivity model for sorption by soils and sediments: Conceptual basis and equilibrium assessments. *Environmental Science & Technology*, 26, 1955-1962.
- World Health Organization. (1993), Polychlorinated biphenyls and terphenyls. *Environmental Health Criteria*, 140. WHO Geneva.
- World Health Organization. (1997, August):.WHO Toxic Equivalency Factors (TEFs) for Dioxin-like Compounds for Humans and Wildlife. Presented at DIOXIN' 97, 17th International Symposium on Chlorinated Dioxins and Related Compounds, Indianapolis, Indiana, USA, 25.-29.

- Willet, P. (1987). *Similarity and Clustering in Chemical Information Systems*. Letchworth, Research Studies Press, Wiley, New York.
- Williams, W. A. (1994). Microbial reductive dechlorination of trichlorobiphenyls in anaerobic sediment slurries. *Environmental Science & Technology* 28:630-635.
- Wirgin, I., Roy, N. K., Loftus, M., Chambers, R. C., Franks, D. G., & Hahn, M. E. (2011). Mechanistic Basis of Resistance to PCBs in Atlantic Tomcod from the Hudson River. *Science* 331, 1322-1325
- Wisconsin Department of Natural Resources. (2003). Cncensus based sediment quality guidelines. Recommendations for use and application. Department of interior, Washington D.C. 20240 p 17.
- Wolfgang, W., Krauss, M., Safronov, G., Fokin, A. D., & Kaupenjohann M. (2006). Polychlorinated biphenyls (PCBs) in soils of the Moscow region: Concentrations and small-scale distribution along an urban-rural transect. *Environmental Pollution*, 141(2), 327-335.
- Wong, M. H., & Poon, B.H.T. (2003). Sources, fates and effects of persistent organic pollutants in China, with emphasis on the Pearl River Delta. In Fiedler, H. (Ed.), *The Handbook of Environmental Chemistry*. Persistent Organic Pollutants, vol. 3. Springer-Verlag, Berlin Heidelberg, pp. 355-369.
- Woods, S. L., & Trobaugh D. J. (1999). "Polychlorinated Biphenyl Reductive Dechlorination by Vitamin B12s: Thermodynamics and Regiospecificity". *Environmental Science & Technology*, 33 (6), 857-863.

- Wurl, O. & Obbard, J. P. (2005). Organochlorine pesticides, polychlorinated biphenyls and polybrominated diphenyl ethers in Singapore's coastal marine sediments. *Chemosphere*, 58,925-933.
- Xinzhu. P., Lee, L. S., Galinsky, R. E., & Carlson, G. P. (2006). Bioavailability of 2,3',4,4',5-pentachlorobiphenyl (PCB118) and 2,2',5,5' tetrachlorobiphenyl (PCB52) from soils using a rat model and a physiologically based extraction test. *Toxicology*, 217(1, 5) 14-21
- YanJun, C., Gopal, A., & Cooper H. L. (2010). Effect of Co-contaminants on the Remediation of PCB-Impacted Soils by Hydrogen Peroxide. *Pract. Periodical of Haz. Toxic, and Radioactive Waste Management*. 14(4), 266-268.
- Yawson, D. O., Kwakye, P. K., Armah, F. A., & Frimpong, K.A. (Jan. 2011) The dynamics of potassium (k) in representative soil series of Ghana. *Journal of Agricultural and Biological Science*, 6(1), 1990-6145
- Yu, L., Xin, G., Gang, W., Zhang, Q., Su, Q., & Xiao, G. (2008). *China, Journa. Environmental. Science*. 20, 607-612.
- Yu, X. Y., Ying, G. G., & Kookana, R .S. (2006). Sorption and desorption behavior of diuron in soil amended with charcoal. *Journal of Agricultural and Food Chemistry*, 54, 8545-8550.
- Zennegg, M., Kohler, M., Tremp, J., Seiler, C., Minder-Kohler, S., & Beck M. (2004). Joint sealants, an overlooked diffuse source of polychlorinated biphenyls (PCB) results of a nationwide study in Switzerland. *Organohalogen Coumpounds*, 66, 899-904
- Zeeb, B. A., & Amphlett, J. S. (2006). "Potential for phytoremediation of

polychlorinated biphenyl-(PCB)contaminated soil." *International Journal of Phytoremediation*, 8(3), 199-221

Zhang, J. Y., Qiu, L. M., He, J., Liao, Y., & Luo, Y. M. (2007). Occurrence and congeners specific of polychlorinated biphenyls in agricultural soils from Southern Jiangsu, China. *Journal of Environmental Sciences (China)*. 19(3), 338-42.



APPENDIX A

PCB NOMENCLATURE CONVERSION TABLE

Two different systems are used for naming PCBs: In the IUPAC system the numbers at the beginning of the name specify the sites where chlorines are attached to the two phenyl rings. In this table (A2), the top row indicates the position of the chlorine atoms on one phenyl ring and the first column their position on the second phenyl ring. Another system developed by Ballschmiter & Zell (1980) assigns a separate number, from 1 to 209, to each of the 209 specific PCB congeners. These numbers are indicated inside the table below. An example how to relate the two systems is provided in the conversion table.

Example (illustrated by shaded area in table): To determine IUPAC and alternative names for PCB 156:

- [1] Locate PCB 156 within table.
- [2] Identify the associated column heading (2345) and row heading (34) values.
- [3] The IUPAC name for PCB 156 is 2,3,3',4,4',5-hexachlorobiphenyl.

Various additional names for this congener include 2,3,4,5,3',4'-hexachlorobiphenyl, 2345-3'4'-hexachlorobiphenyl (group starting with lower number appears first), 2345-34-hexachlorobiphenyl, and 233'44'5-hexachlorobiphenyl. Adapted from Frame *et al.* (1996)

Table A1: PCB Nomenclature Conversion Table

Chlorine positions on each ring	None	2	3	4	23	24	25	26	34	35	234	235	236	245	246	345	2345	2346	2356	23456
23456																				
2356																				209
2346																			202	208
2345																		197	201	207
345																	194	196	199	206
246																169	189	191	193	205
245															155	168	182	184	188	204
236														153	154	167	180	183	187	203
235													136	149	150	164	174	176	179	200
234												133	135	146	148	162	172	175	178	198
35											128	130	132	138	140	157	170	171	177	195
34										80	107	111	113	120	121	127	159	161	165	192
26								77	79	105	109	110	118	119	126	156	158	163	190	
25							54	71	73	89	94	96	102	104	125	143	145	152	186	
24						52	53	70	72	87	92	95	101	103	124	141	144	151	185	
23					47	49	51	66	68	85	90	91	99	100	123	137	139	147	181	
4				40	42	44	46	56	58	82	83	84	97	98	122	129	131	134	173	
3			15	22	28	31	32	37	39	60	63	64	74	75	81	114	115	117	166	
2		11	13	20	25	26	27	35	36	55	57	59	67	69	78	106	108	112	160	
None	0	1	2	3	5	7	9	10	12	14	21	23	24	29	30	38	61	62	65	116

APPENDIX B

RESULTS OF RECOVERY AND PRECISION STUDIES

Table B1: Precision of PCB analysis expressed as Relative Percent Different (RPD%)

PCB Congener	Area-Count		$A=C_2-C_1$	$B=\frac{1}{2}(C_1+C_2)$	RPD% = A/B
	C_2	C_1			
28	114278	123797	9519	119037	8.00
52	111527	120817	9290	116172	8.00
101	148329	160684	12356	154507	8.00
118	199394	216003	16609	207699	8.00
138	203236	220165	16930	211701	8.00
153	190069	205901	15833	197985	8.00
180	231833	251144	19312	241489	8.00
Total	2576512	2791136	113557	142003	8.00

C_1 and C_2 are area counts of duplicate analysis of a 0.2 ppm PCB mix standard

Table B2: Recovery of 0.2 ppm PCB mix standards from spike duplicate soil samples

PCB Congener	Area Count		$R=C_s-C_n$	$R\%=100R/C_n$
	C_s	C_n		
28	215985	114278	101707	89
52	210786	111527	99259	89
101	280342	148329	132013	89
118	376855	199394	177461	89
138	384116	203236	180880	89
153	359230	190069	169161	89
180	438164	231833	206331	89
Total	2576512	1363234	1213278	89

C_s = mean area count of duplicate spike soil samples

APPENDIX C

SOME DISTRIBUTION TRANSFORMERS IN THE CENTRAL REGION OF GHANA

APPENDIX

DISTRIBUTION TRANSFORMERS

GENERAL INFORMATION		TRANSFORMER DATE	
DISTRICT NAME	LOCATION	YEAR OF MANUFACTURED	YEAR OF COMMISSIONED
Winneba	N.T.L.(Not in Service)	1957	1960
Winneba	Lodge P/M	1960	1962
Winneba	Police T. Depot	1972	1974
Winneba	Basic Chemicals	1064	1965
Winneba	Apam Mamfam	1975	1976
Winneba	Baah Ld	1975	1976
Winneba	Brick & Tile	1976	1978
Winneba	Pumping Station	1977	1978
Winneba	Apam Sec. School	1984	1985
Winneba	Pomadze Feed Mill	1991	1992
Winneba	Owinase	1991	1992
Cape Coast	Ankaful Hospital	1963	1964
Cape Coast	Brimso Water Works	1964	1965
Cape Coast	Brofoyedur	1970	1971
Cape Coast	District Police Station	1970	1971
Cape Coast	Ashanti Road	1970	1972
Cape Coast	Elmina Market	1970	1971
Cape Coast	Fruits and Flavour	1970	1972
Cape Coast	Leprosarium	1971	1972
Cape Coast	Pedu Estate	1971	1972
Cape Coast	Yanka Farms	1972	1998
Cape Coast	Mfantshipim School	1972	1973
Cape Coast	Kudos	1977	1978
Cape Coast	Nurses Flat	1975	1976
Cape Coast	Cape Coast Poly	1975	1976
Cape Coast	Brimso Water Works	1981	1982
Cape Coast	SSNIT Flar	1982	1983
Cape Coast	Amen	1983	1984
Cape Coast	Elmina Clinic	1986	1986
Cape Coast	Pan Sawmill	1987	1988
Cape Coast	Peshie	1988	1989
U.C.C.	Science Audit	1967	1968
U.C.C.	C.S.D.	1967	1968
U.C.C.	New Library	1967	1968
Agona Swedru	GWSC	1963	1965
Agona Swedru	ECG Main Yard	1964	1965
Agona Swedru	Besease	1972	1995
Agona Swedru	Asare Sawmills	1973	
Saltpond	Saltpond	1970	
Saltpond	Saltpond	1970	
Saltpond	Mankessim	1961	
Saltpond	Anomabu	1971	
Saltpond	Mankesim	1972	
Saltpond	Ekurabadzd	1976	
Saltpond	Saltpond	1978	

APPENDIX D

REAGENTS AND SOLUTIONS

Potassium dichromate powder, acetone, orthophosphoric acid (85% sg. 1.77), sulphuric acid (96%, sg), hydrochloric acid (36% w/v), Barium diphenylamine sulphate indicator, sodium hexametaphosphate, pH standard buffer mixtures (pH 4 ± 0.02 and pH 9 ± 0.02 Buffer tablets), silver nitrate, anhydrous sodium nitrate, ammonium ferrous sulphate, potassium chloride, 96% ethanol potassium nitrate, ammonium chloride, sodium hydroxide, sodium fluoride, silica gel (30 -70 mesh) for column, nitric acid (sg 1.4), mono-ethanol, ammonia solution (35%), diethyl ether, ethyl acetate, phenolphthalein, all analar grades were obtained from BDH of UK. Acetone and hexane were obtained from Fizmerk, India. Ethyl acetate (99%, sg 1.62) was obtained from Spark Scientific Limited, UK

Reagents

Calgon (5%)

50 g of sodium hexametaphosphate and 5.724 g of sodium carbonate were dissolved in a litre of double distilled water.

0.1 M Hydrochloric acid solution

Approximately 8.6 ml of concentrated hydrochloric acid (36%) was transferred into a one liter volumetric flask and diluted with distilled water to the mark.

Sodium fluoride Solution (4% w/v)

4 g of sodium fluoride was dissolved in 20 ml of distilled water in a beaker, transferred into 100 ml volumetric flask and dilute with of distilled water to the mark.

Phenolphthalein Indicator

0.1 g of Phenolphthalein was dissolved in 20 ml of distilled water in a beaker. This was transferred into 100 ml volumetric flask and diluted with distilled water to the mark

Buffer pH 5

16.4 g of Sodium ethanoate was dissolved in 200 ml of 0.1M ethanoic acid in a beaker. This was transferred into one litre volumetric flask and diluted to the mark with 0.1M ethanoic acid.

Barium diphenylamine sulphate Indicator

2.0 g of Na_2CO_3 was dried at 105°C in an oven for 2 hours. 1.0 g of the Na_2CO_3 and 1.0 g of Barium diphenylamine sulphate were dissolved in 100 ml of double distilled water.

0.167 M $\text{K}_2\text{Cr}_2\text{O}_7$ Standard Solution

49.04 g of $\text{K}_2\text{Cr}_2\text{O}_7$ was dried at 105°C and then dissolved in double distilled water and dilute to one litre.

0.5 M Fe^{2+} Standard Solution:

196.1 g of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4) \cdot 6\text{H}_2\text{O}$ was dissolved in 800 ml of water containing 20 ml of concentrated H_2SO_4 and diluted to litre.

$\text{AgNO}_3/\text{H}_2\text{SO}_4$ Mixture

10 g of AgNO_3 was dried at 105°C in an oven for 2 hours. 5.0 g of the dried AgNO_3 was dissolved in 200 ml of concentrated sulphuric acid. It was transferred into a 500 ml volumetric flask and concentrated H_2SO_4 added up to the mark.

0.2 M Ammonium chloride Solution

107g of NH_4Cl was dissolved in about 100 ml of distilled water. This was transferred into a one litre volumetric flask and made up to the mark with distilled water.

0.5 M Potassium hydroxide Solution

28.0 g of potassium hydroxide pellet was dissolved in one litre of distilled water.

1.0 MKCl Replacing Solution

74.6g of potassium chloride was placed in a 300 ml beaker. 250 ml of double distilled water was added and stirred to dissolve. It was transferred into one litre volumetric flask and diluted with distilled water to the mark.

1.0 M Ammonium acetate (NH_4OAc) Saturating Solution

57 ml glacial acetic acid (99.5%) was diluted with 800 ml of distilled water in a one litre volumetric flask. 68 ml of concentrated ammonia solution ($\approx 35\% \text{NH}_3$ w/v) was added, mixed and cooled. The pH was adjusted to 7.0 with ammonia and diluted to one litre.

0.01 M Sodium hydroxide Solution

0.04 g of sodium hydroxide was dissolved in 200 ml of distilled water in a beaker. This was transferred into one litre volumetric flask and diluted to the mark with of distilled water

DRY WEIGHT OF SOILS

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No	Sampling Site/ID		Sample A (0-10 cm)			Sample B (10-20 cm)			Sample C (20-30 cm)		
			1	2	mean	1	2	mean	1	2	mean
1	UCC Science Library	UL	99.02	99.60	99.21	99.2	98.80	99.00	98.80	97.60	98.20
2	UCC Auditorium	UA	99.50	99.66	99.58	99.80	99.80	99.80	99.80	99.60	99.70
3	UCC CDS	UCDS	99.00	99.04	99.02	99.00	99.00	99.00	98.0	98.80	98.40
4	Nurses Flat	NF	99.00	99.04	99.02	98.60	97.80	98.20	99.00	99.40	99.20
5	Pedu	P	99.76	99.64	99.70	99.79	99.81	99.80	96.20	96.20	96.20
6	Mfantsipim Sec. Sch.	MSS	99.00	9.00	99.00	98.06	98.06	98.07	99.80	99.20	99.50
7	Ashante Road	AR	98.00	99.60	98.80	99.60	98.8	98.70	98.90	99.0	98.95
8	Brofoyedur	B	98.84	98.78	98.81	99.60	99.20	99.40	98.80	98.80	98.80
9	Elmina Market	EM	99.5	99.64	99.57	99.0	98.40	98.70	98.40	97.80	98.20
10	Elmina Clinic	EC	98.60	98.80	98.70	97.20	97.20	97.20	98.80	98.60	98.70
11	Elmina SSNIT Flat	ESF	96.60	97.96	97.28	98.40	98.40	98.40	98.58	98.62	98.60
12	Anomabo	A	96.31	96.31	96.31	96.20	96.0	96.10	98.27	97.20	97.74
13	Salt Pond, Aahamadyah	SA	95.80	97.84	96.82	99.80	99.80	99.80	97.60	98.80	98.70
14	Salt Pond, ECG Office	SEC	98.58	98.54	98.58	99.20	99.20	99.20	98.76	98.80	98.78
15	Mankesim	M	99.20	99.22	99.21	99.20	99.40	99.30	99.20	99.30	99.25
16	Mankesim, ECG Office	MEC	98.76	98.22	98.49	99.8	99.6	99.70	98.02	98.62	98.32
17	Apam Manfam	AM	96.27	95.21	95.29	95.60	95.60	95.60	96.0	96.44	96.22
18	Apam Sec. Sch	ASS	93.11	92.68	92.90	91.25	90.65	90.95	95.60	94.4	95.00
19	Winneba	NVTI	96.26	96.15	98.20	97.00	97.00	97.0	97.0	96.6	98.80
20	Winneba Baah Ltd.	WBL	97.42	97.58	97.50	98.00	99.20	98.80	98.80	98.6	98.70
21	Winneba, Police Dep,	WPD	99.92	99.88	99.90	98.01	98.09	98.05	96.80	97.8	97.30
22	Winneba Basic Chemicals		99.10	99.18	99.14	99.40	99.60	99.50	99.20	99.20	99.20
23	Swedru ECG Office	ASEC	99.04	98.90	99.02	99.80	99.60	99.70	98.80	98.92	98.86
24	Swedru Saora park	ASSP	95.69	95.94	95.82	94.40	94.80	94.60	95.6	95.6	95.6
25	Nsaba ,Post Office	AN	95.68	95.74	95.71	96.20	96.20	96.20	96.20	96.6	96.40
26	Konyako GWCL	KGW	93.99	93.74	93.82	98.40	98.20	98.20	96.30	95.5	95.90

Table F1 Results of Soil Analysis

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Sample	Moisture	pH	OM	Acidity	Base	CEC	sand	silt	clay	Zn	Cu	Fe	Pb	Al
UL ₀₋₁₀	0.79	6.36	2.97	0.28	1.53	1.56	55.73	38.67	5.6	4.12	1.77	240.8	0.5	7.06
UA ₀₋₁₀	0.42	8.3	3.75	0.23	1.58	1.61	80.4	10.8	8.8	1.06	0.19	0.56	0.48	0.92
CDS ₀₋₁₀	0.98	6.8	4.64	0.29	1.68	1.97	62.92	34.68	2.4	1.48	2.21	11.93	0.22	6.24
NF ₀₋₁₀	0.98	8.1	4.75	0.27	1.45	1.48	69.34	23.46	7.2	1.32	0.21	0.58	0.29	1.5
P ₀₋₁₀	0.3	7.21	4.64	0.37	1.04	1.08	76.38	7.62	16	0.03	0.1	0.4	1.35	1.04
MSS ₀₋₁₀	1	7.53	5.92	0.47	0.78	1.25	74	19.6	6.4	2.6	0.62	132.2	0.81	7.35
AS ₀₋₁₀	1.2	7.92	2.04	0.35	0.72	1.07	68.53	25.07	6.4	2.34	0.88	154.3	1.19	4.88
B ₀₋₁₀	1.19	4.96	2.12	1.29	3.00	4.3	78.26	12.16	9.6	3.02	0.64	39.88	0.84	6.11
EM ₀₋₁₀	0.43	8.16	1.79	0.81	1.59	2.4	71.08	26.52	2.4	3.83	0.04	0.43	0.08	0.54
EC ₀₋₁₀	1.3	5.97	4.78	0.36	1.21	1.57	41.52	48.08	10.4	2.99	8.44	167.2	0.18	5.36
ESF ₀₋₁₀	2.72	6.66	14.14	1.07	2.95	4.02	63.95	34.45	1.6	3.8	0.82	104	0.6	8.4
A ₀₋₁₀	3.69	7.08	1.96	0.23	0.69	0.92	81.42	2.58	16	0.93	0.42	46.52	0.28	7.11
SA ₀₋₁₀	4.18	7.65	4.22	0.26	1.24	1.5	80.4	10.8	18.8	2.72	0.25	5.01	0.91	4.56
SEC ₀₋₁₀	1.43	6.83	2.23	0.32	0.49	0.81	66.74	26.86	6.4	1.7	0.74	104.6	0.47	6.85
M ₀₋₁₀	0.78	6.32	3.18	0.25	3.11	3.46	81.59	14.41	4	42.84	2.49	42.14	2.68	8.52
MEC ₀₋₁₀	1.56	7.51	4.56	0.32	1.39	1.71	62.17	26.63	11.2	3.24	0.07	162.5	0.34	1.12
AM ₀₋₁₀	4.76	7.12	4.93	0.26	3.02	3.28	62.92	31.48	5.6	2.38	0.06	3.44	0.03	0.39
ASS ₀₋₁₀	7.11	6.83	4.93	0.23	2.07	2.3	33.09	39.71	27.2	2.92	0.33	3.01	0.44	3.00
NVT ₀₋₁₀	3.8	7.38	3.27	0.26	1.53	2.79	59.22	20.78	20	1.26	0.1	2.09	1.16	4.48
WBL ₀₋₁₀	2.5	7.7	1.32	0.21	0.91	1.12	76.37	18.83	14.8	2.16	0.24	12.62	0.43	4.97
WPD ₀₋₁₀	0.1	8.67	0.65	0.23	0.95	1.18	95.82	2.18	2	1.66	0.32	36.35	0.15	3.3
BC ₀₋₁₀	0.86	6.94	5.08	0.25	0.58	0.83	86.94	8.26	4.8	1.05	1.19	134.4	0.38	5.51
ASE ₀₋₁₀	1.03	6.86	2.07	0.3	0.94	1.24	92.01	5.99	2	2.95	1.19	158.6	0.32	6.62
ASP ₀₋₁₀	4.19	8.05	6.14	0.35	2.06	2.41	74.64	21.36	4	4.32	0.82	20.04	1.73	7.6
AN ₀₋₁₀	4.29	6.35	3.12	0.23	1.78	2.01	69.34	13.8	16.8	3.85	0.79	42.54	1.11	10.36
KGW ₀₋₁₀	6.14	5.63	5.43	0.25	1.77	2.02	70.18	24.22	5.6	1.41	1	20.9	1.01	4.4

TABLE 1.1

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Sample	Moisture	pH	OM	Acidity	Base	CEC	sand	silt	clay	Zn	Cu	Fe	Pb	Al
UL ₁₀₋₂₀	1	7.3	2.27	0.29	2.41	2.7	64.79	28.81	6.4	1.45	0.74	366.4	0.25	7.36
UA ₁₀₋₂₀	0.2	6.97	6.96	0.37	1.48	1.85	80.45	16.35	3.2	0.88	0.18	0.51	0.44	0.79
CDS ₁₀₋₂₀	1	6.7	5.45	0.26	1.24	1.5	66.44	31.16	2.41	1.48	2.54	42.86	0.27	4.58
NF ₁₀₋₂₀	1.8	6.63	4.35	0.42	1.28	1.7	61.4	18.6	20	1.33	0.66	43.4	0.72	4.48
P ₁₀₋₂₀	0.2	7.23	3.2	0.41	2.34	2.75	78.13	19.47	2.4	1.62	0.64	129.5	1.32	4.02
MSS ₁₀₋₂₀	1.3	7.44	7.36	0.39	0.86	1.25	71.58	22.02	6.4	4.05	1.9	134.4	3.18	6.05
AR ₁₀₋₂₀	1.3	7.58	7.97	0.38	2.3	2.68	63.69	31.51	4.8	0.06	0.06	0.2	1.12	0.15
B ₁₀₋₂₀	0.6	6.56	6.08	0.2	7.43	7.63	76.35	19.5	4	3.68	1.46	127.2	1.38	5.93
EM ₁₀₋₂₀	1.3	7.54	5.5	0.77	1.52	2.29	86.76	6.84	6.4	4.07	0.76	3.35	0.09	1.92
EC ₁₀₋₂₀	2.8	6.15	9.13	0.45	1.2	1.65	43.09	46.51	10.4	3.17	3.46	217.5	0.26	6.26
ESF ₁₀₋₂₀	1.6	6.75	9.08	0.51	4.71	5.22	69.57	20.83	5.6	3.88	0.8	104.6	0.63	8.4
SA ₁₀₋₂₀	0.2	6.65	4.68	0.25	1.83	2.08	80.61	17.79	1.6	2.22	0.52	42.52	0.33	4.15
SEC ₁₀₋₂₀	0.8	6.93	4.86	0.25	1.06	1.31	69.85	18.15	12	3.18	1.78	163.9	0.63	5.12
M ₁₀₋₂₀	0.7	6.6	4.13	0.28	4.89	5.17	65.44	29.76	4.8	1.64	0.72	0.47	0.03	0.24
MEC ₁₀₋₂₀	0.3	7.11	4.6	0.19	1.08	1.27	89.76	6.24	4	3.83	1.78	162.5	0.9	4.89
AM ₁₀₋₂₀	4.4	6.83	4.05	0.23	2.27	2.5	61.46	33.74	4.8	2.22	2.06	3.44	0.02	10.46
ASS ₁₀₋₂₀	9.05	6.5	5.08	0.34	1.87	2.21	20.74	58.46	20.8	2.85	0.48	3.47	0.48	3.54
NVT ₁₀₋₂₀	3	6.64	3.12	0.34	2.01	2.34	61.56	21.64	16.8	0.74	0.12	1.59	0.25	2.15
WBL ₁₀₋₂₀	1.4	6.84	3.04	0.33	0.61	1	82.97	15.43	1.6	1.43	0.47	21.14	0.34	4.39
WPD ₁₀₋₂₀	1.5	7.66	1.04	0.24	0.54	0.78	91.35	4.65	4	1.03	0.46	43.55	0.16	2.3
BC ₁₀₋₂₀	0.5	6.73	4.55	0.25	0.37	0.62	80.4	15.6	4	1.35	1.72	150.9	0.8	4.7
ASE ₁₀₋₂₀	0.3	6.88	5.18	0.27	0.89	1.15	85.21	18.19	1.6	2.9	1.04	137.3	0.54	5.78
ASP ₁₀₋₂₀	5.4	7.8	3.59	0.25	4.07	4.32	68.54	28.26	3.2	14.2	5.36	15.4	0.01	1.86
AN ₁₀₋₂₀	3.8	6.63	3.81	0.24	2.07	2.31	67.85	27.35	4.8	2.56	1.85	37.4	1.27	5.66
KGW ₁₀₋₂₀	1.8	6.11	3.27	0.3	1.69	1.99	66.01	29.19	4.8	1.84	1	9.76	0.54	4.32

U20-30	0.3	7.51	4.69	0.34	1.58	1.92	77.79	15.81	6.4	0.96	0.14	0.46	0.42	0.82
CD	1.6	6.5	5.07	0.28	1.29	1.57	58.87	30.73	10.4	1.48	2.24	42.86	0.27	4.58
NF20-30	0.8	6.8	4.14	0.34	1.32	1.66	62.58	12.05	25.61	1.51	0.59	43.04	0.8	4.51
P20-30	3.8	7.8	3.62	0.36	2.31	2.67	73.45	19.35	7.2	1.66	0.71	128.2	1.36	4.12
MSS20-30	0.5	7.7	3.82	0.47	0.77	1.24	69.36	21.04	9.61	4.05	1.9	134.4	3.18	6.15
AR20-30	1.05	8	6.6	0.34	2.35	2.79	51.66	35.54	12.81	0.16	0.09	0.81	0.01	0.19
B20-30	1.2	6.6	5.14	0.22	7.98	8.2	57.61	28.79	13.6	3.58	1.41	127.7	1.35	5.87
EM20-30	2	6.8	4.83	0.25	1.5	1.75	88.42	1.98	9.6	4.11	0.72	3.35	0.09	1.92
EC20-30	1.35	7.6	5.81	0.38	1.26	1.54	41.71	40.69	17.6	3.21	3.52	217.4	0.28	6.17
ESF20-30	1.4	6.74	6.72	0.37	4.45	4.82	39.36	48.64	12.05	3.86	1.08	104.7	0.79	8.4
A20-30	2.26	6.86	4.97	0.28	1.61	1.89	70.11	18.69	11.23	3.23	0.28	42.49	0.31	8.21
SA20-30	1.3	6.66	3.66	0.23	1.05	1.28	68.93	21.47	9.6	3.88	0.72	42.57	0.33	4.19
SEC20-30	0.75	6.9	3.62	0.27	1.15	1.42	65.4	27.4	7.2	1.08	1.95	162.8	0.64	5.08
M20-30	0.75	6.88	3.41	0.26	2.49	2.75	61.23	29.97	8.8	2.34	0.78	1.07	0.1	0.44
MEC20-30	1.68	7.21	3.66	0.22	1.07	1.29	51.68	37.12	11.2	3.12	1.88	163	0.97	4.87
AM20-30	3.78	6.91	3.4	0.32	2.29	2.61	52.58	40.22	7.2	2.81	2.16	3.83	0.08	10.51
ASS ₁₀₋₂₀	5.03	6.5	4.26	0.23	1.91	2.14	35.32	40.68	24	2.88	0.88	3.97	0.49	3.6
NVT ₁₀₋₂₀	3.2	6.71	3.45	0.25	2	2.25	59.22	23.18	17.6	0.88	0.42	1.59	0.29	2.19
WBL ₁₀₋₂₀	1.3	6.65	2.6	0.32	0.81	1.23	71.09	18.16	10.4	1.43	0.77	21.31	0.41	4.43
WPD ₂₀₋₃₀	2.7	7.11	0.85	0.22	0.94	1.16	94.84	1.51	3.6	1.12	0.56	42.97	0.19	2.23
BC ₂₀₋₃₀	0.8	7.8	4.35	0.27	2.17	2.47	80.07	12.73	7.21	1.43	1.68	160	0.84	4.67
ASE ₂₀₋₃₀	1.14	6.71	4.31	0.32	1.01	1.33	61.73	19.87	18.4	3.01	1.24	137.7	0.61	5.75
ASP ₂₀₋₃₀	4.4	7.6	3.62	0.36	1.36	1.72	59.81	30.62	9.61	33.98	5.51	15.47	0.07	1.86
AN ₂₀₋₃₀	3.6	7.7	3.38	0.22	1.78	3	61.92	26.88	11.2	2.55	1.79	38.04	1.31	6.06
KGW ₂₀₋₃₀	4.1	6.7	3.33	0.23	2.44	2.67	77.81	10.99	11.2	2.01	1.05	9.59	0.59	4.33

RESULTS OF ANALYSIS OF SOIL CHARACTERISTICS AND PCCBs

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Table G1: Mean results of soil characteristics and polychlorinated biphenyls in soils in the Central Region of Ghana

