CHEMICAL ENVIRONMENTAL POLLUTION: HOW SIGNIFICANT IS THE LOCAL CONTRIBUTION?

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UNIVERSITY OF IBADAN

CHEMICAL ENVIRONMENTAL POLLUTION: HOW SIGNIFICANT IS THE LOCAL CONTRIBUTION?

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The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), The Registrar and other Principal Officers, Provost of the College of Medicine, Dean of the Faculty of Science, Deans of other Faculties and Postgraduate School, Dean of Students, Distinguished Ladies and Gentlemen.

Preamble

I belong to the Department of Chemistry, that unique Department where even as a Professor, one may never have the opportunity of becoming the Head of Department before retiring! We can deduce easily from this that this opportunity of my giving this second inaugural lecture of the 2014/15 session on behalf of the Faculty of Science, is a chance and rare priviledge for which I am thankful to God, my Dean and my Head of Department. My lecture is the 12th to be delivered from the Department of Chemistry since its inception.

Our Department of Chemistry is organised into five specialist units: Analytical, Industrial, Inorganic, Organic and Physical. I belong to and currently coordinate the Analytical Chemistry unit which consists of ten lecturers out of the forty-two in the whole Department. The sub-discipline of Analytical Chemistry harnesses the subject matter of the other sub-disciplines towards the development of new analytical methods/techniques, and the assessment and improvement of existing ones. The other chemistry specialisations on the other hand employ the chemical analytical techniques in their operations. Details of the functions of analytical chemists and growth of the Analytical Chemistry unit in the Department has already been reviewed by Prof. Oladele Osibanjo in his 2008 inaugural lecture which was the first from the Analytical unit. Mine is the second from that unit.

In addition to fundamental research involving analytical methods development, most analytical chemists usually have another primary area of interest to which the analytical techniques are applied. Thus, we have special application interests in food analysis, drug analysis, environmental samples analysis, and so on. I belong to the group which

specialises in environmental chemistry. My first exposure to research in Environmental Analytical Chemistry was as a final year project student of Professor Osibanjo during the 1977/78 academic session. I subsequently returned for the Masters programme in Analytical Chemistry and was supervised by Prof. S.O. Ajayi. My PhD programme was jointly supervised by Professors S.O. Ajayi and O. Osibanjo of the Department of Chemistry, along with Professor A. Egunyomi of the Department of Botany, on the use of bioindicators for monitoring atmospheric heavy metal pollution. From then, these three eminent professors had shaped the direction of my future research.

Chemical Environmental Pollution

A more generalised definition of the term 'pollution' may be adapted from that of the Joint Group of Experts on the Scientific Aspect of Marine Pollution (GESAMP). By this, "Pollution is the introduction by man, directly or indirectly, of substances or energy into the natural environment, resulting in such deleterious effects as harm to living resources, hazards to human health, impairment of quality of ecological media and limitation of their use, and damage to physical infrastructure with consequent economic loss". My lecture is expectedly limited only to the introduction of chemical substances that possess any of the usual characteristics of substances classified as hazardous; i.e. substances that may be explosive, flammable, spontaneously combustible, poisonous, corrosive, toxic, ecotoxic, powerfully oxidising, or capable of liberating toxic gases when in contact with air or water (UNEP 2006).

Chemical environmental pollution began to attract global attention, particularly in the developed countries, only after the second world war, from the 1950s. This was catalysed by the numerous incidents of the period, such as the severe deterioration of air quality as evident in the catastrophic London smog and the Donora (USA) smog, the Minamata tragedy, and the palpable fear of radiation contamination from nuclear reactors and weapons tests. Rapid industrial development following the war years only aggravated the

environmental problems in the 1960s and 1970s, and drastic protection-related laws and regulations were quickly enacted by most of the developed world nations. A classical example of such regulations is the 1970 USA Clean Air Act (Gerard and Lave 2005).

Chemical pollution can affect every environmental media, including air, surface water, ground water, sediment, soil, subsoil and biota. The complex interaction amongst these components ensures that the contamination of one often results in subsequent contamination of some or all others. The most important sources of pollution have been well recognized to be anthropogenic activities related to energy generation and use, transportation, waste disposal, agriculture, industrial production, civil constructions, and household domestic activities. A minor contribution to chemical contamination may also result from non-anthropogenic phenomena such as volcanic emissions, forest fires and biogenic emissions.

A wide range of chemical pollutants are known to have deleterious effects on human health (table 1). Epidemiological statistics related to toxic chemical pollution can be somewhat staggering. A 2012 report by the Blacksmith Institute (now known as "Pure Earth" from March 2015), an international not-for-profit organisation dedicated to pollution control in developing countries, indicates that about 125 million people are at risk from toxic pollution across 49 low to middle-income countries. Of these, about 20 million are children, who unfortunately are usually most susceptible to the impacts of chemical pollution. The World Health Organisation (WHO) has also reported that globally in 2004, 4.9 million deaths (8.3 per cent of total) and 86 million disability-adjusted life years (DALYs, which address a blend of death and disease impact) (5.7 per cent of total) were attributable to exposure to selected chemicals for which data were available. It regards this as being underestimated (Prüss-Ustün et al. 2011) as data was not available for quite a number of important chemical substances.

Table 1: Health Outcomes and Examples of Suspected or Confirmed Linkages to Chemicals

Health effect	Suspected or Confirmed Number of Chemicals	Examples (not comprehensive)
Asthma (via non-respiratory sensitization)	N/A	*inorganics* (chlorine, hydrochloric acid, sulfuric acid); *other organics* (ethylene oxide); *pesticides* (acephate, diazinon, malathion, safrotin)
Cancer	1070	*aromatics* (benzene); *aromatic amines* (benzidine, 4,4'-methylenebis 2-chloroaniline); *combustion byproducts* (2,3,7,8-tetrachlorodibenzo-p-dioxin, polyaromatic hydrocarbons); *fibers/dust* (asbestos, silica); *halogenated compounds* (methylene chloride, trichloroethylene); *inorganics* (sulfuric acid); *metals* (arsenic, beryllium, cadmium, chromium, lead, nickel); *other organics* (butadiene, ethylene oxide, formaldehyde); *pesticides* (chlordane, DDT)
Diabetes	N/A	*combustion byproducts* (2,3,7,8-tetrachlorodibenzo-p-dioxin); *metals* (arsenic), *pesticides* (N-2-pyridlmethyl-N'p-nitrophenyl urea)

Table 1 contd.

	466	*aromatics* (benzene); *halogenated compounds* (carbon tetrachloride, pentatchloroethane); *metals* (beryllium, chromium compounds, mercury, nickel and compounds); *other organics* (methanol, methyl butyl ketone); *pesticides* (aldrin, DDT, dieldrin, mipafox, leptophos, cyanofenphos)
Neurotoxicity	201	*aromatics* (benzene, toluene); *halogenated compounds* (trichloroethylene, vinyl chloride); *inorganics* (hydrogen sulfphide, phosphorus); *metals* (arsenic and compounds, lead and compounds, manganese and compounds, methylmercury, tin compounds); *pesticides* (aldrin, carbofuran, chlorpyrifos, coumaphos, diazinon, endosulphan, endrin, fonofos); *phthalates* (dibutyl phthalate); *other organics* (caprolactum, cumene, ethylene, ethylene glycol, ethylene oxide, methanol, polychlorinated biphenyls)
Reproductive Toxicity (e.g. Impaired Fertility, Birth Defects)	261	*halogenated compounds* (1-bromopropane, 2-bromopropane); *metals* (chromium and compounds, cobalt and compounds, lead and compounds, mercury); *phthalates* (dibutyl phthalate, di(2-ethylehexyl)phthalate (DEHP), benzylbutylphthlate); other organics (n-hexane); *pesticides* (1,2-dibromo-3-chloropropane (DBCP), mirex)

Table 1 contd.

Skin Burns/Irritation;	867	*isocyanates* (chlorophenylisocyanate , hexamethylene diisocyanate, methyl isocyanate, methylene bisphenyl isocyanate, naphthylene diisocyanate); *other organics* (caprolactam, hydroxylamine); *pesticides* (guazatine, dodemorph, paraquat dichloride, sabadilla)
Serious Eye Irritation/ Damage;	892	
Respiratory Irritation	224	
Skin Sensitizers (e.g. Dermatitis, Allergy)	997	*acid anhydrides* (maleic anhydride, phthalic anhydride, trimellitic anhydride); *amines* (ethylenediamine, triethanolamine); *diisocyanates* (methylene bisphenyl isocyanate, naphthylene diisocyanate, hexamethylene diisocyanate, toluene diisocyanate); *metals* (chromium and compounds, nickel and compounds); *other organics* (formaldehyde, glutaraldehyde)
Respiratory Sensitizers (e.g. Allergy, Allergic Asthma)	114	

Source: UNEP (2013)

The global community recognises the critical risks to mankind from chemical pollution, and is taking steps to mitigate these. At national, regional and international levels, various organs have been established to stem chemical pollution through the sound management of chemicals and wastes. At the global level, not less than fourteen UN agencies and their subsidiaries are involved in the management of chemicals and wastes. Notable examples are UNEP, OPCW, UNFCCC, WHO, FAO, UNIDO, IAEA, World Bank, etc. Several international conventions and protocols also address the management of chemicals and wastes to achieve sustainability in "green" economies. Examples include the Basel convention, the Stockholm convention, the Rotterdam convention, the Montreal protocol, the Minamata convention, the Kyoto protocol, the Bamako convention, etc. Nigeria is signatory to most of these conventions.

The magnitude of the global chemical pollution problem differs among countries. We may broadly place countries in three categories for the purpose of describing the magnitude of the problem. On one extreme are the very developed countries which produce, consume and export very large quantities of chemicals and chemical products, and should therefore ordinarily be expected to have the highest chemical pollution problems. This is not the case however, because this group of countries often possess the capacity to deploy appropriate technologies for very sound management of chemicals and wastes. Appropriate regulations are in place in such countries, public awareness is usually high, and offenders are adequately sanctioned. The result in such countries is that chemical pollution has to a large extent been effectively curtailed. The other extreme includes the least developed countries which produce, import and consume very low quantities of chemical products. These countries do not possess the expensive technologies for chemicals and wastes management. However, due to the usually low emissions levels, the environmental burden of pollutants is low and

chemical pollution is usually often not yet at critical levels. The countries most at risk belong to the third or "middle" category. These include countries often described as "middle-income", "emerging", "transition", to which our dear country, Nigeria, rightly belongs. Here, production, import and consumption figures for chemical products are relatively high, albeit not as much as for the developed countries. Unfortunately, the infrastructure for the sound management of chemicals and wastes is either also non-existent or very poorly developed (Adegoroye 1994). Pollution control regulations are often mouthed and hardly ever enforced. The result is often higher magnitudes of pollution problems than those of the developed countries.

In Nigeria, chemical pollution issues have never been the subject of serious national discourse. Even the highly politicised hydrocarbon oil pollution of parts of the Niger Delta is often regarded more as "their problem" by the majority of persons from the other zones of the country. Reasons adducible for the lack of interest in pollution issues may include a high level of illiteracy, extreme superstition and corruption. Among the literate elite, there is also the lack of awareness of the risk levels and of incidents of local chemical pollution incidents. The average Nigerian only exhibits a momentary fleeting concern for a form of pollution that is physically visible, such as floating oil in a river, and heaps of garbage on street corners. This is a rather unfortunate situation that portends grave dangers in the event of a major environmental catastrophe. Chemical environmental pollution is a global problem and Nigeria has been contributing to its growth and history. A few examples of our contribution to global chemical pollution issues will illustrate this.

Heavy Metals Pollution

Heavy metals are often described as metals whose specific gravity values are greater than 5.0, and which are also toxic to man when they occur above certain relatively low threshold concentrations. The mechanism of toxicity is often at the

cellular level, and may involve processes such as binding by chelation, ion-exchange, ion-replacement, etc, to critical functional groups of enzymes and other molecular structures that are important in physiological functions. The most toxic and infamous three of the heavy metals are lead, mercury and cadmium.

