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Exploration, Mining and Energy Generation in Nigeria: Exposure to Organo-Chlorinated Compound and Other Chemicals — Environmental and Public Health Implications

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Abstract: As an oil producing Nation with large mineral deposits, coal is one source of energy generation in Nigeria. However, bye-products of these minerals as alternative energy sources include heavy soot, high emissions of greenhouse gases and resultant organo-contaminates, which are bye-products (i.e., wastes) of heavy machineries. These wastes constitute hazards to the environment and public health. Consequently, Nigeria faces the challenge of organic waste with reverberations and negative impacts on the social, political and economic development of the nation. In this paper we examine the exploration, mining and generation of energy in Nigeria and how the practices involved results in hazards that include exposure to Organo-Chlorinated Compound, Poly-Chlorinated Biphenyl (PCB), classified amongst a group of persistent organic pollutants (POPs). Drawing from empirical data captured, we analyze the environmental and public health implications of PCB and other chemicals such as mercury. Our findings reveal that environmental pollution from POPs and indeed chemical sources have increased in Nigeria, due mainly, to the expansion of urban, agricultural and industrial activities. We conclude by providing recommendations for the management and governance of POPs and address the policy implementations of the findings.

Key words: PCBs, POPs, hazards, exploration, mining and energy generation, Nigeria

1. Introduction

Poly-Chlorinated Biphenyl (PCB), classified amongst a group of persistent organic pollutants (POPs), was earlier used in variety of products such as coolants in hydraulic machinery. Environmental pollution from POP sources has increased in Nigeria, due mainly, to the expansion of urban, agricultural and industrial activities. The persistence of these organic compounds enables their accumulation in humans, animals and plant tissues thereby facilitating their passage on to food supply and into humans resulting in health problems such as cancer and disruption of the immune system. PCBs, although no longer used in many countries, could still be found as trace elements in oil from many machineries and products of energy exploratory and generation. In Nigeria, this remains a major source of concern to environmental experts and health service providers due to lack of awareness and infrastructure to handle the consequences and the seeming lack of commitment and strong political will to enforce rules on environmental safety. Baseline National inventory (BNI) of PCB contaminated oils and equipment conducted in Nigeria, commissioned by the World Bank was not exhaustive and therefore

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inconclusive. However, the study combined with this research point to streams of contaminated oils and equipment, with possible variables in chemical composition of the dielectric fluid, bearing diversity in origin. The BNI report shows total amount of PCB-contaminated waste in Nigeria to be 3,400 tons; PCB-contaminated oil (421 tons), and the combined weight of PCB-contaminated equipment (1,061 tons). These results are estimates, with possibility of a more precise and higher values with a comprehensive inventory as corroborated with this research. The main source and major users of this contaminate was identified, following this study to include oil exploratory, mining and allied companies in the energy sector. With this knowledge, we traced and schematically present the main sources, consisting formal and informal sector with, and show immediate route to ordinary Nigerian citizens. We discuss the hazard posed by PCB oils, in current Nigeria reality where such hazardous wastes are unknowingly used for cooking. Major reasons identified for the import/exports of these oils include cheap pricing, lack of environmental and occupational standards, ignorance, economic factors (such as poverty and greed), and finally weak or non-existence of adequate public policies, regulations and control mechanisms. Put within the global reality, the concerted management of POPS in general and PCB in particular, is a public good. As such the broadest possible stakeholders' organizations (both locally and internationally) must play active roles in shaping PCBs and POPs management cycle. In this study, we identify the main stakeholders in Nigeria and suggest ways to strengthen their roles — a task we ascribe to POPs management in general, and PCB in particular. Thus, increasing public awareness of the danger associated with exposure to PCBs, with a view to mitigating public health risks, is a key consideration of the study. Achieving this requires the adoption of best available technology (BAT) that meets international best practices. In this research, we propose a "best" available technology on managing these pollutants taking ratable and non-ratable criteria into cognizance. We conclude that to effectively address the challenges and risks posed by PCBs and POPs in Nigeria, good governance coupled with adequately managed regulations and sustainable environmental practices, are critical. Achieving this aim will require capacity building of key actors, sustained public awareness campaigns and effective coordination of the various roles and functions of relevant Ministries, Departments and Agencies so identified in this study.