Site	pH	Soil Characteristics								PCB Congener (µg/kg)								ΣPCB
		Moist%	ex A	ex B	ECEC	OC%	sand%	silt%	clay%	28	52	101	118	138	153	180		
UCL	7.09	1.20	0.29	2.12	8.57	0.77	61.15	31.50	7.47	1.04	2.34		0.52	0.91	1.26	1.45	6.86	
AUD	7.59	0.31	0.31	1.55	6.51	0.56	79.55	14.32	6.13	2.34	1.20	3.12		0.82	1.74	1.64	12.21	
CDS	6.67	1.19	0.28	1.40	5.81	0.55	62.74	32.19	5.07	4.20	1.28	2.29	0.69	0.68	0.81	0.89	9.99	
NFL	7.18	1.19	0.34	1.35	5.76	0.16	64.37	18.04	17.60	0.84	0.83	2.48	0.70	1.68	2.33	0.58	7.76	
PDU	7.41	1.43	0.38	1.90	7.96	0.43	75.99	15.48	8.53	1.05	0.71	0.01	1.86	0.78	0.38	0.12	3.58	
MSS	7.56	0.93	0.44	0.80	3.65	0.34	71.65	20.89	7.47	0.96	2.85	2.80	0.46	2.08	0.97	3.75	8.96	
ARD	7.83	1.18	0.36	1.79	7.43	0.16	61.29	30.71	8.00	6.56	0.24	nd	nd	1.76	1.51	1.32	11.39	
BRO	6.04	1.00	0.57	7.71	19.46	0.30	70.74	20.15	9.07	0.33	0.70	2.35	0.00	0.72	0.78	0.29	5.17	
ELM	7.50	1.24	0.61	1.54	6.81	0.33	82.09	11.78	6.13	2.47	2.30	1.19	2.50	0.14	1.00	nd	9.50	
ELC	6.57	1.82	0.40	1.22	5.23	0.21	42.11	45.09	12.80	1.77	0.52	2.19	nd	2.86	0.39	0.36	6.81	
ESF	6.72	1.91	0.65	4.04	16.69	0.28	57.63	34.64	6.42	1.74	0.29	4.49	0.30	0.58	0.45	0.63	8.29	
ANO	6.90	3.28	0.26	1.12	4.76	0.40	74.79	8.41	16.81	0.51	32.79	9.50	4.34	0.99	nd	1.85	3.22	
SAH	6.99	1.89	0.25	1.37	6.77	0.39	76.65	16.69	10.00	2.26	3.53	2.43	0.30	1.79	1.72	1.38	12.94	
SEC	6.89	0.99	0.28	0.90	4.81	0.40	67.33	24.14	8.53	2.37	2.06	0.12	1.45	0.23	0.48	1.57	7.19	
MAN	6.60	0.74	0.26	3.50	12.22	0.29	69.42	24.71	5.87	4.88	1.99	0.95	0.31	0.41	0.21	1.07	9.65	
MEC	7.28	1.18	0.24	1.18	4.94	0.26	67.87	23.33	8.80	1.95	3.82	nd	0.38	1.09	2.76	0.47	8.79	
AMF	6.95	4.31	0.27	2.53	10.38	0.56	58.99	35.15	5.87	5.82	0.93	6.52	1.08	1.48	1.46	2.08	11.86	
ASS	6.61	7.06	0.27	1.95	7.97	0.21	29.72	46.28	24.00	3.54	2.42	0.90	0.94	0.98	1.59	0.99	10.73	
NVT	6.91	3.33	0.28	1.85	7.67	0.31	60.00	21.87	18.13	0.78	nd	0.01	0.79	0.43	0.74	1.97	4.46	
WBL	7.06	1.73	0.29	0.78	3.38	0.23	76.81	17.47	8.93	2.65	3.40	0.92	0.87	0.98	1.73	0.86	8.53	
WPD	7.81	1.43	0.23	0.81	3.24	0.15	94.00	2.78	3.20	5.98	1.65	0.49	0.70	1.46	1.95	1.80	12.72	
BCH	7.16	0.72	0.26	1.04	4.48	0.21	82.47	12.20	5.34	0.45	0.37	4.09	0.51	0.46	1.21	1.95	7.39	
ASE	6.82	0.82	0.30	0.95	4.08	0.23	79.65	14.68	7.33	0.80	3.06	0.92	1.09	0.27	0.33	0.52	6.61	
ASP	7.82	4.66	0.32	2.50	8.95	0.22	67.66	26.75	5.60	0.89	0.98	4.42	0.56	1.06	0.95	0.92	6.79	
ANP	6.89	3.90	0.23	1.88	8.95	0.48	66.37	22.68	10.93	0.62	nd	0.30	0.10	0.40	0.30	nd	1.32	
KGW	6.15	4.01	0.26	1.97	8.54	0.21	71.33	21.47	7.20	1.93	0.83	0.94	0.16	0.24	0.45	nd	3.77	

APPENDIX H
CHROMATOGRAPHS OF SOIL PCB ANALYSIS

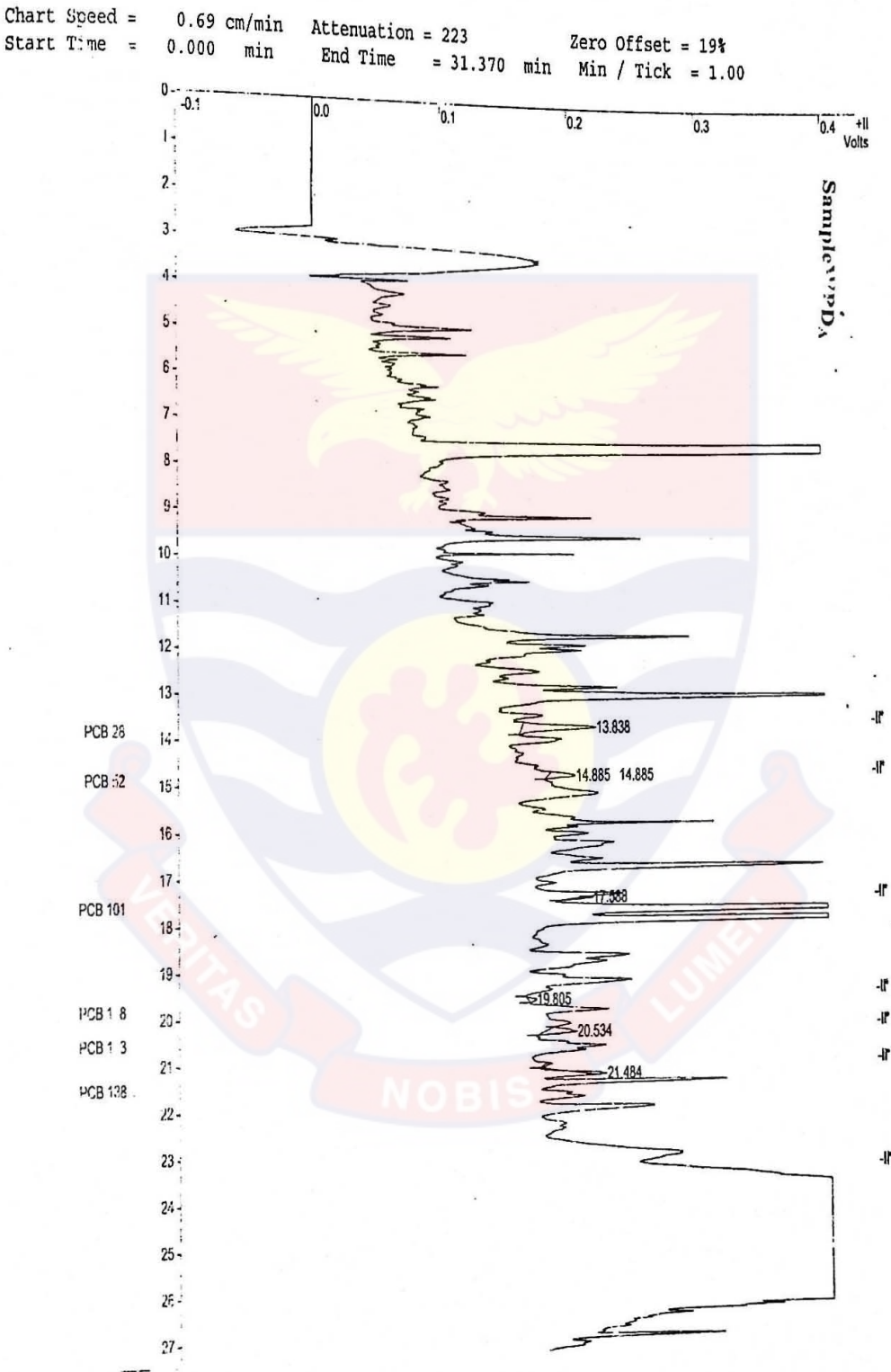
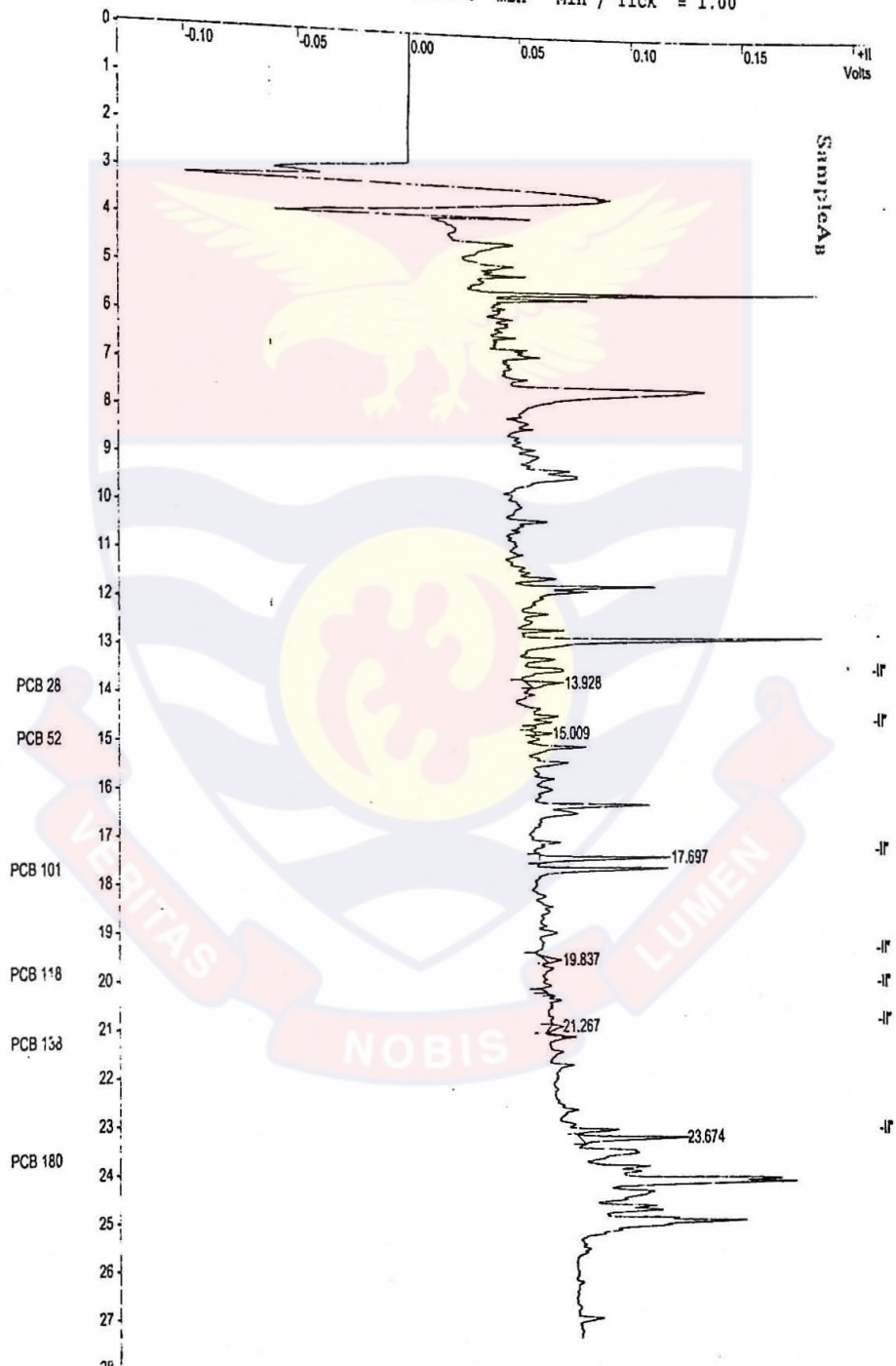


Chart Speed = 0.69 cm/min Attenuation = 138 Zero Offset = 38%
 Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



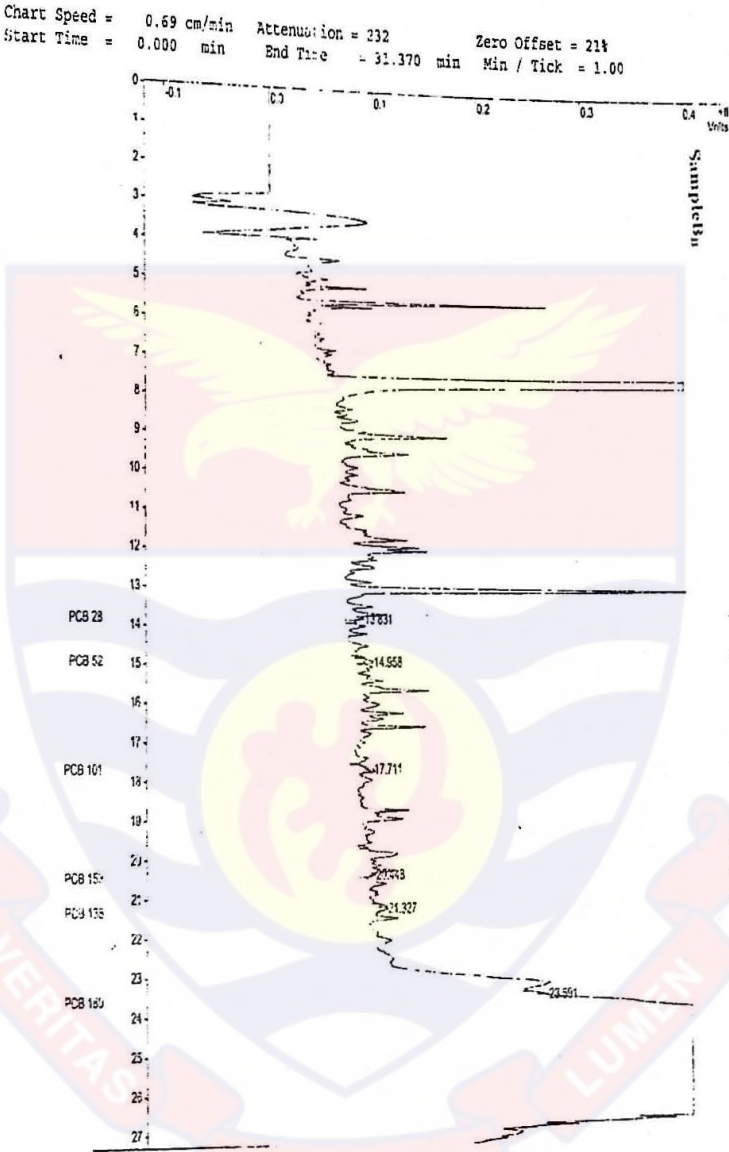


Chart Speed = 0.69 cm/min Attenuation = 226 Zero Offset = 19%
 Start Time = 0.000 min End Time = 31.368 min Min / Tick = 1.00

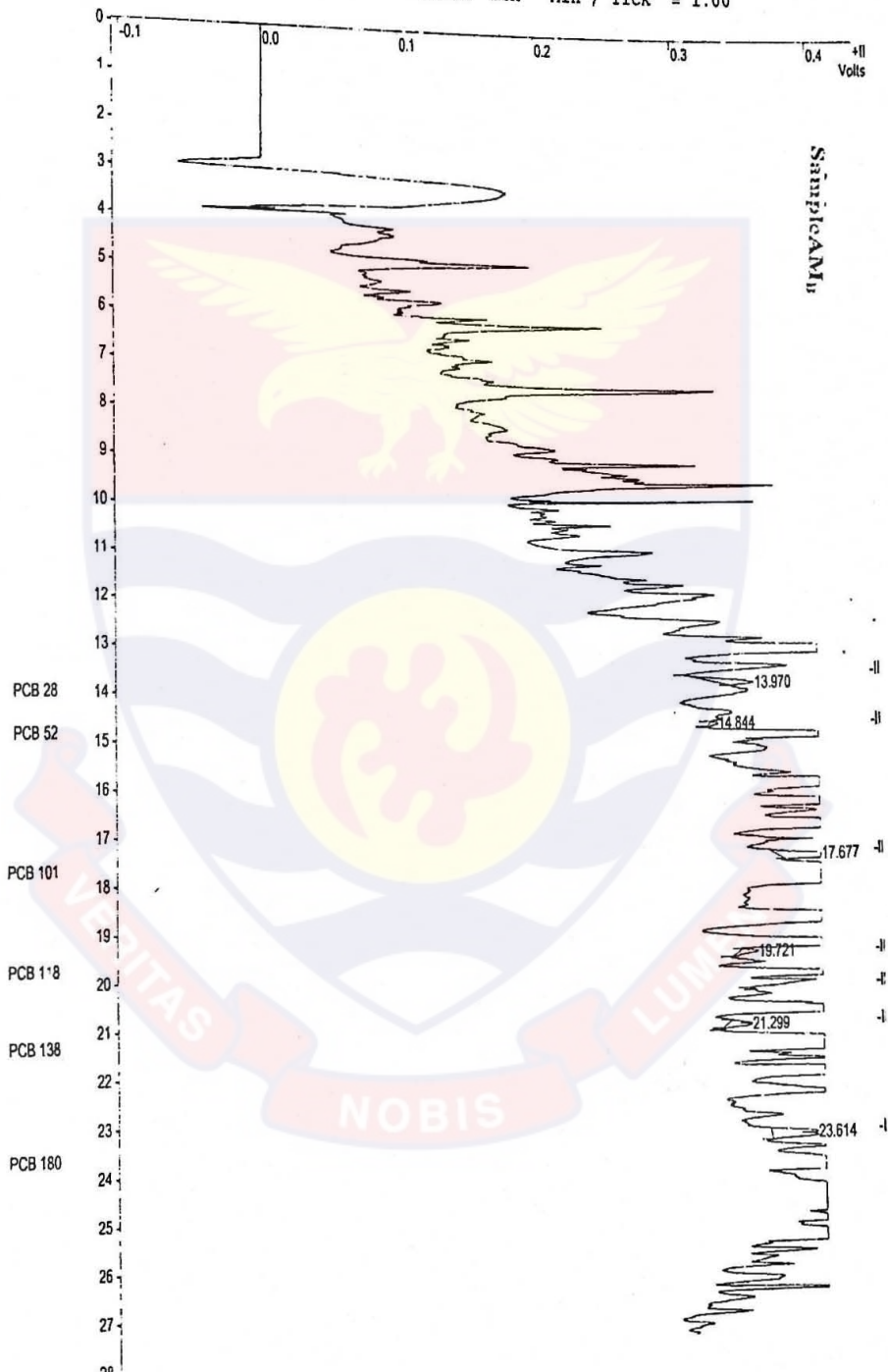


Chart Speed = 0.69 cm/min Attenuation = 223 Zero Offset = 18%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

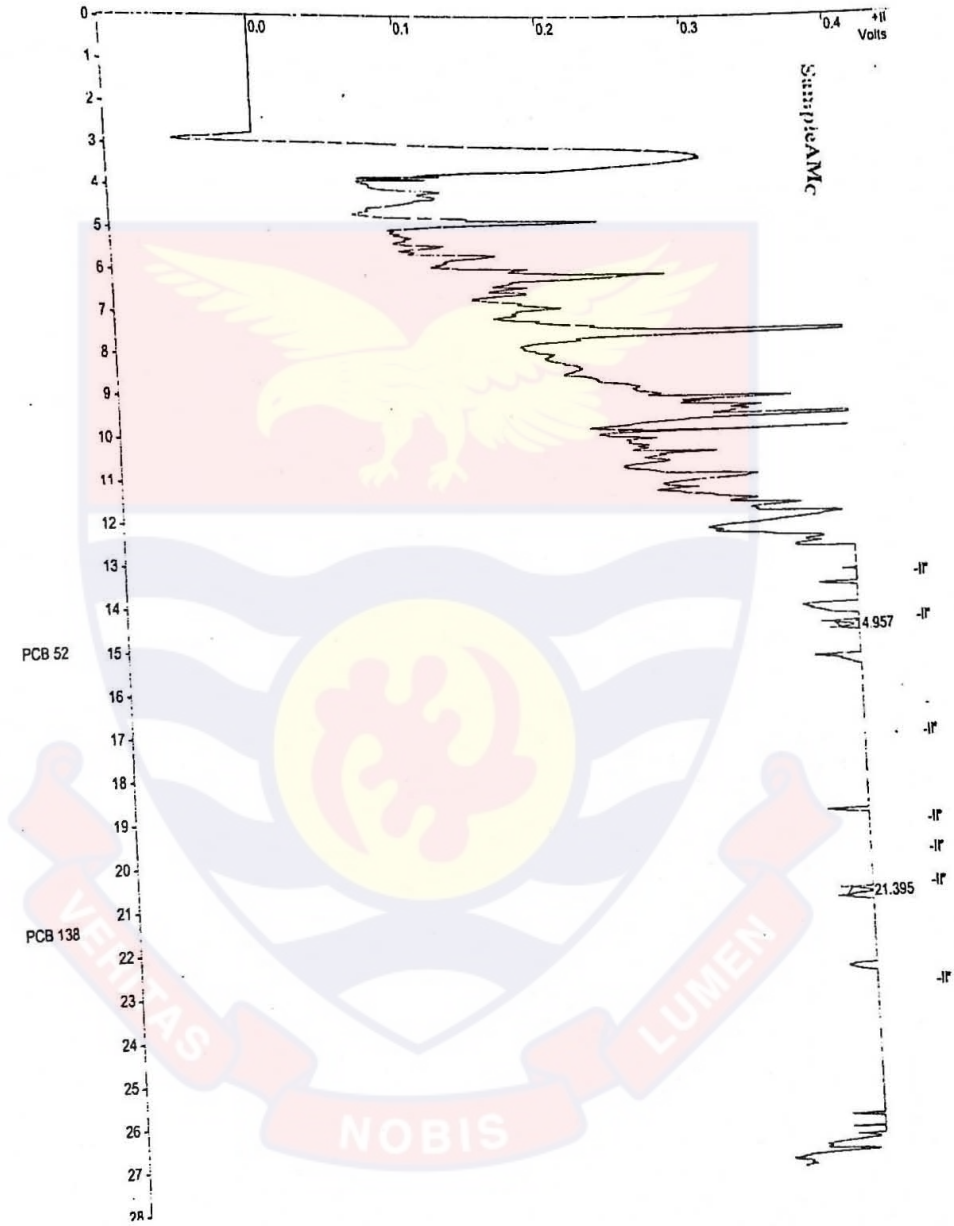


Chart Speed = 0.69 cm/min Attenuation = 216 Zero Offset = 17%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

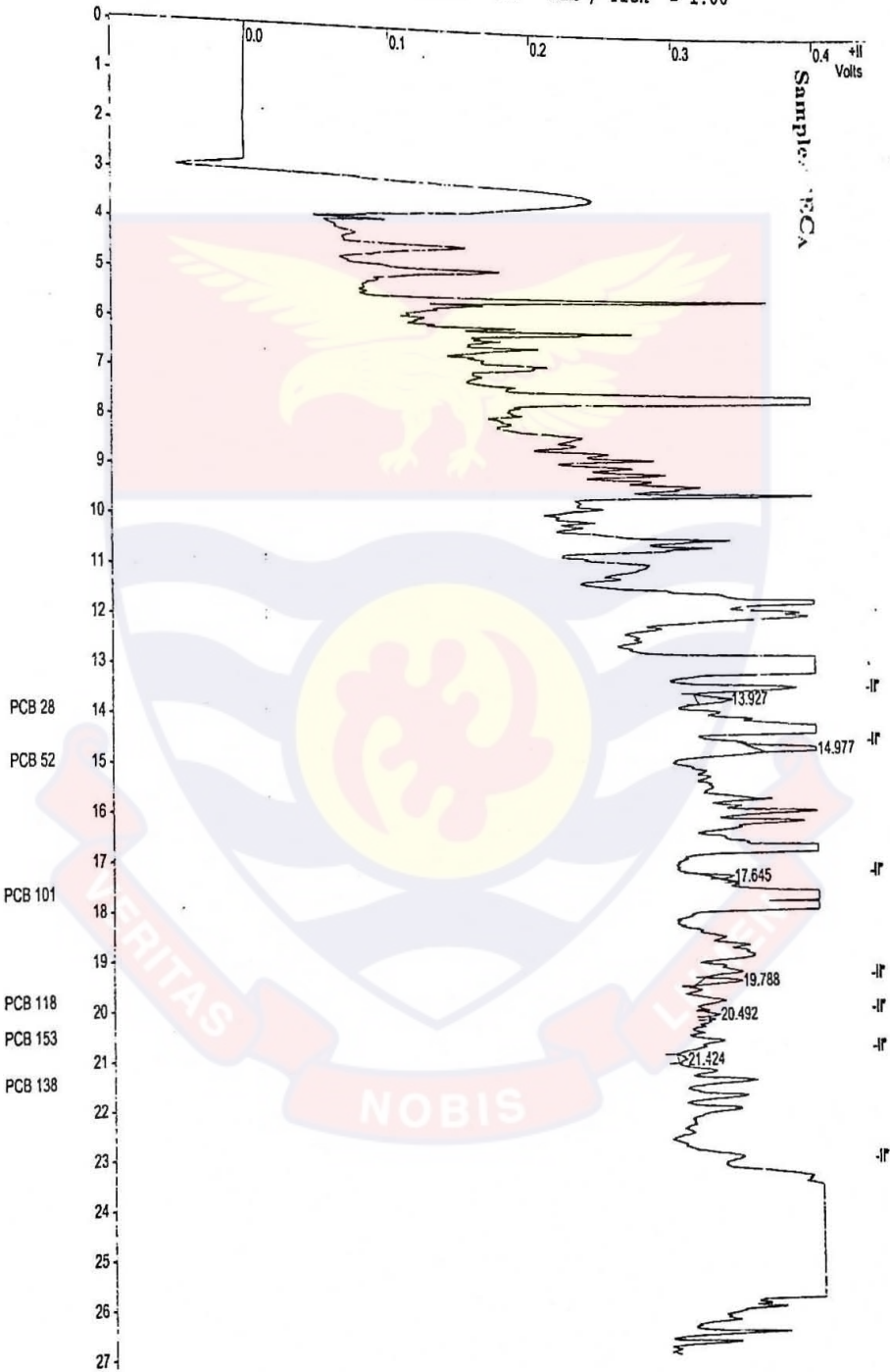


Chart Speed = 0.69 cm/min Attenuation = 226 Zero Offset = 19%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

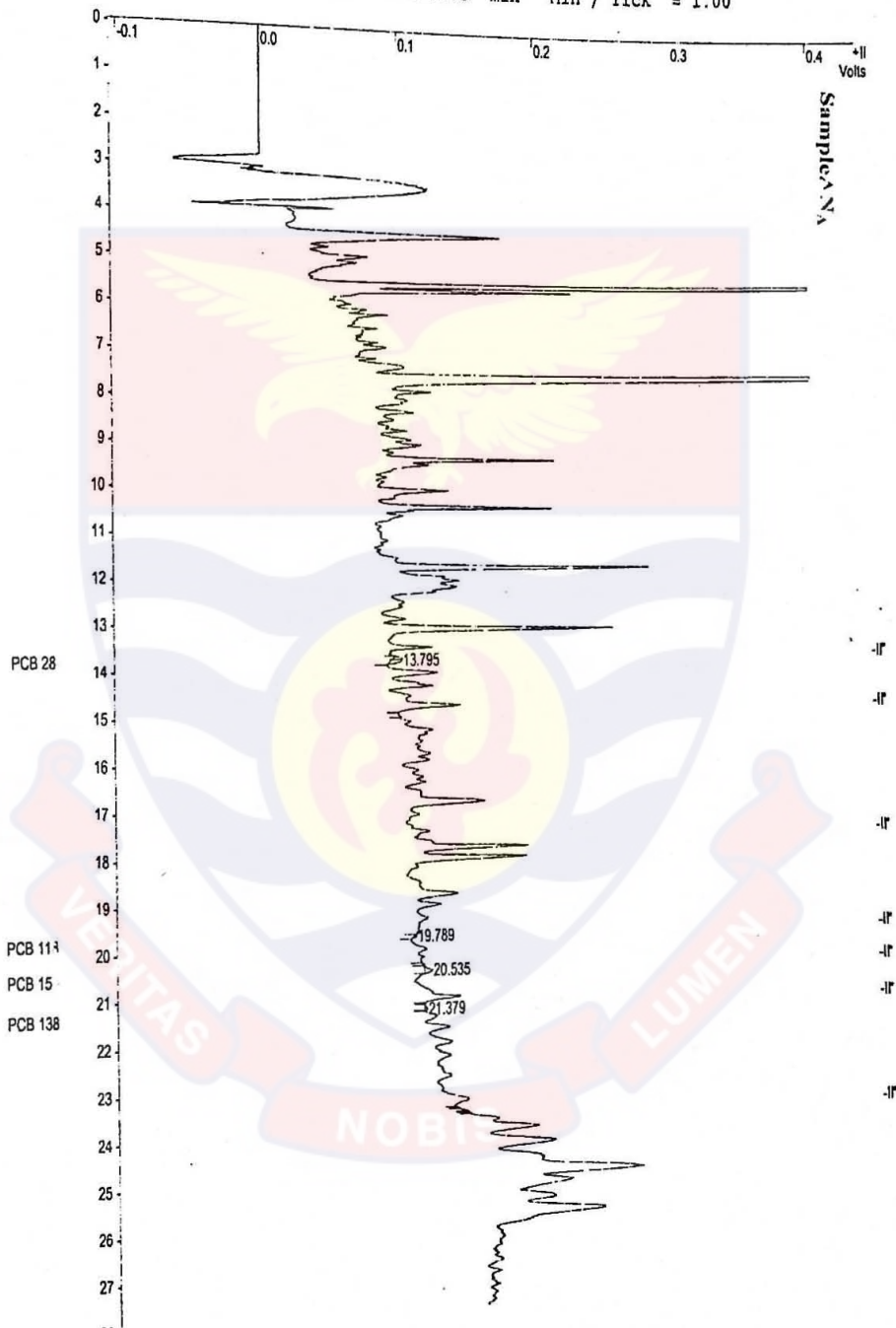
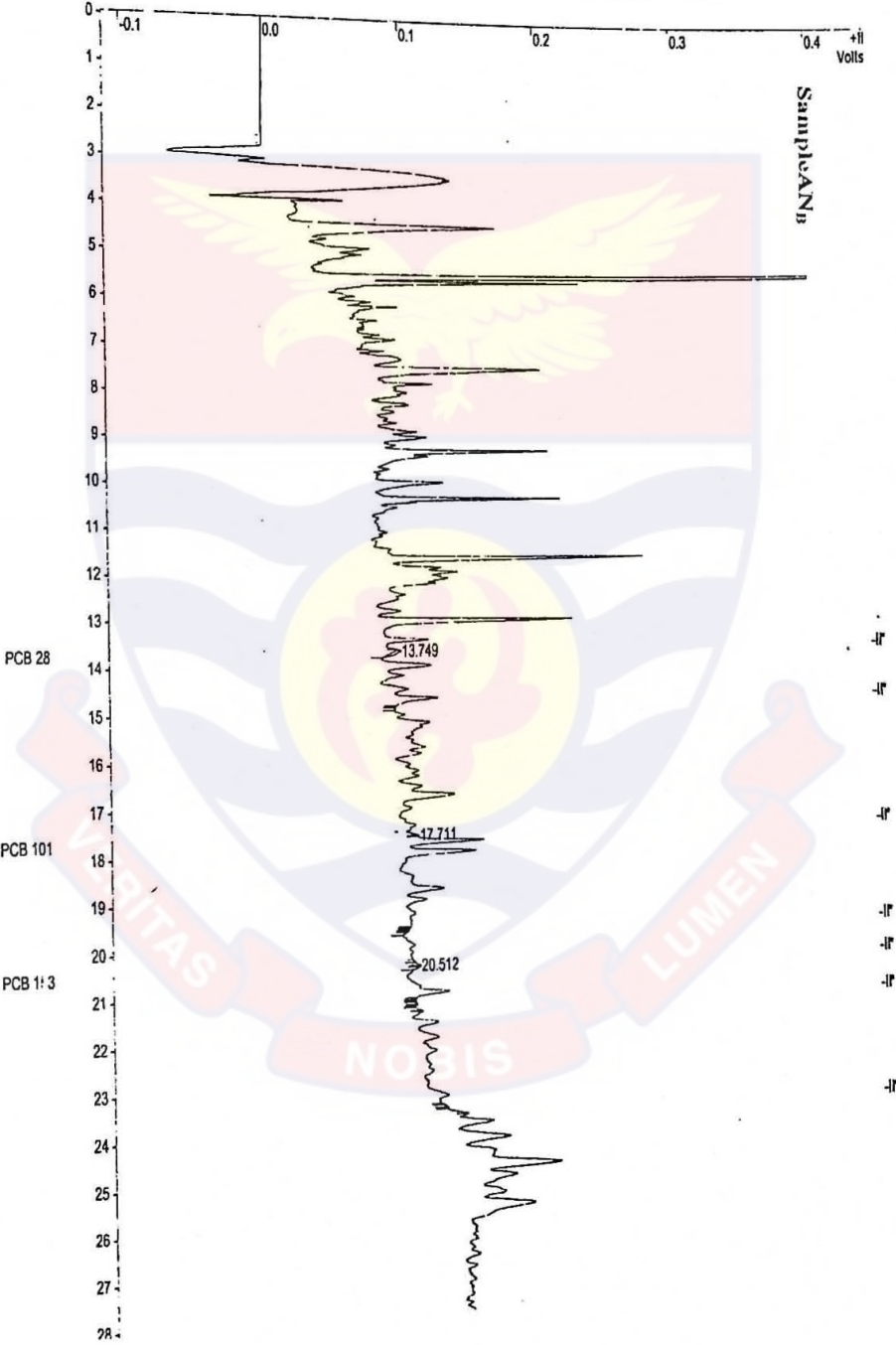
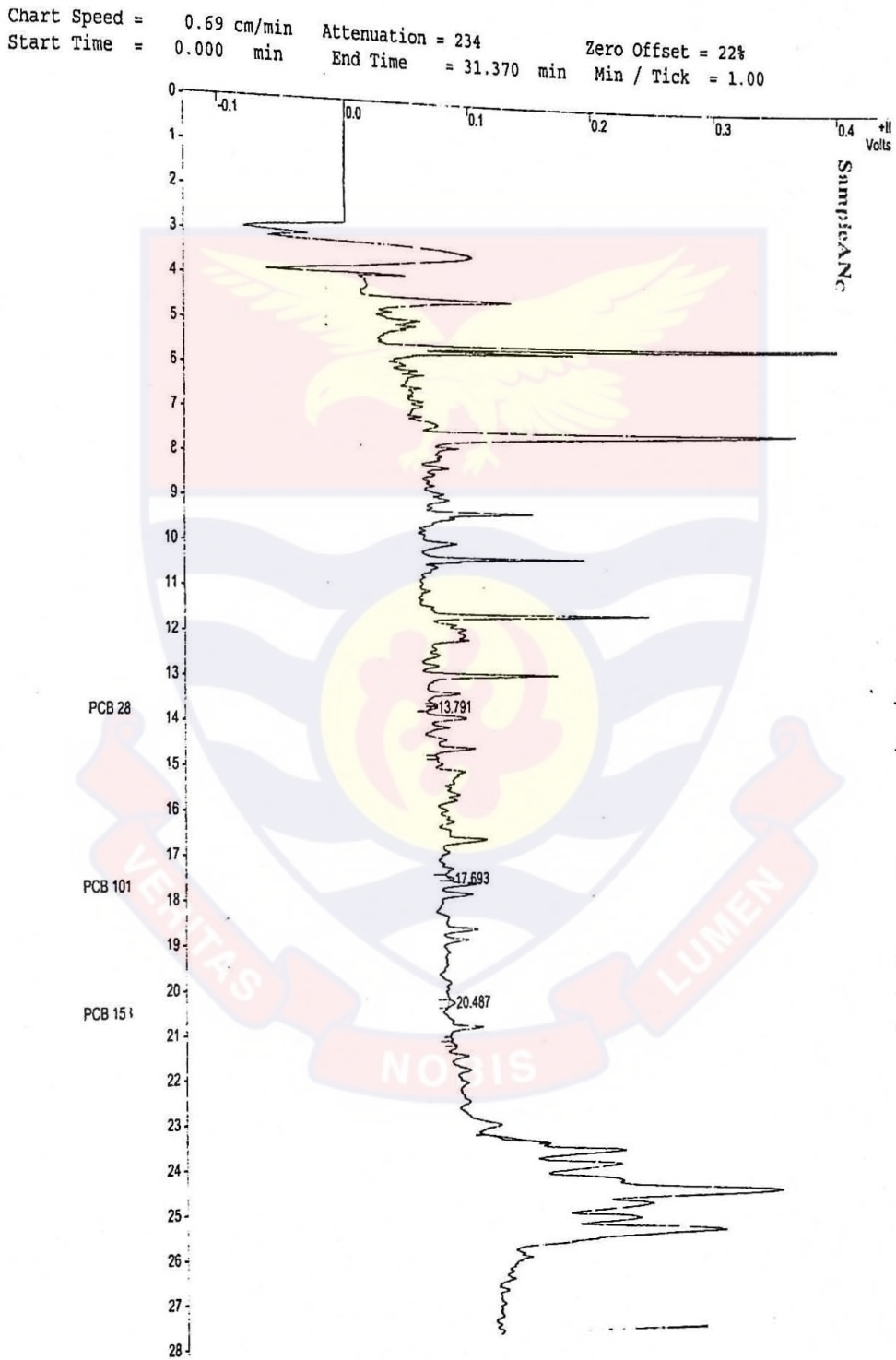


