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Research Article

Impact of Burnt Brick Production on Soil Physicochemical Properties and Polycyclic Aromatic Hydrocarbons Load in Suburbs of Makurdi, Nigeria

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Abstract— Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds formed during the incomplete combustion of organic materials, such as coal, oil, gas, and biomass. PAHs were investigated in soils of five villages outskirts of Makurdi, known for burnt bricks production (geographical coordinates latitude 7.723^o N – 7.819^o N and longitude 8.663^o E – 8.905^o E, 1-3 km) east of the River Benue, Makurdi, Nigeria. The soil's physicochemical parameters were determined and the soils were extracted using Soxhlet extraction in acetone-hexane 1:1. PAHs were eluted with hexane/dichloromethane (1:1). Some PAHs were identified and quantified using gas chromatograph - mass spectrometer (GC-MS). The results showed the presence of naphthalene, fluorene, 1-methyl- and 2metlyl naphthalene, acenaphthene benzo[*a*]anthracene, benzo[*b*]fluoranthene, Benzo[a]pyrene, phenanthrene, fluoranthene and pyrene in the soil samples of all the five sites considered. Concentrations of PAHs ranged from 0.011 to 60.00 ppb across all sites. The obtained concentrations of PAHs are significant (ANOVA, $p<0.05$) and higher than the threshold limits for a rural and agricultural environment set by USA and Canadian regulations but negligible in the adjourning (control) soil. while traditional methods for producing fired clay products remain popular among many communities living near Makurdi due caution must still be taken when assessing their potential impacts on local environments whilst still allowing people access to necessary construction materials without compromising public health standards as long-term effects may be associated with increased concentrations of PAHs present within affected soils from continued usage.

Keywords— PAHs, Burnt bricks, physicochemical properties, Soil, combustion, Organic materials

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are simply defined as a class of distinctive organic compounds containing two or more fused aromatic rings made up of carbon and hydrogen atoms. PAHs are a subset of a category of chemicals referred to as aromatic hydrocarbons. They are generally produced from incomplete combustion of organic materials, fossil fuels, petroleum product spillage, and various domestic and industrial activities. PAHs are widely dispersed in air, water, soil, and sediment but soil is the most important sink for PAHs in the natural environment due to their hydrophobicity and lipophilicity [1]. Many PAHs are mutagenic, teratogenic, and carcinogenic and due to their potential toxicity concerns have been raised over their occurrence in the environment. Polycyclic aromatic hydrocarbons (PAHs) have been listed as priority pollutants by the European Union and the U.S. Environmental Protection Agency (USEPA). USEPA identified 16 PAHs as priority pollutants, the International Agency for Research on Cancer (IARC) has considered 7 of 16 priority PAHs as probable/possible human carcinogens and they are considered as candidates of persistent organic pollutants (POPs) in the Stockholm Convention on POPs [2], [1], [3]. Among the common PAHs typically analyzed in standard laboratory 18 of them have been listed by the Environmental Protection Agency (EPA) among 129 priority pollutants. A few of them are also listed among the 25 hazardous substances thought to pose the most significant potential threat to human health [4]. PAHs may be divided into two groups, depending on their physical and chemical properties. Low molecular weight (LMW) PAHs, containing four or fewer aromatic rings which include Acenaphthalene, Biphenyl, Naphthalene, 1-methyl naphthalene, 2-methyl naphthalene, and 2,6-dimethyl naphthalene, 3-ring compounds which are: Anthracene, Fluorene, Phenanthrene, and 1-methyl phenanthrene, and 4-ring compounds which are: Benzo(a)anthracene, Fluoranthene, and Pyrene.

High molecular weight PAHs which contain more than four aromatic rings. They include 5-ring compounds such as Chrysene, Benzo(a)pyrene, Benzo(a,h)anthracene, and Perylene. Though the study of PAHs in the environment has attracted the interests of scholars lately, however, there has been less research on the concentration, and distribution of

PAHs in burnt bricks-producing soils, as compared to urban, agricultural soils, and petroleum-contaminated soils, hence the need for this research.