2. Literature Review

The term polychlorinated biphenyls or PCBs, refers to a group of 209 chlorinated isomers (congeners) of biphenyls [1, 2]. PCBs were produced commercially for approximately 60 years with a wide of application in a variety of products, such as coolants, insulating materials, and lubricants in electrical equipment (such as transformers and capacitors). Other areas of PCB use and application include hydraulic fluids, plasticizers, surface coatings, adhesives, pesticides, carbonless copy, dyes, and waxes. The properties of PCBs that made them valuable for industrial applications included extreme stability, chemical inertness, resistance to heat, and high dielectric constant [1, 3].

PCBs, classified among a group of persistent organic pollutants (POPs), have been catigorized by the United Nations Environment Program [1, 4]. This categorization is necessitated by the fact that although PCBs are no longer produced in commercial quantity, they are however found to be persistent in the environment for many years and can be found in air, water, soil, and food. As a result of their peculiar properties, such as low flammability, good insulating potential, "low electrical conductivity, high thermal conductivity and high resistance to thermal degradation" [5], PCBs are valuable commodities to manufacturers. Consequently PCBs have been used extensively in a number of electrical equipment such as transformers, capacitors and household electrical appliances, heat transfer and hydraulic systems. PCBs are also used openly in agricultural pesticides, sealants, insulators, carbonless copy paper, industrial oils, paints, adhesives, plastics, and fire retardants, indicating that PCBs can be found in many of the daily products we use as humans [6].

PCBs are insoluble in water but are soluble in organic or hydrocarbon solvents, oils, and fats [7]. This characteristic, combined with their persistence, means that they do not degrade easily in the environment and may bio-accumulate up the food chain [8]. As PCBs move through the environment, the absolute and relative concentrations of individual chloro-biphenyls change over time and from one environmental medium to another because of physical and chemical processes and selective bioaccumulation and metabolism by living organisms. These processes result in mixtures that are substantially different from the original mixtures that were released to the environment. These changes in the composition of the PCB mixtures complicate the identification, quantification, and risk assessments associated with PCBs. In recent years, substantial progress has been made in the scientific understanding of the dynamics of PCBs in the environment and the effects of PCBs on humans and the ecosystems [6].

In Nigeria, work on hazardous waste management is comparatively few. However, a wide range of literatures, are available on the generation and management of organic waste, especially in the developed countries. Thus, to protect Nigeria's environment from toxicants, knowledge of the pollution sources, pollutants, and toxic organic compounds, such as PCBs and POPs is important [9].

Environmental pollution has increased in Nigeria, as a consequence of the expansion of urban, human, agricultural and industrial activities. The persistence of the organic compounds allows pollutants to accumulate in human, animals and plant tissues and pass on more to food supply and get into our bodies causing major problems. Actual or potential health effects that are associated with PCBs include cancer, reproductive and development toxicity, impaired immune function, effects on the central nervous system, and liver changes [10-14].

2.1 Chemistry of PCBs

PCBs, have been used industrially since 1929, and are entirely of anthropogenic origin. The backbone of the chemical structure is a biphenyl, consisting of two hexagonal "rings" of carbon atoms connected by carbon-carbon bonds. The specific manner by which the carbon atoms share electrons forming the hexagonal rings leads to the biphenyl being an "aromatic" compound. Polychlorinated biphenyls have between 1 and 10 chlorine atoms substituting for hydrogen atoms on the biphenyl rings. The various number and positions of the chlorine atoms on the biphenyl molecule result in up to 209 possible chemical structures designated as congeners in the scientific literature. PCBs are subdivided into groups based on the degree of chlorination or number of chlorine atoms per biphenyl molecule (e.g., trichlorobiphenyls (three chlorines) and tetrachlorobiphenyls (four chlorines). The PCBs within a series of structures of specific chlorine content are known as homologues (i.e., the mono-, di-, tri-, tetra-, penta-, hexa-, hepta-, octa-, nona-, and decachlorobiphenyl homologues). Within a homologue group (e.g., the trichlorobiphenyls), the individual chlorobiphenyl molecules are isomers of each other, meaning that they each have the same number of chlorine atoms, but these chlorine atoms are arranged at different positions on the biphenyl rings (see Fig. 1) [15, 16].