Chart Speed = 0.69 cm/min Attenuation = 229 Zero Offset = 20%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00





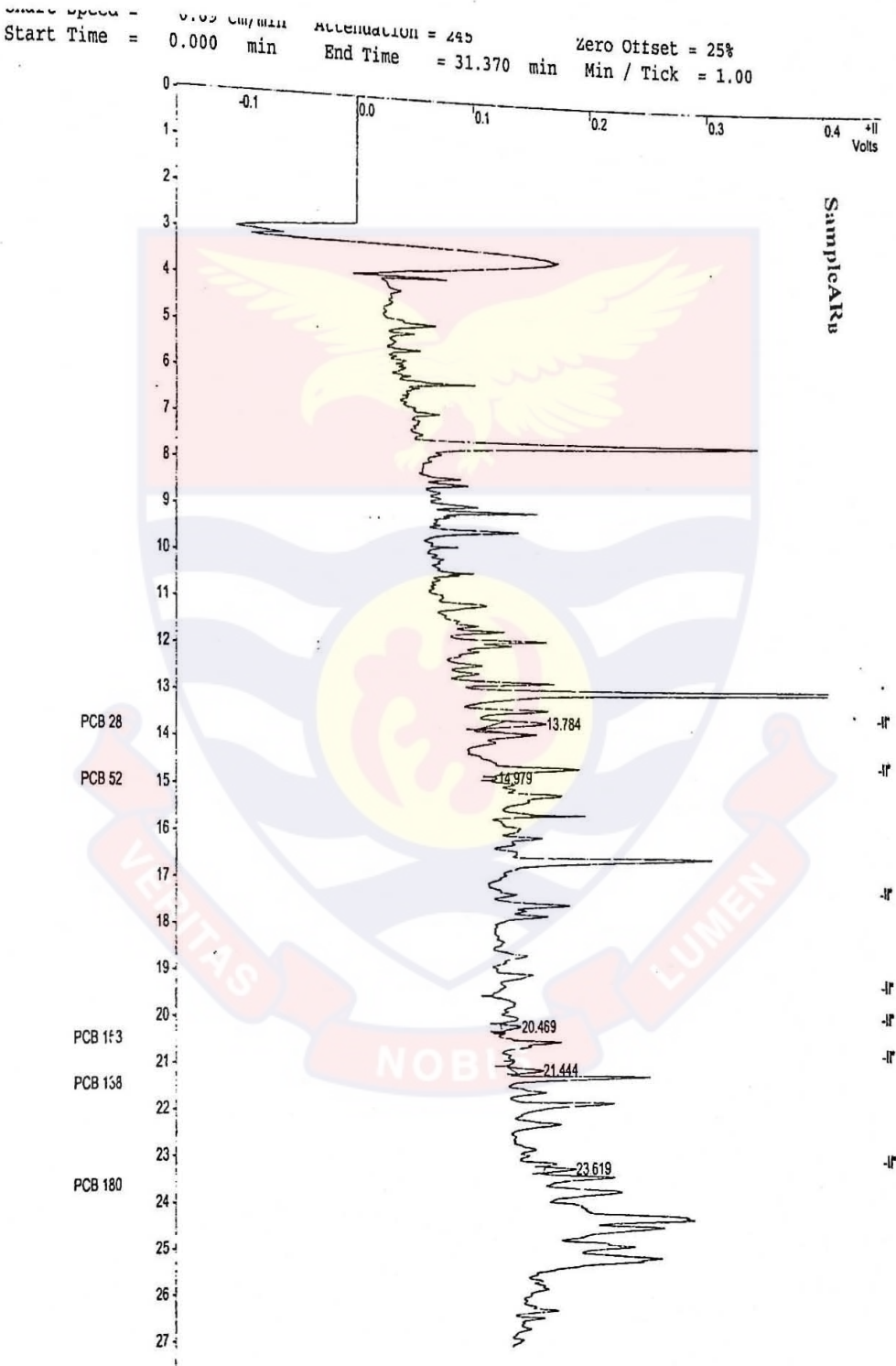
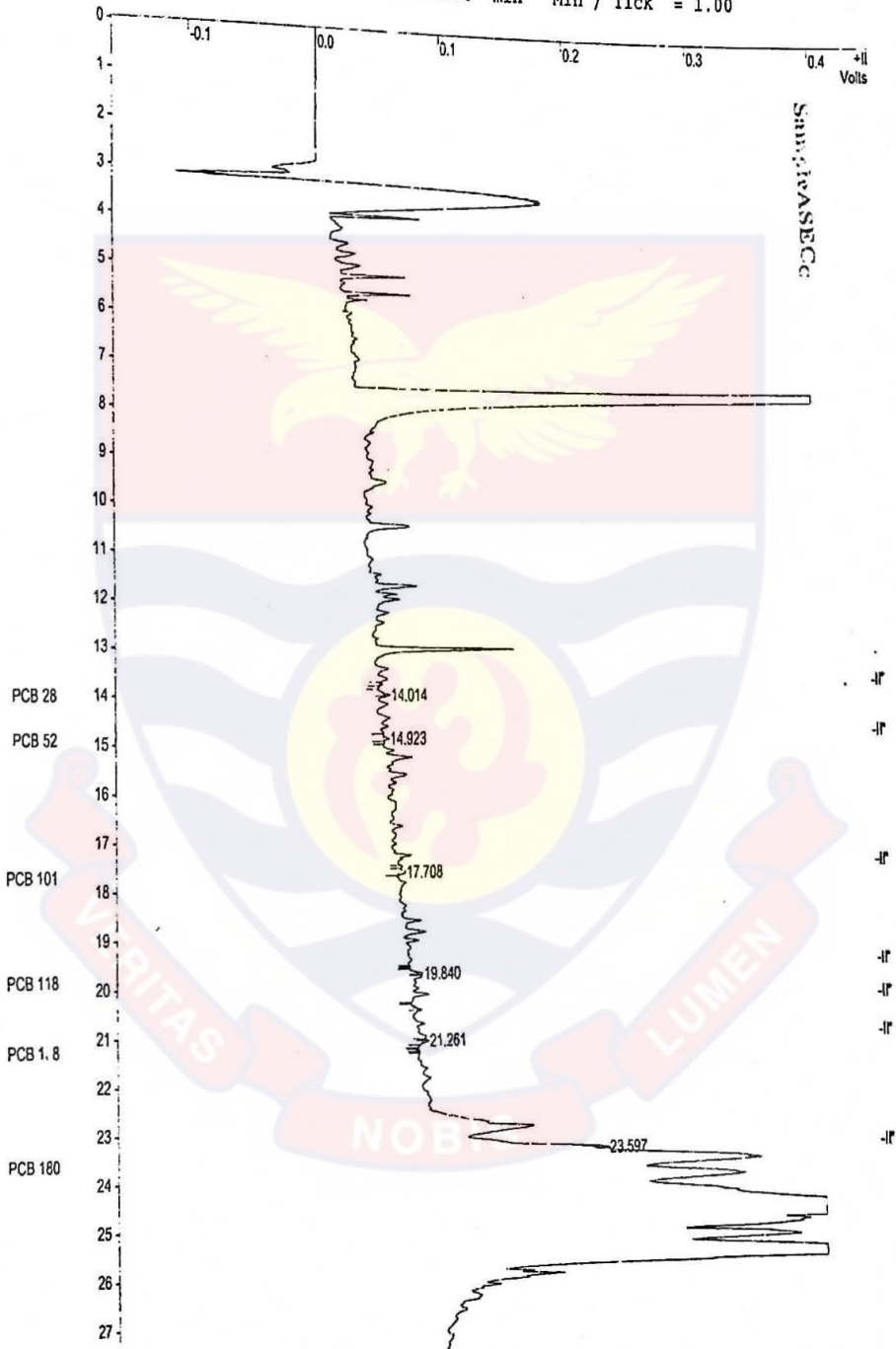


Chart Speed = 0.69 cm/min Attenuation = 250 Zero Offset = 26%
 Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



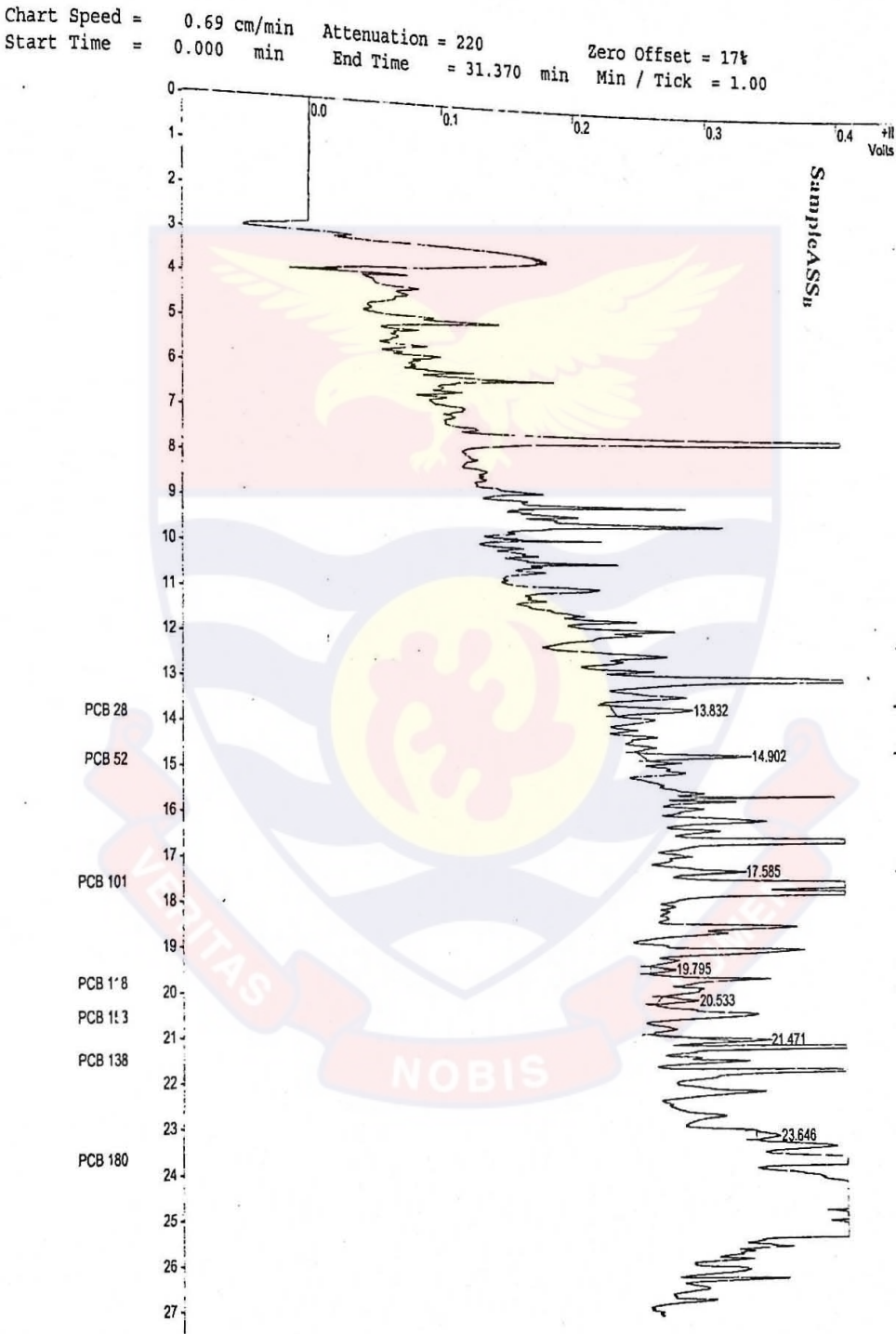


Chart Speed = 0.69 cm/min Attenuation = 224 Zero Offset = 1.5%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

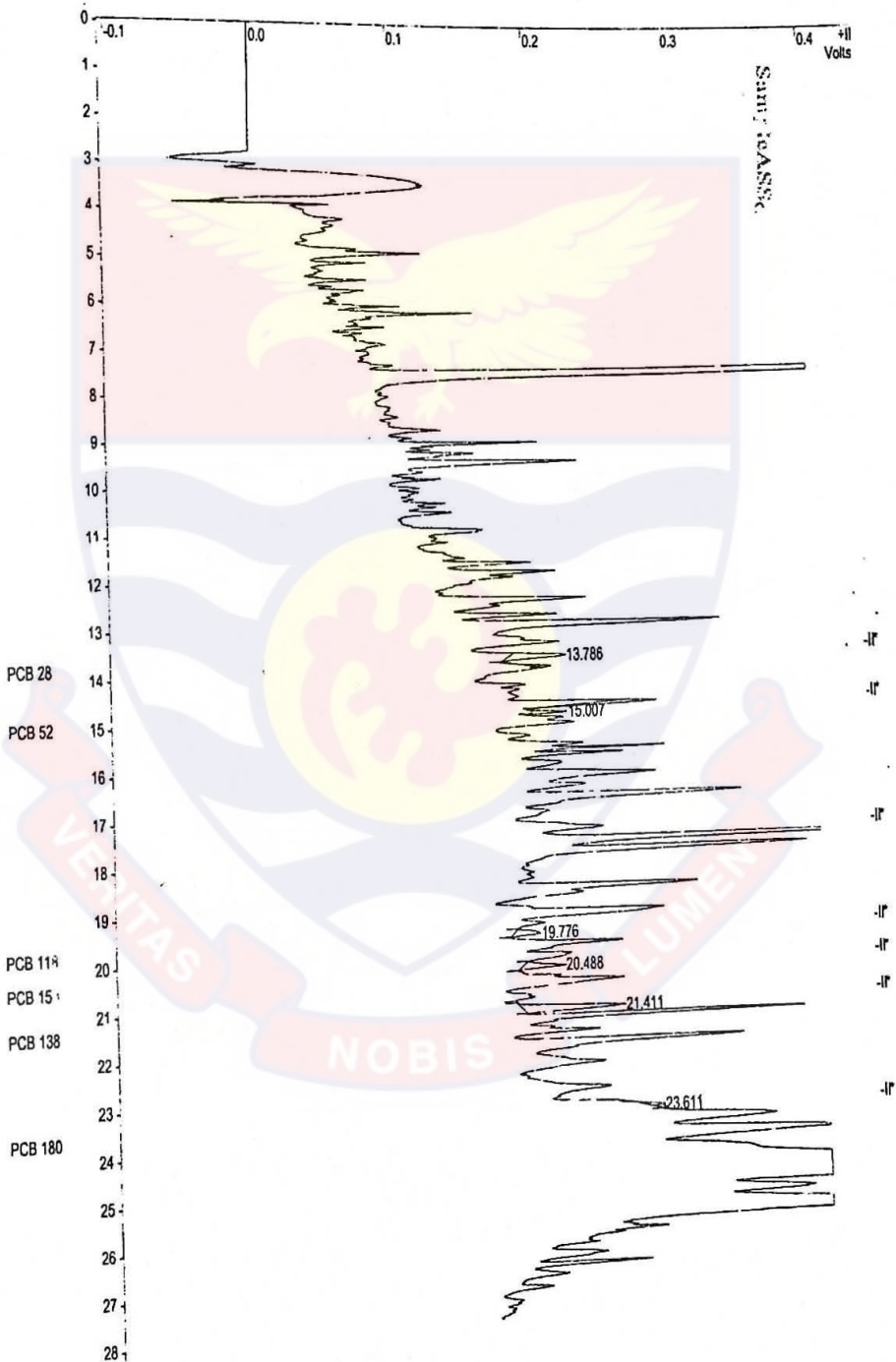


Chart Speed = 0.69 cm/min Attenuation = 220 Zero Offset = 18%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

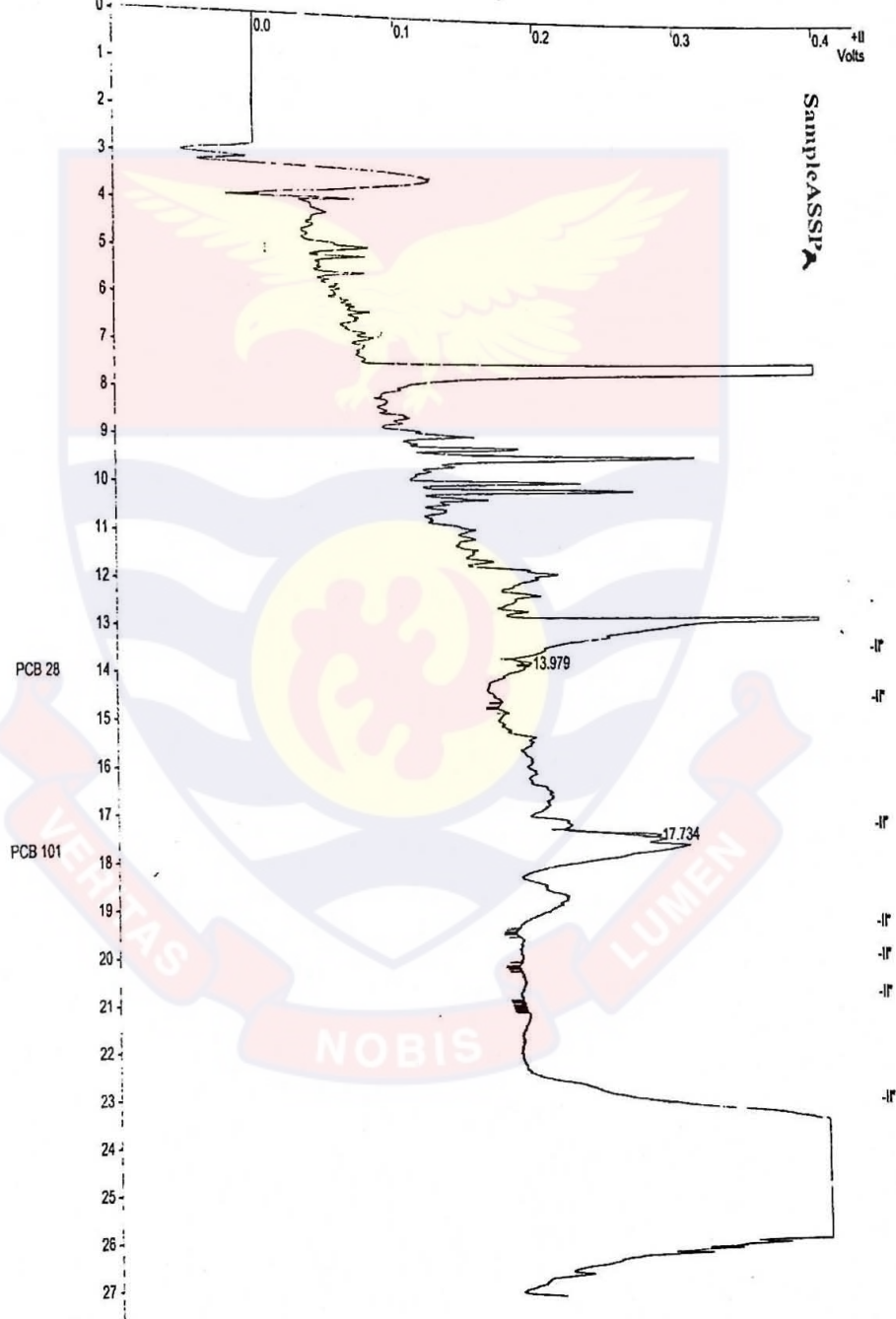


Chart Speed = 0.69 cm/min Attenuation = 255 Zero Offset = 28%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

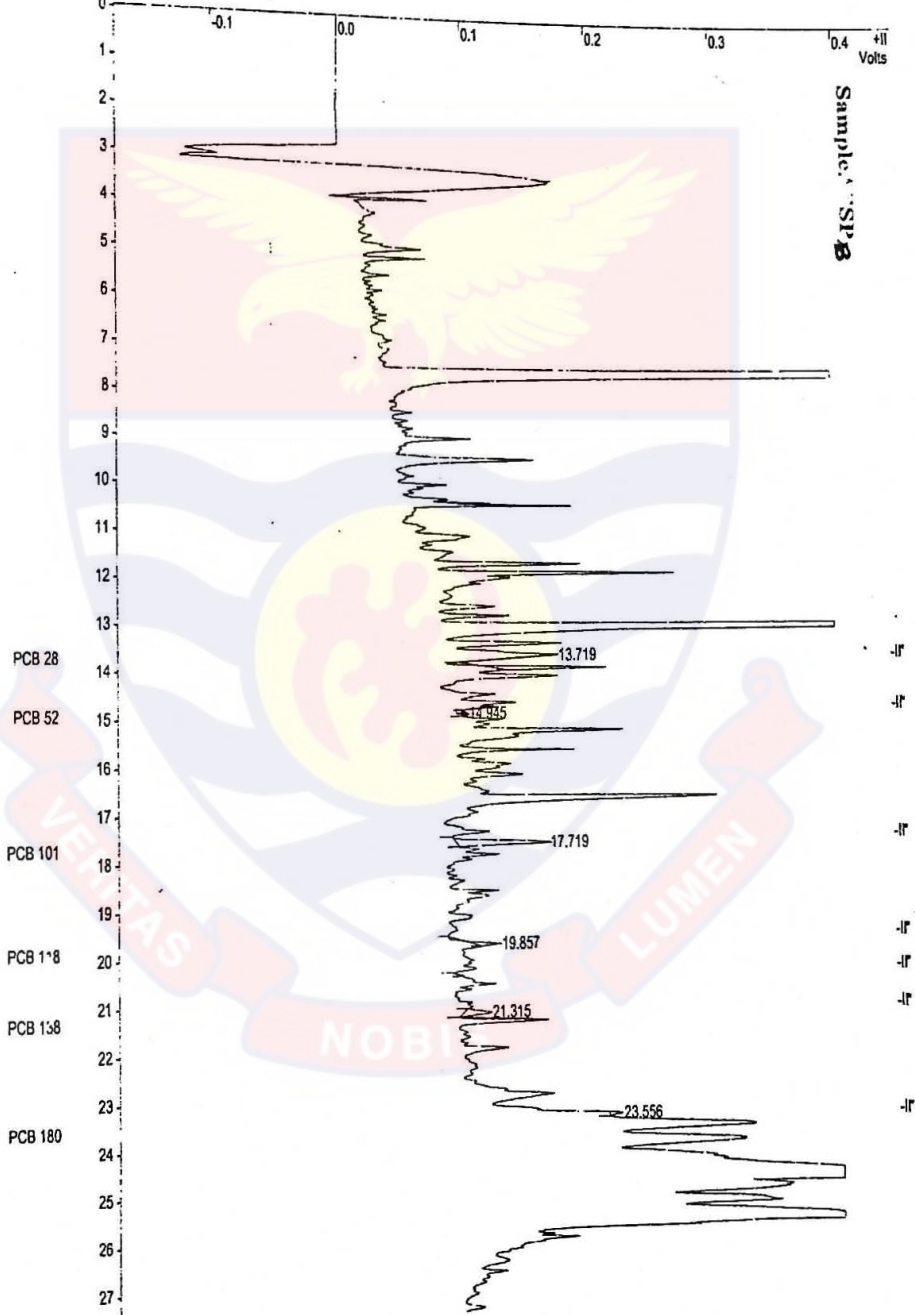


Chart Speed = 0.69 cm/min Attenuation = 253 Zero Offset = 28%
 Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

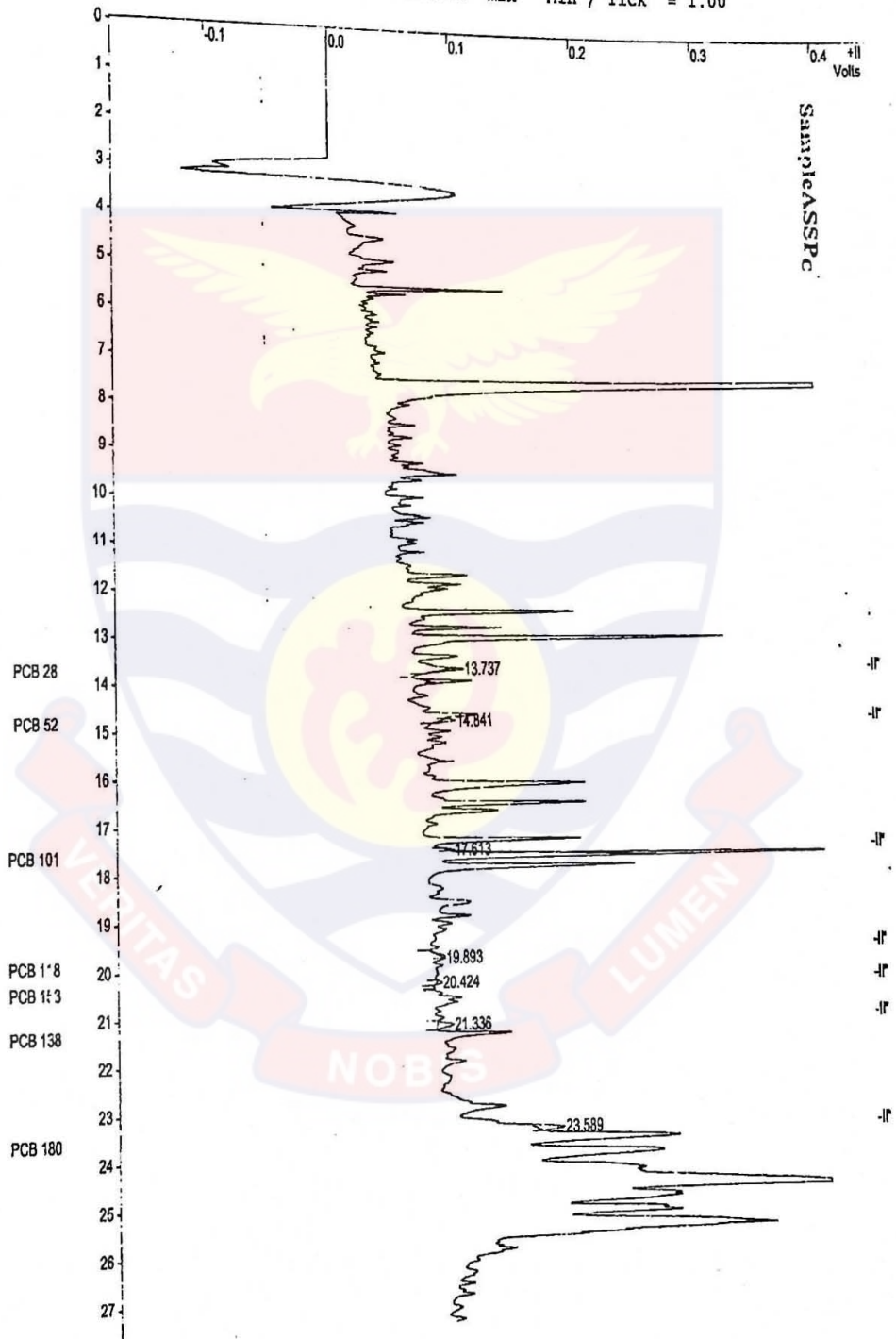


Chart Speed = 0.69 cm/min Attenuation = 219 Zero Offset = 219
Start Time = 0.000 min End Time = 21.310 min Min / Tick = 1.00