Mercury acquired its infamy through the "minamata" incident/disease in Japan. By the early 1950s, Chisso Corporation, a plastic manufacturing company, had dumped about 27 tons of mercury compounds into the Minamata bay, on the coast of the Shiranui Sea. Fishes in the bay became contaminated, and those who ate these also became poisoned and developed the "Minamata" disease characterised by numbness of limbs and lips, difficulty hearing or seeing, tremors in arms and legs, difficulty walking, and even brain damage. Some of those affected went crazy and shouted uncontrollably (Harada 1995; Ekino et al. 2007). Subsequently, poisoned women gave birth to severely deformed children (fig. 1). According to the Japanese government, some 2,955 people contracted the Minamata disease, out of which 1,784 died.

Fig. 1: Mother bathing a minamata-diseased "child".

Cadmium acquired notoriety through the "itai-itai" disease in Japan which resulted from the discharge of effluent containing cadmium compounds into the Jinzugawa River by the Mitsui Mining and Smelting Company around 1910. This con-taminated the drinking water and crops (particularly rice) irrigated with the water (Kasuya et al. 1992). Symptoms of the disease included kidney failure, softening of the bone, and severe pains in the bone (fig. 2).

Fig. 2: A Japanese suffering from "itai-itai" disease.

Lead has always been recognised as a neurological toxin, particularly to children. But the world did not have a classical case of lead poisoning-related disaster similar to those of cadmium and mercury, for reference, until Nigeria offered one in the form of the now classic incident of the Zamfara lead poisoning. The poisoning incident occurred in some seven villages within three local government areas (Anka, Bukkuyum and Maru) of Zamfara State (Lo et al. 2010; Plumlee et al. 2013). About 400 children are known to have so far died since March 2010, with about half of these deaths occurring within the first few months of the incident (Biya et al 2010; Blacksmith Institute 2011; Greig et al. 2014). This

lead pollution was derived from illegal artisanal mining for gold in these villages. The ores contained high levels of associated lead. The extraction procedure involved grinding, crushing, amalgamating and washing of the lead/gold bearing rocks, and some of these activities were carried out in the vicinities of homes (fig. 3). Soon, the topsoils, surface and ground water, as well as food items became contaminated. Children began to fall ill (fig. 4), and many died! Blood samples collected from 205 living children aged <5 years all revealed lead poisoning (≥10 μg/dL), and 97% of children had levels above the threshold (≥45 μg/dL) for initiating chelation therapy. Blood lead concentrations ranged from 33.3 to 445 μg/dL. Lead concentrations in soil and dust ranged from 45 parts per million (ppm) to >100,000 ppm; 85% of family compounds exceeded the U.S. Environmental Protection Agency standard (400 ppm) for areas where children are present (CDC 2010). In the words of top officials of the Blacksmith Institute (2011): "Never before has there been a lead poisoning epidemic of this magnitude anywhere in the world." Note that amalgamation, involving the use of very toxic mercury, is one of the steps involved in the artisanal extraction of gold.

Fig. 3: Crushing of lead/gold bearing rock in Zamfara.

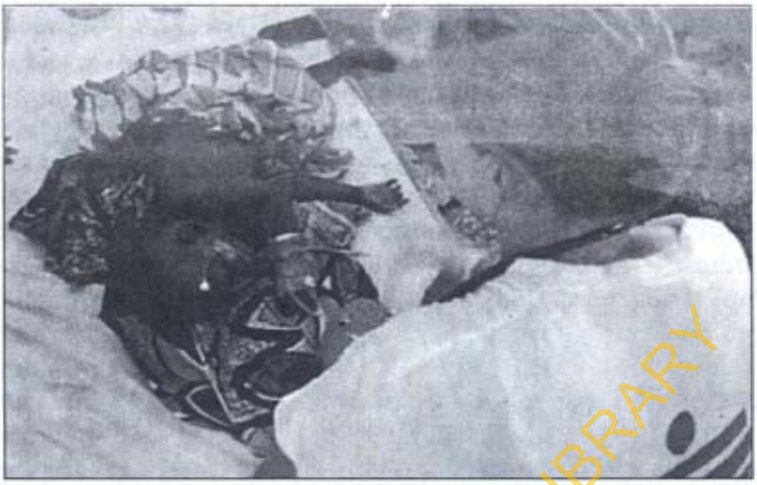

Fig. 4: A child being treated for lead poisoning in Zamfara State.

The world rose to the occasion in support of Nigeria. To the rescue came several international agencies, including Medecins Sans Frontieres (MSF) which assisted with medical treatment and chelation therapy, the Blacksmith Institute and Terragraphics which carried out remediation by top soil replacement (fig. 5). The WHO, UNICEF, USAID, and others also supported. Altogether, these organisations spent about US $2 million to execute the first phase of assessment, evaluation, treatment, evacuation and remediation. The Nigerian government was then expected to provide the follow-up funding for the completion of the rehabilitation works. The Government eventually announced that it had completed the remediation at a cost of ₦837million (Nnodim 2013).

Fig. 5: Evacuating lead-contaminated topsoil in a Zamfara village.

Lead pollution also arises from the use of leaded compounds as anti-knock additives to gasoline. For this reason, the developed countries have all, since the 1980s, phased out the use of leaded gasoline. Nigeria is one of the countries in the world that are yet to fully phase out the addition of lead to gasoline (table 2).

Table 2: Amount of Tetraethyl Lead in Gasoline, by Country

Country	Concentration, g/L
Nigeria	0.65-0.74
Algeria	0.60
South Africa	0.33
Libya	0.60
Morocco	0.30
Tunisia	0.50
Sudan	0.40
United Kingdom (UK)	0.00
USA	0.00
Highest in the World	1.0

Source: Galadima et al. (2012)

Pollution of Ogoniland

Petroleum hydrocarbon oil pollution is of significant importance worldwide, and many classical examples abound. Most have resulted from major spill incidents during shipping accidents in international waters, or during accidents in the production process onshore and offshore. Celebrated classical cases include those of the Amoco Cadiz, Exxon Valdez, Atlantic Express, Gulf War spills, Deepwater Horizon, etc. The cases have all involved the spilling of hundreds of thousands of tons of crude hydrocarbon oils, with very grave consequences for the ecologies of the surroundings.

The Niger Delta region of Nigeria has attained prominence worldwide for the political and humanitarian crisis arising from the ecological damage of the area due to crude oil pollution derived from the activities of oil companies. The problem was so visible and severe in Ogoniland (figs. 6 and 7) that the natives (Ogonis) resorted to self-help and forcibly shut down oil exploration and production activities in the area around the early 1990s. Subsequent illegal artisanal production of crude and refined oils by the natives in the region only further worsened the pollution problem (Pyagbara 2007). The Federal Government of Nigeria then had to invite the United Nations Environment Programm (UNEP) to carry out a comprehensive assessment of the crude oil-related pollution status of Ogoniland.

Fig. 6: A village in Ogoniland in the midst of oil pollution.

Fig. 7: An Ogoni man in his oil-polluted neighbourhood.

Over a 14-month period, the UNEP team examined more than 200 locations, surveyed 122 kms of pipeline rights of way, reviewed more than 5,000 medical records and engaged over 23,000 people at local community meetings. Detailed soil contamination investigations were conducted at 69 sites. Altogether, more than 4,000 samples were analyzed, including water taken from 142 groundwater monitoring wells drilled specifically for the study, and soil extracted from 780 boreholes (UNEP 2011). The 262-page report, which is now a classical reference document, provided a systematic and scientific evidence for the contamination and damage of every ecological media in the region and called for a massive restoration and rehabilitation project by the Federal government, with adequate follow-up monitoring and assessment. The situation, once again, placed Nigeria prominently on the world map of chemical pollution problems.

The Koko Toxic Waste Dump Incident

The Koko toxic waste saga was a scandal of international proportion! Owing to the high level of public awareness of environmental issues in developed countries from the 1970s onwards, most communities in these countries refuse to allow industries to dispose toxic wastes within their neighbourhoods. This has usually resulted in clandestine moves to trade such wastes to poorer countries where awareness is lacking or the money is critically needed (Vir 1989; Clapp 1994, 2001).

In 1987, following some unethical business agreements between some businessmen in Italy and one 67 years old Mr. Sunday Nana of Koko town in Delta State of Nigeria, five shiploads of highly toxic wastes departed the port of Pisa in Italy, headed for and deposited their deadly load on a portion of land owned by Mr. Nana in Koko, for a rental fee of about $100 per month!

Fig. 8: Section of stack of drums of toxic wastes dumped in Koko.

The waste dumped in Koko consisted of about 3,780 tonnes of toxic materials that included about 8,000 drums of polychlorinated biphenyls (PCBs), formaldehyde, asbestos dust, etc. (fig. 8). They were clandestinely labelled as materials related to the building industry. Following the international uproar and diplomatic row that resulted from the disclosure, the Italian government had to pay for the evacuation of the wastes back to Italy. But not before some damage had been done! Many of the 100 workers of the Nigerian Ports Authority who participated in the assessment and evacuation without the use of adequate protective gears became seriously ill and many received government compensation years later. Some of the drums leaked the toxic wastes into soil which was subsequently leached to contaminate water bodies in the area. Many cases of premature births were suddenly recorded in the local hospital during the period (Ihonvbere 1994).

The Koko waste saga, though unfortunate, had its positive fallouts. The international community rose to the occasion and established the Basel Convention on the control of trans-boundary movements of hazardous wastes and their disposal. The Federal Government of Nigeria immediately promulgated the Harmful Waste Decree 42 of 1988, which facilitated the establishment of the defunct Federal Environment Protection Agency (FEPA) that has now been replaced by the National Environmental Standards and Regulations Enforcement Agency (NESREA). These benefits notwithstanding, the episode represented another unfortunate contribution of Nigeria to the global database of international toxic waste/chemicals dumping.

Incident of Smog in Lagos

Smog is derived from the words "smoke" and "fog", and describes a hazy, toxic condition which overhangs the atmosphere of highly polluted large cities from time to time (fig. 9). It usually occurs early in the morning and lasts for several hours until disappearance towards late afternoon. Modern day type of smog is known as the "Los Angeles smog" or photochemical smog, or oxidising smog, and is mostly related to a high density of polluting automobiles in cities (fig. 10). Cities that have experienced smog incidents at some point in time include London, Los Angeles, Sao Paulo, New Delhi, Mexico City, Tokyo, Beijing, Cairo, New York, Calcutta, among others. It is currently the most significant environmental problem in some Chinese cities.

Fig. 9: Smog over an Asian city.

Lagos joined the league of these big "smoggy" cities on 12 October, 2005 when residents woke up to behold a dense, hazy, eye-irritating and choking smog which reduced visibility tremendously, and lasted till the later part of the day. Smog is known to have deleterious effects on human health, physical strength of materials (e.g. rubber), atmospheric quality, and on vegetation in particular. There are three primary ingredients for smog: nitrogen oxides, hydrocarbons and ultraviolet radiation (Manahan 2000; Akinyemi 2007; Itua 2007; fig.10). The first two are readily available in a city such as Lagos with a very high density of automobiles (about one million vehicles ply the streets of Lagos daily). Reactions in hot internal combustion engines of automobiles readily yield nitrogen oxides. Unburnt hydrocarbons leak from many parts of automobiles into the atmosphere, and is supplemented by other sources such as household and industrial electricity generators. In the presence of sunlight, the nitrogen oxides undergo complex stepwise photochemical reactions that lead to the formation of the very active scavenging and powerfully oxidising hydroxyl radical. This radical oxidises the hydrocarbons to a variety of

oxidised particulate products which are suspended in the air and cause the poor visibility. The particulates include aldehydes, peroxyacetyl nitrates (PANs), tropospheric ozone, and a variety of volatile organic compounds. The occurrence of a temperature inversion which inhibits thermal convection usually enhances the smog phenomenon. It is rather surprising that, given the ready availability of the precursor ingredients, there has been only one major smog incident in Lagos. However, it should be noted that Lagos, and perhaps other fast growing Nigerian cities, such as Ibadan, Kano, Port Harcourt, etc, are very susceptible to incidents of smog. The classical case of the 1952 smog incident in London lasted for four days, and resulted in the immediate death of about 4000 persons, and varied health injuries to some other 100,000! (Bell et al. 2004). The toll for the Lagos incident has never been known!