3. Methods

This study was commissioned by the World Bank, 2014 to identify, PCB disposal technologies using best available technology (BAT). The study was designed to meet, Framework for Environmental Health Risk Management (Fig. 2) below.

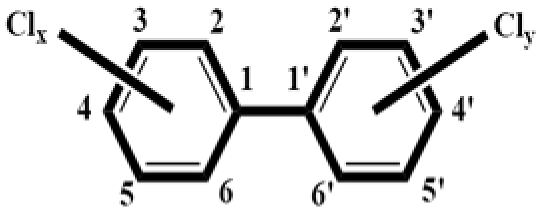


Fig. 1 Chemical structure of PCB. Source [16]

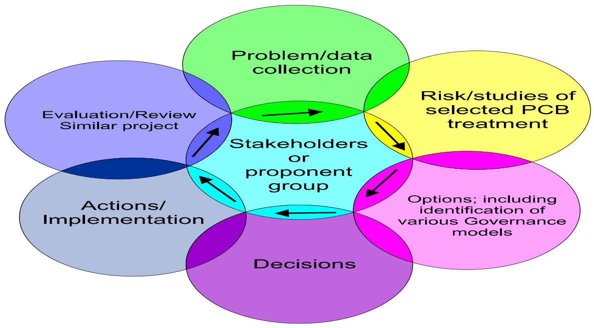


Fig. 2 Framework for environmental health risk management. Source: modified from [26]

Criteria for data collection: applicability to various contamination concentration, commercial availability, capital and operating cost, theoretical soundness, human requirements for operations, environmental performance and monitoring requirements, health and safety performance, inherent advantages and disadvantages. ***Review of similar Projects:*** As such project is far in between in Nigeria, similar projects undertaken elsewhere oversea was use for benchmarking using following: health and safety performance, capital and operating cost and human resource requirements for operation. ***Identify and conduct Interview of Proponents:*** with a view to conduct separate interview with different groups in mining, exploration and energy generation, to spot the needs and plans as it relate their waste acceptance criteria, their disposal performance and capacity, possible collaboration and encourage to identify needs in terms of finance and management. ***Governance model:*** model was studied and gaps identified and discussed. ***Selecting disposal option***: different technological options were assessed using technological applicability, economic soundness and environmental impact and friendliness, as criteria. Data from these, thematic area put together, recommendation on best technology was made.

4. Results and Discussion

4.1 Inventory of PCB in Nigeria

Nigeria has never produced PCB and PCB-contaminated equipment, but it has imported PCBs in dielectric fluids from 58 different countries (World Bank, 2009[1]) [17]. During the project life cycle of the inventory, over 90% of historical data were collected for electrical equipment, mostly transformers belonging to the defunct Power Holding Corporation of Nigeria (PHCN). Moreover, field surveys conducted were geared towards gathering information from selected mining, oil and gas industries, Nigeria Electrical company (defunct-PHCN) substations in the country to get estimate of PCBs status. In the course of the field inventory, testing for PCB oil were conducted on selected transformers at different locations. A total of 281 transformer oil samples were analyzed using PCB screening test kits to establish chlorinated compound concentration greater than 50 ppm. PCBs would be among the chlorinated compounds whose presence in concentrations are greater than 50 ppm and, would result in a positive test (Baseline National Inventory of PCBs and PCB containing equipment-Nigeria, 2009) [17].

The study found PCB in the equipment sampled. The total weight of dielectric fluid contained in such equipment sampled, were extrapolated nationally as presented in Table 1 below.

However, because the study was not holistic there remains a significant data gap. Our study, help to situate the immediate needs for wholesome national inventory for enriched information to be available on PCB volume.

[1] The World Bank Baseline Inventory of PCBs and PCB containing Equipment, Nigeria, 2009.

Table 1 Estimate of PCBs volume in Nigeria.

Weight of Oil (Tonnes)	Inspected	Inventoried	Extrapolated
Total	2,840	14,290	32,500
Potentially PCB-contaminated	316	1,278	3,400
% contaminated	11	11	10

Source: the Baseline National Inventory (BNI) of PCBs and PCB containing equipment - Nigeria, 2009.