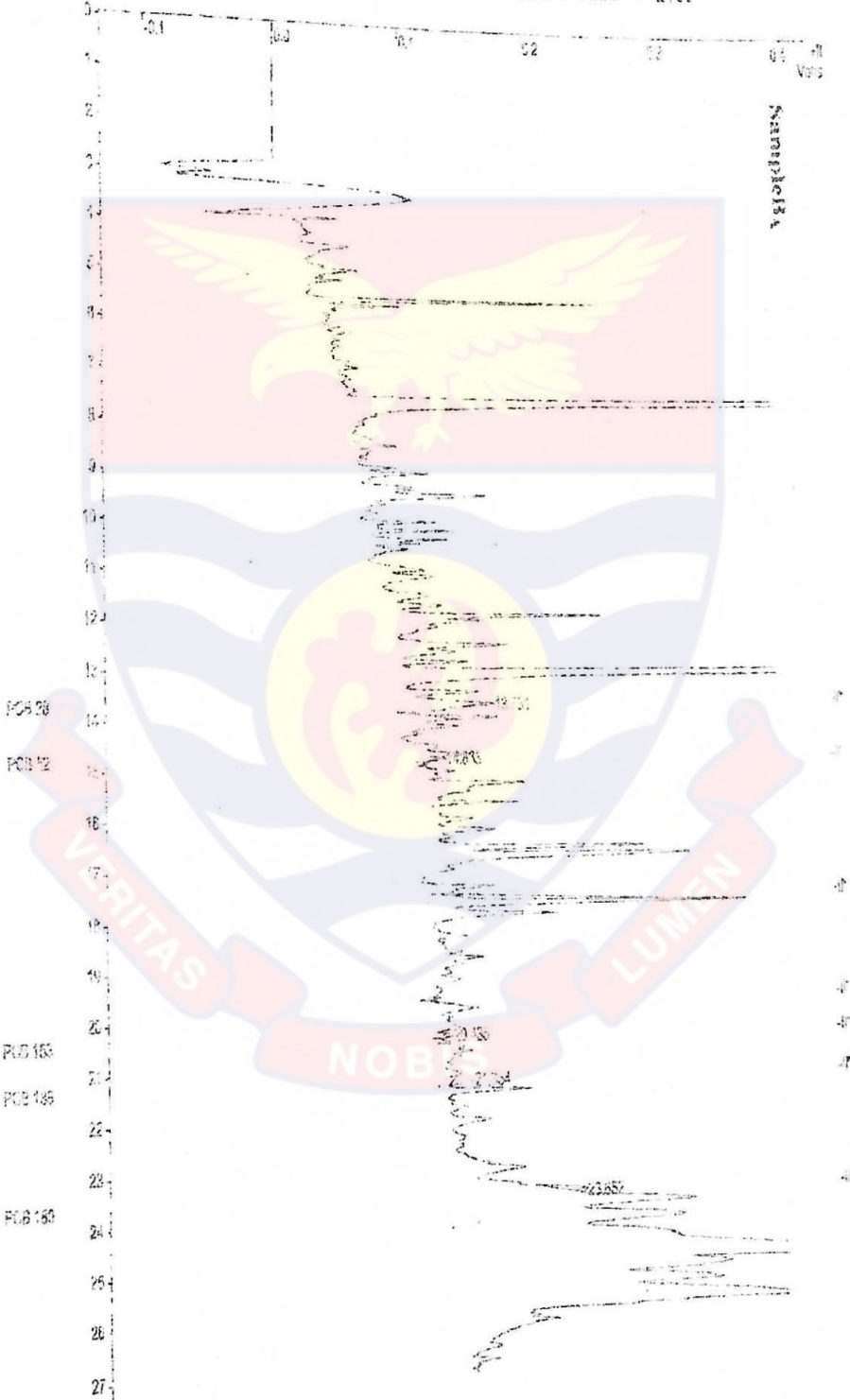


Chart Speed = 0.69 cm/min Attenuation = 232 Zero Offset = 21%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

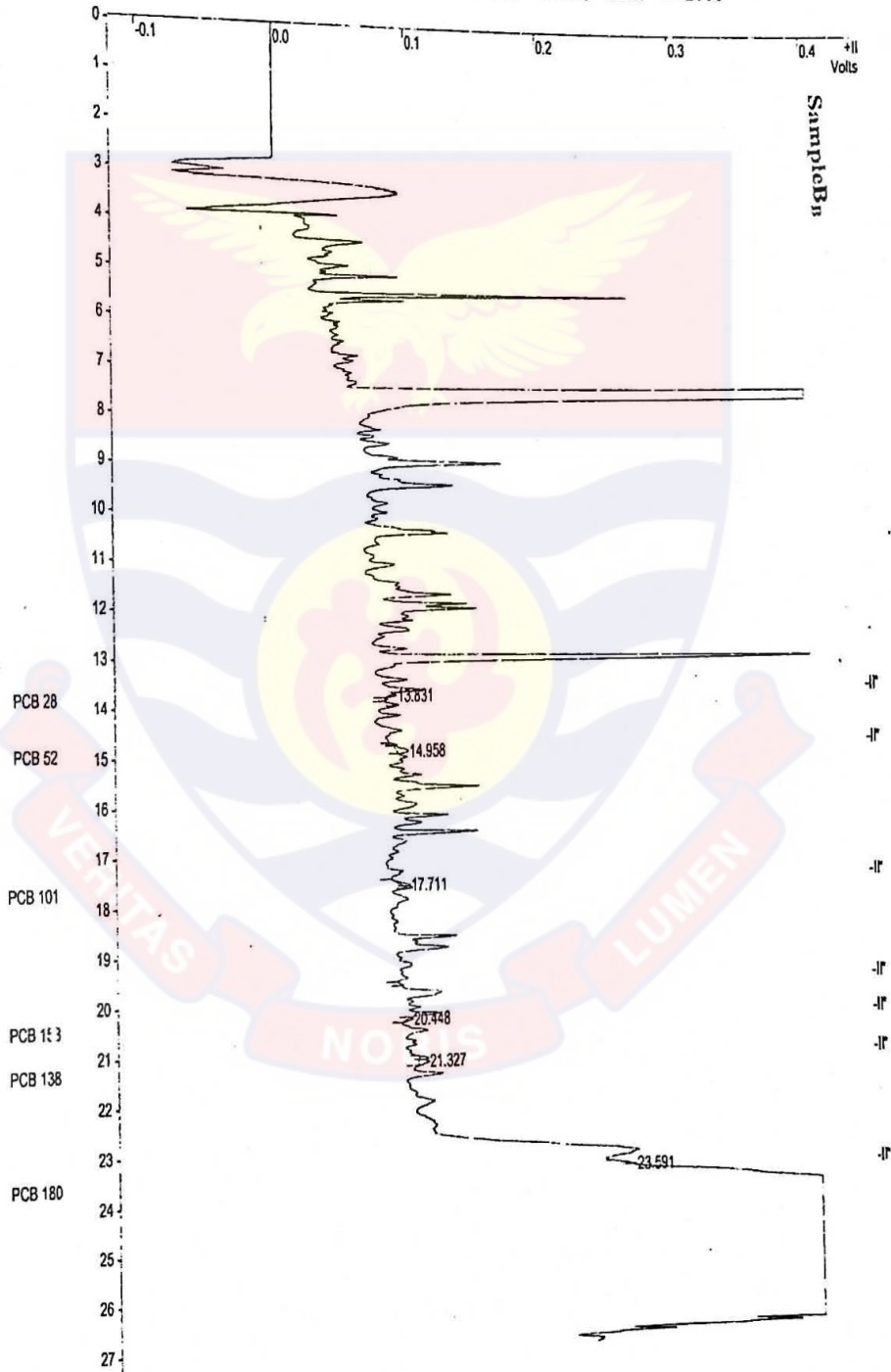
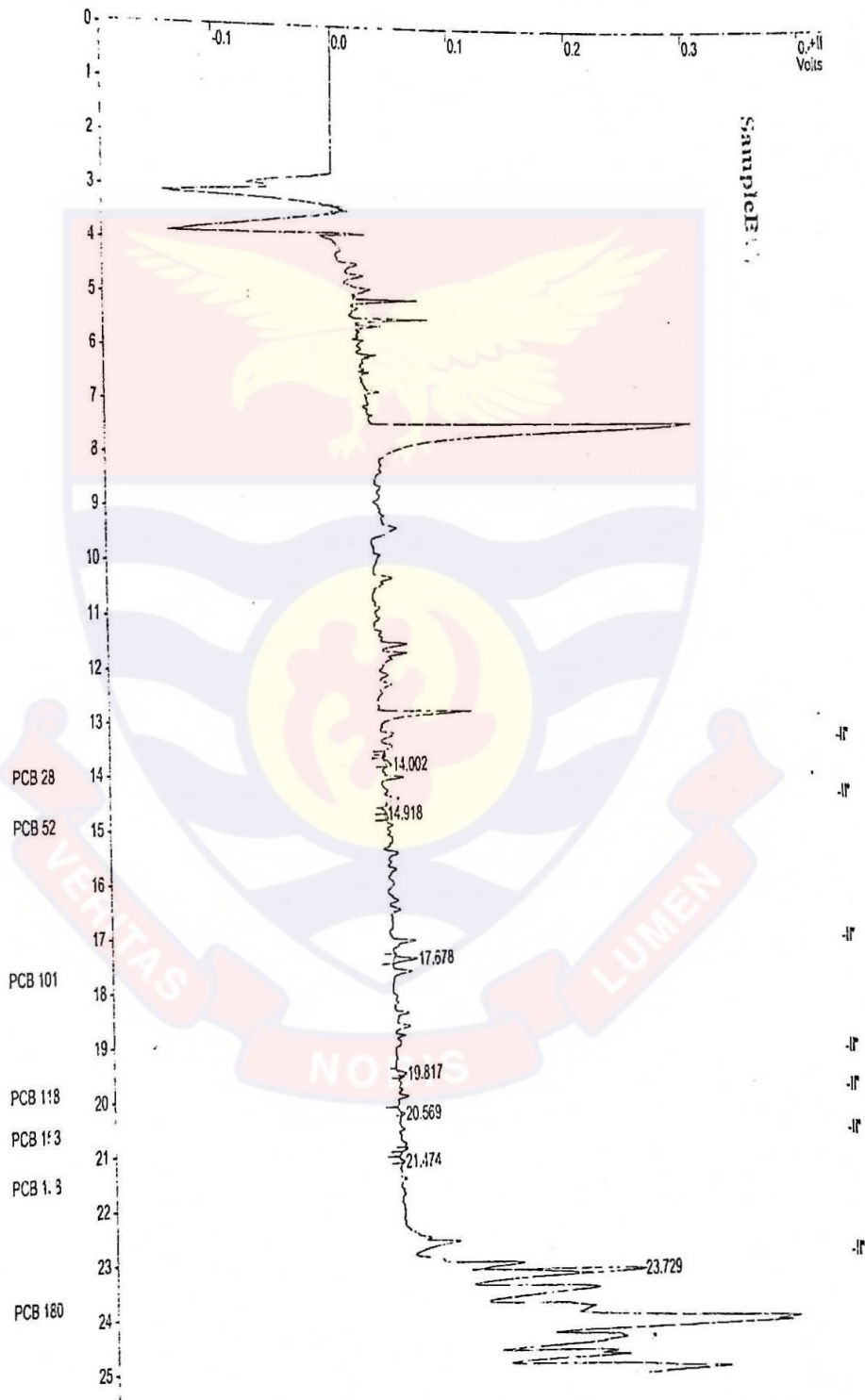


Chart Speed = 0.69 cm/min Attenuation = 252 Zero Offset = 514
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



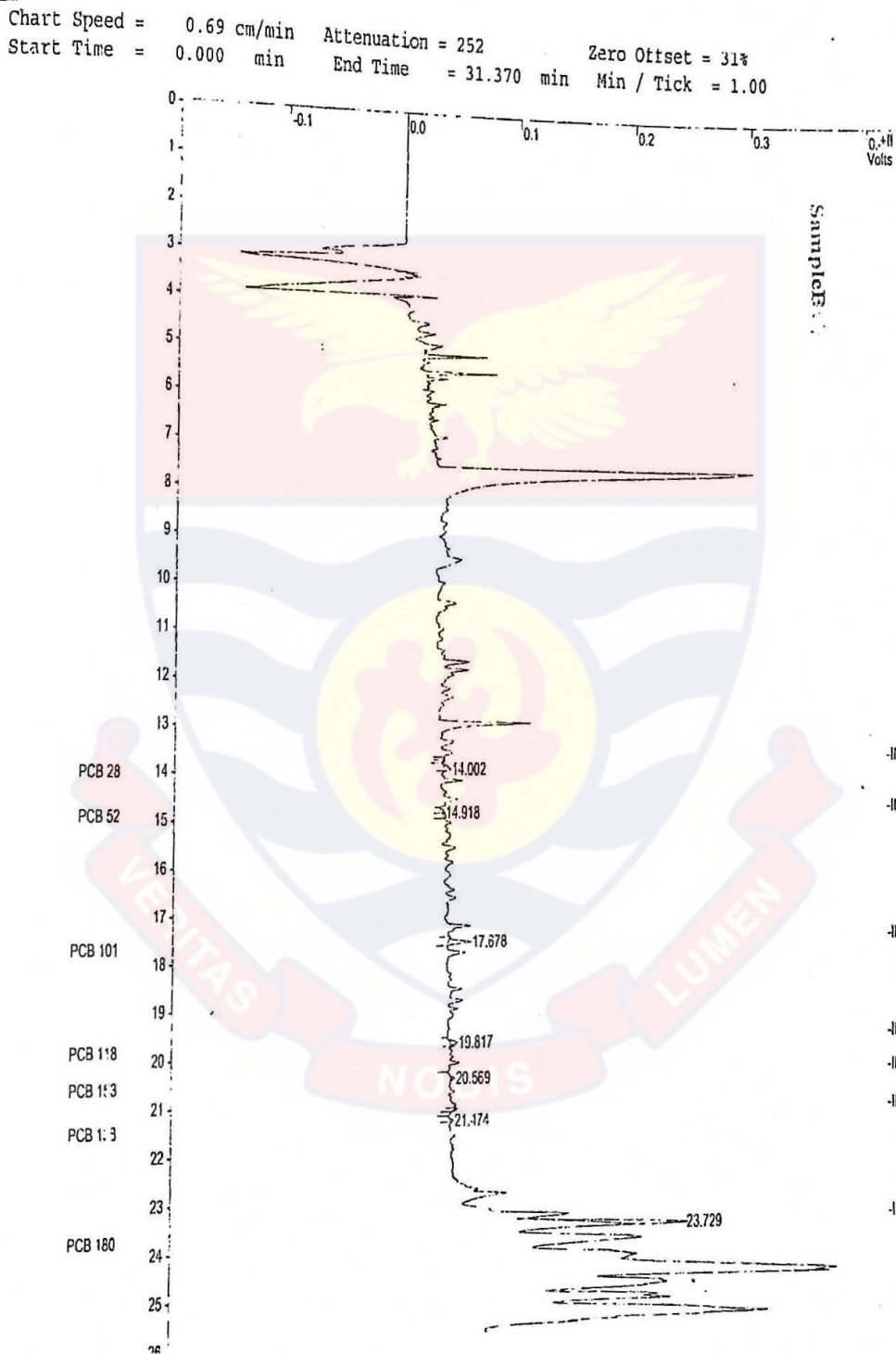
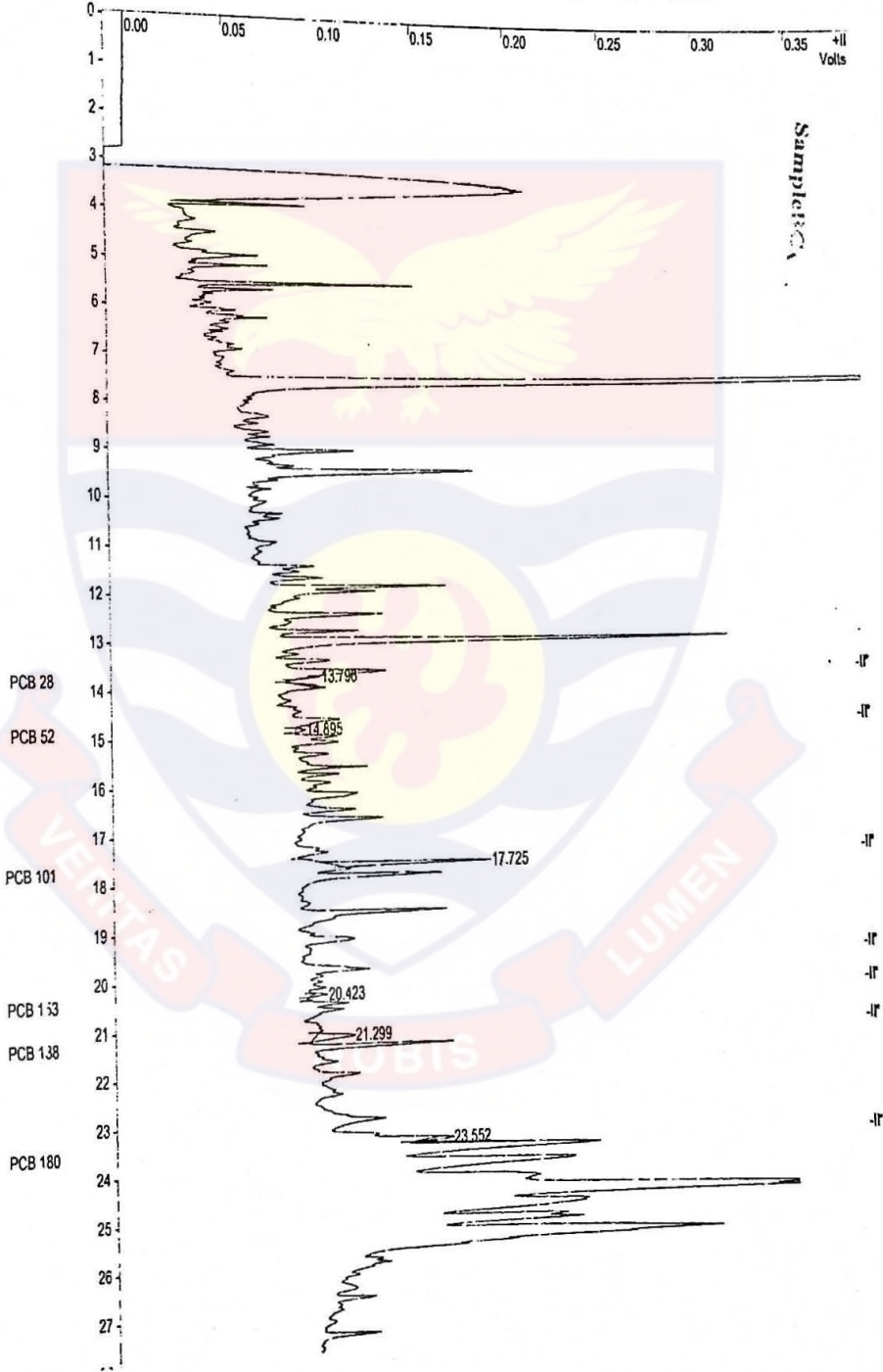


Chart Speed = 0.69 cm/min Attenuation = 161 Zero Offset = 2%
Start Time = 0.000 min End Time = 31.368 min Min / Tick = 1.00



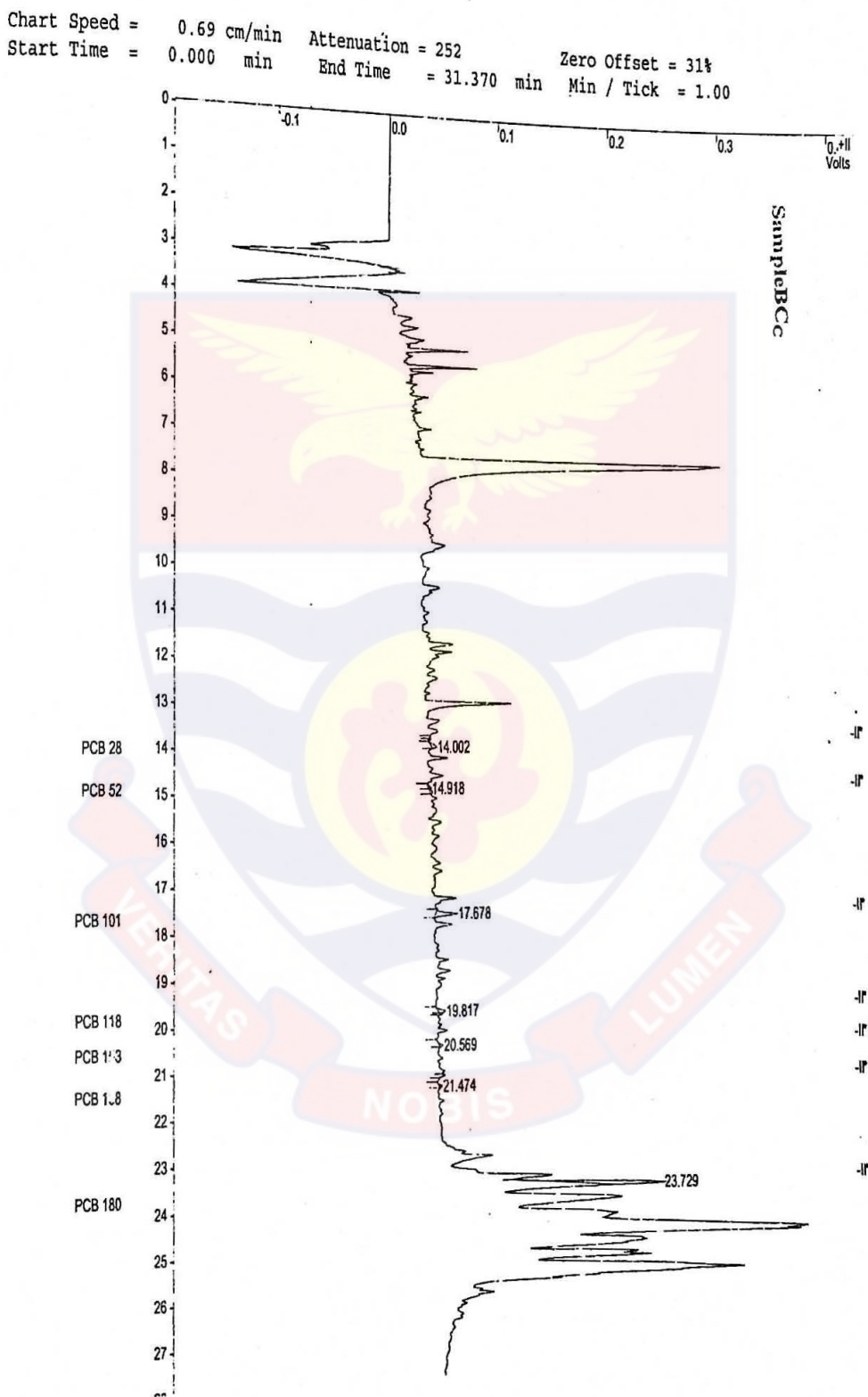


Chart Speed = 0.69 cm/min Attenuation = 210 Zero Offset = 14%
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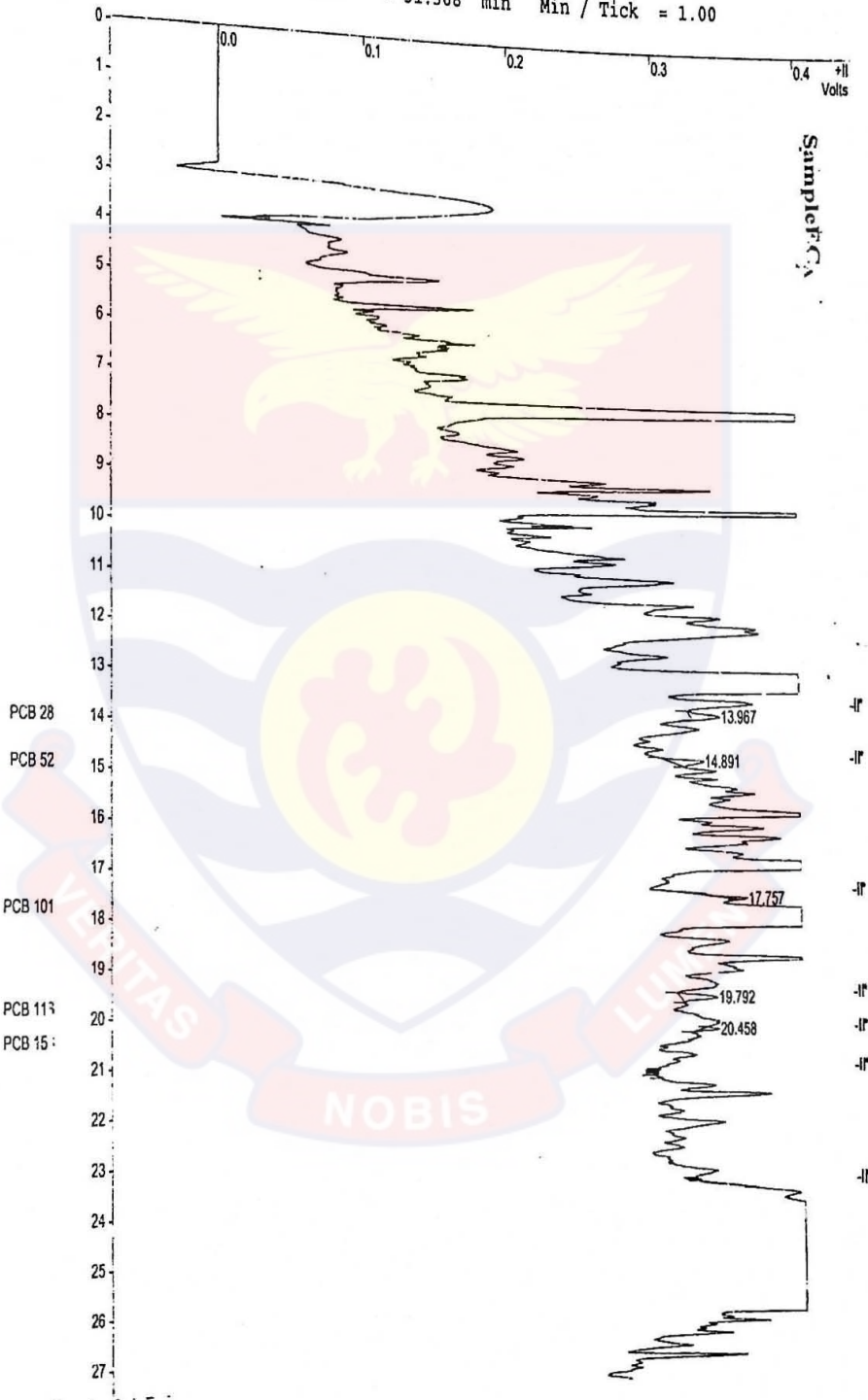


Chart Speed = 0.69 cm/min Attenuation = 243 Zero Offset = 25%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

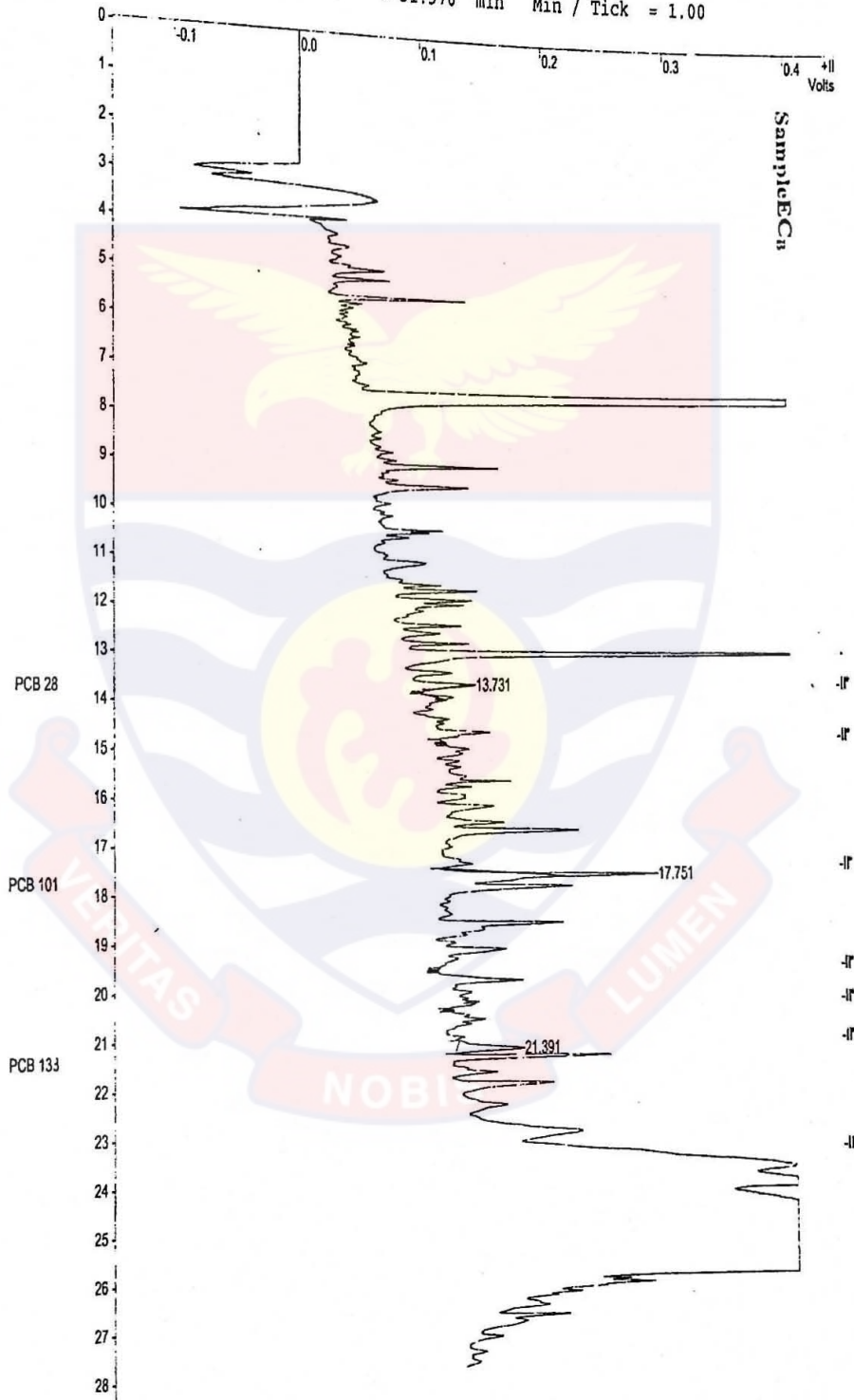
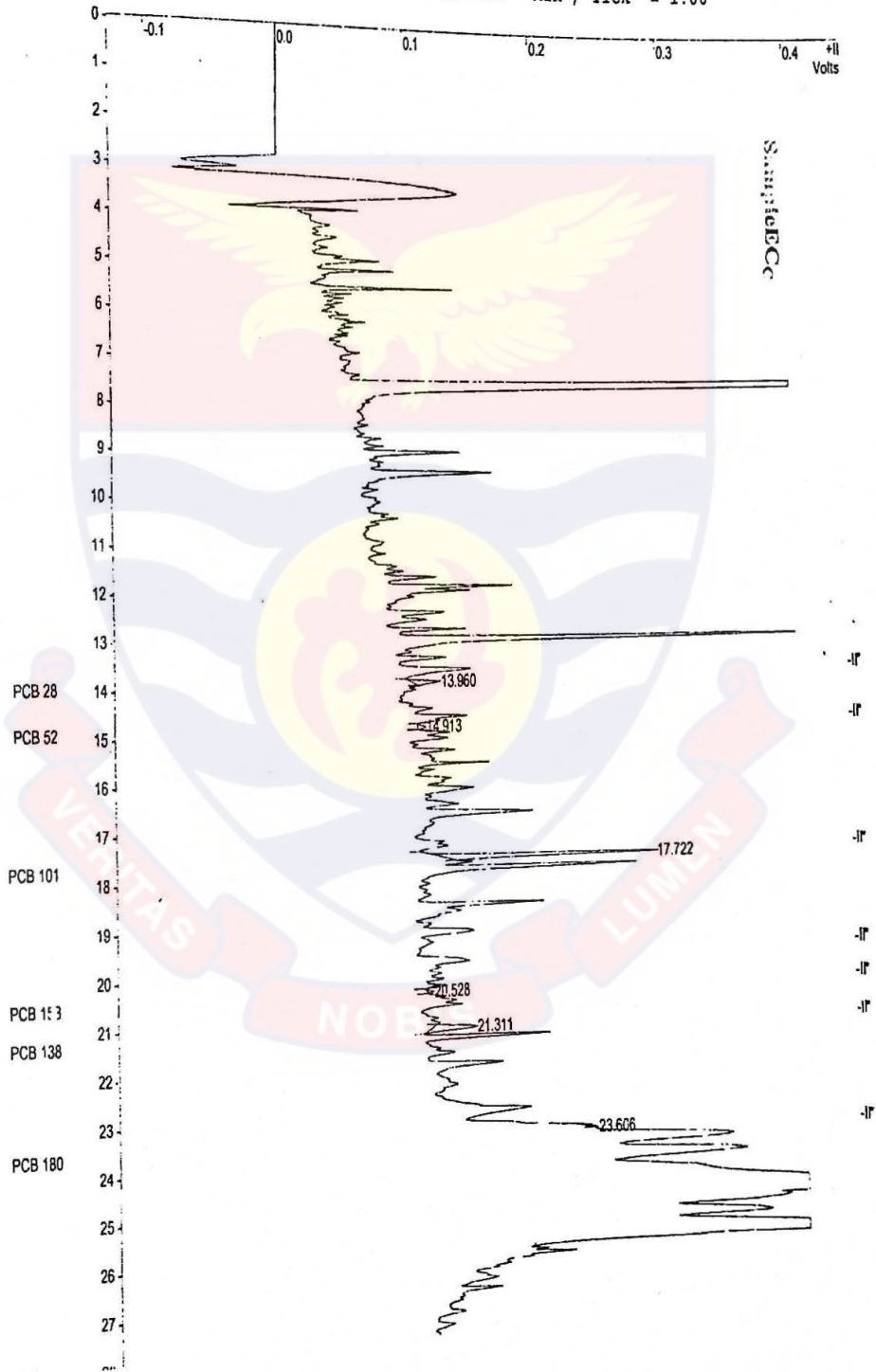