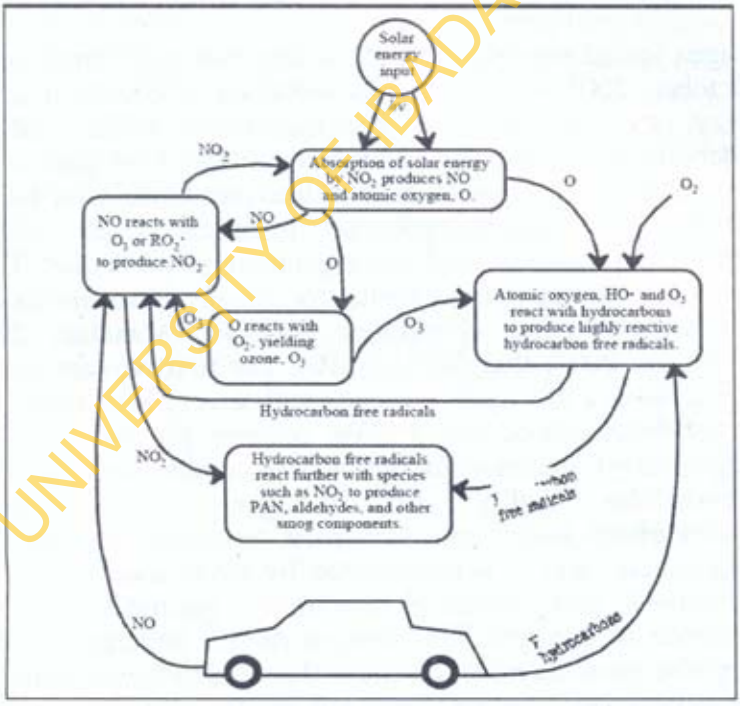

Fig. 10: Generalised mechanism of smog formation (Manahan 2000).

Nigeria's Contribution to Global Warming via GHG Emissions

Global warming and climate change are the topical environmental issues of the last ten years or more. It is already well established that anthropogenic releases of greenhouse gases (most especially carbon dioxide) is the prime cause of global warming. The greenhouse gases distort the natural heat balance of the earth by absorbing and trapping heat-bearing infrared radiation that is reflected from the surface of the earth into space. Global efforts have been targeted towards the reduction of this emission. Industrial production and other processes involving fossil fuel combustion lead to the release of large amounts of carbon dioxide which is the main culprit despite its relatively low global warming potential. About 50% of the total 2011 global greenhouse gas emission (43,372.71 $MtCO_2e$) was contributed by only six countries (China, USA, Russia, Japan, Brazil and India), out of about 188 countries for which the 2011 inventory was made (table 3). Nigeria is not a major contributor to this problem, being only the 25th largest contributor with 0.75% of the total. Nigeria is however the second largest contributor in Africa, next to South Africa. But, should Nigeria even be ranked up to the 25th contributor? Do we come anywhere near this ranking in terms of volume of manufactured goods that ought to lead to more fossil fuel combustion as is the case with China? We certainly are not. We rank about 136 in Gross National Product. Our newly rebased high GDP has been derived mostly from sectors of the economy that are not high energy consuming. We have been contributing that much from gas flaring, cooking with firewood, kerosene, use of electricity, home and industrial generators, etc. Nigeria is clearly one of the countries that the global community can focus on to achieve some reduction in greenhouse gas emissions.

However, the total contribution from Nigeria can still be significantly reduced if appropriate policies for this purpose are put in place and implemented.

Table 3: 2011 Greenhouse Gas Emission by Selected Countries

Country	GHG Emission ($MtCO_2e$)*
World	43372.71
Angola	223.35
Argentina	372.46
Australia	563.45
Bangladesh	128.85
Benin	16.98
Botswana	11.46
Brazil	1131.10
Cameroon	89.51
Canada	716.21
Chad	38.36
China	10552.61
Cote d'Ivoire	56.85
Cuba	53.83
Denmark	53.69
Egypt	286.32
Ethiopia	124.61
Finland	70.19
France	487.39
Gabon	6.78
Germany	882.93
Ghana	28.03
Guinea	19.96
Hungary	65.75
India	2486.17
Iran	715.53
Israel	87.03
Italy	491.07
Japan	1307.41

Table 3 contd.

Kenya	46.26
Korea, Rep. (South)	687.74
Kuwait	195.68
Libya	117.00
Mexico	699.05
Morocco	88.45
Netherlands	205.76
New Zealand	70.95
Niger	19.83
Nigeria	324.51
Norway	50.00
Pakistan	308.38
Philippines	149.56
Poland	374.42
Portugal	74.02
Russian Federation	2374.31
Saudi Arabia	532.89
Sierra Leone	5.92
South Africa	456.85
Spain	351.59
Sweden	59.68
Switzerland	49.95
Turkey	403.65
United Arab Emirates	211.21
United Kingdom	543.55
United States	6550.10
Venezuela	267.00
Zimbabwe	20.85

* Data do not include land-use change and forestry

Source: World Resource Institute (2011)

Nigeria's Contribution to Other Global Chemical Environmental Problems

Nigeria's contribution to global chemical environmental issues spans more than the examples highlighted above. A few more brief examples should underscore this.

One source of exposure of children to lead is from the use of lead in the formulation of household interior and exterior paints, and in pigments for children's toys. There has been concerted global efforts to drastically reduce and even eliminate the inclusion of lead in paints and toys. Some countries have since phased this out, while in 2009 the USA and WHO took proactive steps to initiate the Global Alliance to Eliminate Lead Paints which was geared towards the phasing out of the manufacture and sale of leaded paints. Today, Nigeria's paint still ranks among one of the highest in lead levels (Adebamowo et al. 2006, 2007; Nduka et al. 2008).

The African Pesticide Stockpile Programme is another global issue bordering on a problem that is unique to several African countries, including Nigeria. Over the years, many African countries have accumulated a stockpile of obsolete hazardous pesticides dotted over many areas of each country. Obsolete stockpiles cause cancer, allergies, reproductive disorders, damage to the nervous system and disruption to the immune system (The World Bank 2013). Out of the estimated 50,000 tonnes of the stockpile, Nigeria is said to have a rather disproportionately low contribution of 6000 tonnes (Akinboade 2010)! But, did we have to contribute at all? International organisations (especially the World Bank, GEF, FAO, WHO, WWF, UNEP, CropLife, etc.) and the governments of Germany, Canada, Japan, Sweden, Switzerland and the EU have made significant progress at resolving the problem through prevention, safe evacuation and disposal (fig. 11).

Fig. 11: Disposal of obsolete pesticide stockpiles in Africa (World Bank 2013).

Acid rain was perhaps the most serious global issue of the 1970s. The industrial emission of acidic, polluting gaseous oxides of sulphur and nitrogen was the major source. It became such a big problem due to the transboundary transport of this form of pollution, often far beyond the vicinities of the sources of emission. Global and regional cooperative actions were put in place to stem the tide of acid rains that destroyed vast expanses of vegetation, water bodies, and adversely affected respiration in the most susceptible of human populations. Today, acid rain is no longer a problem in Europe and the Americas. Unfortunately, it is still one in the Delta region of Nigeria, arising from indiscriminate and continuous gas flaring in addition to other industrial emissions (Nduka et al. 2008; Efe 2010).

The transboundary shipment of electronic/electrical wastes (e-waste) from the developed countries and the subsequent dumping in third world countries has become a subject of global proportion, and is receiving huge international attention. Nigeria is one of such dumping

grounds of these end-of-life electronic/electrical equipment which are ultimately disposed by dumping and burning, sometimes after stripping them of some useful components. Apart from their nuisance values as solid wastes, these e-wastes contain very toxic substances such as metals (Cd, Pb, Hg, Li), polyvinyl chloride, brominated flame retardants, etc, which can be leached out into environment media, under certain environmental conditions (Olafisoye et al. 2013; Sindiku et al. 2014). It has been estimated that in 2009, about 3 million tonnes of such electrical/electronic equipments were imported into Nigeria, out of which about 75% were second-hand, and would soon end up in the dumps (Egwali and Imouokhome 2013; Breivik et al. 2014; Sullivan 2014).

Managing the Problem: Need for Assessment and Monitoring

The foregoing examples are still not exhaustive of evidence of Nigeria's contribution to the global chemical pollution problems. They however serve adequately to affirm that Nigeria's contribution is not insignificant. Almost every major chemical environmental issue has a Nigerian stamp on it. Should there be a world map drawn, of countries contribution to the global pollution problem, Nigeria will certainly be located with a bright spot. The solution to the problem lies in effective environmental management that must include the critical steps of assessment, monitoring, remediation, rehabilitation, prevention, reduction, sound disposal, public information, risk assessment, regulations and enforcement. Assessment and monitoring are the critical first few steps in the quest for scientific evaluation and decision making on the problems of the environment (fig. 12). Data obtained from environmental assessment are valuable for a variety of purposes such as understanding spatial and temporal distribution of pollutants, prediction of future status, land-use planning, risk assessment, planning of emergency response, formulation and enforcement of regulations, and determining the effectiveness of remediation actions. Much of

my research contribution to the solution of the problem is related to the assessment of various components of environmental media, and the modelling of data obtained for useful management decisions.

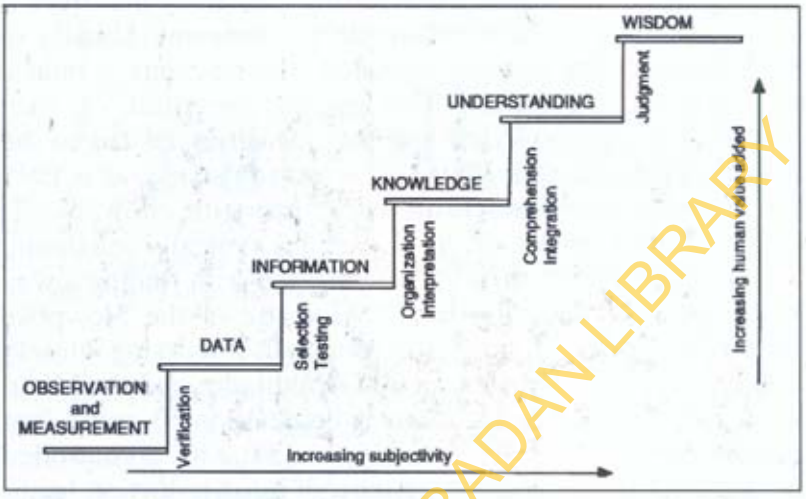

Fig. 12: The staircase of knowing (Roots 1997).