3.2 Main Sources of PCB Waste

There are formal and informal means of PCB supply and availability in Nigeria. An illustration of the various means by which, PCB get to the environment or to citizens, represented in the flow-chart (Fig. 3). Fig. 3, indicates, the involvement of various sectors this further compounds the sources of generation.

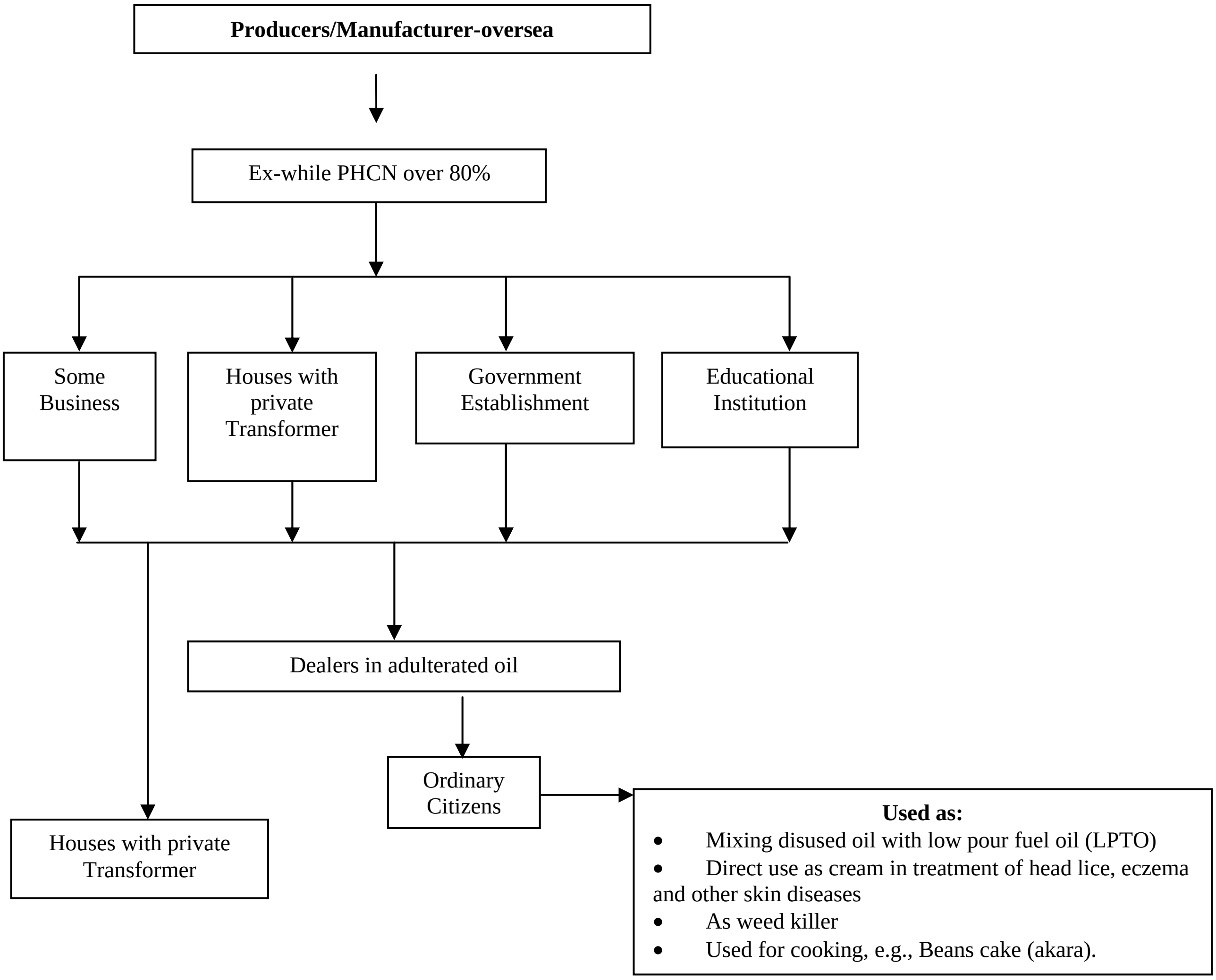


Fig. 3 Main sources of PCB waste in Nigeria.

Modified from [14]

3.3 Organic Pollutants with Respect to Nigeria

The mining, oil exploration, electrical and power generating industries, has emerged as a growing segment of Nigeria industry both in terms of production and demands.