Chart Speed = 0.69 cm/min Attenuation = 235 Zero Offset = 22%
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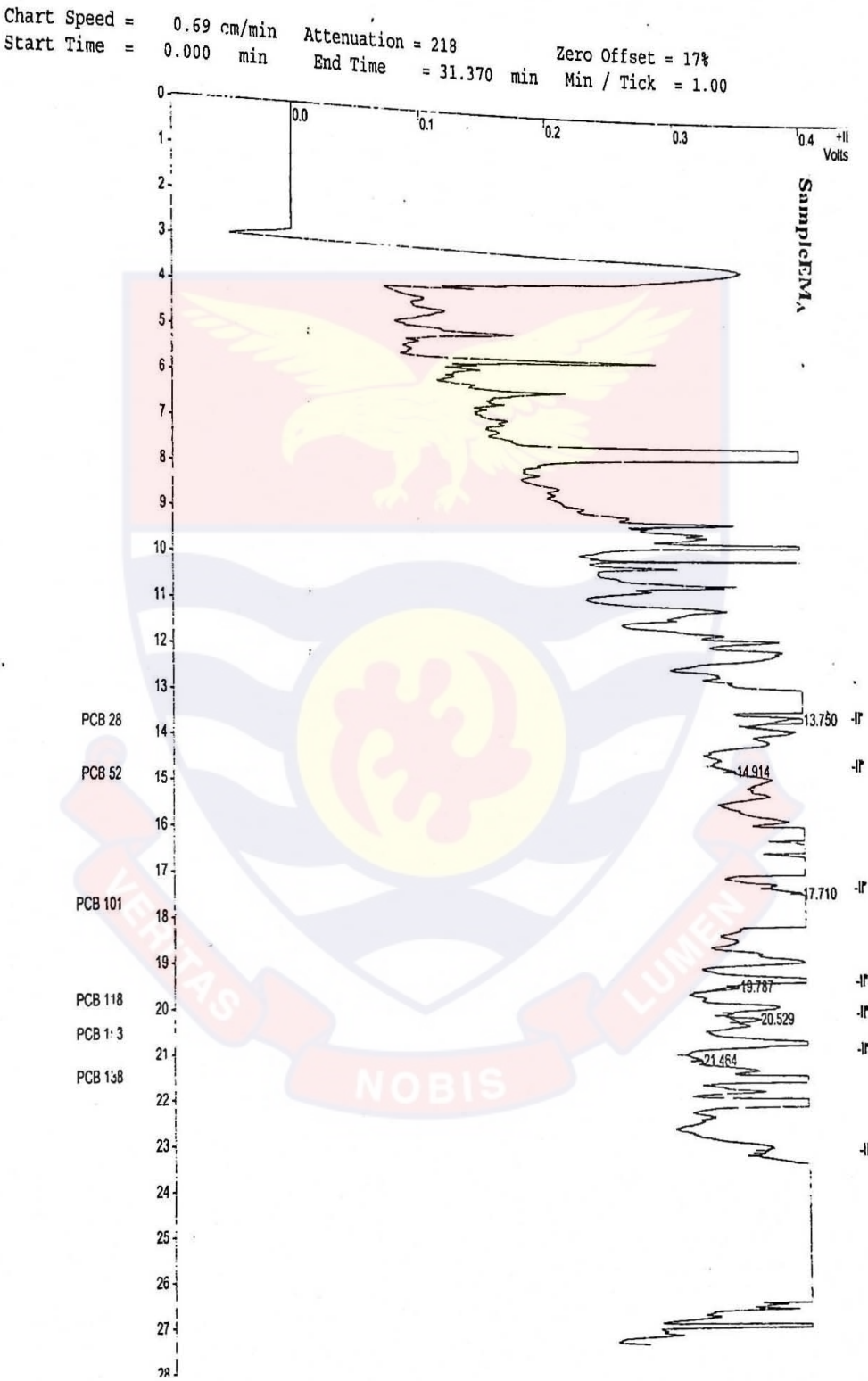
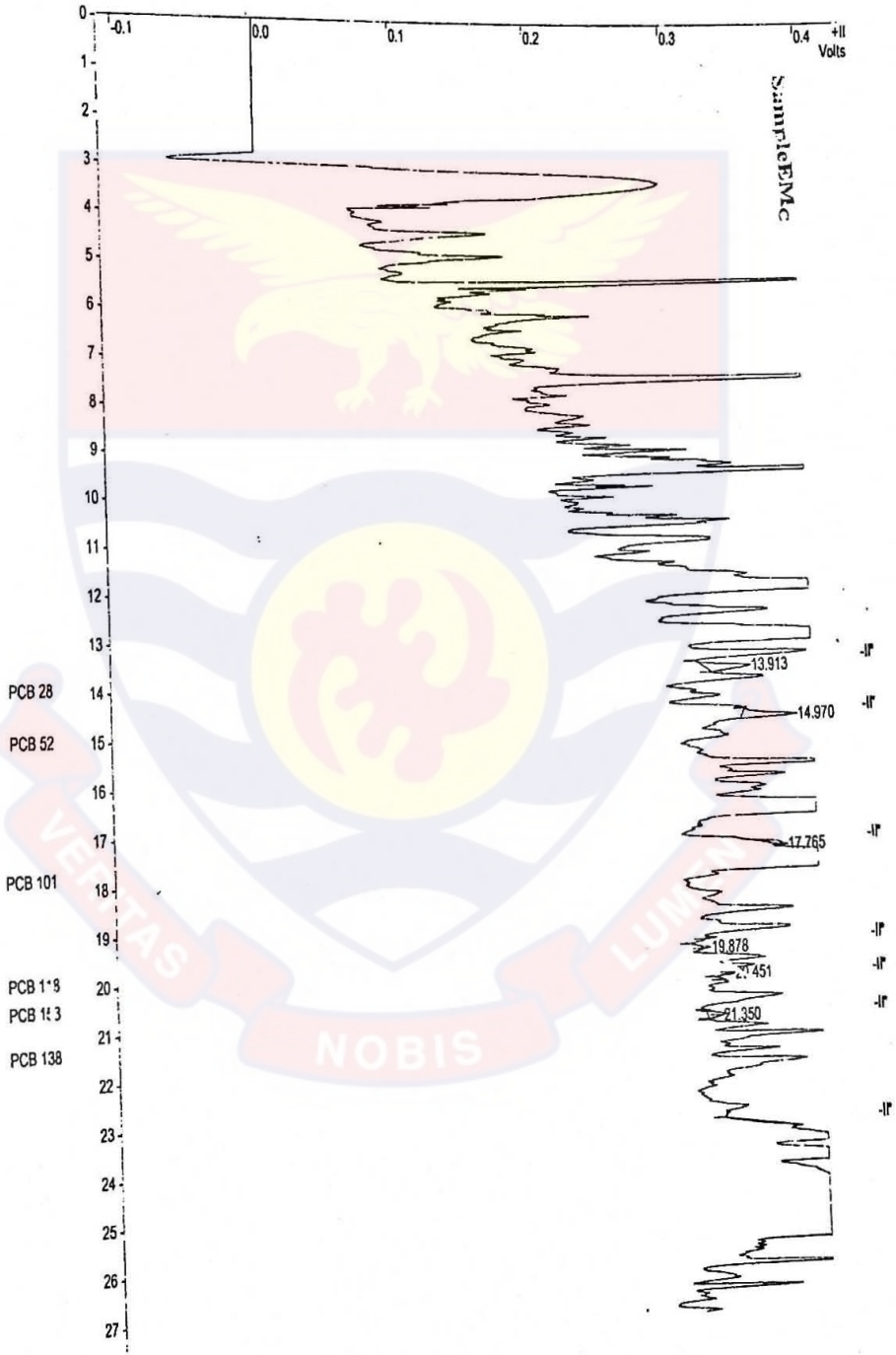


Chart Speed = 0.69 cm/min Attenuation = 226 Zero Offset = 20%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



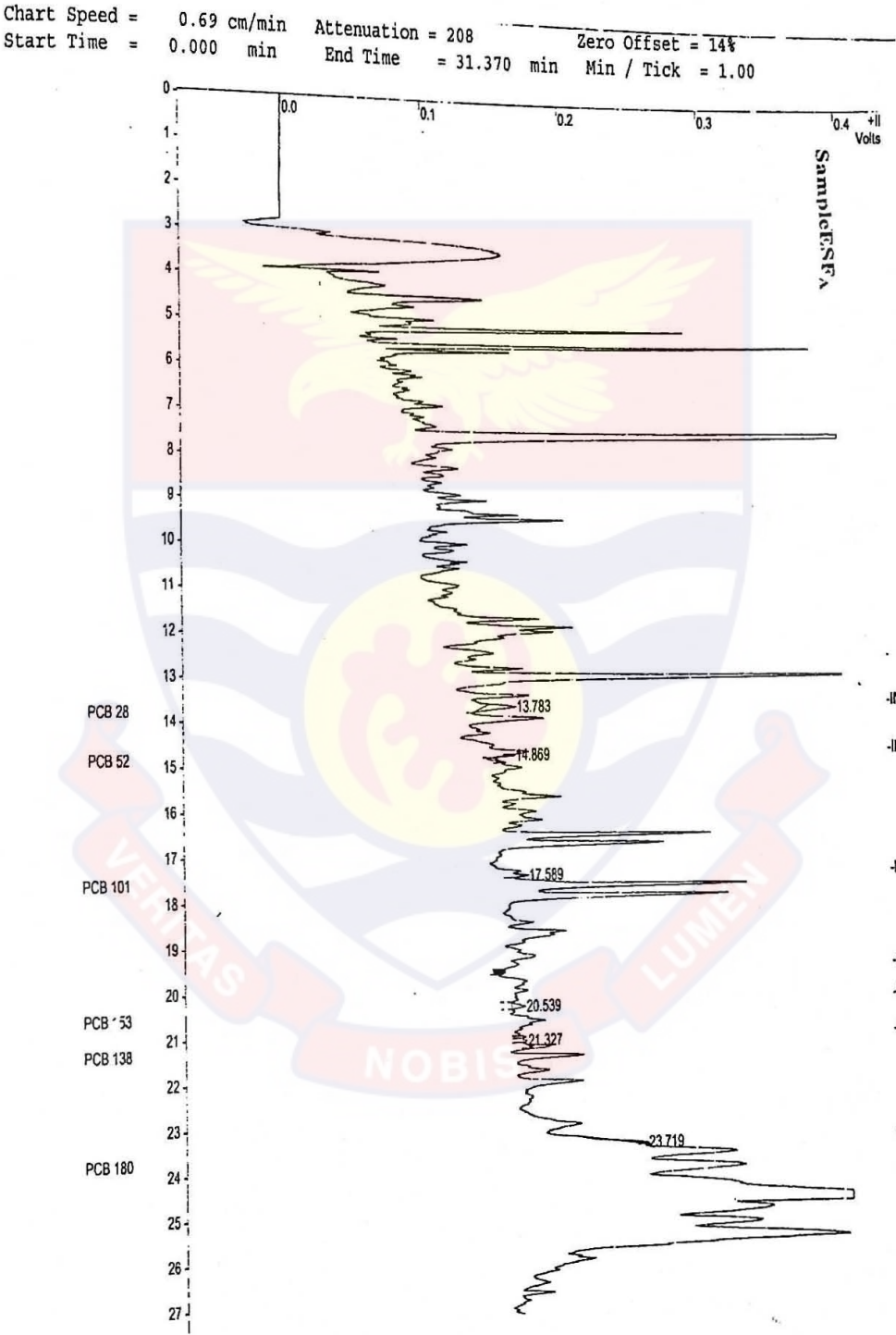


Chart Speed = 0.69 cm/min Attenuation = 108 Zero Offset = 2%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

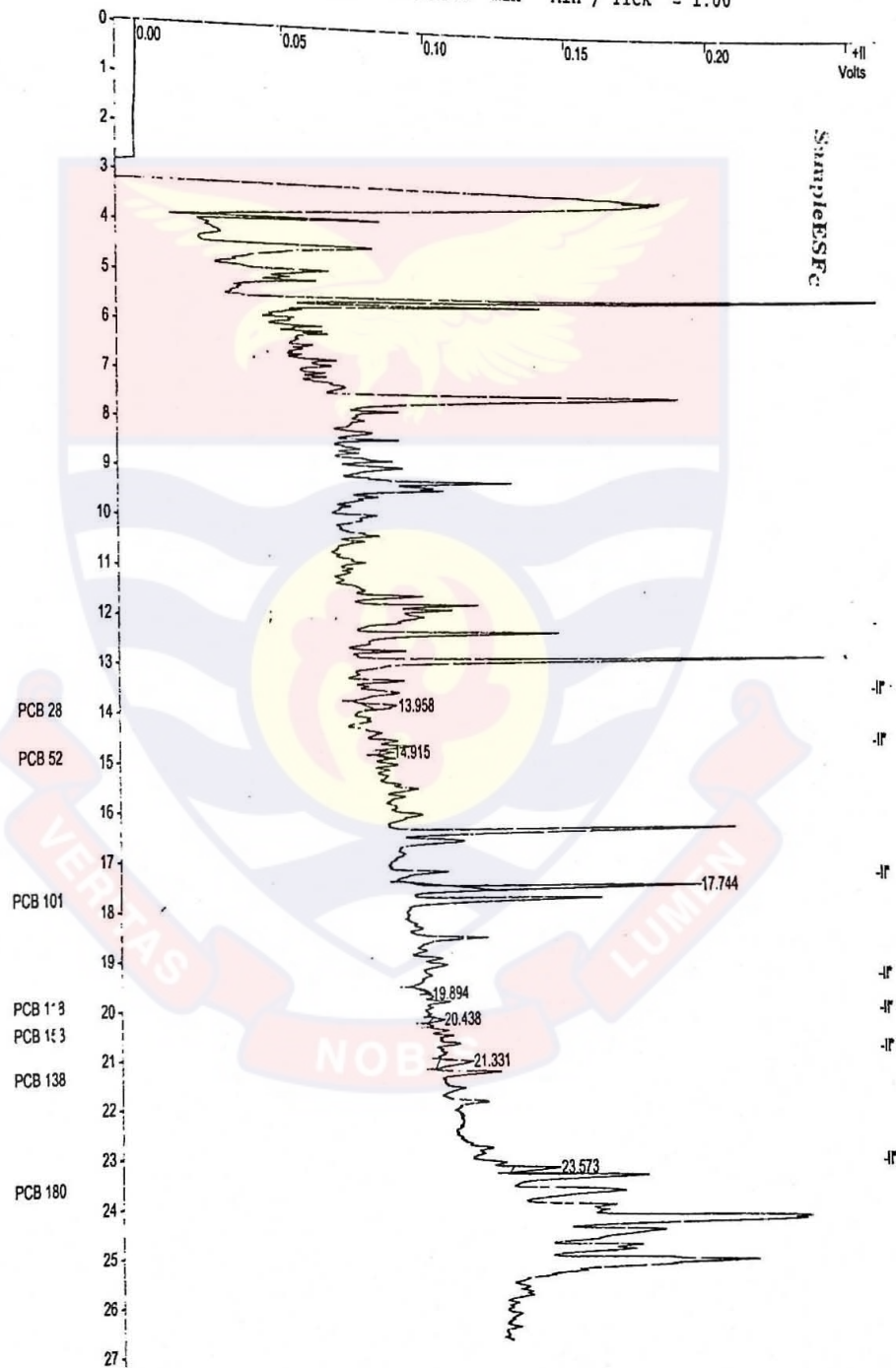
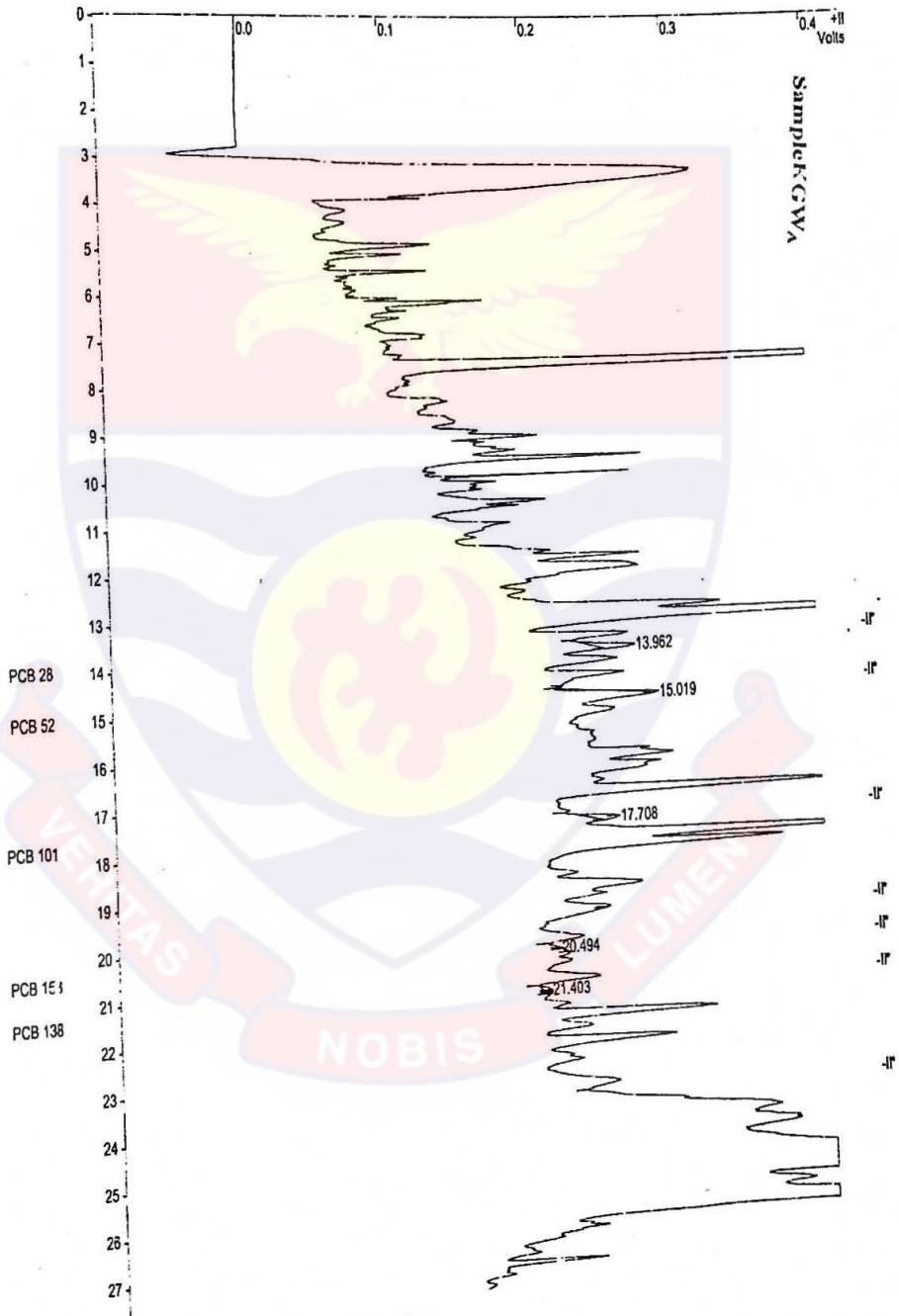
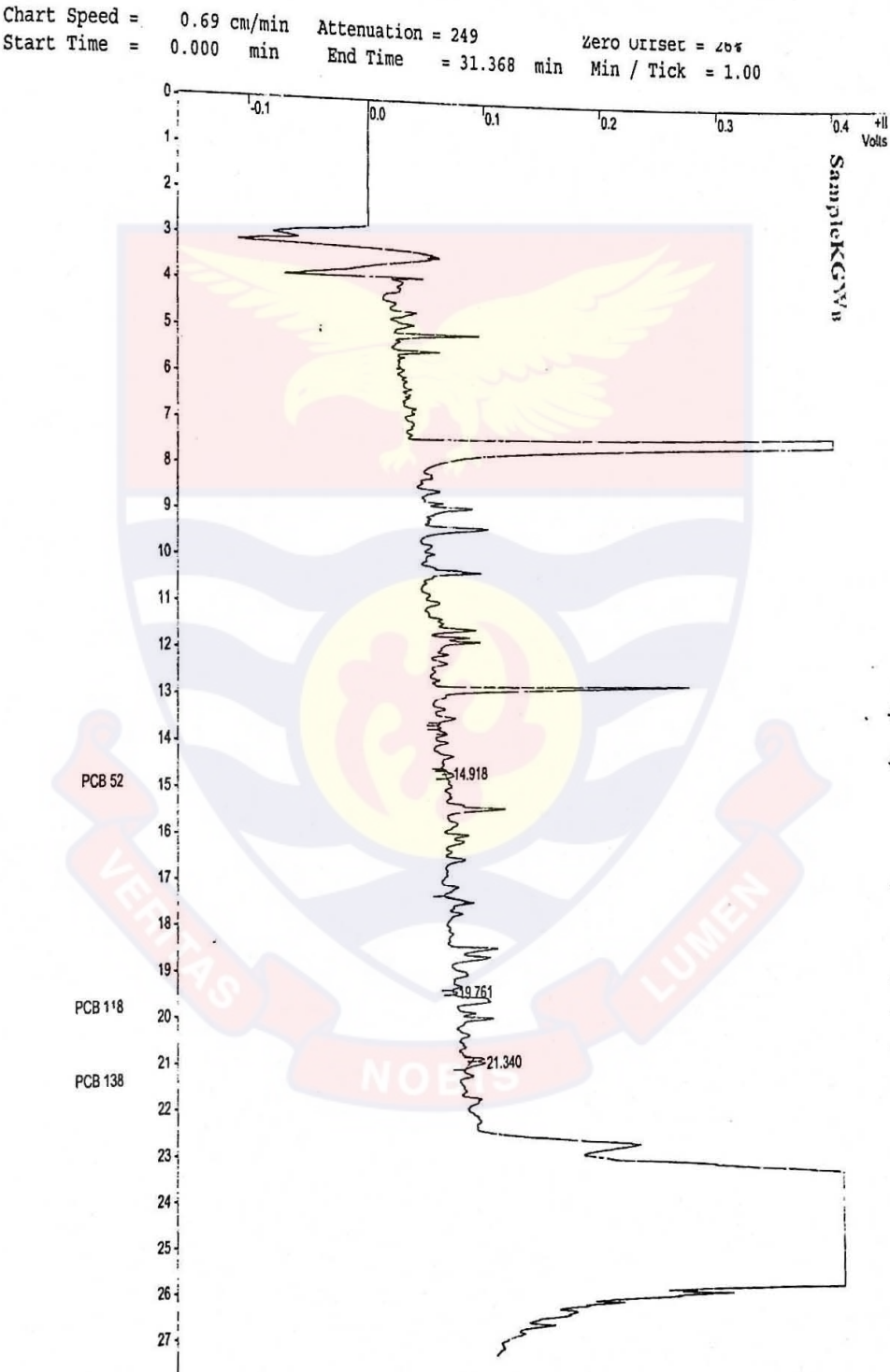


Chart Speed = 0.69 cm/min Attenuation = 217 Zero Offset = 10.
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00





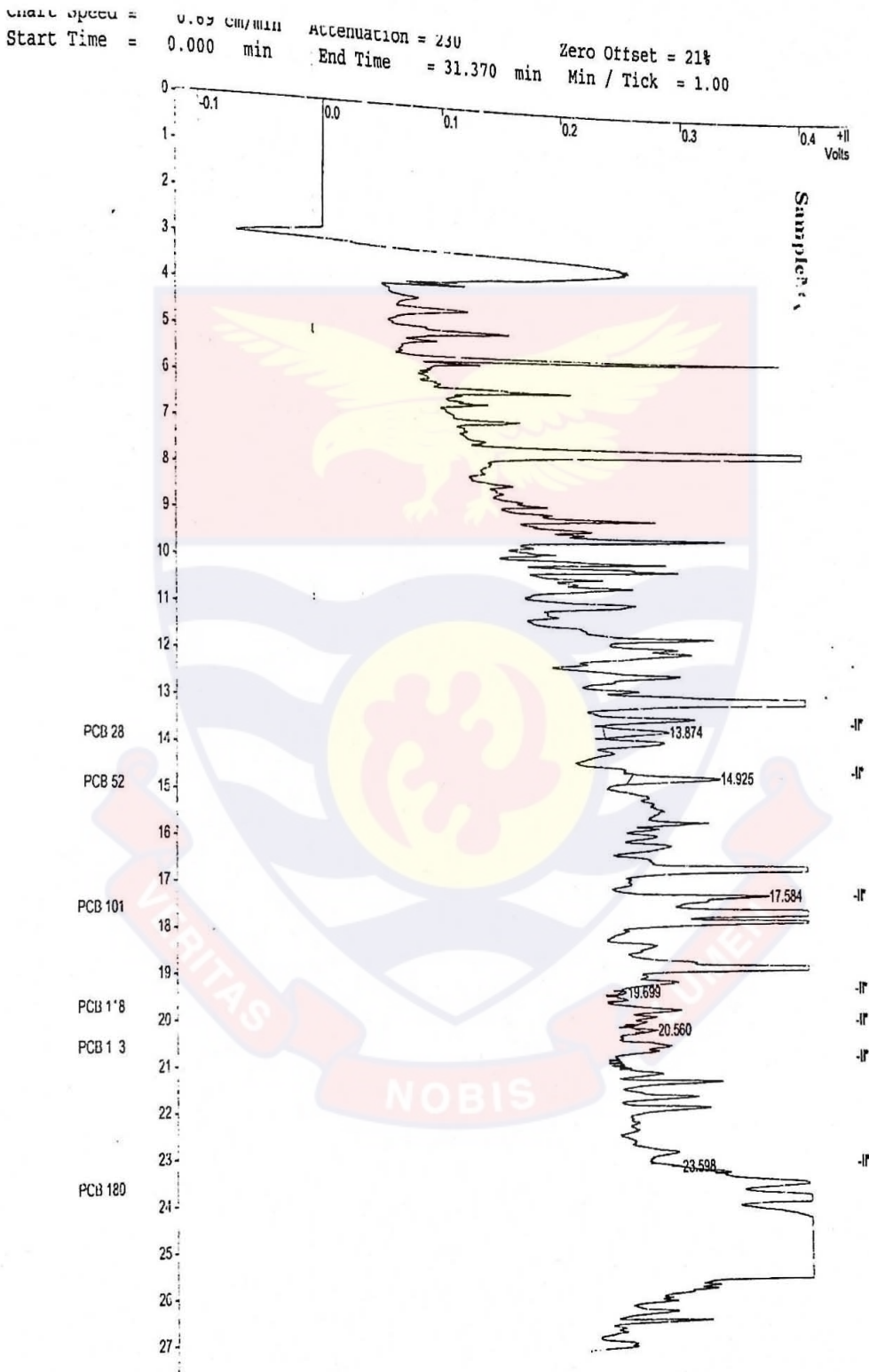


Chart Speed = 0.69 cm/min Attenuation = 225 Zero Offset = 21%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