2. Related Work

PAHs are found in air, water soils, and sediments, generally at trace levels except near their sources. PAHs are also present in some foods and in a few pharmaceutical products based on coal tar that is applied to the skin. Tobacco smoke also contains high concentrations of PAHs [2]. PAHs are commonly released to the environment via three major sources/origins: *pyrogenic*, *petrogenic*, and *biogenic* origin. The destructive distillation of coal into coke and coal tar, or the thermal cracking of petroleum residuals into lighter hydrocarbons, the incomplete combustion of motor fuels in cars and trucks, the incomplete combustion of wood in forest fires and fireplaces, and the incomplete combustion of fuel oils in heating systems are pyrolytic processes that generate PAHs. Pyrogenic PAHs are produced at very high temperatures and they are identified with fewer alkylated chains. Sources of *petrogenic* PAHs include oceanic and freshwater oil spills, underground and above-ground storage tank leaks, and the accumulation of vast numbers of small releases of gasoline, motor oil, and related substances associated with transportation. They are formed at lower temperatures as low as (100–150 °C) and consist majorly of 5-membered rings. PAHs can be produced *biogenically*. For example, they can be synthesized by certain plants and bacteria or formed during the degradation of vegetative matter.

When PAHs are deposited onto the earth's surface, they can become mobile. Soil can store approximately 90% of PAHs and the majority of PAHs in the soil will be bound to soil particles [1]. The most important factors influencing PAH mobility of particulate in the subsurface will be sorbent particle size and the pore throat size of the soils. Such pore throat can be defined as the smallest opening found between individual grains of soil. If particles to which PAHs are sorbed cannot move through the soil then the movement of PAHs will be limited because they tend to remain sorbed to particles [2], [5].

PAHs in soils can be carried into surface/ground water through precipitation and surface runoff, emitted into the atmosphere by volatilization, and transported into crops from polluted soil and air via root and leaf adsorption, which may further accumulate in human and other organisms via food chains [2], [3]. The persistence of PAHs in the environment poses a potential threat to human health through bioaccumulation and biomagnifications via food chains. Human exposure to PAHs occurs in three ways, inhalation, chemical contact, and consumption of contaminated foods. Diet is the major source of exposure to PAHs as it accounts for 88 to 90 % of such contamination [6].

A study by Lim et al. [3] showed that the local wood source contributed to 98% of Benzo (a) pyrene emissions in the Stockholm area and 2% from the local traffic. Benzo (a) pyrene and other PAHs are widespread environmental contaminants formed during incomplete combustion or pyrolysis of organic materials.

The study by Tsiodra et al. [7] showed that PAH concentrations are significantly enhanced during the cold period of the year and linked to a multitude of incomplete combustion sources; Fireplace and woodstove usage for domestic heating.

It is well-established that PAHs are carcinogenic, mutagenic, and teratogenic. PAHs have moderate to high acute toxicity to aquatic life and birds. Adverse effects on these organisms include tumors, reproduction malfunctioning, development defects, and immunity deficiency. PAHs are typical pollutants of soil that result in alteration in grain size, porosity, and water-holding capacity of soil and affect the diversity/population of microbes adversely. Significant changes in permeability, volume, plasticity, etc., are also brought about resulting in poor quality of PAHs contaminated soils. PAHs like phenanthrene and pyrene also decrease net photosynthesis. In higher plants, phenanthrene and pyrene exposure caused a decrease in growth, photosynthetic pigment contents, stomatal conductance, maximal quantum yield, effective quantum yield of PSII, and photochemical quenching coefficient. PAHs can enter plants through plant leaves or settle into the soil from the atmosphere, and then migrate, metabolize, and accumulate in plants through plant roots, thereby threatening human health through the food chain. Furthermore, PAHs are known to migrate and transform among different environmental matrices, including those interfacing with food chains, thus affecting both animal and human health [8]. Health risks associated with PAH exposure include respiratory issues, skin conditions, and increased cancer risk. Benz[a]anthracene and other high-molecular-weight PAHs are particularly hazardous. Long-term exposure to these compounds, even at low concentrations, can lead to significant health problems [9]. Monitoring the concentration of PAHs in soils is important for understanding their environmental fate.