Some of My Contributions

Analytical Methods Development and Assessment

During some months in 1999 and 2000, I was on a Third World Academy of Science (TWAS)-sponsored study leave to the International Centre for Environmental and Nuclear Sciences (ICENS) located on the campus of the University of the West Indies, Kingston, Jamaica. ICENS had then completed a geochemical mapping of the topsoils of Jamaica and had obtained some startling results. The study showed naturally elevated levels of cadmium, lead and arsenic in some parts of the country. Analysis of the samples had been carried out mainly by neutron activation analysis (NAA) in addition to a few other techniques. There was then the need to analyse some plants, foods, and other biological materials to ascertain if these metals had also accumulated in them. The NAA configuration used at ICENS was noted not to be

sufficiently sensitive to determine some heavy metals at the levels at which they occur in many biological samples. Ordinarily, NAA is one of the most accurate and interference-free techniques for simultaneous multi-elemental analysis because of its none-destructive testing capability that frees it from losses associated with sample pretreatment. Usually in NAA, samples are directly irradiated with neutrons to induce radioactivity in samples. The gamma spectrum of such products are then analysed and the intensities related to the concentrations of the analytes. The neutron source at ICENS was a low-power research nuclear reactor (the Slowpoke-2) with a thermal power of 20 Kw, and a typically maximum flux of about 10^{12} n $cm^{-2}s^{-1}$. I was charged with finding a way to improve the detection limit of the use of the Slowpoke reactor for NAA of biological materials. Working closely with my research hosts, Professor Gerald Lalor and Dr. Mitko Vutchkov, we reasoned that the biological matrix could first be converted into an inorganic-type matrix by a controlled dry ashing process, and the consequent mass-reduction factor then considered in the direct analysis of the ash. It was likely that this proposal would not be straight-forward as dry ashing itself often leads to some elemental loss, and the new matrix achieved would really not be exactly identical to the semi-inorganic ones usually more easily analysed by NAA. However, by careful control of the procedures of ashing, and the thermal flux of the reactor, we eventually succeeded in developing a sample treatment protocol which improved the detection limit, about tenfolds, for some 20 elements, with acceptable margins of errors relative to what would have been obtained for the unashed samples (fig. 13). While the dry ashing produced improved analytical results for samples that were of low ash contents, the increased background gamma counts observed in ashed samples was found to sometimes negate the detection limit gain, particularly in certain plant samples which had high ash contents but low levels of analyte (Lalor et al. 2003).

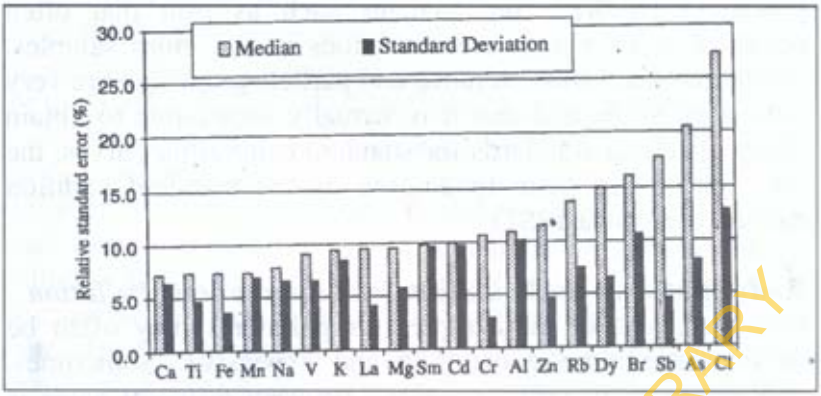

Fig. 13: Relative errors of results from ashed samples compared to direct plant tissue analysis.

In another of such studies, I assessed the features of analysis of moss plant samples by four very varied techniques, the atomic absorption spectrophotometry (AAS), differential pulse anodic stripping votammetry (DPASV), direct current plasma spectroscopy (DCPS), and xray fluorescence spectrometry (XRF) (wavelength dispersive configuration). The assessment was necessitated by suggestions in the literature that the disparities observed in metal levels in mosses from different studies may sometimes be due to differences in the analytical techniques utilised. It had been suggested that the complex nature of the matrix of the moss may account for certain uniqueness in its analysis by different techniques. Since I was then studying levels of metals in mosses as indicator of atmospheric pollution, the assessment came in handy as not only a quality assurance tool for my own study, but a contribution to the controversy of the period. The equipment were made available to me in three different institutions in Sweden through the Swedish International Fellowship in Chemistry. My main observation was that results obtained by AAS, DCPS and DPASV did not differ significantly, while that obtained by XRF tended to be somewhat slightly but systematically higher. There were issues related to the difficulty with the standard addition

procedure by XRF for analytes such as iron that often occurred in very high concentrations in the moss samples. Given that matrix interference and particle/grain size are very critical in NAA, and that it is virtually impossible to obtain cheap matching standards for standard calibration curves, the only option had been to analyse by the standard addition method (Onianwa 1987).

Study of Mosses as Bioindicators of Atmospheric Pollution

Direct analysis of air samples for pollutants may often be cumbersome, time consuming and expensive. Sometimes, only relativity in pollution levels between different areas is required, and in such cases the use of indicators becomes very valuable to attain cheap, integrative estimates of temporal and spatial variations in pollutant levels. As early as the 1970s, some moss species found in Europe had been identified for this purpose and applied in different modes (Ruhling and Tyler 1973; Rasmussen and Johnsen 1976; Onianwa 2001). Mosses are lower green plants that have the potential of being good indicators of atmospheric metal levels because they are epiphytic, have no developed vascular system and cuticle, and receive nutrients directly from the atmosphere. The leaves are known to contain chemical substances, including uronic acids, that can trap different kinds of pollutants. A preliminary investigation of some local species obtained from various parts of Nigeria appeared to reflect expected variations in pollution levels (Onianwa and Egunyomi 1983). We then carried out further empirical investigations on a few species to understand the sorption and accumulation characteristics towards metals. Some questions were clearly pertinent here; e.g., Can the active uptake sites be saturated? What are the accumulation capacities? Are some metals displaced, as in classical ion exchange systems, when other heavy metals are sorbed? Species studied for this purpose were: *Rhacopilopsis trinitensis* (C. Muell) Britt. Et Dix., *Stereophyllum virens* Card., and *Thuidium gratum* (C. Muell) Jaeg. Sorption was found to be high even at relatively high

heavy metal levels in various solutions (table 4), while exchange and displacement of other metals were minimal, suggesting some mechanism of ion exchange and chelation for the uptake, and a high accumulation potential (Onianwa et al. 1986a) (table 5). Subsequently, these and several more species were used to carry out a detailed survey of atmospheric heavy metal deposition patterns in the southwestern region of Nigeria. Gradients in ambient metal pollution levels were to a large extent reflected in the levels in mosses. Contour maps of heavy metal levels in mosses were derived. Some surprising local hot spots were also identified. For example, very high copper levels (100-1000 μg/g compared to background levels of 10-30 μg/g) were found in forest mosses around Ondo State, which appeared to have been derived from the heavy use of certain copper-based fungicides in cocoa farms of the area (Onianwa et al. 1986b, Onianwa and Ajayi 1987, Onianwa 1987). Subsequently, the study was also conducted for parts of the northern and southeastern regions of Nigeria (tables 6 and 7). We also addressed and proffered opinions on the controversies regarding inter-species variation in accumulation capacities of mosses, and the significance or otherwise of uptake of metals from the substrates.

Table 4: Sorption of Pb, Cu and Cd from Neutral Solutions by the Mosses

Conc. of metals ($\mu g\ mL^{-1}$)	% Pb sorbed			% Cu sorbed			% Cd sorbed		
	Rt[a]	Sv[a]	Tg[a]	Rt	Sv	Tg	Rt	Sv	Tg
10	90.0	94.6	92.5	80.4	71.7	79.2	95.3	85.4	90.8
20	87.2	93.6	95.5	85.6	80.8	87.6	95.8	94.3	93.4
50	90.2	98.2	95.0	87.9	86.6	88.8	96.1	99.4	95.9
80	90.7	96.1	95.0	87.1	87.0	91.2	94.3	94.9	93.0
100	79.8	93.1	92.5	85.1	87.5	91.8	94.8	93.4	93.0
200	91.6	94.8	95.6	84.0	89.2	88.2	90.0	88.7	85.8
500	97.3	99.0	94.3	65.0	59.4	50.3	74.7	68.9	61.7
1000	96.6	93.7	81.8	35.7	30.8	26.6	46.0	50.7	39.3
20 (mixed)	98.9	98.6	98.6	87.3	83.2	88.1	97.3	96.9	96.6
100 (mixed)	93.0	97.9	97.8	66.3	72.9	82.8	89.9	88.4	83.3
200 (mixed)	97.1	96.9	94.8	92.0	87.9	87.1	94.7	93.8	90.7

[a]Rt, *R. trinitensis*; Sv, *S. virens*; Tg, *T. gratum*

Table 5: Proportion of Original Metal Contents released from Moss Tissue upon Sorption of Pb

Conc of Pb solution ($\mu g\ mL^{-1}$)	% Ca			% Mg			% Zn			% Mn			% Fe			% Cu		
	Rt	Sv	Tg	Rt	Sv	Tg	Rt	Sv	Tg	Rt	Sv	Tg	Rt	Sv	Tg	Rt	Sv	Tg
10	1.0	0.7	0.6	12	5.6	3.4	21	8.0	2.6	ND	1.3	1.2	0.3	0.1	0.1	21	15	5.5
20	0.8	1.0	0.6	16	7.6	3.1	21	14	2.6	ND	0.8	1.2	0.3	0.1	0.1	26	16	23
50	1.2	1.1	1.2	19	6.0	5.7	22	8.0	0.9	ND	1.5	1.5	0.2	0.2	0.4	30	21	16
80	1.1	1.5	1.1	18	9.2	6.0	17	12	2.6	ND	1.1	1.9	0.2	0.1	0.3	21	16	8.2
100	1.2	1.6	1.6	20	14	7.6	25	8.0	1.7	ND	2.1	1.8	0.2	0.1	0.1	23	12	2.7
200	2.1	3.6	5.3	23	17	14	21	6.9	1.7	ND	2.1	2.5	0.2	0.1	0.1	23	15	8.2
500	5.9	28	30	68	39	33	10	15	2.6	ND	4.8	7.4	0.2	0.1	0.1	26	26	2.7
1000	28	62	65	108	57	44	11	18	13	20	12	15	0.2	0.1	0.1	21	16	3.0

Table 6: Summary of Concentrations of the Metals in Roadside Moss Samples from the South-west Region of Nigeria

Zones		Pb	Zn	Cd	Cu	Ni
Higher Pollution	Mean	136 ± 77	99 ± 34	0.35 ± 0.21	26.3 ± 6.0	10.2 ± 2.7
	Range	26.7 - 281	53.4 - 153	<0.05-0.70	17.4–38.1	5.2 – 13.5
Medium Pollution	Mean	42 ± 19	150 ± 110	0.16 ± 0.17	17.8 ± 4.8	8.0 ± 2.3
	Range	12.4 -127	31.6 - 496	<0.05 – 0.77	8.1 – 29.7	3.6 – 15.7
Low Pollution	Mean	14.3 ± 7.5	70 ± 34	0.12 ± 0.15	14.1 ± 6.2	7.0 ± 2.3
	Range	6.6 – 33.3	26.3 - 140	<0.05 – 0.65	8.1 – 30.9	3.5 – 13.5

Source: Onianwa and Ajayi (1987)

Table 7: Summary of Results for Moss Metal Concentrations (ppm) in Southeastern and Northern Regions

Metal	Parameter	Northern Region	South-eastern Region	Average for Entire Study Area
Pb	Mean	44.4	58.8	-*
	Range	1.25 - 327	7.0 - 272	
Zn	Mean	38.2	60.7	50.9
	Range	11.6 - 189	12.5 - 319	
Cd	Mean	1.38	1.01	1.17
	Range	<0.02 – 4.6	<0.02 – 4.2	
Cu	Mean	12.4	10.4	11.3
	Range	4.0 – 79.5	2.1 – 68.8	
Ni	Mean	5.38	5.78	5.60
	Range	<0.05 – 16.5	<0.05 – 18.1	

*Difference between northern and south-eastern region is statistically significant

Studies on Top-Soil Heavy Metals Pollution

Topsoil is a critical sink for assessing the health of the total environment. It receives direct deposition from the atmosphere, leachates from runoffs, and direct deposition of solid wastes on it. It is not mobile and can thus integrate deposition over time. The soil can be a useful indicator of overall pollution of the environment as long as suitable control samples can be obtained to enable distinction between natural mineralization and anthropogenically derived contents. With several of my research students, I have focused assessment on topsoils in Ibadan and elsewhere mainly on heavy metals (especially lead) composition. We have studied a number of "hotspots" as well and non-hotspot locations. One of the really alarming results was obtained in 1992 when we studied the distribution of lead and other heavy metals in soil and vegetation in the vicinity of a battery factory (the Exide Batteries Ltd.), which had been established in 1982 and located in the Kute area, near Monatan in Ibadan (Onianwa and Fakayode 2000).