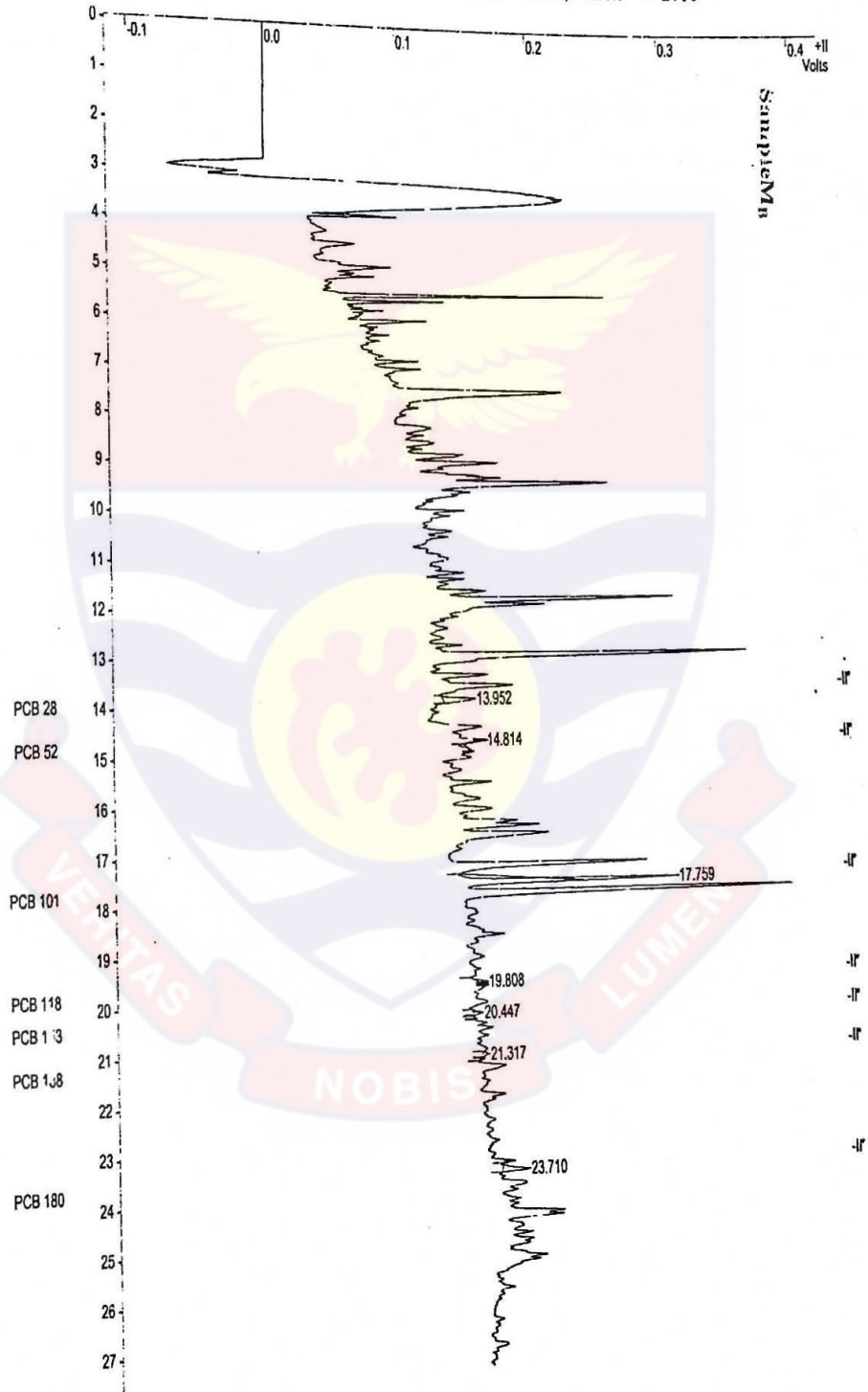
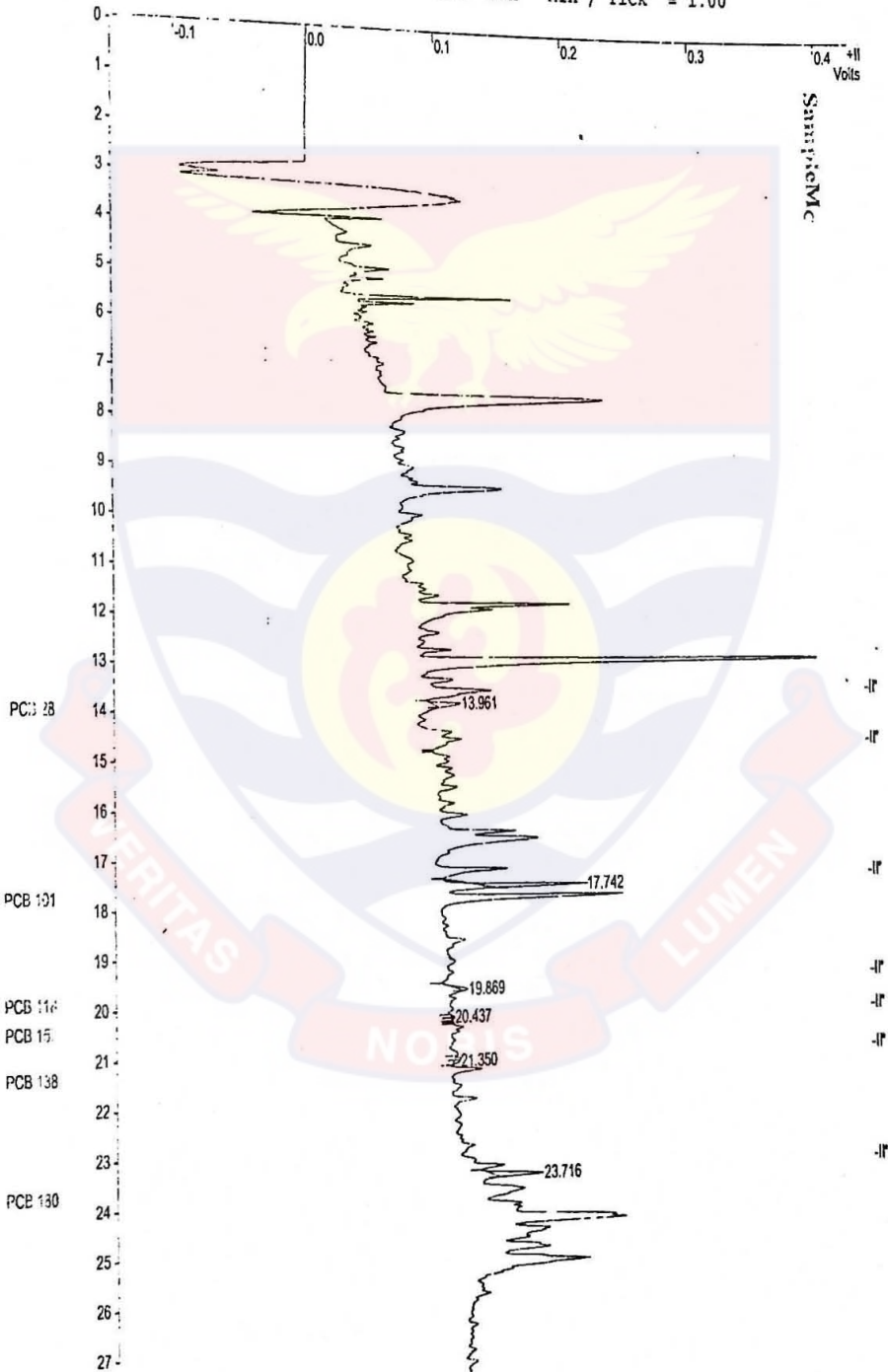


Chart Speed = 0.69 cm/min Attenuation = 240 Zero Offset = 25%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



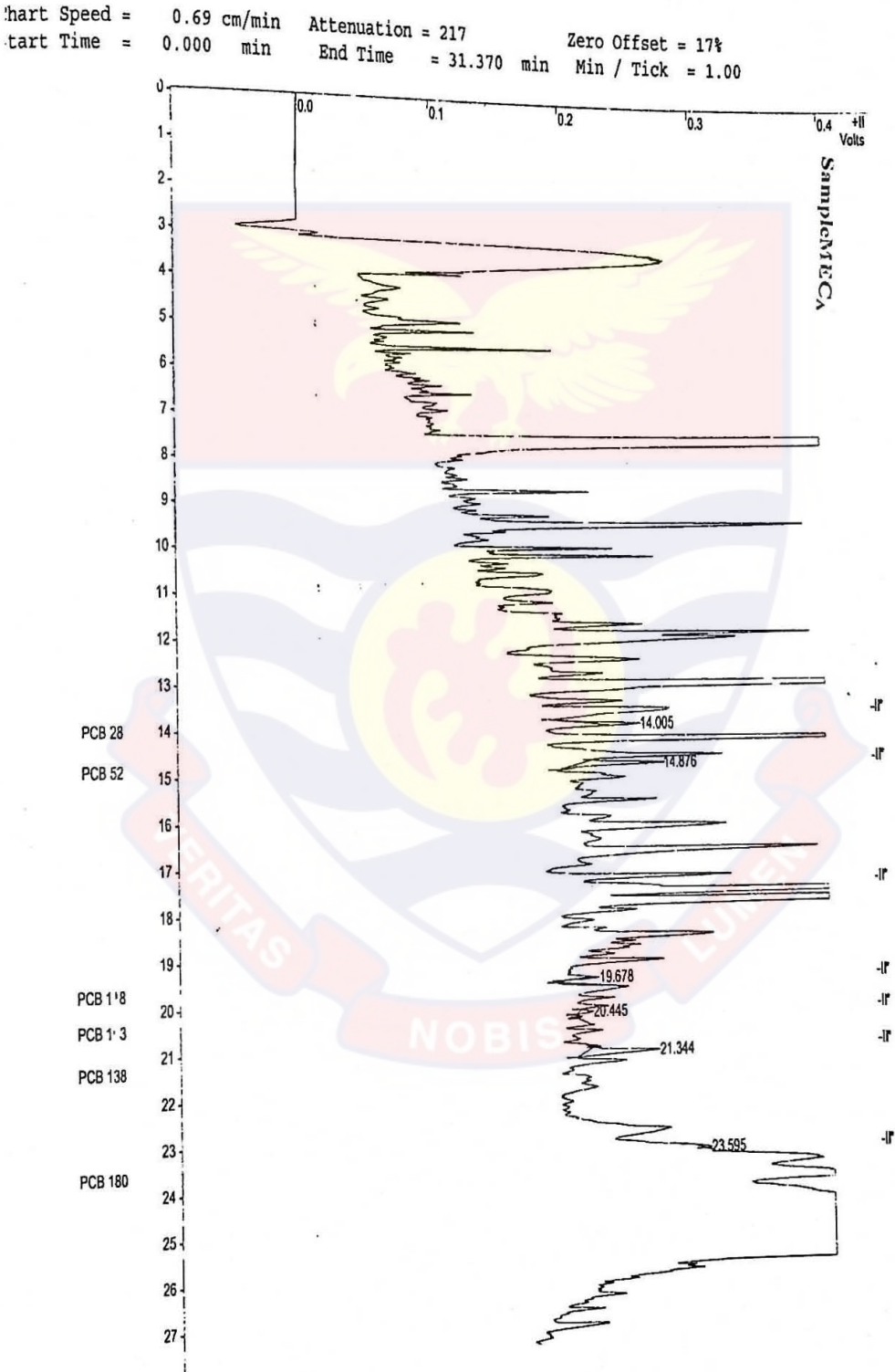


Chart Speed = 0.69 cm/min Attenuation = 242 Zero Offset = 25%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00

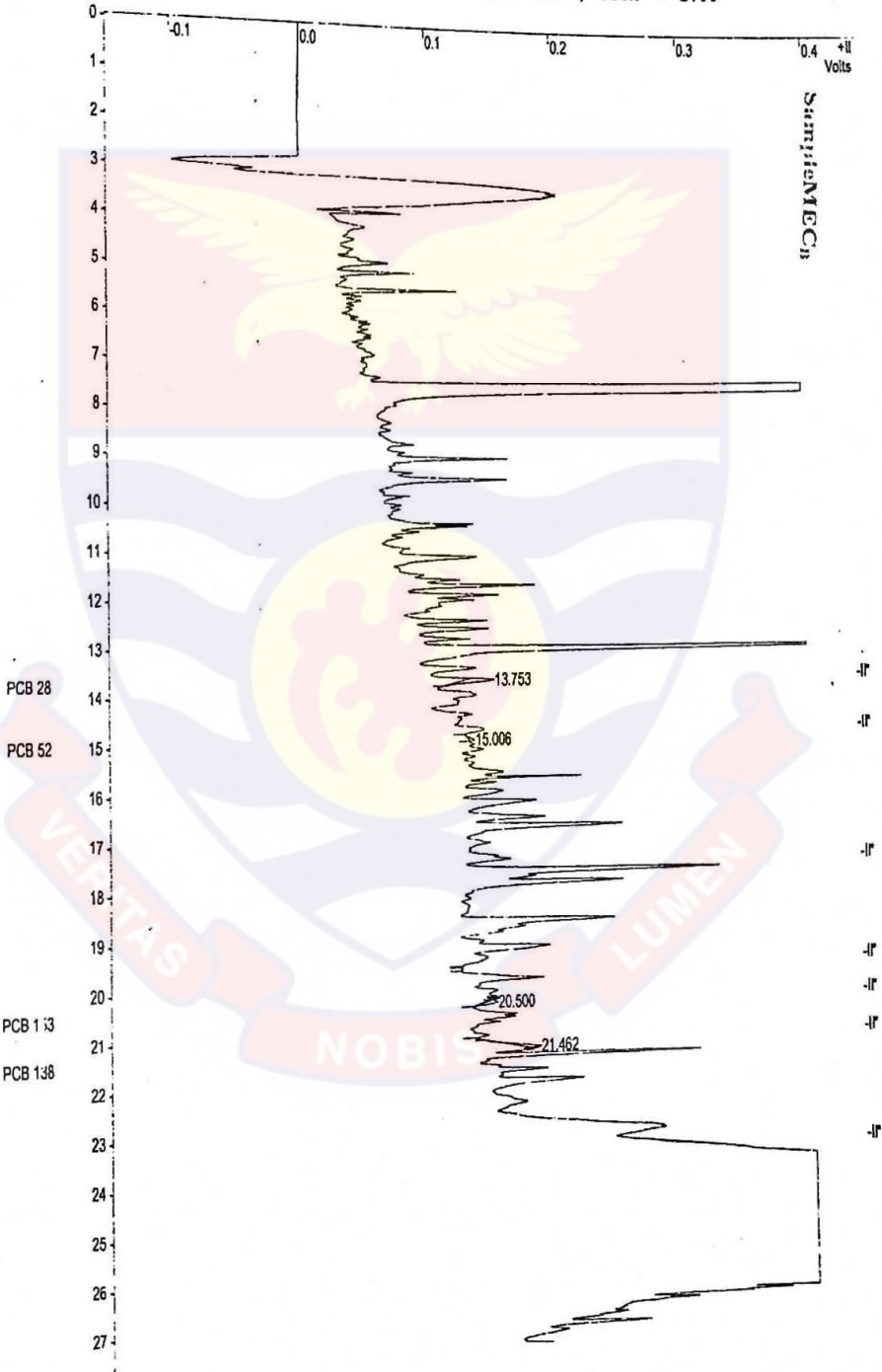
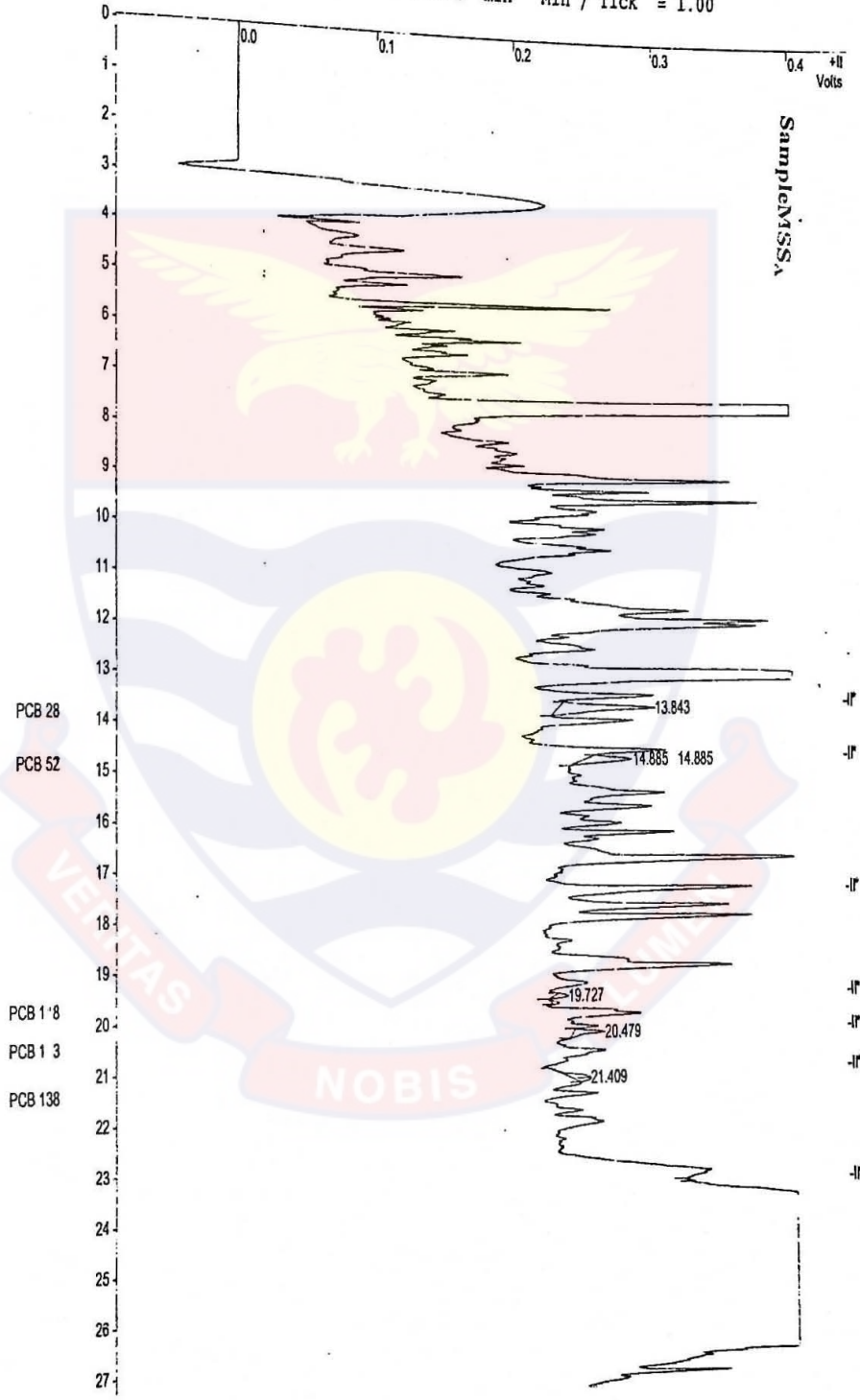
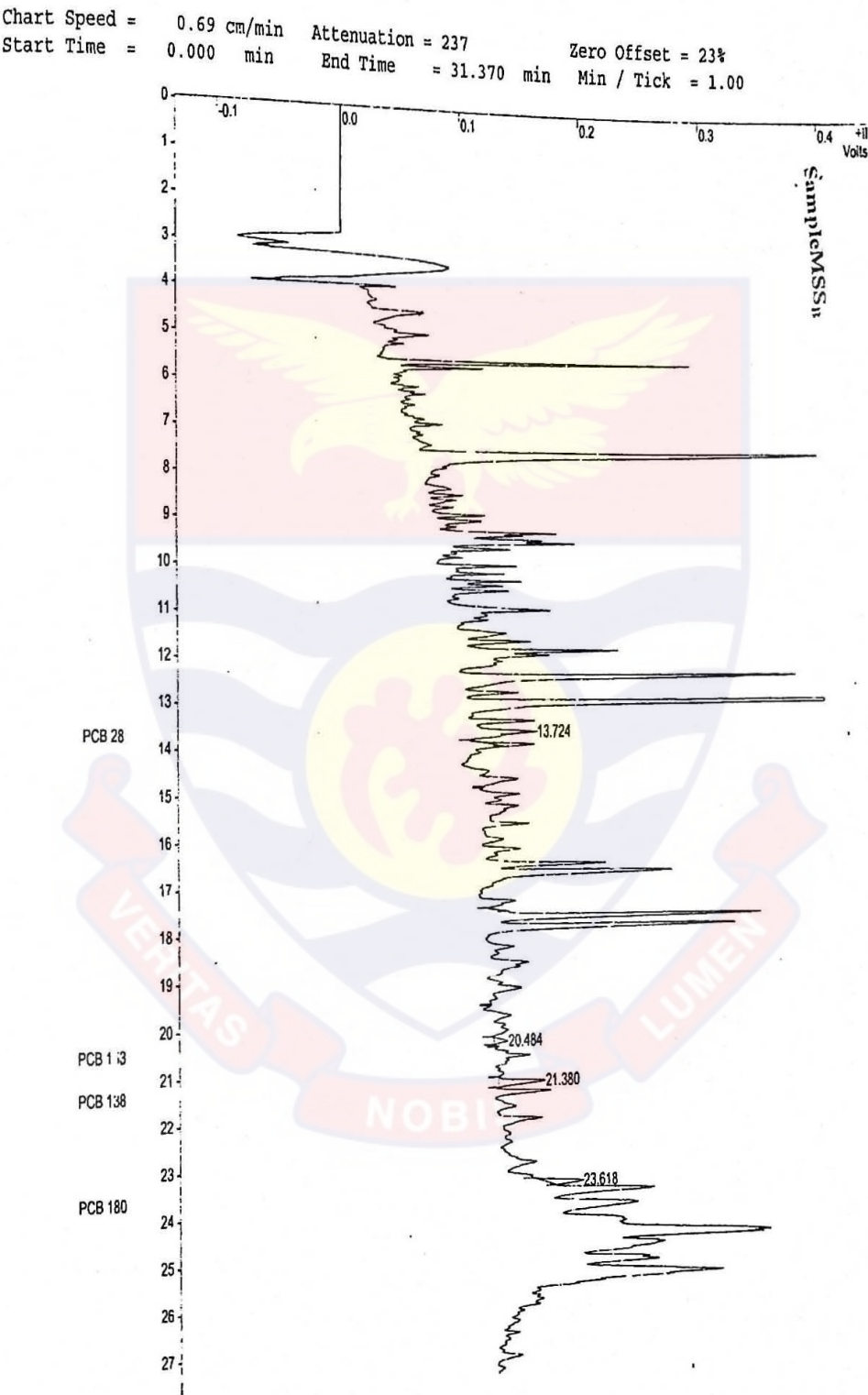




Chart Speed = 0.69 cm/min Attenuation = 216 Zero Offset = 16%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00





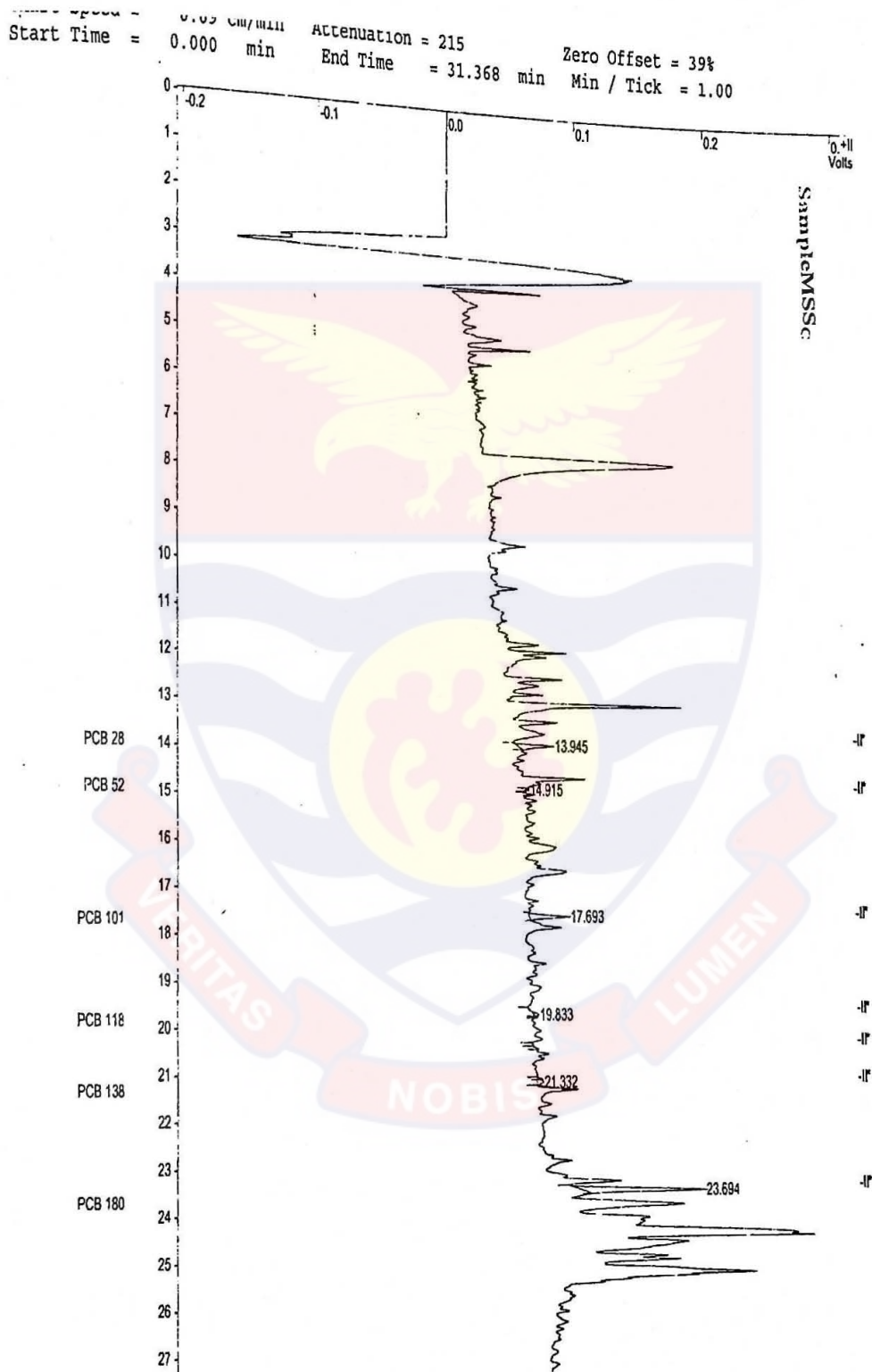
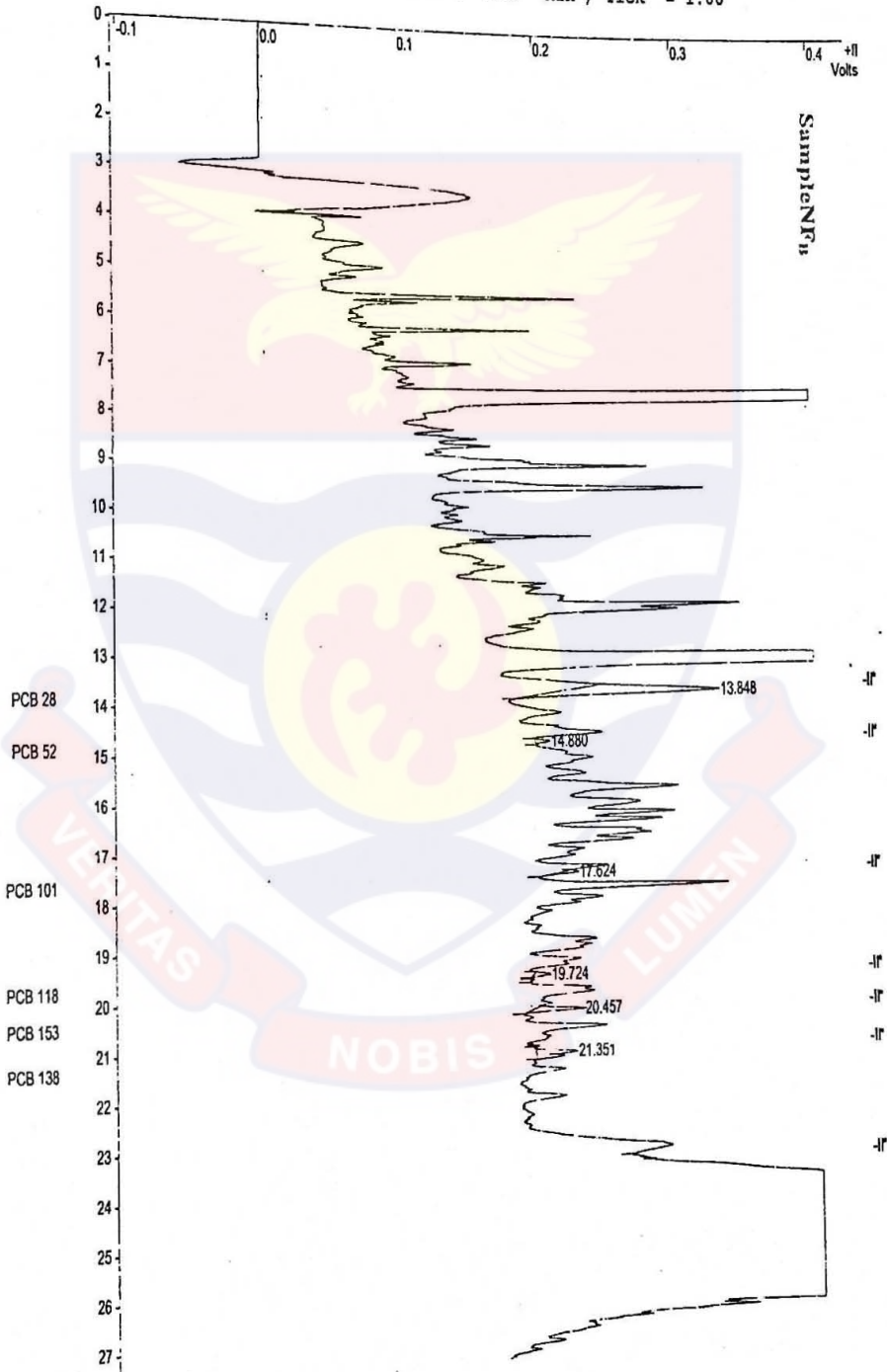


Chart Speed = 0.69 cm/min Attenuation = 223 zero offset = 19%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