The usage of burnt bricks dates back to the Stone Age (2500 BC) as recorded in the Bible story of "The Tower of Babel" in Genesis chapter 11 verse 3 where the people were said to "make bricks and burn them thoroughly [10]. Bricks are used as raw material for the construction of buildings and the raw material for bricks is topsoil that has great value for agricultural crop production [11]. The brick-making process involves digging the soil and gathering them together in the hips. In the evening time water is added to the soil and the soil is mixed with the feet and left over the night to make it more workable. Molding is done the next day and the molded blocks are allowed to dry for 2-3 weeks. The blocks are gathered together and arranged very well with a small space at the bottom where some logs of wood are fixed in for firing and burning as shown in Fig 1.

Fig. 1: Bricks arranged and set for burning

The bricks are covered completely with mold and burning and are done slowly until the bricks become brick-red in color as displayed in Fig. 2[12], [11].

Fig 2: already burnt bricks

Burning of bricks is one of the popular methods of stabilization. The sources of fire for burning the bricks are mostly wood biomass. Wood burning produces smoke during the combustion and compared to other sources of air pollution, wood burning is a particularly large contributor of PAHs to our environment, and because of this "a higher mutagenic and carcinogenic potential" exists for wood smoke compared to other sources [13].

Sarigiannis et al. [14] assessed cancer risk associated with PAH exposure attributed to increased biomass for space heating in Greece and concluded that the actual cancer risk is attributable to PAH on PM emitted from biomass burning.
Aside from PAHs, the brick production process poses other negative effects on the environment such as the production of greenhouse gases, destruction of soil structure, and soil erosion amongst others [12].

Ikpe, [15] worked on the evaluation of how burnt-brick production has impacted the vegetation and potential flood in the Naka urban center. The investigation showed that the repeated cases of flooding in the southern part of Naka in recent years are significantly caused by the continuous soil excavation and expansion of borrow pits to get soil for molding of bricks and he concluded that burnt-brick production has positive building economic benefits but exerts significant adverse effects on the richness of stream ecology, underground organisms and air pollution at the kiln, depleting certain species of trees (vegetation) used for firing the bricks
Agbidye et al. [16] investigated the effect of burnt brick production on soil bacteria and fungi at brick Sites in Benue, Nigeria. They concluded that the firing of bricks in the brick production activity decreased bacteria and total viable counts.
Agera et al. [17] investigated the particulate matter concentration at wood-based burnt brick sites in Benue State. They concluded that the burning of wood contributes to high particulate matter in the environment and coincides with the dry season than in the wet season.

3. Theoretical Framework

Polycyclic aromatic hydrocarbons (PAHs) represent a significant class of organic compounds characterized by two or more fused aromatic rings composed of carbon and hydrogen atoms. They are a subset of aromatic hydrocarbons and are typically generated from the incomplete combustion of organic materials, fossil fuels, petroleum product spillage, and various domestic and industrial activities. PAHs are ubiquitously found in air, water, soil, and sediment, with soil acting as a primary sink due to their hydrophobic and lipophilic properties.

The environmental and health implications of PAHs are profound, given their mutagenic, teratogenic, and carcinogenic properties. This has led to their classification as priority pollutants by both the European Union and the U.S. Environmental Protection Agency (USEPA). Out of the 16 PAHs identified as priority pollutants by the USEPA, the International Agency for Research on Cancer (IARC) has recognized seven as probable or possible human carcinogens. Moreover, PAHs are included as candidates for persistent organic pollutants (POPs) under the Stockholm Convention on POPs. Among the PAHs commonly analyzed in environmental studies, 18 are listed by the EPA as priority pollutants, with some also being included among the 25 hazardous substances that pose the most significant threat to human health.

PAHs can be categorized into two groups based on their molecular weight and the number of aromatic rings. Low molecular weight (LMW) PAHs contain four or fewer aromatic rings and include compounds such as Acenaphthalene, Biphenyl, Naphthalene, and Phenanthrene. High molecular weight (HMW) PAHs contain more than four aromatic rings and include compounds such as Chrysene, Benzo(a)pyrene, and Perylene.

Despite the extensive research on the occurrence and effects of PAHs in various environments, there is a noticeable gap in studies focusing on the concentration and distribution of PAHs in soils associated with burnt brick production. Most existing research has concentrated on urban, agricultural, and petroleum-contaminated soils. The paucity of data on PAHs in burnt brick-producing soils highlights the need for targeted research in this area to understand better the environmental impact and potential health risks associated with PAHs in these specific contexts.