The management of PCBs and other organic pollutants are a major concern in Nigeria in recent times. The other major hazardous waste streams in

Nigeria, are: used oil (from treaded machineries), battery wastes, biomedical wastes, e-wastes etc. Thus, analysis of current environmental health issues in the country presents a picture of a developing country in "double jeopardy, with antecedent poverty, combined with unprecedented pace of development characterized by massive exploitation of natural resources leading to environmental degradation. Whilst, recycling, until recently has been dominated by the urban poor workers with very low literacy levels and with little awareness regarding the potential hazards of PCBs. Moreover, among the urban poor, there are a substantial number of women and children engaged in various recycling activities, which further compromise and exacerbate quality of health due to daily exposure to hazardous waste in general.

One of the major concerns related to PCB management, particularly in Nigeria, is the dumping of PCB contaminated products from developed countries. For instance large quantities of treaded equipment in the oil, mining and used transformers often find their ways into Nigeria due to activities of private businessmen. Some of such equipment and transformers could be in the phasing out process in the parent countries but due to demands in Nigeria and else where in developing countries, there is high accumulation of such products. Major reasons for these imports, are cheap pricing and lack of environmental and occupational standards. Thus, the Basel and Stockholm convention [9] has helped to stop the toxic effluent of the developed nations flowing towards the world's poorest nations.

3.4 Health and Environmental Implications of PCBs, POPs and Other Chemicals

Humans and animals do get exposed to PCBs through their diet. PCBs are soluble in fat, thus, are readily absorbed in the fat of animals hence, they bio-accumulate in aquatic and terrestrial species. This accumulation is biomagnified in higher species (such as humans), up the food chain.

Many regions across the globe face the challenges of effective disposal of organic wastes. This challenge is compounded in Nigeria, due to absence of laws, regulations and enforcement methodologies necessary for supporting efforts to combat waste pollution and its health consequences.

Open air burning is a regular occurrence in Nigeria thus toxic fall-out from such activity affects the local environment and broader global air currents, depositing highly toxic by-products in many places throughout the world (http://www.step-initiative.org). A Most recent study by the World Health Organization (WHO) [18] indicated that 4.9 million deaths were attributable to environmental exposure to POPs including PCBs and other chemicals in 2004. Such study, are revealing and relevant to Nigeria where life expectancy is placed at 53 years (World Health Organization), for the general population. In Nigeria and, some other countries, hazardous waste streams are mixed with municipal or solid wastes and then either dumped or burned in the open air. Such habits, requires a concerted governmental efforts if, to be abated. Moving forward this direction, is so far gloomy hence, a concern for many health and environmental experts. Bearing, earlier studies of cancer in humans in occupational settings implicated PCBs as a carcinogenic compound [8, 13, 19].

Increasingly, it is recognized that the poor management of chemicals adversely affects human health and the environment, disproportionately affecting the urban and rural poor, particularly women and children. PCBs are a dangerous neuro-toxicants as they share similar kinetics with, e.g., cyanide, as both are irreversible inhibitors. The kinetic effects of irreversible inhibitors primarily, are to decrease the concentration of active enzyme. The hazard associated with PCB is profound, with such recognition, coupled with the inherent environmental risks associated with handling PCBs, due diligence must therefore be enforced with the intents of minimizing risk to the environment, human health and surrounding communities. Thus, using data available from various scientific and toxicological studies on these materials along with information from actual levels found in most work place, occupational safety exposure of these toxicants should be strictly enforce in Nigeria. Here, safe exposure refers, exposure limits based on studies that defined safe levels to workers, working in a contaminated environment [20, 21].