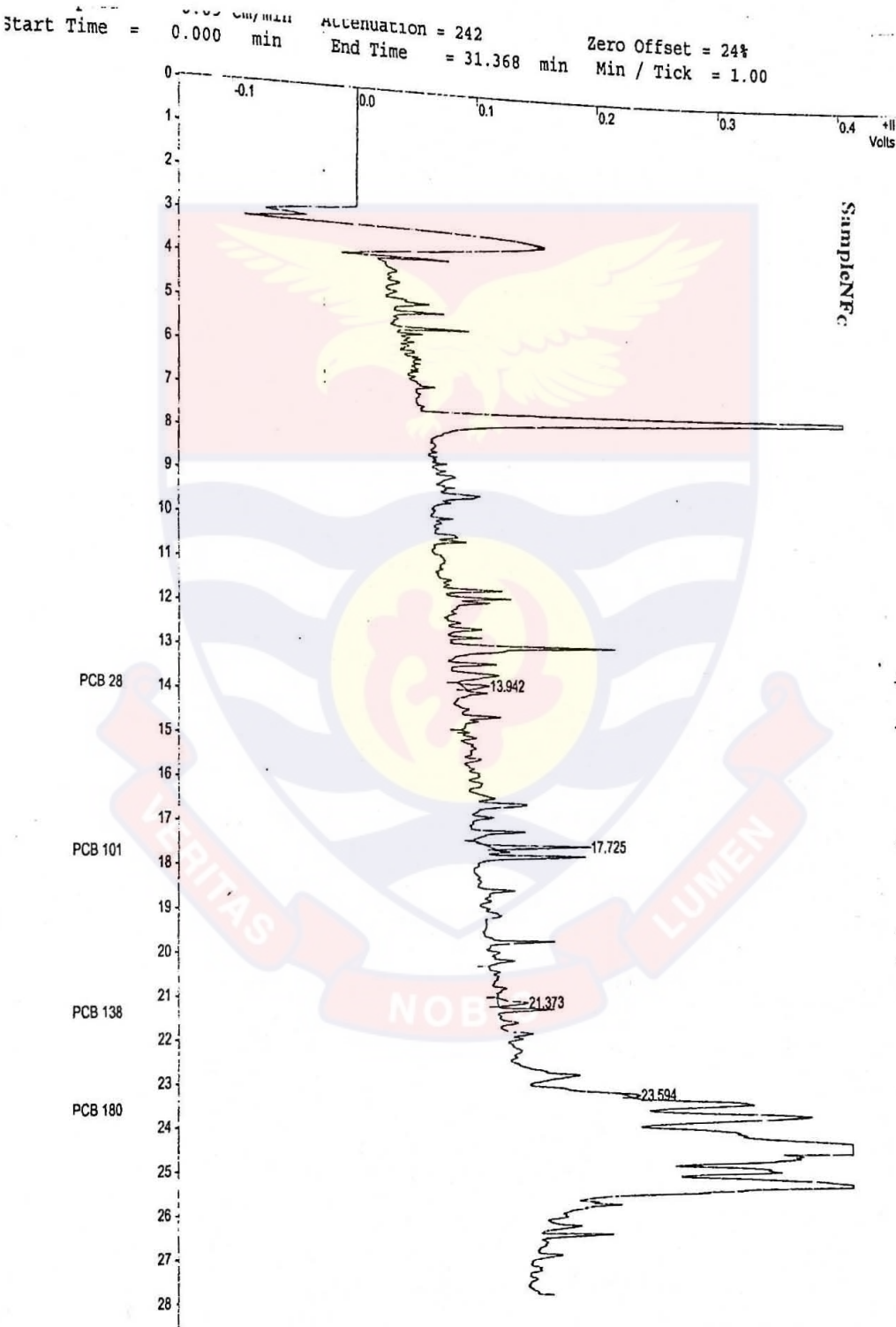
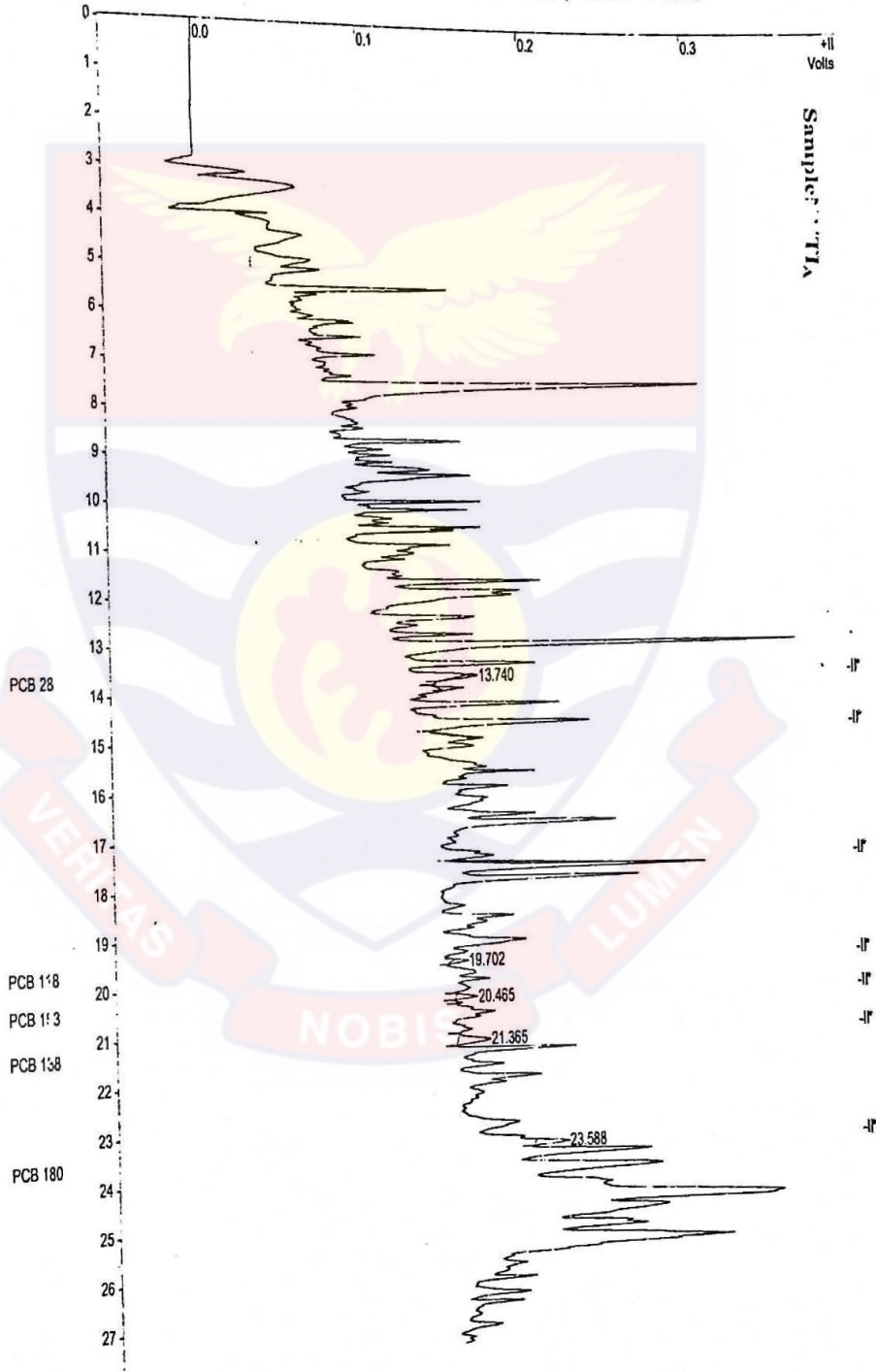
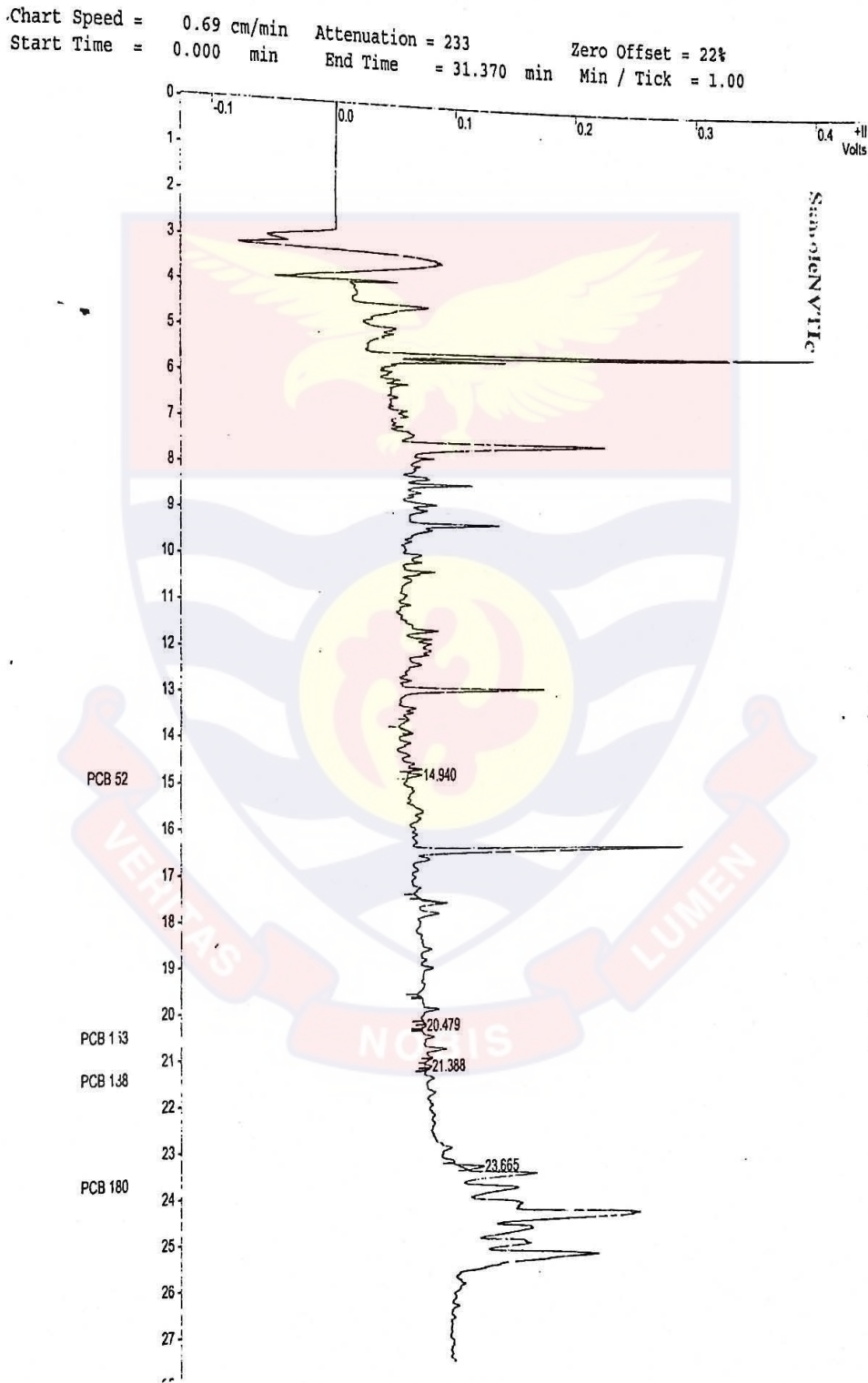
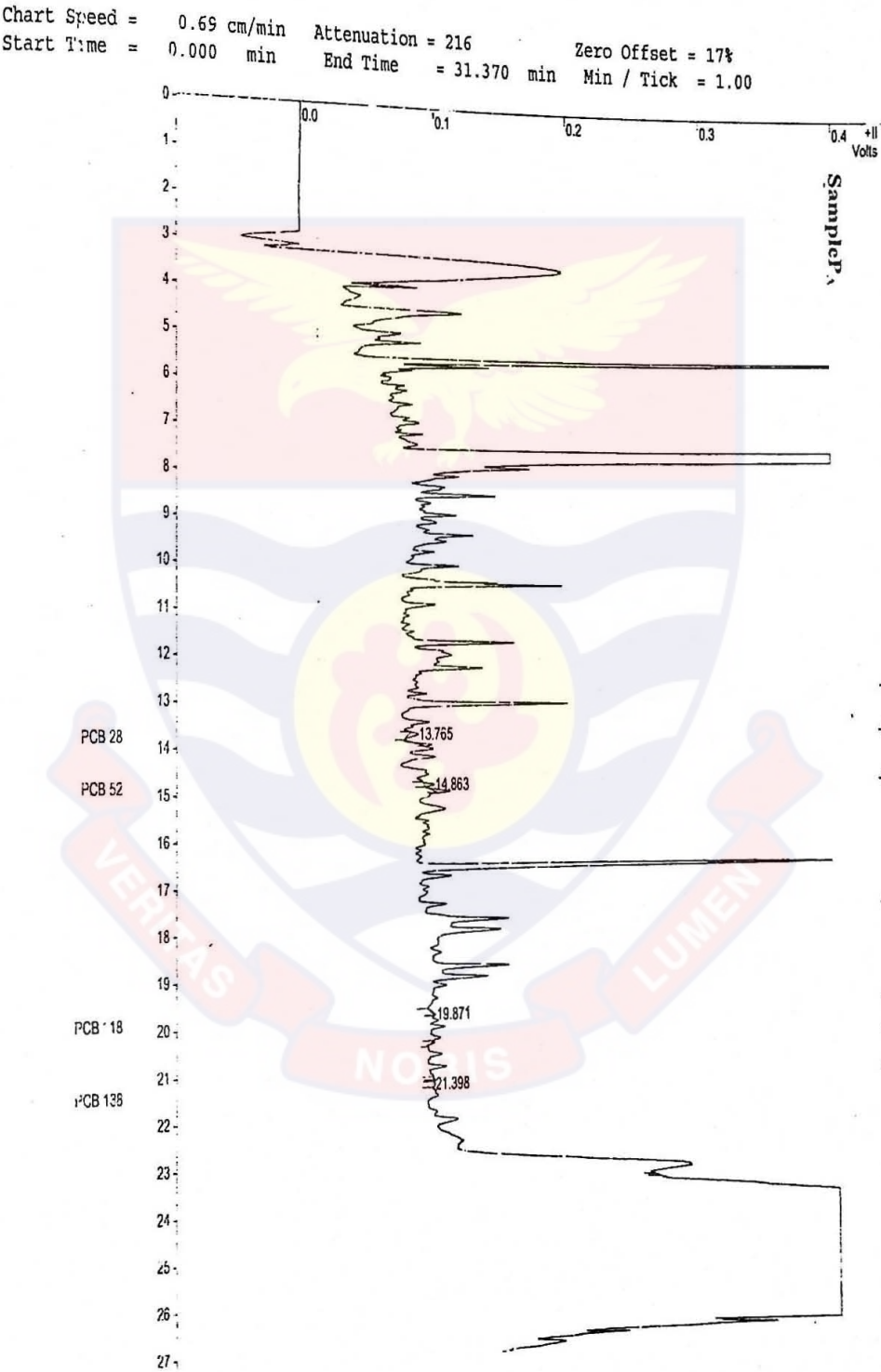
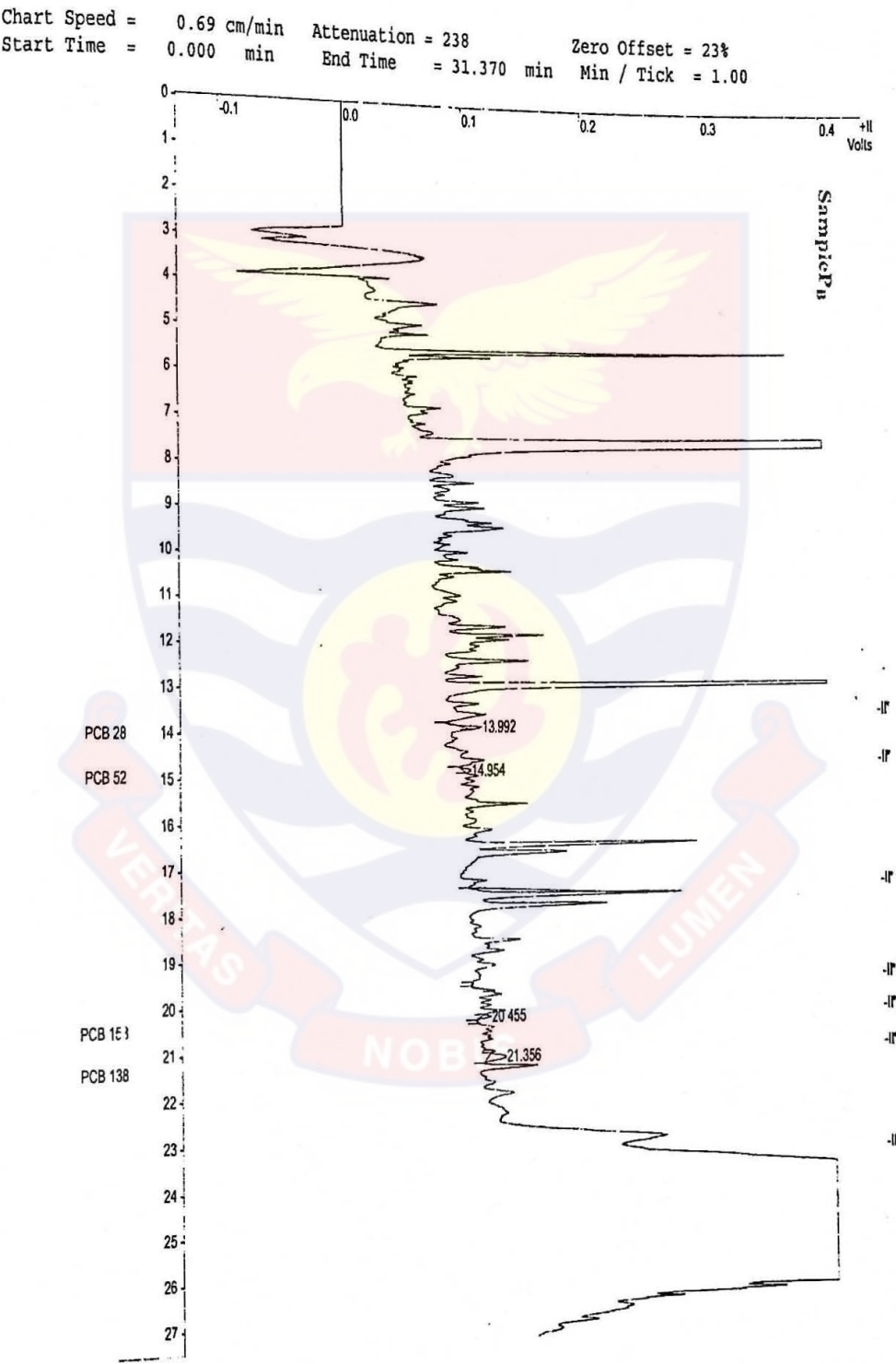


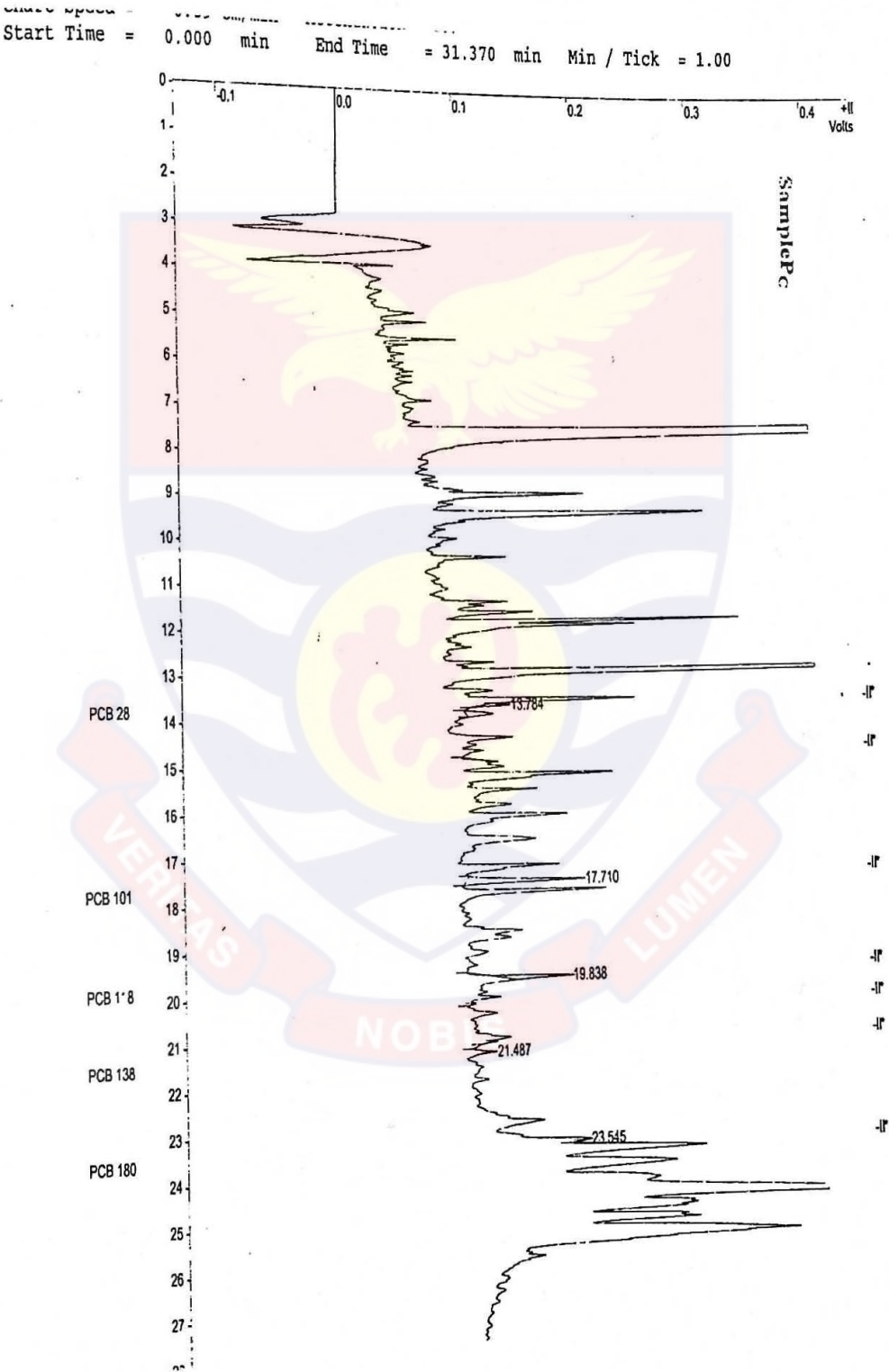
Chart Speed = 0.69 cm/min Attenuation = 185 Zero Offset = 12%
Start Time = 0.000 min End Time = 31.368 min Min / Tick = 1.00











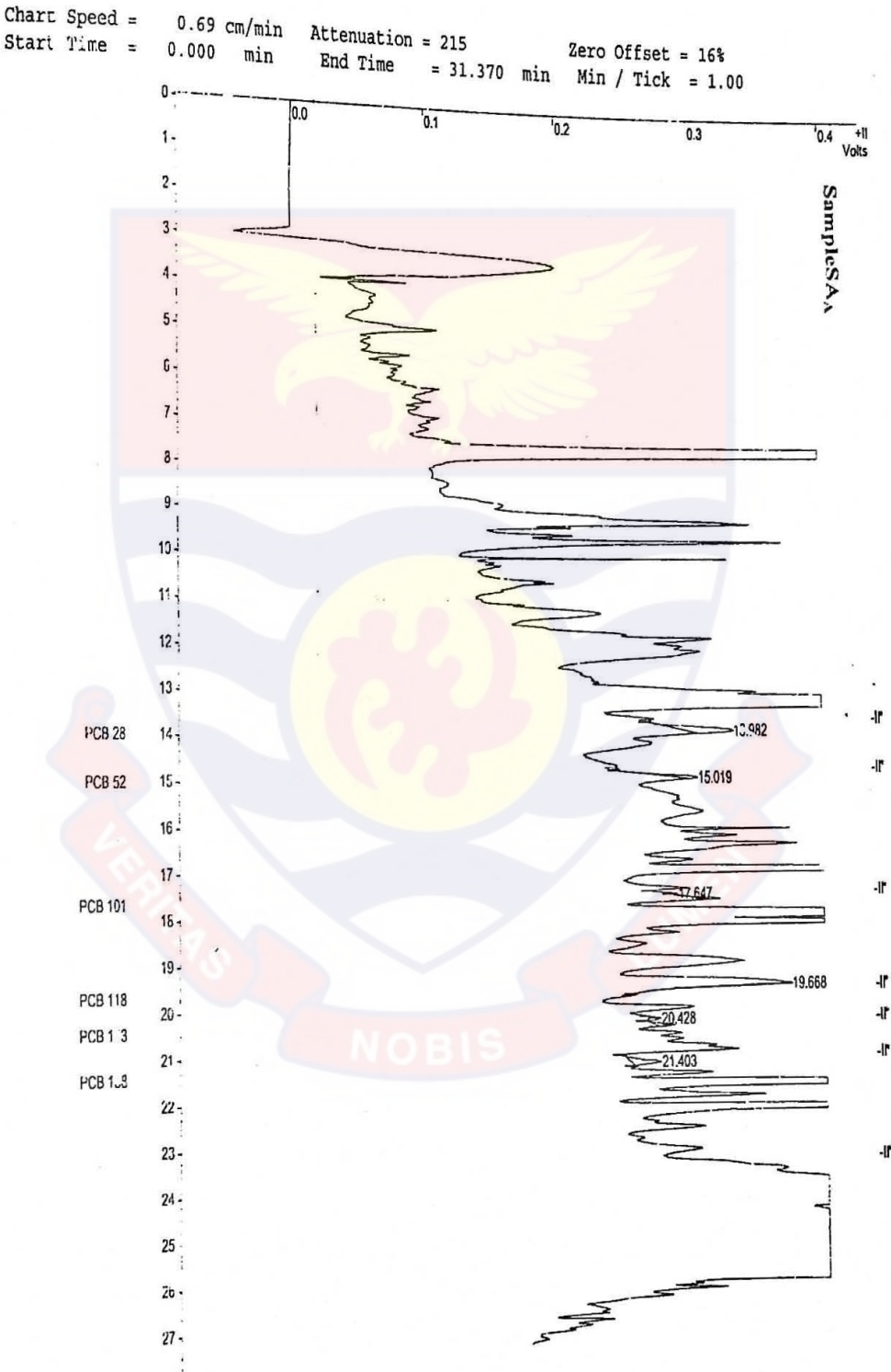
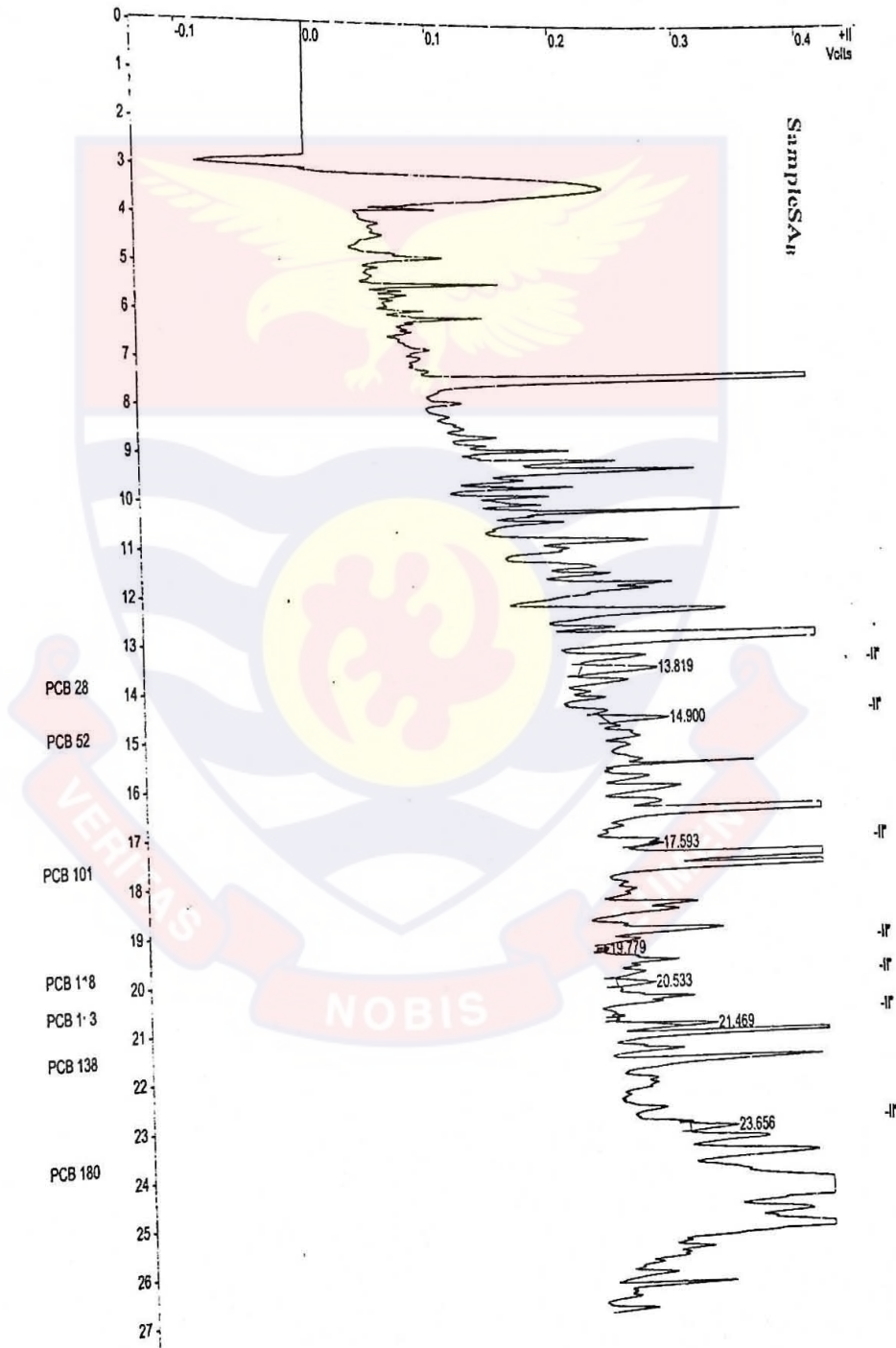
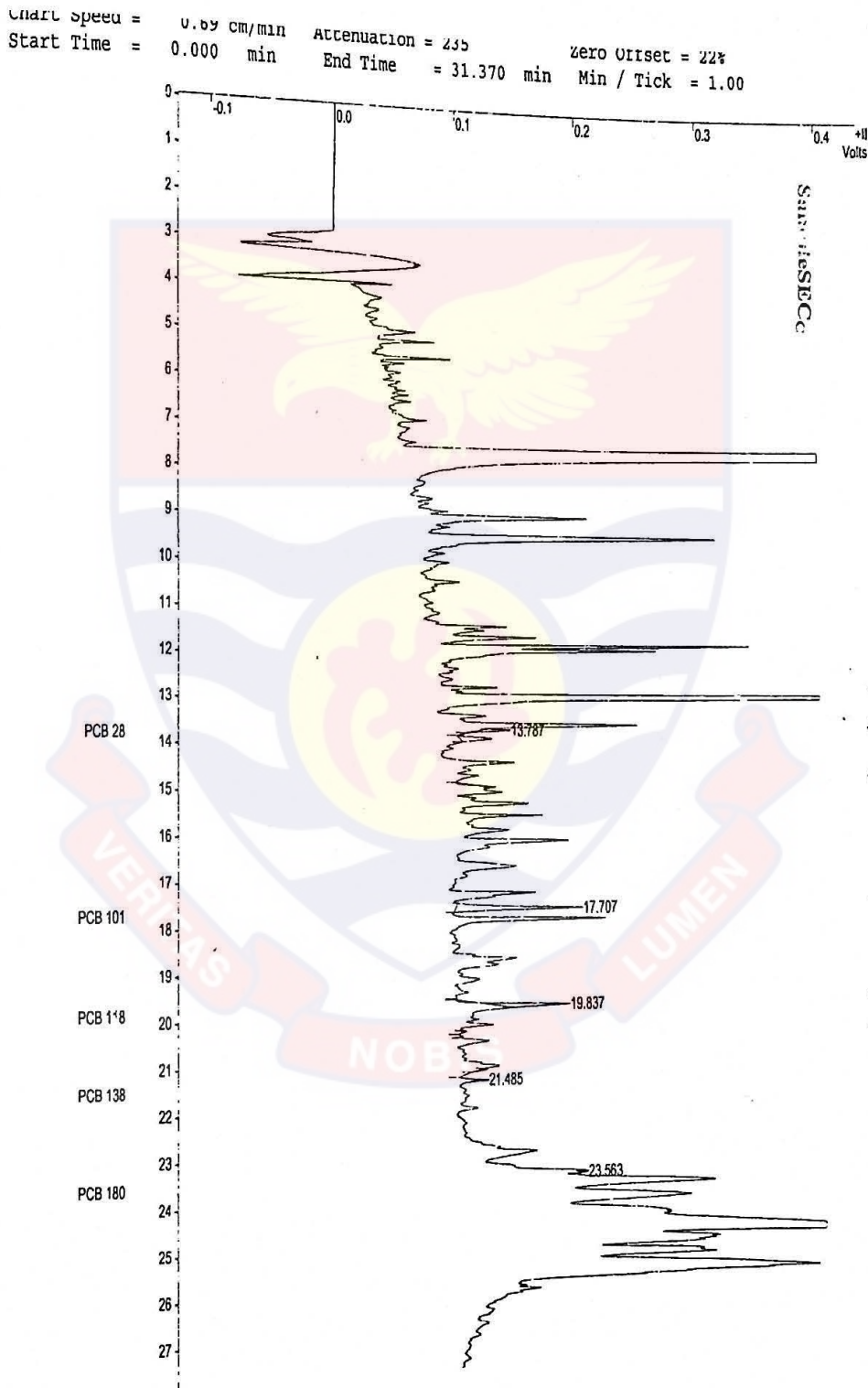
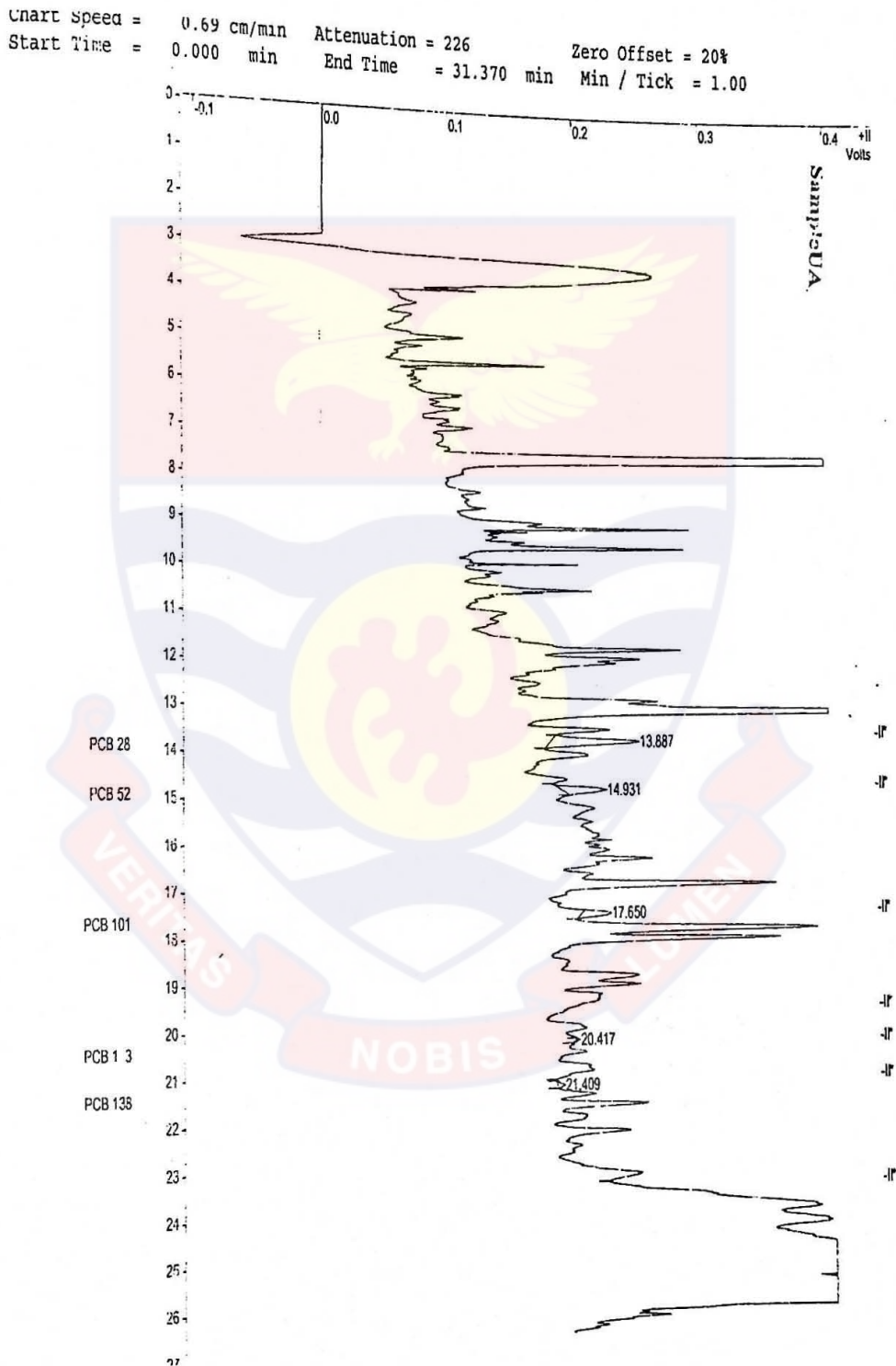
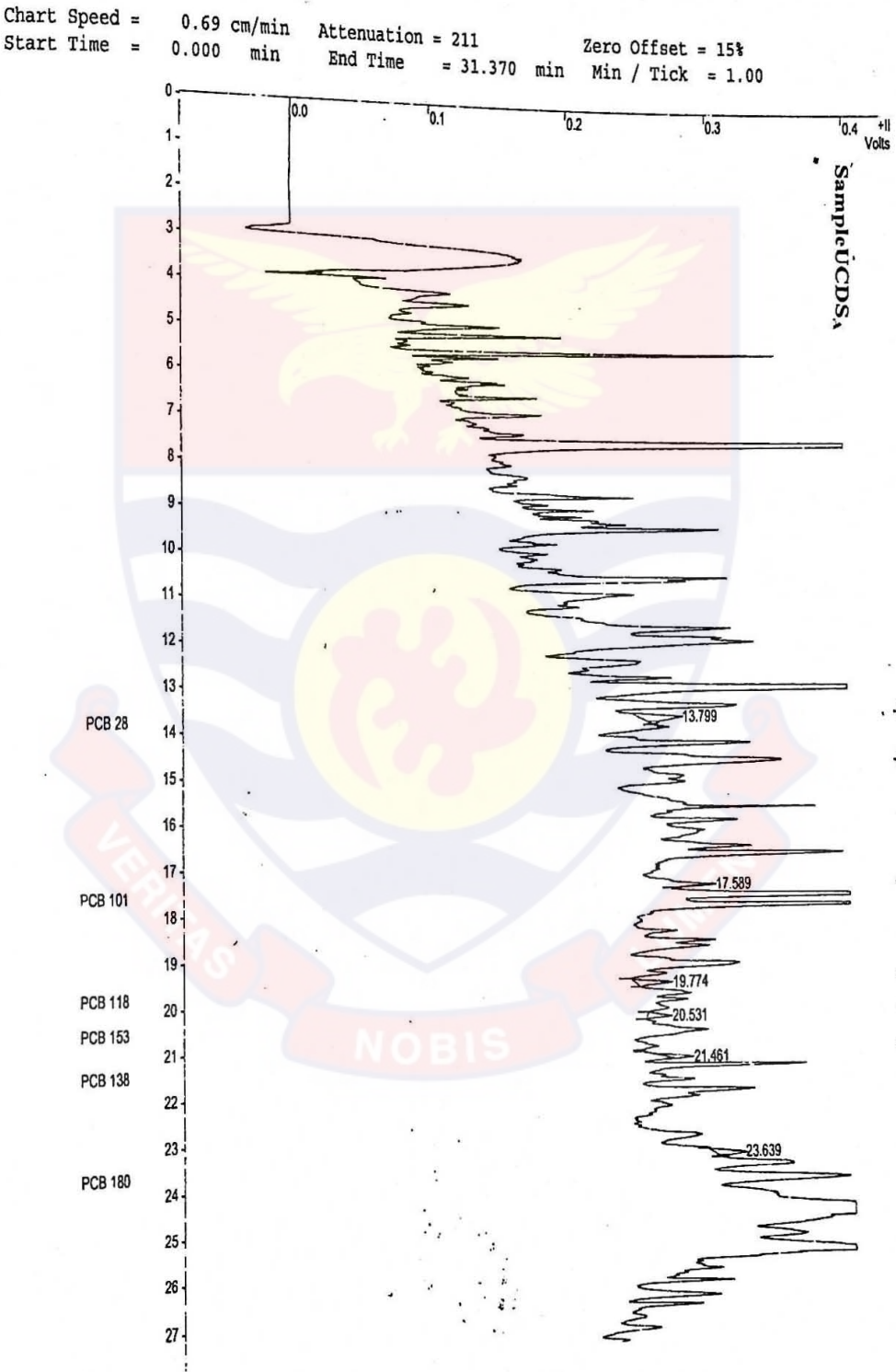