4. Experimental Method/Procedure/Design

4.1 Study Site

Fig 3 shows a map that displays the location of the location of research study area. Five villages were selected along Makurdi-Guma Road starting from Tyo-mu to Agasha which is located in Makurdi-Guma Local Government Area of Benue State North-Central of Nigeria. The geographical coordinates are latitude 7.723^o N – 7.819^o N and longitude 8.663^o E – 8.905^o E, 1-3 km east of the River Benue. The areas experience distinct wet and dry seasons with the mean annual rainfall of about 1100 mm falling between April and October of most years. The mean monthly maximum air temperature is about 32 ^{o}C while the minimum air temperature is 25^{o}C. The area is an extensive floodplain along the river Katsina-Ala bank with a mean width of about 1.2 km. The geomorphology of the area reveals a raised levee just by the river bank which slopes gently southwards into the depression with gilgai formation in some places. This depression forms the lowest portion of the floodplain and seems to run parallel to the river course. The depression rises gently into the undulating plain of the upland.

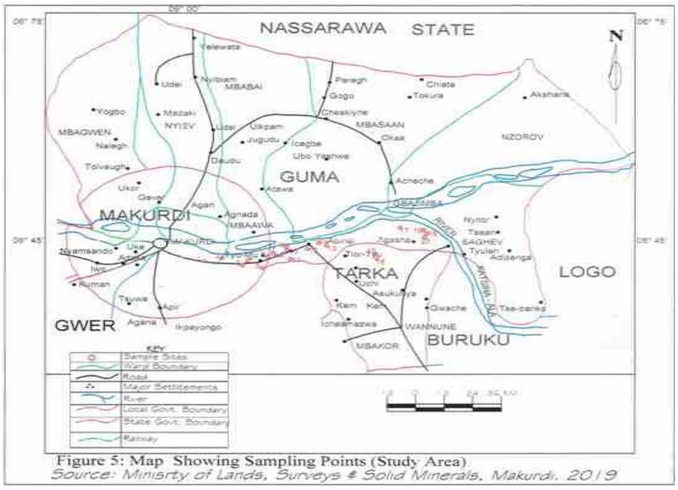

Figure 5: Map Showing Sampling Points (Study Area)
Source: Minisrty of Lands, Surveys & Solid Minerals, Makurdi. 2019

Fig.3. Map of the research study area

These sites were chosen based on their unique activities (burnt brickmaking). The major occupations are farming, fishing, and brickmaking. Rice, maize, cassava, yam, and vegetables (particularly dry season okra) are the major crops of the areas. More than 70% of the working population in the area practice both manual and mechanized agriculture. During the dry season, the youth in the area engage in brick-making business.

4.2 Materials

soxhlet extraction apparatus, oven, rotary vacuum evaporators, aluminum foil, flat plates, a core sampler (20-25 cm), a hand trowel, mortar, sieve (2 mm sieve), amber vials, mixer and reagent bottles (made of glass), analytical weighing balance, global positioning system (GPS), Gas Chromatography-Mass Spectrometry (GC-MS), PAH standard containing 18 PAHs of interest and routine laboratory apparatus. All reagents used in the course of this analysis were of analytical grade (AR).

4.3 Methods

4.3.1 Sample collection and preparation

A total of 20 homogeneously distributed soil samples in Tyo-mu to Agasha and surrogated areas were in February when the brick-making is high with core samples from the soil surface into aluminum foil and transported on ice to the laboratory. The samples were air-dried for 2 weeks, crushed, and sieved with a 2 mm sieve to remove residual roots, grasses, and stones, and then immediately stored at 25^{o}C in pre-cleaned amber glass bottles until further analysis.

4.3.2 Physicochemical analysis

Five physicochemical properties (pH, MC, T, BD, and TOC) of the soil collected from all 20 brick-producing sites were determined. In all cases, the sample from adjourning unaffected agricultural soils was also done as a control experiment and the average was recorded as a control. The physicochemical parameters were investigated according to procedures defined in the Standard Method for soil analysis. The total organic carbon was determined using the methods described by Walkley and Black [18]. The moisture content of the air-dried soil was determined according to Prem [19]. Bulk density was determined following the method adopted by [11]. The temperature of the soil was taken on-site using a 10 cm depth soil thermometer (Mercury-based). The thermometer was dipped into the dug ground and the reading was taken. PH was determined following the SERAS standard operating system using a pH meter, Cole Parmer Digi-sense.