The factory, which derives its lead for battery production by smelting and refining impure lead obtained from scrap batteries, was surprisingly co-located with a primary school (now converted to a secondary school) right adjacent to it (fig. 14). Remember the Zamfara lead poisoning episode of 2010! Topsoil lead levels were as high as 4000 ppm within the playground of the then primary school, and declined gradually in all directions (table 8). Even at 1 km from the factory, the levels had not declined to normal background levels at control points within the city. The factory was thus a really dangerous hotspot of lead emission in all directions from the site. The questions I have since then asked are: Which facility was first sited at this location? The school or the battery factory? Who gave the approval for the location of the second facility? How knowledgeable on environmental pollution issues are staff of the town planning authority? In what ways could the exposure to such high levels of lead have affected the children? We note that the factory was shut down in 2000 purely for economic reasons of non-viability.

Although lead toxicity is likely to be more fatal in children of less than five years, it is still significantly serious in adults where it is known to cause high blood pressure, muscular and joint pains, decline in mental functioning, memory loss, reduced sperm count, and miscarriages in pregnancy. We repeated the study in 2014 (Atere 2014) and still found levels of lead in soil still as high as 4000-5000 ppm in the outer perimeters of the factory. Heavy metals persist in the environment!

Table 8: Concentrations (mg kg^{-1}) of Lead in Soil and Plant around the Battery Factory

Transect	Distance from Factory (m)	Soil	Plant
NW	0	2010 ± 1400	1350 ± 1050
NW	20	1160 ± 590	1090 ± 780
NW	50	294 ± 150	830 ± 120
NW	100	150 ± 70	109 ± 68
NW	250	83 ± 43	352 ± 56
NW	500	77 ± 71	77 ± 33
NW	750	39 ± 23	52 ± 25
NW	1000	290 ± 330	154 ± 230
SW	0	4100 ± 1800	970 ± 730
SW	50	3150 ± 2000	780 ± 410
SW	100	2790 ± 2000	440 ± 190
SW	250	2500 ± 1900	490 ± 270
SW	500	1450 ± 740	186 ± 100
NE	0	950 ± 890	3640 ± 2100
NE	50	860 ± 200	790 ± 580
NE	100	1060 ± 480	310 ± 230
NE	250	140 ± 36	170 ± 100
NE	500	104 ± 53	61 ± 35
NE	750	69 ± 39	79 ± 41
W	0	3010 ± 2100	1710 ± 790
SE	0	590 ± 1500	2400 ± 1500
SE	50	1400 ± 600	2000 ± 1300
SE	100	830 ± 54	1110 ± 580
CTR* 1	About 15 km	11.4 ± 7.2	10.6 ± 6.4
CTR 2	About 15 km	14.7 ± 9.1	9 ± 13
CTR 3	About 15 km	10.5 ± 9.3	10.7 ± 9.0

* Controls

Fig. 14: The school located directly beside the battery factory (April, 2015).

Etim and Onianwa (2012) have also investigated lead levels in soils in the vicinity of the military shooting range in Ojoo area of Ibadan. As suspected, levels were very high at the impact berns or targets, reaching levels of 5680 ppm in topsoil and 6370 in subsoil at this point, compared to about 20 ppm at background control points within the city. The shooting range is located in some remote location from normal residential area, and it is pleasing to note that migration of the high lead levels from the berns was not yet significant. At about 250 m from the bern, lead levels were within the background control levels. Copper levels were also elevated about 15-fold at the bern. Speciation studies indicated that most of the lead in the soil was held in the non-exchangeable soil phases. Further monitoring of this vicinity is essential.

We have similarly investigated the levels of lead and other metals in topsoil and vegetation in several other

important locations, including industrial estates in Ota and Ikeja (Fakayode and Onianwa 2002; Etim and Onianwa 2013), inside nursery school playgrounds and classroom dusts in Ibadan (Ibrahim et al. 2002), automobile repair workshops (Onianwa et al. 2001) and roadsides of Ibadan city (Onianwa 2001). Within the city of Ibadan, we have also determined topsoils contamination from hydrocarbon oils (Onianwa 1995), and aerial deposition of suphate-sulphur (Onianwa and Babajide 1993). The results generally provide baseline/current data that indicate some growing degree of contamination, and the need to be proactive to curtail the trend.

Studies on Surface and Groundwater Qualities

Water is a valuable resource for drinking, recreation, transportation, domestic cooking and washing, aquaculture, aquatic life support, livestock production, irrigation and industrial production. Each of these uses of water requires the water to possess certain specific characteristics. Water that naturally meets these characteristics is in very short supply in comparison to the magnitude of need. Of the estimated 1.4 x $10^{18}m^3$ of water on Earth, more than 97% is in the oceans. Only about 35 x 1,015m^3 of Earth's water is freshwater, out of which about 0.3% is held in accessible rivers, lakes and reservoirs (Shiklomanov and Rodda 2003; Pimentel et al. 2004). Unfortunately, much of the available freshwater is not fit for purpose due to pollution related to discharge of sewage, agricultural wastes, industrial effluent, municipal runoffs, municipal wastes, domestic/kitchen wastes, and oil spills (UN Water 2005). Water quality assessment is therefore critical for determining the degree of contamination of local resources. My research team has studied the qualities of a number of surface and ground water resources in various parts of the country. Sediments of rivers integrate the long-term conditions of surface water bodies and thus often represent a better indicator of water quality. Over a one-year period of monthly sampling, we investigated the quality

status of Qua Iboe and Cross rivers (Umoren and Onianwa 2012), each at seven specially selected, spatially dispersed and non-visibly impacted points. Apart from determining the general physicochemical characteristics of the waters and sediments, analyte concentration data was used, in conjunction with thermodynamic data and the PHREEQCI model, to carry out chemical speciation of the major ions. For the Qua Iboe river system, the speciation showed that the predominant species were the free ions of Ni^{2+} (97.6%), Co^{2+} (97.7%), Zn^{2+} (92.6%), Cu^{2+} (70.2%), and Pb^{2+} (62.0%) as well as the hydroxide species, $CrOH^{2+}$ (58.7%) and chloride species, $CdCl^{2+}$ (82.3%). From the model calculations, solubilities of the minerals atacamite, tenorite and pyromorphite showed positive values of the saturation indices, which indicate supersaturation and mineral precipitating conditions of the water for these species (table 9).

Table 9: Saturation Indices of Some Mineral Phases at Some Stations in Qua Iboe River System

Phase	Saturation Indices (SI)						log K_{sp}	Formula
	SQ-1	SQ-2	SQ-3	SQ-4	SQ-5	SQ-6		
Anglesite	-7.28	-7.80	-7.12	-3.15	-2.38	-2.70	-7.91	$PbSO_4$
Atacamite	3.04	2.42	3.09	-12.55	-10.53	-11.79	14.26	$Cu_2(OH)_3Cl$
$Cd(OH)_2$	-1.64	-1.41	-0.13	-10.61	-10.25	-10.35	13.73	$Cd(OH)_2$
$CdCr_2O_4$	-4.00	-5.22	-0.14	5.09	4.82	4.15	15.00	$CdCr_2O_4$
Cerrusite	-1.62	-2.13	-1.63	-2.16	-1.61	-2.05	-3.24	$PbCO_3$
$Co(OH)_2$	-7.94	-8.24	-8.15	-8.43	-7.92	-7.98	12.30	$Co(OH)_2$
CrO_2	-7.17	-7.75	-6.13	-3.36	-4.00	-4.28	-19.14	CrO_2
$CuCr_2O_4$	-6.71	-8.27	-4.31	5.13	4.73	3.93	16.22	$CuCr_2O_4$
Cuprite	-1.23	-1.74	-0.84	-3.22	-2.09	-2.56	-1.91	Cu_2O
Hydrocerrusite	-1.52	-2.74	-1.77	-9.14	-7.95	-9.19	1.85	$Pb_3(OH)_2(CO_3)_2$
Malachite	0.25	-0.30	0.53	-6.23	-5.32	-5.85	5.90	$Cu_2(OH)_2CO_3$
Nantokite	-7.13	-7.47	-6.96	-3.45	-2.32	-2.71	-6.77	CuCl
$Ni(OH)_2$	0.89	0.64	0.64	-8.58	-7.88	-7.94	12.75	$Ni(OH)_2$
Otavite	-1.13	-1.22	0.58	-4.13	-3.32	-3.49	-1.77	$CdCO_3$

Table 9 contd.

Paralaurionite	-2.51	-2.79	-2.76	-4.37	-3.71	-4.24	0.20	PbClOH
$Pb_3(PO_4)_2$	-4.41	-6.02	-4.72	-5.92	-5.15	-6.19	-19.97	$Pb_3(PO_4)_2$
$PbHPO_4$	-1.45	-2.16	-1.49	1.06	1.41	1.07	-15.73	$PbHPO_4$
Pyromorphite	4.04	1.45	3.44	3.19	4.96	3.06	-47.90	$Pb_5(PO_4)_3Cl$
Smithsonite	-3.43	-3.92	-3.44	-4.38	-4.07	-4.16	0.44	$ZnCO_3$
Tenorite	2.89	2.77	2.92	-3.34	-3.12	-3.35	7.65	CuO
Tsumebite	0.65	-0.38	0.37	-9.62	-9.00	-9.94	2.53	$Pb_2CuPO_4(OH)_3{:}3H_2O$
Zincite	0.75	0.58	0.52	-6.18	-6.33	-6.36	11.20	ZnO
$ZnCO_3{:}H_2O$	-3.19	-3.69	-3.22	-4.16	-3.86	-3.95	0.14	$ZnCO_3{:}H_2O$
CO_2	-6.95	-7.25	-6.70	-0.94	-0.46	-0.53	-7.83	CO_2
O_2	-0.74	-0.72	-0.82	-0.74	-0.85	-0.78	-2.89	O_2

Akporido and Onianwa (2015) also assessed heavy metals and petroleum hydrocarbon levels over a period of two years at some selected locations of the Esi river, a major water body in the Western Niger Delta region, with the purpose of fingerprinting the contaminants and determining the provenance. General physicochemical parameters for surface and subsurface waters were also documented during the study. Nickel:Vanadium ratios in the water and sediment tended to closely match the values for Forcados blend, which suggested that some contamination must have been derived from oil exploration activities in the area.

One of my doctoral students (Olayiwola 2012) studied the Osun river system for which only very little chemical quality-related information was available in the literature. It was surprising to find out that even the Ogun-Osun River Basin Development Authority had never embarked on quality analysis of the river system, did not have the capacity/facility to so do, and had no existing quality data for parts of the river network. We sampled along the main course of the river and 31 of its tributaries, locating 90 carefully selected points for water collection and 63 for sediment collection. Sampling was carried out bimonthly for a period of 24 months at all these sites. Using the Pratti model, water from 37% of the sampling points were found not to be fit for drinking. Data obtained for BOD, phosphate and nitrate were found to give good time series model fits with high regressions, and were thus used to make a 10-year projection of the concentrations of BOD, phosphate and nitrate (i.e. 2008 to 2018) in water at some of the sampling points, baring changes in the current nature and trend of anthropogenic inputs. These three quality parameters are valuable for estimating gross organic pollution and the tendency towards eutrophication.

Within the city of Ibadan, the rivers and streams have also been studied for the levels of various quality parameters (Onianwa and Essien 1999; Onianwa et al. 2001; Onianwa et al. 2012).