Chart Speed = 0.69 cm/min Attenuation = 239 Zero Offset = 43%
Start Time = 0.000 min End Time = 31.368 min Min / Tick = 1.00









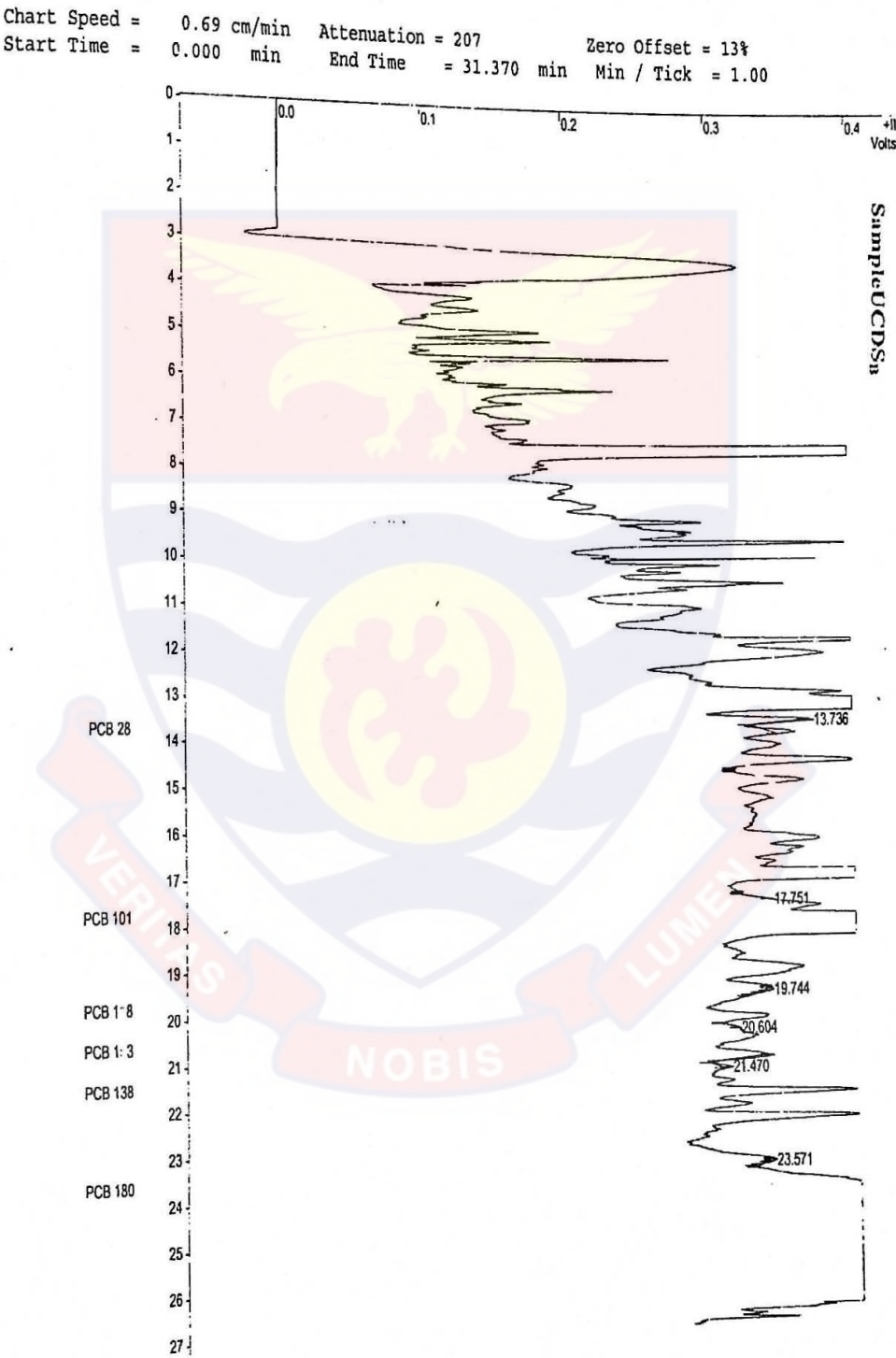
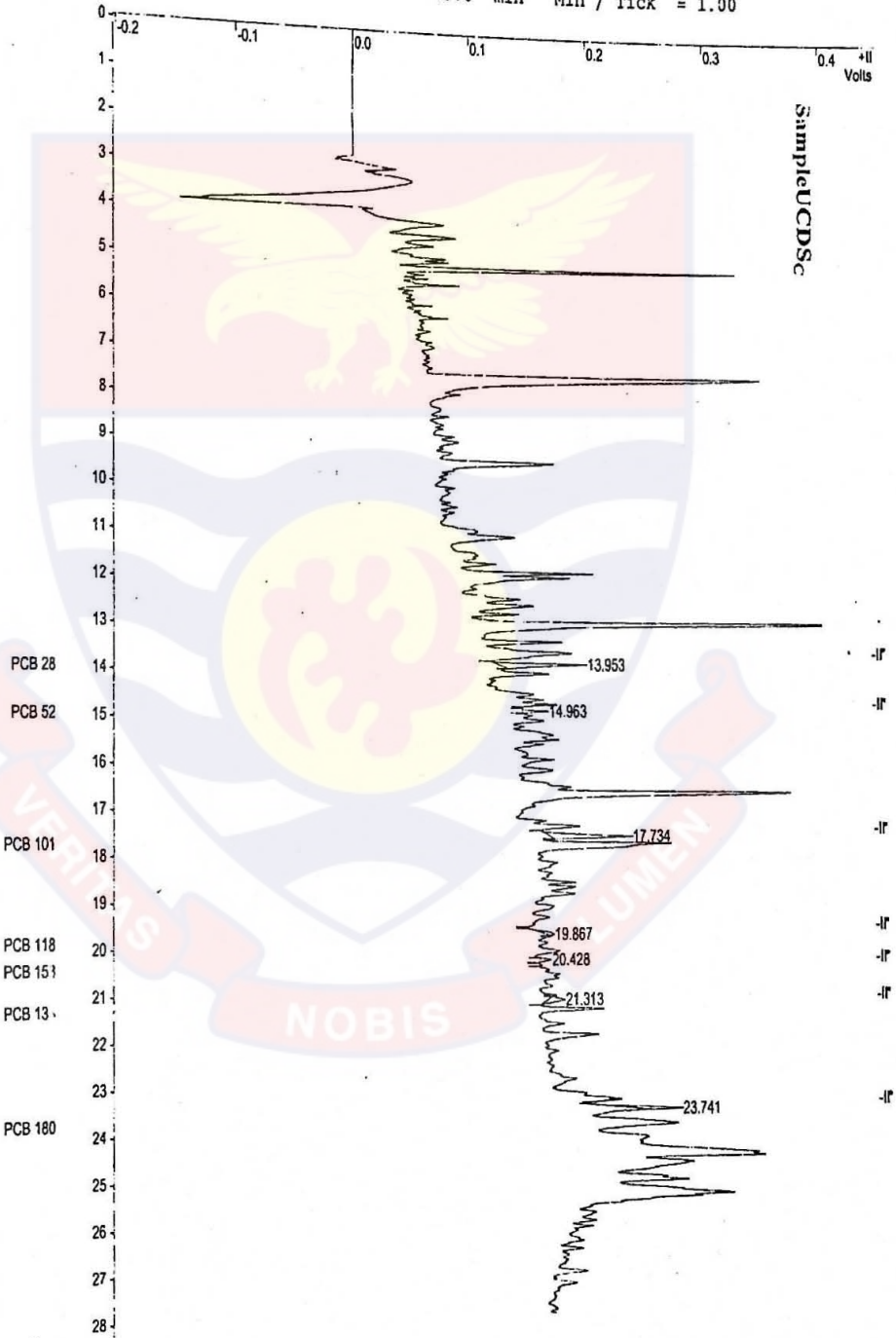


Chart Speed = 0.69 cm/min Attenuation = 267 Zero Offset = 31%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00



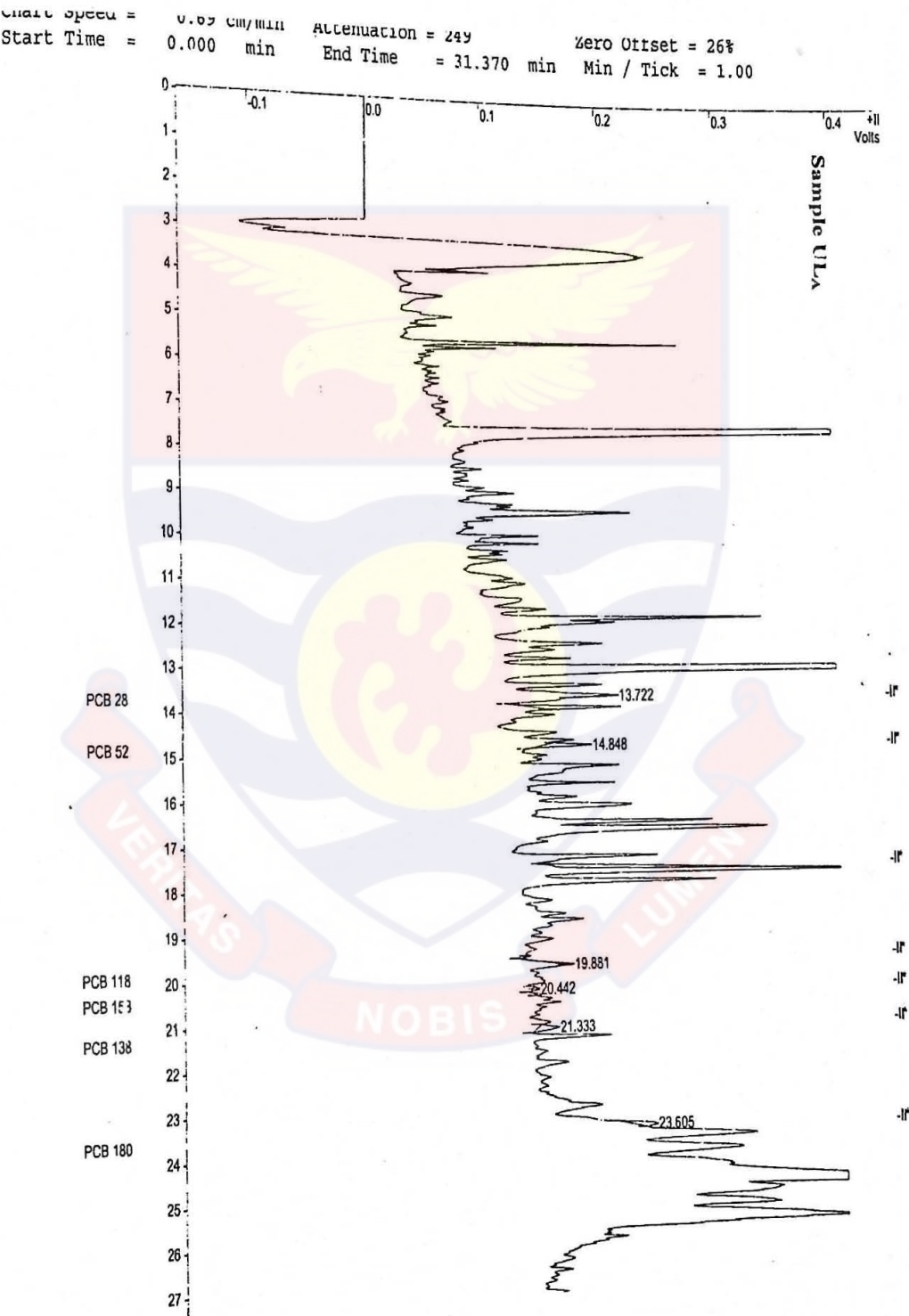


Chart Speed = 0.69 cm/min Attenuation = 236 Zero Offset = 234
Start Time = 0.000 min End Time = 31.368 min Min / Tick = 1.00

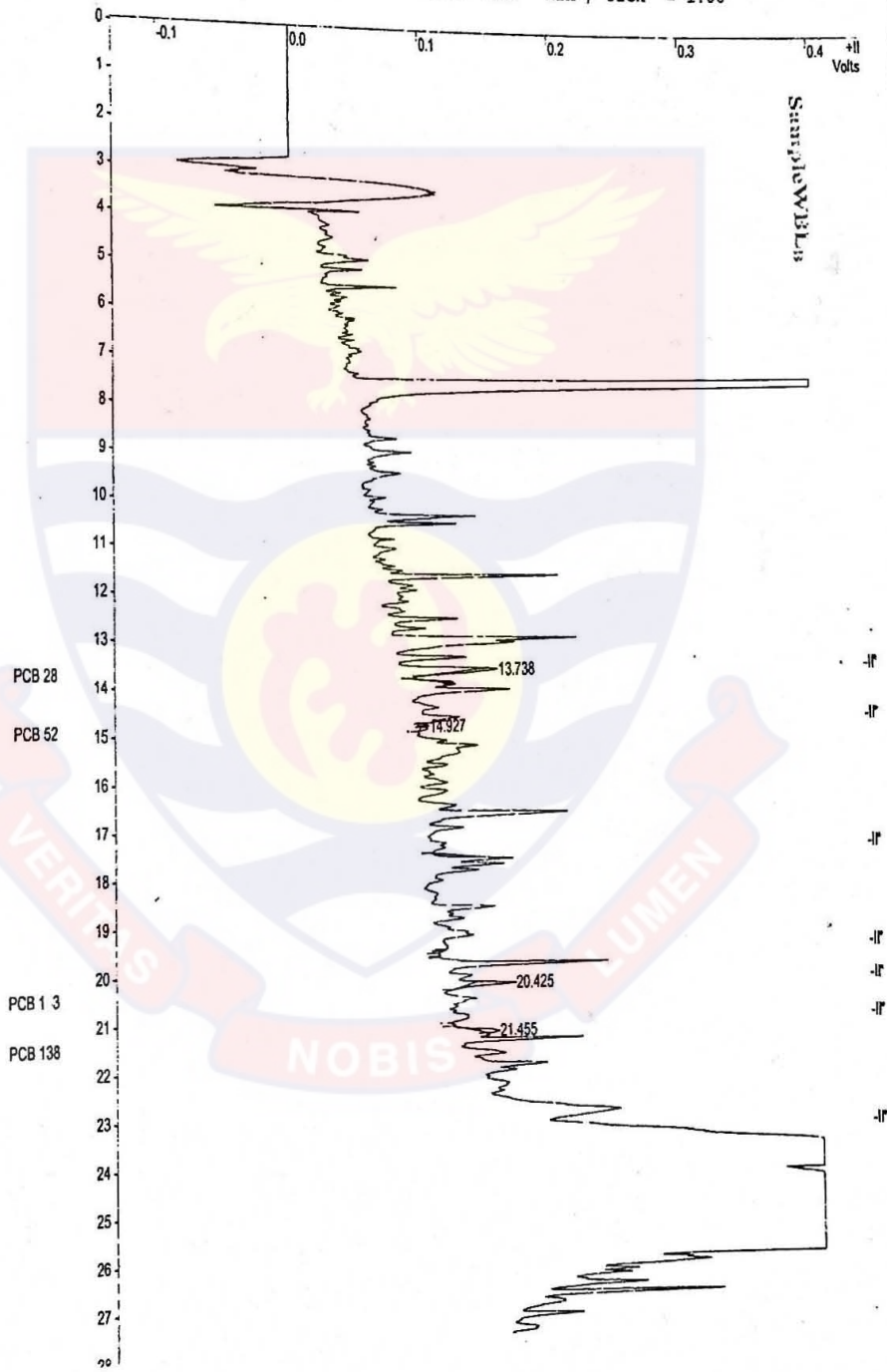


Chart Speed = 0.69 cm/min Attenuation = 227 Zero Offset = 20%
Start Time = 0.000 min End Time = 31.368 min Min / Tick = 1.00

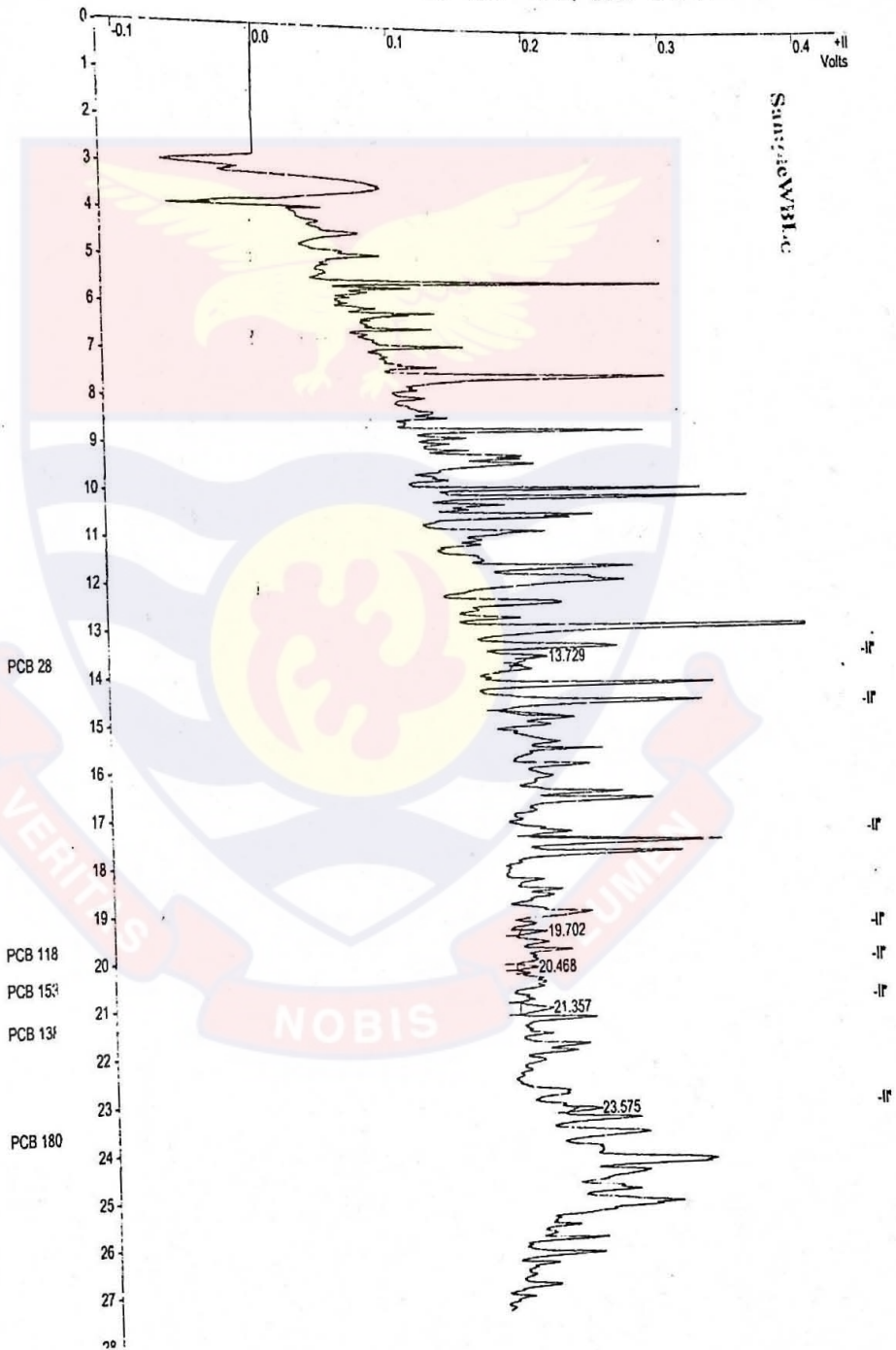
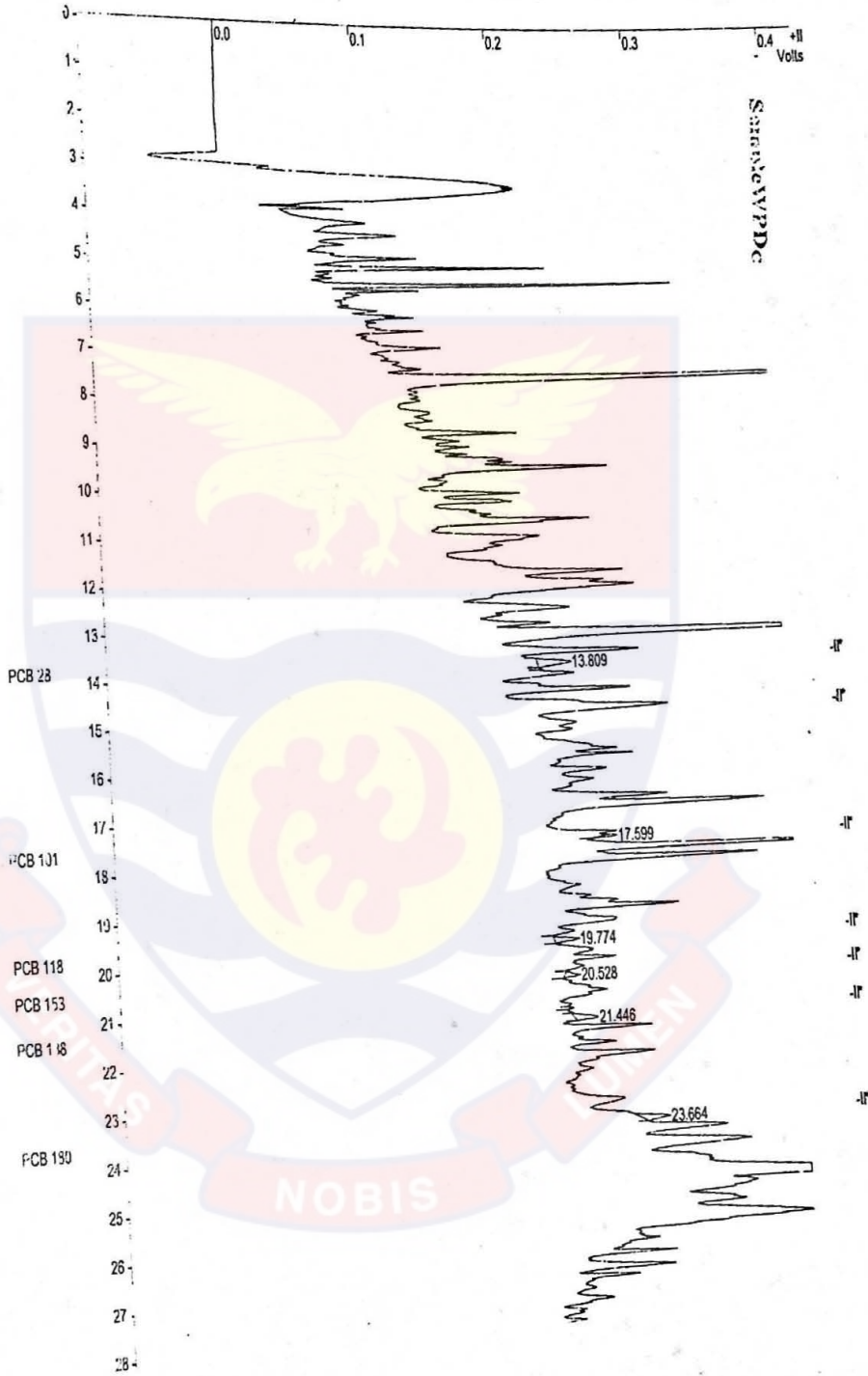
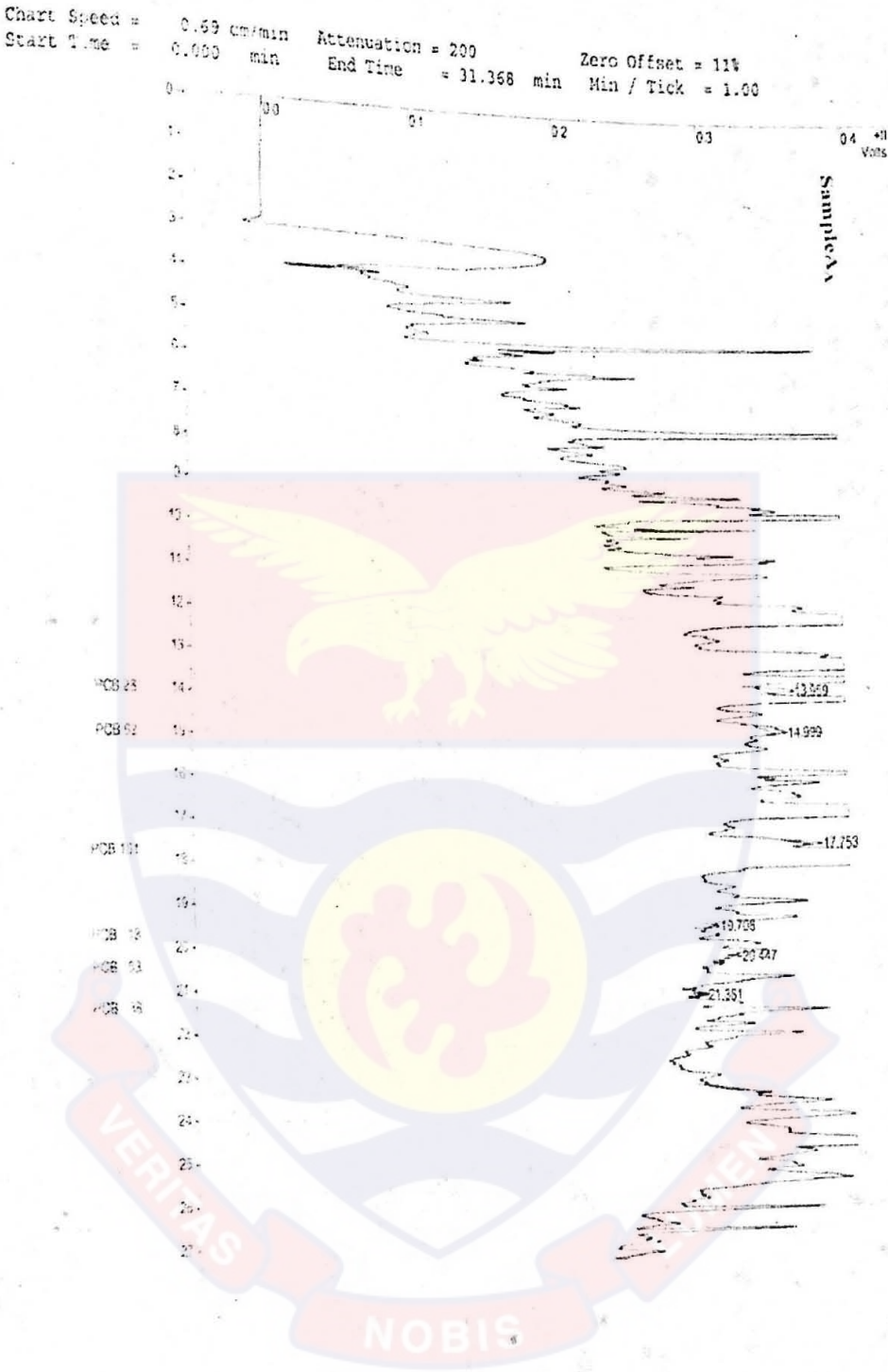


Chart Speed = 0.69 cm/min Attenuation = 218 Zero Offset = 18%
Start Time = 0.000 min End Time = 31.370 min Min / Tick = 1.00





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