4.3.3 Sample extraction, fractionation, and clean-up

Sample extraction was performed as established in the US EPA Method adopted by Sonja and Angelika [19]. The pretreated soil samples were extracted with dichloromethane using a Soxhlet extractor concentrated and cleaned up using silica gel column chromatography. The soil sample (10 g), was weighed into the extraction thimble followed by the addition of 60 mL dichloromethane. The extraction continued for 2 hours. The extract, concentrated to dryness using a rotary evaporator, was transferred to amber vials and kept in the refrigerator before cleanup. Clean-up **(**purification) of the soil extract was done using silica gel-packed column chromatography and eluted with dichloromethane. The eluate is then put into an amber vial and kept in the refrigerator for further analysis [20].

5. Results and Discussion

5.1 Physicochemical properties

The result of five physicochemical properties of soil from 21 sample sites is presented in Table 1. The value pH of the samples ranged from 4.40 to 6.44 for the brick soils and 7.02 for the control soil. The burnt bricks soils were found to have low pH values indicating that the soils are acidic while that of the control soil was near neutral. This may be due to the burning activities in the production process during brick-making since burning operations decrease the pH of the surrounding soil [21]. All kinds of crops grow well in the pH range of 5.6-7.3 because all types of essential nutrients are available in this range. Therefore, soils from some of the sites in this range are likely to support plant growth. The moisture contents were low ranging from 29.00 – 33.01. The soil moisture content is the quantity of water it contains. The soil moisture content was low compared to that of the control. This is due to the inability of the soil to hold water. The values for total organic carbon from all sites were also low (ranging from 0.1 – 0.35%) compared to that from the control (1.08%) which is considered to be high based on Walkely and Black's (1934) soil organic matter rating. It is well known that soil organic matter is a reservoir for plant nutrients and enhances water holding capacity, protects soil structure against erosion, and compaction, and thus determines soil productivity hence maintenance of organic matter is critical for the prevention of land degradation as observed by Ikpe [15]. One of the importance of organic matter in the soil is due to its capacity to affect plant growth as both a source of energy and a trigger for nutrient availability and water-holding capacity. The low soil organic carbon could be responsible for the low moisture content observed in the brick-making sites. The study sites recorded high soil bulk density as well as high soil temperatures. This finding is in agreement with that of Rajonee and Uddin [11]. Soil bulk density reveals poor soil structure which is unfavorable for plant growth. It is recorded that high-intensity fire results in nutrient volatilization, the breakdown of soil aggregate stability, an increase in soil bulk density, and an increase in hydrophobicity of soil particles leading to water infiltration with increased erosion and destroying soil biota [22].

Table 1: Results for Five Physicochemical properties of soil from 21 sample sites

Samples Site	pH	Moisture Content (%)	Total Organic Carbon (%)	Temperature (℃)	Bulk Density (g/cm^3)
1	5.00	30.20	0.35	29.21	1.52
2	5.20	31.00	0.51	30.16	1.55
3	5.50	32.10	0.32	32.14	1.62
4	6.00	30.00	0.13	32.07	1.73
5	4.40	29.80	0.52	31.78	1.77
6	4.90	29.00	0.27	29.96	1.74
7	5.00	30.10	0.18	31.05	1.69
8	5.10	30.30	0.10	31.02	1.67
9	5.50	31.20	0.31	29.60	1.72
10	5.80	30.89	0.28	29.13	1.74
11	5.60	32.92	0.35	31.23	1.68
12	5.82	33.01	0.23	30.28	1.56
13	5.56	29.10	0.12	29.28	1.54
14	5.86	32.11	0.25	30.65	1.76
15	6.44	31.80	0.16	31.03	1.55
16	5.19	30.61	0.27	30.25	1.75
17	5.78	30.76	0.21	29.27	1.74
18	6.01	30.61	0.30	30.16	1.65
19	6.32	31.90	0.16	30.49	1.59
20	5.89	32.71	0.28	29.19	1.72
Control	7.02	51.21	1.08	27.02	1.28

5.2. PAHs load in the soil samples

The analysis of polycyclic aromatic hydrocarbons (PAHs) in soil samples from burnt brick-making sites on the outskirts of Makurdi, North-Central Nigeria using GC-MS reveals significant insights into environmental contamination. The GC-MS result is shown in Fig 4 and also presented in Table 2. The result indicated the presence of various PAHs including naphthalene, fluorene, 1-methyl- and 2-methyl naphthalene, acenaphthene benzo[*a*]anthracene, benzo[*b*]fluoranthene, Benzo[a]pyrene, phenanthrene, fluoranthene, and pyrene, with concentrations ranging from 0.10 to 60.00ppb.