Surface waters and sediments of lakes are particularly suitable for indicating the general levels and trends of pollution in an environment, particularly if the water body is not located close to a polluting hotspot. Lakes are fed by and drained by streams and rivers, but because they represent a large relatively stagnant mass of water, they tend to better reflect the degree of accumulated pollutants. Four lakes in Ibadan city were recently studied by my MSc student (Anazonwu 2012) to determine the physicochemical and heavy metals levels. The aim was partly to compare her data with that which had been obtained in a 1977-1979 survey carried out by Mr. Casper Mombeshora, then a doctoral student in the Department of Chemistry. This comparison should indicate if any significant changes in metal levels in the aquatic system had occurred over a period of thirty years. The data obtained by Mombeshora had been published as: Mombeshora et al. (1981), Mombeshora et al. (1983), Ajayi and Mombeshora (1989).

The lakes studied by Anazonwu were the IITA lake, the Awba lake of our University, the Agodi lake and the Eleyele lake. Mombeshora studied only the first three of these. The comparison (table 10) indicated mostly insignificant differences in surface water metal levels. Significant differences involving increases after the elapsed period were noted in the sediment contents of metals such as Co, Ni, Pb and Zn. The factor of amplification was quite significant for lead in the IITA (x8.5) and Awba lake (x16) sediments. As pointed out earlier, sediments are a better indicator of the overall status of the aquatic system than the surface water.

Table 10: Comparison of Average Results obtained by Ajayi & Mombeshora /Mombeshora et al. (1977-79 studies) with that of Anazonwu (2012 studies)

Lake	Media	Conc. Unit	Study	Cd	Co	Cu	Cr	Ni	Pb	Zn
Awba	Sediment	mg/kg	Anazonwu*	1.31	20.6	27.5	41.1	20.3	54.1	141
Awba	Sediment	mg/kg	Ajayi & M.**	1.2	30.5	48.7	14.5	27.4	26.0	91.5
Agodi	Sediment	mg/kg	Anazonwu	1.36	10.3	27.1	45.0	18.3	50.3	223
Agodi	Sediment	mg/kg	Ajayi & M.	1.5	23.9	48.0	20.7	29.6	77.5	165
IITA	Sediment	mg/kg	Anazonwu	1.13	18.0	20.7	48.0	26.6	21.0	74.0
IITA	Sediment	mg/kg	Ajayi & M.	1.2	41.2	44.2	17.1	29.3	20.4	85.0
Eleyele	Sediment	mg/kg	Anazonwu	1.13	18.4	33.9	31.6	22.4	48.1	155
Eleyele	Sediment	mg/kg	Ajayi & M.	-***	-	-	-	-	-	-
Awba	S. Water*	µg/L	Anazonwu	4.8	6.3	0.63	13.0	15.0	34.0	5.4
Awba	S. Water	µg/L	Mombeshora++	5.8	1.9	0.9	-	1.1	2.1	1.6
Agodi	S. Water	µg/L	Anazonwu	5.9	13	3.8	15	15	7.7	13
Agodi	S. Water	µg/L	Mombeshora	8.4	2.6	2.3	-	1.6	4.9	4.7
IITA	S. Water	µg/L	Anazonwu	5.8	15.4	2.4	12	21.4	11	12
IITA	S. Water	µg/L	Mombeshora	1.0	0.7	0.8	-	0.9	1.3	1.5
Eleyele	S. Water	µg/L	Anazonwu	5.6	4.2	3.9	8.2	13	23	4.8
Eleyele	S. Water	µg/L	Mombeshora	-	-	-	-	-	-	-

* Anazonwu (2012) – conducted in 2012
** Ajayi & Mombeshora (1989) – conducted 1977-1979
*** Not studied by Ajayi & Mombeshora and Mombeshora et al.
* Surface Water
++ Mombeshora et al. (1981) – conducted 1977-1979

Impacts of Industrial Effluents

Most thriving chemical material producing industries in Nigeria discharge their liquid effluent untreated or inadequately treated unto some land or water course. The impact on some small water courses is sometimes devastating as this often makes such waters no longer drinkable, "fishable" or "swimmable". Some of such water bodies become coloured, smelly and sterile with regards to aquatic life. The case is not different for some industries and streams in Ibadan. We have studied some Ibadan rivers with respect to the impacts of effluent discharges on them. In one case, a major brewery discharges partially treated, coloured waste into the Olosun River. Over a period of two years, we examined the characteristics of the river water and sediment at various locations up to 700m upstream and 700m downstream (as access would permit), as well as the somewhat hidden discharge point. It was observed that at 700m downstream, the water body was still stressed, as the natural self-purification capacity of the river had not restored the water to its upstream quality, particularly with respect to the level of nutrients and gross organic pollution parameters (table 11; Ipeaiyeda and Onianwa 2009).

A similar study was carried out on the impact of the discharge of effluents of several food and beverage industries on the Alaro River in the Oluyole area of Ibadan (Ipeaiyeda and Onianwa 2011). For both river systems, we related the data on the dispersion of contaminant inputs downstream to the hydrology of the water courses and modelled this to produce a means of predicting the water quality parameters downstream. Etim and Onianwa (2013) also determined the impact of effluent discharge from the Ota Industrial Estate on the Oruku River.

Table 11: Average Levels of Water Quality Parameters at Upstream, Discharge Point and Downstream of the Olosun River during Wet and Dry Seasons, 2004

	Wet season 2004			Dry season 2004		
Parameter	**Upstream**	**Discharge point**	**Downstream**	**Upstream**	**Discharge point**	**Downstream**
pH	8.2 ± 0.2^{b}	6.9 ± 0.3^{a}	7.1 ± 0.4^{a}	7.3 ± 0.1^{a}	4.6 ± 0.2^{c}	$6.3 \pm 0.3a$
Temperature	26.7 ± 0.6^{a}	27.0 ± 0.1^{a}	27.1 ± 0.2^{a}	26.7 ± 0.6^{a}	26.7 ± 0.5^{a}	27.0 ± 0.2^{a}
Total solids (mg/L)	200 ± 16^{a}	1960 ± 160^{b}	1440 ± 120^{c}	303 ± 15^{a}	2430 ± 110^{d}	1880 ± 83^{b}
TDS (mg/L)	147 ± 32^{b}	1490 ± 71^{a}	1160 ± 67^{d}	204 ± 15^{b}	1490 ± 87^{a}	1220 ± 140^{b}
TSS (mg/L)	85.7 ± 29.0^{b}	476 ± 92^{a}	284 ± 87^{c}	99.3 ± 27.3^{b}	940 ± 60^{d}	674 ± 160^{e}
Turbidity (FTU)	8.3 ± 4.1^{b}	38 ± 16^{a}	20.7 ± 8.0^{c}	8.0 ± 4.9^{b}	32.3 ± 6.8^{a}	20.9 ± 5.6^{ac}
Total hardness (mg/L)	107 ± 9^{b}	298 ± 79^{a}	214 ± 51^{c}	175 ± 52^{c}	725 ± 380^{d}	562 ± 260^{f}
Alkalinity (mg/L)	77 ± 13^{b}	173 ± 39^{a}	126 ± 16^{a}	120 ± 6^{a}	298 ± 61^{c}	224 ± 41^{c}
Cl^{-} (mg/L)	108 ± 1^{b}	330 ± 42^{a}	276 ± 32^{c}	120 ± 2^{b}	403 ± 28^{d}	333 ± 23^{a}
NO_3^{-} (mg/L)	12.0 ± 5.0^{b}	50 ± 19^{a}	33 ± 12^{c}	12.9 ± 1.8^{b}	53 ± 11^{a}	37.3 ± 9.1^{c}
NH3 (mg/L)	2.81 ± 0.53^{b}	16.8 ± 7.5^{a}	9.9 ± 4.8^{c}	3.08 ± 0.83^{b}	15.4 ± 4.3^{a}	10.4 ± 1.8^{c}
SO_4^{2-} (mg/L)	9.7 ± 2.9^{b}	40.2 ± 5.3^{a}	25.4 ± 4.4^{c}	14.6 ± 3.8^{b}	40.6 ± 1.8^{a}	27.8 ± 4.5^{c}
PO43- (mg/L)	0.07 ± 0.02^{b}	0.57 ± 0.06^{a}	0.34 ± 0.05^{c}	0.15 ± 0.03^{d}	0.55 ± 0.12^{a}	0.37 ± 0.08^{c}
DO (mg/L)	6.2 ± 0.4^{b}	1.71 ± 0.55^{a}	2.91 ± 0.15^{c}	$3.3 \pm 0.8c$	1.36 ± 0.28^{a}	2.2 ± 1.0^{c}
BOD (mg/L)	2.40 ± 0.46^{b}	14.6 ± 1.9^{a}	8.7 ± 2.2^{c}	2.60 ± 0.47^{b}	13.5 ± 0.95^{a}	9.0 ± 0.5^{c}

Table 11 contd.

COD (mg/L)	133 ± 35^{b}	800 ± 45^{a}	528 ± 110^{c}	170 ± 23^{b}	1240 ± 100^{d}	883 ± 90^{a}
Ca (mg/L)	87.9 ± 5.5^{b}	272 ± 76^{a}	184 ± 45^{c}	119 ± 10^{b}	497 ± 150^{d}	377 ± 130^{a}
Ni (mg/L)	0.08 ± 0.02b	0.15 ± 0.02^{a}	0.11 ± 0.02^{a}	1.18 ± 0.16^{c}	1.97 ± 0.45^{d}	1.33 ± 0.19^{c}
Zn (mg/L)	0.37 ± 0.27^{b}	2.03 ± 0.93^{a}	1.24 ± 0.61^{c}	1.12 ± 0.45^{c}	6.81 ± 2.9^{d}	5.3 ± 3.1^{d}
Cr (mg/L)	<0.02	<0.02	<0.02	<0.002	0.14 ± 0.13^{a}	0.06 ± 0.04^{b}
Co (mg/L)	<0.01	<0.01	<0.01	0.27 ± 0.05^{b}	0.49 ± 0.17^{a}	0.31 ± 0.08^{b}
Cu (mg/L)	0.20 ± 0.13^{b}	0.31 ± 0.15^{a}	0.23 ± 0.13^{b}	0.33 ± 0.09^{a}	0.42 ± 0.14^{ac}	0.36 ± 0.07^{a}
Cd (mg/L)	<0.002	0.03 ± 0.01^{a}	<0.002	0.04 ± 0.01^{a}	0.14 ± 0.09^{b}	0.06 ± 0.03^{a}
Pb (mg/L)	<0.05	0.07 ± 0.05^{a}	0.02 ± 0.01^{b}	0.06 ± 0.05^{a}	0.24 ± 0.07^{c}	0.12 ± 0.02^{d}
Depth (m)	0.33 ± 0.14^{a}	0.35 ± 0.16^{a}	0.25 ± 0.06^{b}	0.26 ± 0.09^{b}	0.28 ± 0.09^{b}	0.19 ± 0.04^{d}
Velocity (m/s)	0.19 ± 0.01^{b}	0.42 ± 0.02^{a}	0.37 ± 0.02^{c}	0.15 ± 0.01^{b}	0.41 ± 0.01^{a}	0.33 ± 0.03^{c}

Note: Means within rows with different superscripts (a,b,c,d,e,f) are significantly different ($p < 0.05$)

Another of my graduate students (Onwordi 2014), among other studies, investigated the physicochemical characteristics of the raw effluents discharged from several industries located in three industrial estates (Ikeja, Ilupeju and Isolo estates) in Lagos metropolis. The study was conducted for a period of two years, and sampling was carried out bimonthly. Industry types covered included food and beverages, textiles, pharmaceuticals, basic metals, paints, conglomerate, and a central treatment facility. None of the effluents, over the study period, met the regulated limits of NESREA. We further used the data to generate a model for predicting the gross organic loading (in form of COD) and the potential to cause eutrophication (in form of phosphate) of the effluent. Thus, from results of other parameters, it is possible to estimate what the COD and phosphate concentrations would be. The textile industry effluents were the worst contaminated, and we examined different bench scale options for chemical treatment of the effluent, and monitored the efficiencies via the COD levels after treatment. Application of fentoin reagent gave the best results.