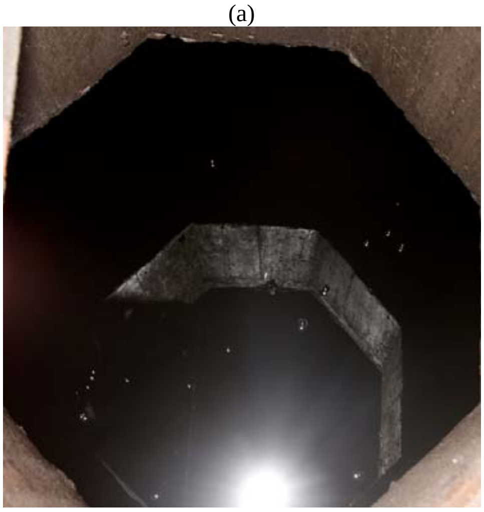
3.5 Management of PCBs Waste in Nigeria

In a recent inventory of PCB contaminated equipment carried out in Nigeria (*The World, 2009*), and a feasibility study for PCB disposal completed (feasibility studies of disposal options of PCB, 2014), it became apparent that the defunct Power Holding Company of Nigeria (PHCN) PHCN, mining industries are the greatest user of dielectric fluid in the country. In many cases it was observed that, electrical items (transformers) are stored unattended mostly, because of lack of knowledge about their management. Such transformers and other electrical hazards lie in warehouses and substations across the federation. These waste particularly the PCBs oil find, their ways to the market via dealers and, could be use for cooking unknowingly. Thus, implementation of appropriate management measures including stringent regulations of sales of such organic waste is very necessary. The management practices currently operational in the country, has inherent dangers with severe health and environmental implications.

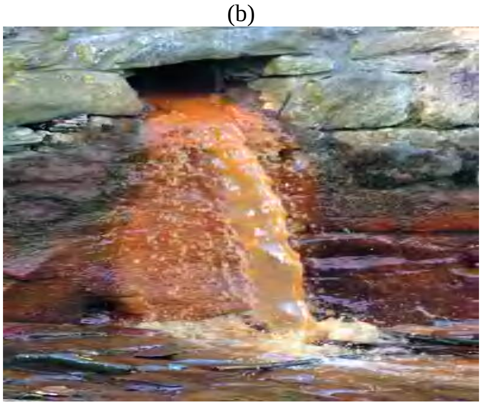
In a specific manner, Unyimadu et al. (2014) showed the present of PCB in Nigeria water bodies, by testing fishes from the Lagos lagoon. Moreover, our study showed the composition of PCB waste in Nigeria, are of diverse nature due to divergent in supplies. Therefore, in such circumstance major approach would be via treatment by established methods (such as, incineration) and dispose thereof, dangerous materials and waste in a globally acceptable manner.

With the study, feasibility studies of disposal options of PCB in Nigeria, World Bank, 2014, sound management procedures were recommended for disposal and treatment of PCB in Nigeria (details as published in World Bank report, 2014). Above all, during the study, oil spills and leaks were observed in the immediate surroundings of transformers and its contamination with other solids and its, leaks into the Lagos-lagoon (see Fig. 4).

(a)



(b)



(c)

Fig. 4 (a): Possible PCB oil mix with solid debris, (b): man-hole with direct evacuation to the lagoon, (c): Effluent from the man-hole to the lagoon.

Nigeria has national regulations on hazardous/toxic chemicals for which PCBs fall under, and is also involved in the implementation of the International Convention, Procedures and Protocols on Hazardous/Toxic Wastes and Chemicals and Radioactive Waste Management. Since 1998, Nigeria develop national regulations on the Basel Convention on Trans-boundary Movement of Toxic Wastes; Procedures/Protocols on "Prior Informed Consents" (PIC) under the Rotterdam convention, on Hazardous Chemicals in International Trade. Achieving these objectives require inter-agency cooperation (Fig. 5). Various studies show that substantial gaps remain in the management efforts of POPs and PCB in particular, in Nigeria [14].

Fig. 5 Scheme of governance model for PCB to enhance delivery. Modified from [14]

4. Heavy Metals in Mining

Generally, there exists an extensive scientific knowledge relating the impacts of chemicals and wastes on humans and the environment. However, the global understanding of the complexity of properties and environmental impacts of chemicals and wastes is markedly, deficient in Nigeria. The fourth Global Environmental Outlook [22] indicated that data were incomplete globally thus, for many regions, a comprehensive evaluation is important to ascertaining the magnitude of chemical contamination and its impacts on the environment and human health.