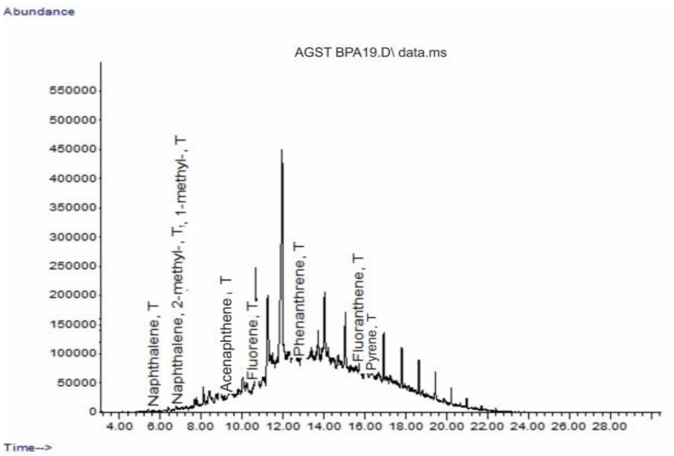

Fig. 4. GC-chromatogram of a brick site soil

There are high concentrations of naphthalene and its derivatives, acenaphthene, fluorene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, Benzo[a]pyrene, phenanthrene, (up to 60.00,31.41, 30.25, 20.11, 9.80, 48.41, 6.45 and 2.45) respectively. These high values of the mentioned PAHs are an indication that they are of pyrogenic origin from biomass burning as studies have shown that the incomplete combustion of organic matter, such as wood used in brick kilns, is a primary source of PAHs [23].

The distribution of PAHs in soil at burnt brick sites indicates significant environmental contamination. This aligns with findings from other regions where brick-making contributes substantially to soil PAH load [24]. Naphthalene (60.00ppb), 2-methyl and 1-methyl naphthalene (31.41ppb), acenaphthene (30.25ppb), and fluorene (20.11ppb) are mid-weight PAHs that serve as markers for related pollution because they are usually produced from incomplete combustion of biomass. Their presence in the soil highlights the direct impact of brick-making activities on soil quality and such contamination can persist for extended periods due to the stability of PAHs in the environment [24]. The persistence of these contaminants poses long-term risks to soil health and can affect local agriculture and water quality. The control of the experiment is shown in Fig. 5.

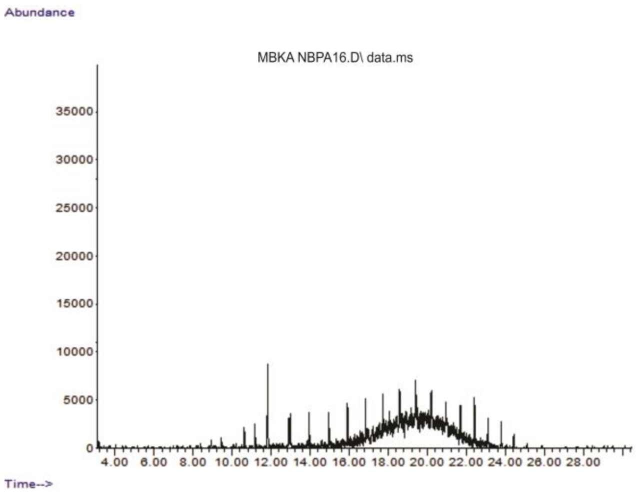

Fig.5. GC- GC-chromatogram of control

The presence of Pyrene (0.61ppb) and Fluoranthene (10.41ppb) in a relatively low quantity in the soil samples suggests that the brick-making sites may also be influenced by other sources of PAHs such as coal tar-based substances and vehicular exhausts. This suggests that the PAHs in soil samples do not come from combustion sources only a small quantity of them comes from petroleum sources [1]. This may be associated with the spent oils used to start or ignite the biomass used for the bricks burning

Table 2: Identified PAHs in the bricks-soil and the various concentrations.