Pollution Associated with Solid Waste Management

The nuisance value of municipal solid wastes is the most recognised and visible environmental problem in our local community today, but hardly is the invisible but severe pollution problem associated with such wastes known to the common man. The total elimination of wastes generation is impracticable, but minimisation is a laudable goal. In Nigeria, wastes are often unsegregated (except by scavengers within landfills), and what is ultimately disposed within the many poorly managed major dumpsites often includes degradeable and non-degradeable municipal and household wastes mixed with some industrial wastes. Burial, dumping and uncontrolled burning are the usual disposal practices, with attendant pollution of air, soil, surface water and ground water.

Waste generation within the city of Ibadan has been estimated in several studies but is believed to be somewhat in the neighbourhood of 1.6 million tonnnes per annum, with some 70-90% estimated to be biodegradable (Ogwuleka 2009; CPE 2010; Awopetu et al. 2014). The earlier dumpsites that are now disused were the Ring Road dumpsite (now the site of an ultramodern shopping complex; fig. 15) and the old Aperin dumpsite. Many scholars have studied these dumpsites from different pollution-related perspectives; and these include studies by members of my research group (Onianwa 1994; Onianwa et al. 1995; Aboho et al. 2011; Aboho et al. 2012; Ibeto and Onianwa 2011). Results from studies by my group have mostly indicated the elevation of topsoil levels of heavy metals, high levels of some metals and other contaminants in leachates, and minimal contamination of nearby ground water and surface water resources). The old dumpsites have now been replaced by newer ones such as the Lapite, Aba-eku and Awotan dumpsites. In a more recent study by one of my Masters students (Omobhude 2012), we segregated representative samples of the wastes from these newer dumpsites and determined the heavy metals contents of these materials (table 12). Using data on the relative composition of each material in the waste stream and the estimated loading of waste at each location, we estimated the total loading to be about 189,000 kg/yr/ha. Using the USEPA Toxicity Characteristics Leaching Procedure (USEPA 1992, 2008), we also determined the leachability of the metals from each type of waste material studied. Etim and Onianwa (2013) have also assessed leachate characteristics at some solid waste dumpsite in Ota Industrial Estate.

Fig. 15: The Shoprite shopping mall at Ring Road, and the former waste dump on which it was built.

Table 12: Mean Concentrations (mg/kg) of Metals in Each Component of Solid Wastes from Awotan Dumpsite

Component	Cd	Co	Cr	Cu	Ni	Pb	Zn
Ash	5.7±3.4	10.0±6.7	85±48	459±210	44±13	536±110	484±89
Metal	7.59±0.19	30.0±3.1	200±35	796±130	111±29	1110±1600	431±110
Plastic	2.6±1.0	<0.18	29±16	29±27	11.9±4.7	335±540	85±53
Rubber	3.7±1.3	<0.18	10.3±3.8	80±70	50±77	248±210	110±61
Nylon	2.39±0.34	<0.18	14.0±2.6	77±33	13.1±4.8	139±110	109±67
Paper	5.5±6.1	0.8±1.4	253±370	44±12	17.7±9.1	59±19	70±10
Textile	2.02±0.45	94±160	26±370	80±25	20±14	60±30	115±61
Glass	1.82±0.81	<0.18	5.4±7.4	29±23	12.4±7.7	92±120	83±51
Kitchen waste	2.87±0.42	1.39±0.81	13.3±7.6	114±72	11.9±4.5	99±57	127±19
Hair	2.85±0.11	0.66±0.61	16.9±6.1	91±29	13.7±5.5	84±41	174±93
Palm kernel	1.8±1.6	0.9±1.1	14.1±8.9	31±15	8.3±4.5	35±26	113±27
Wood	1.40±0.40	0.15±0.20	18.3±7.3	17±14	27±22	12.0±6.1	77±34
Manure	3.53±0.98	0.57±0.60	19±10	46±29	17.8±4.4	75±52	255±72
Leather	3.12±0.71	0.38±0.66	19±17	196±83	15.9±5.5	90±39	250±81

We have not only assessed solid wastes for their potential to contaminate the environment. Another of our projects was targeted towards a waste-to-wealth approach of utilizing the huge amount of wastes available, to a beneficial purpose. My doctoral student (Adekunle 2001) established a methodology for composting urban agricultural waste to extract a concentrate of biogenic, polymeric and polyfunctional fulvic and humic acids (Adekunle and Onianwa 2001). Combinations of these acids were tested on crops in greenhouse experiments and found to stimulate and enhance growth. More interestingly, through further research by Dr. Adekunle after graduation, the extract has found further application in bioremediation as an innovative and eco-safe nanotechnology-based technique which is now at the field-scale trial platform for remediation and restoration of petroleum polluted oil-based mud (POBM) and drill cuttings (Adekunle 2011).

Heavy Metals in Foods

The oral route is perhaps the most important route of entry of most toxicants into human tissues. When environmental media such as soils, air and water are contaminated with heavy metals, for example, the impacts on the adult man largely depends on the extent to which the metals get into human food items and drinking water. While assessing the environment media for specific toxicants therefore, it is also useful to assess the levels in foods and potable water. I noted early, however, that there was a sparcity of literature on the levels of toxic heavy metals in Nigerian foods. Earlier data on elemental composition of Nigerian foods were compiled by nutritionists who had been more interested in the contents of essential elements. It should be noted though that some elements could be essential at trace levels, and toxic above certain thresholds. But some elements such as lead and cadmium have no essential nutritional importance even at trace levels. I, therefore, mostly in the 1990s, studied several local Nigerian foods for their contents of heavy metals such

as lead, cadmium, nickel, copper, aluminium, etc, and in some cases estimated the dietary intake from the consumption of these foods. The data generated are very valuable for assessment of the local exposure risks to these heavy metals (Onianwa et al. 1997; Ketiku et al. 1999; Onianwa et al. 1999a, 1999b; Onianwa et al. 2000a, 2000b).

Pollutant levels in soil, soil chemical characteristics, and plant/crop type may be critical for determining soil-plant relationships and the transfer of pollutants from contaminated soils to plants. This necessitated one of my doctoral student's work which involved a survey of heavy metals in soils of selected farmlands of Kogi State (an important food producing state) and various crops grown in such farms (Emurotu 2014). Present level of contamination of soil and crops with most metals was found not to be significant, with very low risk associated with consuming such crops. Metal concentrations in crops parts were also generally lower than model-derived threshold limits for toxicity in plants.

Inventory of Local Greenhouse Gas Emissions on Campus

Some of my Masters students estimated the release of greenhouse gases on our campus, using a purpose-designed model known as the Clean Air-Cool Planet's Campus Carbon Calculator Model (CACPCCC). The model is widely in use in tertiary institutions in the USA (Sinha et al. 2010; Klein-Banai and Theis 2013), and the American College and University Presidents' Climate Commitment (an association of more than a thousand Presidents of tertiary institutions in the USA committed to mitigation of climate change) has made it mandatory for its member institutions to carry out biannual inventories of their greenhouse gas emissions. In applying the model, the organisational boundaries are determined by consolidated methodologies that attempt to account for greenhouse gas emissions from operations of facilities in which the institution has a partial ownership share or working interest, holds an operating license, or leases, or which otherwise represents joint ventures or partnerships of

some kind. These involve the equity share approach, the operational control approach, and the financial control approach.

Details of the methodology cannot be described here, but it is worthy to note that input data for the University of Ibadan was obtained from representative academic departments, the administration, residential areas, Works and Maintenance Department, farms and botanical garden, car parks, etc. Information obtained for the computation included: data on number of vehicles, electricity consumption, staff travels, household electrical appliances, office electrical appliances and fittings, gasoline consumption, hours of operation of the University and private generators, solid waste generation, number of trees felled, fertiliser application rate, length of campus roads, etc. Highlights of the findings (table 14) were as follows:

- Much higher GHG emission levels were obtained during years 2005, 2006, and 2007 out of the 2005 – 2010 period. These appear to have been derived from much higher contributions from the energy sector during these earlier years.
- Overall, the energy sector contributed to about 95% of the total emissions for the entire 2005 to 2010 study period.
- The highest contribution to the energy sector was derived from purchase of municipal electricity.

The only similar studies available for comparison of our results were those of some American Universities. Table 15 gives some of the comparisons for the 2009 and 2010 values. The emissions from the University of Ibadan appeared to fall within the lower rung of the values for the American universities. We also carried out similar surveys for the public and private hospital facilities within the city of Ibadan.

Table 13: Typical Output of the Clean Air Cool Planet (CACPCCC) Campus Carbon Calculator versions 6.6

MODULE	Summary					
WORKSHEET	Overview of Annual Emissions					
UNIVERSITY	UNIVERSITY OF XXXXXXXX					
Select Year -->	2010	Energy Consumption	CO_2	CH_4	N_2O	eCO_2
		MMBtu	kg	kg	Kg	Metric Tonnes
Scope 1	Co-gen Electricity	-	-	-	-	-
	Co-gen Steam	-	-	-	-	-
	Other On-Campus Stationary	-	-	-	-	-
	Direct Transportation	21,492.4	2,226,845.5	359.8	127.5	16,315.9
	Refrigerants & Chemicals	-	-	-	-	7,912.9
	Agriculture	-	-	436.3	2.1	11.5
Scope 2	Purchased Electricity	3,971,028.9	291,048,762.7	3,879.1	6,709.7	73,386.0
	Purchased Steam/Chilled Water	-	-	-	-	-

Table 13 contd.

Scope 3	Faculty/Staff Commuting	9,379.0	665,141.5	98.5	35.4	1,143.3
	Student Commuting	35,035.6	2,529,140.1	172.0	73.6	4,365.3
	Directly Financed Air Travel	-	-	-	-	-
	Other Directly Financed Travel	-	-	-	-	-
	Study Abroad Air Travel	-	-	-	-	-
	Solid Waste	-	(260,590.0)	-	-	(12,332)
	Wastewater	-	-	-	-	-
	Paper	-	-	-	-	-
	Scope 2 T&D Losses	590,541.3	28,565,262.2	383.6	663.6	48,772.6
Offsets	Additional					-
	Non-Additional					-
Totals	Scope 1	21,492.4	2,226,845.5	796.0	129.7	24,240.3
	Scope 2	3,971,028.9	291,048,762.7	3,879.1	6,709.7	73,386.0
	Scope 3	434,955.8	31,498,953.8	654.2	772.7	11,910.6
	All Scopes	3,327,477.1	325,774,562.0	5,329.3	7,612.1	**109,536.9**
	All Offsets					-
					Net Emissions:	**109,536.9**

Table 14: Contributions from the Different Sectors to the Total Emissions on the University Campus during 2005-2010

Year	Energy sector ($MTeCO_2$)	Transport sector ($MTeCO_2$)	Agriculture sector ($MTeCO_2$)	Waste sector ($MTeCO_2$)	Total emissions ($MTeCO_2$)
2005	522426.6	6029.7	11.5	9717	538,184.8
2006	485238.1	6198.2	11.5	9734	501,181.8
2007	450360.7	6641.2	11.5	10146	467,159.4
2008	337078.5	7239.0	11.5	10146	354,475
2009	92082.8	7682.9	11.5	9936	109,713.2
2010	95810.6	7921.2	11.5	12332	116,075.3

Table 15: Net Carbon Dioxide Equivalence Greenhouse Gas Emissions (metric tons) for Some American Universities compared with University of Ibadan

University	Year of Study	Net Emission (MT of CO_2e)	Per Full-Time Enrollment	Per 1000 sq. Feet
Arizona State University	2010	269,364	4.0	19.6
California State University, Bakersfield	2009	10,127	1.5	10.1
Case Western Reserve University	2009	263,217	28.8	34.6
Clemson University	2009	139,080	7.9	20.8
Colorado State University	2011	219,074	8.5	22.6
Cornell University	2010	225,000	10.9	15.0
George Washington University	2009	128,183	6.4	16.6
Illinois State University	2009	123,768	6.1	19.0
Kennesaw State University	2010	97,494	4.4	28.0
Mississippi State University	2009	114,189	6.4	15.3
New York University	2009	136,486	3.3	11.5
Ohio University	2010	213,545	11.0	26.4
Seatle University	2009	23,787	4.3	10.7
University of California, Berkeley	2009	193,300	5.5	11.9
University of Cincinnati	2010	432,202	16.9	30.2
University of Connecticut	2007	201,770	10.8	18.9
University of Florida	2009	350,312	7.3	17.5

Table 15 contd.