4.1 Artisanal and Small-Scale Gold Mining (ASGM) in Nigeria

Unlike Ghana and Burkina Faso, Nigeria still does not have a well-developed large-scale mining sector, thus, the majority of gold mining in the country, is carried out by artisanal and small scale miners. ASGM activities in Nigeria are almost informal as they operate outside current laws and regulations. In Nigeria, the booming in gold due to the price increase of gold in recent years has triggered significant growth in small scale mining where mercury in particular and other chemicals used to separate gold from the ore-bearing rock. Emissions and releases from these operations form the buck of mercury release for instance, within the Nigeria environment.

Workers and their families involved in small-scale gold mining are exposed to mercury and other organo-pollutants in several ways including through inhalation during the smelting. Mercury is also being released into river systems from these small-scale operations where it can contaminate fish and the food chain. This problem is likely to continue unabated for some years. Although the mining laws and regulations in Nigeria address ASGM activities, the majority mainly focuses on the provision of extension services. As such, they do not provide meaningful incentives, guidance and assistance for the formalization of ASGM. For instance, there is no requirement or incentives for artisanal miners to form cooperatives — a step that can potentially pave the way for them to receive technical assistance from the Ministry of Mines and Solid Minerals (MMSD). This is an obstacle for many miners. The result is that the majority will continue to operate illegally and unable to seek small-scale mining licenses, which is the only license available to them under the mining act/law [23].

4.2 Gender Impact of Chemicals Exposure via ASGM

Mercury exposure and particularly via ASGM have been shown to affects genders differently [23]. While awareness of the risks associated with mercury and other chemicals, e.g., PCBs and POPs are scarce amongst all miners, sociocultural inequalities particularly hinder access to information for women, often leaving them unaware of the risks they and their children face with repeated chemical exposure. Exposure to mercury for instance, during the amalgamation process poses one of the greatest health threats to women working in ASGM [24-25]. Mercury exposure is generally dangerous for both women and men, however, sociocultural factors often lead to greater exposure for women, whilst they suffer more severe physical harm from such exposure. In a number of countries including Nigeria, mercury amalgamation, and amalgam decomposition, are often carried out by women, putting them in direct contact with mercury. This process can frequently take place in the home, especially in Muslim communities under Sharia law (operational in Northern Nigeria, where women typically stay within their family compounds). Direct open-air burning to separate mercury from the mercury-gold amalgam may also take place in the home or small sheds near the mining site, leading to high exposure to mercury vapors in these enclosed spaces. The amalgamation process is also sometimes carried out with cooking stoves and kitchen utensils, items with which women, as the predominant food providers, frequently come into contact with. In addition, because women are usually responsible for caring for young children and babies, their participation in mining activities is often done while carrying their babies on their backs or toddlers at their sides, exposing their children to the same health hazards.

5. Conclusions

Due to their lipophilicity, chlorinated compounds accumulate in aqueous environment and in fatty tissues of fish and shellfish. The dearth of statistical data relating to chemical management in Nigeria implies that empirical number or percentage remain scare. These lapses notwithstanding, the long-term impacts, adverse effects on human population particularly, aquatic lives and damage to the environment is unarguable, necessitating the need for focused attention on exposures to PCBs and other hazardous chemicals, such as mercury, with actions geared towards containment.

There are some laboratories with analytical capability to conduct residue analysis, identify unknown substances and monitor adverse effects of chemicals on the environment, these are found within the Government Ministries, Industries, Universities, Research Institutes and some private entities. However, Most of the laboratories were set up to perform specific functions and may not be readily available for other tasks. Hence, there is an urgent need to upgrade the existing laboratories with up-to-date technology for monitoring and quality control of imported machineries containing dielectric fluids and chemicals generally into the country, in accordance with respective mandates in Nigeria and international treaties. This contributes to a more effective registration, labelling and disposal of equipment, chemicals products or materials containing PCB thereby helping improve the prospects of better environmental management.

It is imperative therefore that pragmatic approaches to mapping, control, disposal and management of general hazardous chemicals, including inventory, transport and storage, treatment are devised and implemented in Nigeria, urgently. Furthermore, the importance of raising awareness on the environmental and health impacts from chemicals contaminations needs to be heightened. As the appropriate governance structures continue to evolve and the necessary policies, laws and regulations are yet to be fully in place; the *Precautionary Principle* must be applied in this context prior to the build up of acceptable level of scientific evidence necessary for a more accurate risk analysis and evidence-based policymaking on chemicals in Nigeria.

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