University of Illinois, Chicago	2009	290,806	11.8	19.8
University of Maryland, Baltimore	2010	169,516	27.8	27.7
University of Massachusetts, Amherst	2010	120,448	4.4	11.1
University of Miami	2009	243,065	16.4	22.9
University of New Hampshire	2009	68,505	4.9	11.0
University of Oregon	2009	89,615	4.1	14.2
University of Pennsylvania	2010	182,866	7.4	13.4
University of Utah	2009	269,589	11.8	23.6
University of Vermont	2010	73,116	6.2	13.6
University of Wyoming	2009	120,238	10.9	16.6
University of Ibadan	2010	116,075	5.9*	5.3**

*student pop. – 19,787; **existing campus area – 670.9 hectares / 30% building floors area

Conclusions and Recommendations

Mr. Vice-Chancellor, sir, ladies and gentlemen, I have within the very strict constraints of time allotted attempted to project some of the global chemical environmental problems, and highlight the fact that Nigeria contributes significantly in variety and magnitude to almost every one of these forms of chemical pollution. I have also described some of my research studies that have been directed toward the first few critical steps of assessment and data generation in the process of achieving environmentally sound management of the Nigerian environment. Nigeria has both the capacity to reduce its pollution profile and to become an even more dangerous higher level polluter. I do not think it is a matter of choice. We must direct our nation in only one direction, one of becoming a cleaner, greener economy in which dangers of pollution related to chemicals and wastes are mitigated.

The energy production and utilization sector is very key to achieving a significant reduction in our pollution emission profile. Because of the lack of adequate municipal electricity supply, there has been a preponderance of use of home electricity generators, domestic cooking with firewood, charcoal, sawdusts, kerosene and natural gas. These have resulted in tremendous amounts of emissions of carbon monoxide, carbon dioxide, polycyclic aromatic hydrocarbons and a variety of other toxic organics. Indoor air pollution which results from this was the silent killer of about 95,300 Nigerians in 2004 (WHO 2004).

I therefore urge the Federal Government to recognize the link between the generation of more electricity for home use, and the improvement of the health of the citizenry. All efforts should therefore be made to achieve a rapid and positive turn-around in our perennial electricity generation problem. The international community must also help Nigeria to solve its energy problem. What is the purpose of building windmills, solar/nuclear power and hydroelectrical systems all over Europe as a means of stemming global warming, when Nigeria alone can, and must have been cancelling the effects of all these efforts through the amounts of carbon dioxide

emitted daily from each of our homes, offices and factories with the increased use of imported private electricity generators. The emitted carbon monoxide knows no boundary and does not warm up only parts of Africa!

I have already highlighted the critical need for regular assessment and monitoring of various environmental media—air, soil, surface and ground water, vegetations, foods, and other suitable indicators. Most of all the data that is currently available on the status of our environmental media have been obtained through the praiseworthy efforts of individual academic researchers who are often limited in resources and so tend to limit the spatial and temporal expanse of their study (Abimbola and Olatunji 2011). What are the dissolved oxygen contents of various parts of the River Niger over the last few years? What was the average carbon monoxide level over the city of Ibadan yesterday? What was the chemical oxygen demand of the effluent from the Nigerian Brewery about midday yesterday? What is the average lead content of the topsoil within the Vice-Chancellor's lodge? We do not have answers to these. Yet, I can go online at any time and find information on the air quality within the last hour, of any major city of the developed countries. Government must take up the responsibility of environmental assessment and monitoring. The various State Environmental Protection Agencies, the Federal Ministry of Environment and NESREA have important roles to play in this regard. They must go beyond their traditional roles of being regulators and enforcers, to one of direct assessors and monitors. They must have functional laboratories, competent staff, effective data management and communication systems. It is time, for example, to develop and Air Quality Index system for Nigeria! This way, perhaps the Lagos smog and the Zamfara lead poisoning episodes could have been averted. I therefore call on all the agencies concerned with regulating the Environment to take on these additional roles, while governments make the necessary financial, personnel and technical facilities available for this purpose.

Finally, Mr. Vice-Chancellor sir, I have had a rewarding management experience in the last six and half years of my position as the Coordinator of the University's Multi-disciplinary Central Research Laboratory (MCRL). I wish to express my gratitude for this opportunity. I also, with the kind permission of the Chairman of the MCRL Administrative Committee, would like to publicly acknowledge the special support which your administration has been giving to the MCRL. The need to adequately equip each and every department cannot be wished away, but recent realities of our individual departmental financial and infrastructural situations has made the central laboratory model a very attractive and effective option which most Nigerian University's are buying into. The concern today, sir, of the MCRL Committee is a very deep-seated worry about the sustainability of the MCRL. We believe that perhaps the various governing organs of the University need to articulate this and propose a more enduring sustainability plan. As it stands now, the MCRL can only depend on the goodwill of the person of each vice-chancellor. We pray that the administration will look into this. It is also on this note that I wish to reach out to the Federal Government to revisit the initial proposal of setting up and fully equipping six zonal central laboratories, one of which was to be located on our campus. Funds were initially budgeted, but never released. If we are to achieve the much touted technological development within a reasonable time, through home-grown research, then the issue of providing state-of-the-art laboratory facilities for departments and central laboratories cannot be over-emphasised.

Likewise, I am aware that the Committee of Vice-Chancellors of Nigerian Universities are making very important arrangements to jointly subscribe to the very versatile and comprehensive Elsevier's databases, *Science Direct* and *Scopus*, to be made available to researchers in our universities. This move should be concretised quickly as it would go a long way in improving the quality of staff and students' literature searches, and hence the derived research

designs and project outcomes. I wish us all well in our academic pursuits under the present rather difficult circumstances.

Acknowledgement

I believe I can adapt/modify the poetic words of the great Winston Churchill and say that my life has been one in which "never was so much owed to so many by one person!" So many have influenced me positively, but I shall be constrained here to acknowledge a few and pray that I be forgiven by those for whom I am unable to find the space and time now.

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Our Department of Chemistry is one of the best places in the world to choose to be a worker/lecturer. The culture there has been one of peace, friendliness, cooperation, hard work and loyalty. I thank the current Head, the energetic, goal-getting, meticulous and very experienced Professor A.A. Adesomoju. I also thank my other colleague professors not

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Finally, but not the least: What is so special about me? Nothing! Nothing, but the abiding Grace of the Almighty Father, who fathomed my being and nurtured me to this day! He made it possible for me to have today, to write this lecture, to open my mouth and lift my hands to speak about His environment—the environment which He gave to us in majestic pristine condition. He has in His infinite mercy watched us degrade His environment! Forgive us Father, for we know not what we do! I give him the best of gratitude for this wonderful day and opportunity. May the Grace of our heavenly Father abide with each and every one of us. Amen.

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BIODATA OF
PROFESSOR PERCY CHUKS ONIANWA

Professor Percy Chuks Onianwa, was born on 10 April 1955 to the family of late Chief Frederick Okonwanji Onianwa (alias Oshimili) and late Mrs. Comfort Egobi Onianwa (nee Nwaezeigwe) of Ogboli quarters in Ibusa town of Oshimili North Local Government area of Delta State. He attended St. Augustine's Grammar School, Ibusa, from 1968 to 1972 and passed with a Division One. Between 1973 and 1974, he was at the Baptist Academy, Obanikoro, Lagos where he undertook his Higher School Certificate programme before being admitted into the University of Ibadan in 1975. In 1978, he graduated with a Second Class Honours, Upper Division, from our prestigious Department of Chemistry. Subsequently, he obtained the degree of M.Sc. (Analytical Chemistry) and PhD (Analytical/Environmental Chemistry) from the same Department in 1980 and 1985 respectively. Professor Onianwa joined the staff of the University of Ibadan on 01 November, 1980 as an Assistant Lecturer in the Department of Chemistry, and rose through the ranks to the position of Professor of Analytical/Environmental Chemistry in 2001.

Professor Onianwa's research interest is in the field of analytical methods development and assessment, and the application to environmental assessment, monitoring and modelling particularly with respect to heavy metals and other pollutants. He has published widely in mostly reputable international journals. He has collaborated locally and internationally in this respect, and has been visiting scholar to a number of reputable foreign research centres, including the University of Uppsala's Department of Analytical Chemistry, the Laboratory for Coastal Research of the National Swedish Environmental Protection Board in Drottinngholm, and the Statens Lantbrukskemiska Laboratorium (SLL), Ultuna, Sweden. He was also a Third World Academy of Science (TWAS) research fellow at the International Centre for Environmental and Nuclear Sciences (ICENS), located on the

campus of the University of the West Indies, Kingston, Jamaica. Professor Onianwa has supervised and graduated eight PhD and one MPhil candidates, and scores of MSc candidates.

He has held several administrative appointments in the University. He is the current representative of the Faculty of Science on the University Appointments and Promotion Committee, and has in the past served on the Telephone Committee, Student's Welfare Committee, Staff Disciplinary Committee, and several ad-hoc committees. He has, since September 2008, till date, held the position of Coordinator of our University's Multidisciplinary Central Research Laboratory (MCRL).

Professor Onianwa has served as external examiner for PhD and MSc programmes to two universities in South Africa, and fourteen Nigerian Universities. He has also served on the National University Commission's accreditation teams to several first and second generation Universities. He is regular reviewer to thirteen international reputable journals, and in February 2013 was appointed substantive Editor of an Elsevier journal, the *Journal of Food Composition and Analysis*. He is a member of several professional organisations, including the Institute of Chartered Chemists of Nigeria (a fellow), Institute of Public Analysts of Nigeria (a fellow), American Chemical Society, Royal Society of Chemistry (UK), Council of Science Editors, International Society for Managing and Technical Editors, and the Society for Environmental Toxicology and Chemistry.

Since 2004, he has held the position of Chairman of Technical Committee on Chemicals and Cosmetics of the Standards Organisation of Nigeria (SON). In February 2013, on the recommendation of the SON, he was appointed "Expert" to the Technical Harmonisation Committee (THC) 05 (on Chemicals/Chemical Engineering products) of the African Standardisation Organisation (ARSO), the standardisation coordinating organ of the African Union, based in Nairobi. He was, also in 2013, appointed Member of

UNEP-WCMC (United Nations Environment Programme – World Conservation Monitoring Centre) Group of Experts on the Development of Indicators for the Global Assessment of Harmful Substances. Professor Onianwa has been involved in some assignments involving chemical pollution management issues for the ECOWAS Commission, and the Basel Convention Coordinating Centre for the Africa Region (BCCC-Africa).

He is happily married to Dr. Patricia O. Onianwa, Deputy Director of Nursing, and current Head of Nursing, University College Hospital, Ibadan. They are blessed with children.

NATIONAL ANTHEM

Arise, O compatriots
Nigeria's call obey
To serve our fatherland
With love and strength and faith
The labour of our heroes' past
Shall never be in vain
To serve with heart and might
One nation bound in freedom
Peace and unity

O God of creation
Direct our noble cause
Guide thou our leaders right
Help our youths the truth to know
In love and honesty to grow
And living just and true
Great lofty heights attain
To build a nation where peace
And justice shall reign

UNIVERSITY OF IBADAN ANTHEM

Unibadan, Fountainhead
Of true learning, deep and sound
Soothing spring for all who thirst
Bounds of knowledge to advance
Pledge to serve our cherished goals!
Self-reliance, unity
That our nation may with pride
Help to build a world that is truly free

Unibadan, first and best
Raise true minds for a noble cause
Social justice, equal chance
Greatness won with honest toil
Guide our people this to know
Wisdom's best to service turned
Help enshrine the right to learn
For a mind that knows is a mind that's free