PAH Con (ppb)	Naphthalene	2-methyl-Naph.1-Methyl-	Acenaphthene	fluorene	Phenanthrene	Fluoranthene	pyrene	Benz[a]anthracene	Benzo[b]fluoranthene	Benzo[a]pyrene
1	ND	0.I8	ND	10.00	ND	ND	ND	10.76	ND	ND
2	0.88	0.67	0.62	ND	0.81	ND	ND	3.54	ND	ND
3	10.68	10.06	0.62	ND	0.01	0.81	0.61	6.25	ND	ND
4	0.85	0.82	0.68	0.42	ND	ND	ND	0.02	ND	ND
5	0.85	0.85	0.58	ND	ND	ND	ND	0.10	ND	ND
6	8.25	6.32	0.96	ND	ND	ND	ND	10.04	ND	ND
7	0.19	0.80	2.65	ND	ND	1.02	ND	0.65	ND	ND
8	6.25	0.21	6.33	4.06	0.32	8.95	0.02	4.98	ND	ND
9	0.51	0.62	8.76	0.78	0.50	0.09	ND	10.03	ND	ND
10	0.31	0.22	6.91	0.65	ND	ND	ND	0.32	ND	ND
11	60.00	10.40	30.25	10.08	8.20	10.41	ND	48.41	ND	ND
12	10.32	10.00	0.63	10.77	ND	ND	ND	10.29	ND	ND
13	20.54	20.21	0.88	0.78	ND	ND	ND	21.38	ND	ND
14	17.03	11.90	26.51	20.11	5.28	0.96	0.25	28.33	0.01	0.60
15	9.09	8.02	16.67	9.84	0.57	0.71	0.00	2.16	0.45	ND
16	17.50	4.89	5.72	0.65	0.09	0.31	0.04	0.08	ND	0.01
17	8.45	8.23	5.87	6.51	0.80	0.67	0.43	0.61	0.15	0.72
18	10.00	8.98	2.53	0.04	ND	2.51	0.38	6.95	ND	0.03
19	10.05	10.98	0.86	8.26	0.26	0.65	0.06	0.17	0.04	0.10
20	30.20	31.00	20.25	10.86	9.80	0.78	0.56	0.86	0.05	2.45
control	0.05	0.01	ND	ND	ND	ND	ND	0.01	ND	ND

6. Conclusion and Future Scope

6.1 Conclusion

The traditional production of burnt bricks in the outskirts of Makurdi is highly valuable due to the importance of such bricks for construction and building as well as income generation for the youths involved. Nevertheless, these acts have demonstrated adverse effects on the soils surrounding the production sites This study clearly showed that the brick production degrades the topsoil quality and gradually loses its fitness for agricultural activities. The deposition of killer PAHs in such areas is a great thing of concern as the residents living near brick-making sites may be at elevated risk due to the continuous release of PAHs into the environment.

Strategies such as adopting cleaner brick-making technologies, using alternative fuels, and confinement of production sites should be employed as pollution control strategies as well as agricultural soil conservation. The high concentration of PAHs in soils calls for a need for employment remediation techniques. Phytoremediation and bioremediation are promising methods that utilize plants and microorganisms to degrade PAHs in soil [25]. These approaches, coupled with stricter regulations on industrial emissions, can significantly lower the environmental and health impacts of PAHs. The present study inspires us to create awareness about the degradation and environmental pollution induced by brick production. Also, further research and implementation of effective remediation techniques are crucial to address this issue and ensure a healthier environment for the local community.

6.2 Future Scope

Building upon the findings of this study, several avenues for future research and development emerge. The traditional production of burnt bricks in the outskirts of Makurdi, while economically significant, poses substantial environmental risks, particularly concerning soil degradation and PAH contamination. To mitigate these adverse effects and enhance the sustainability of brick production, the following future research and intervention strategies are proposed:

i. Development and Implementation of Cleaner Technologies: Research should focus on developing and implementing cleaner brick-making technologies that reduce the emission of PAHs. This includes exploring alternative fuels that produce fewer pollutants and designing more efficient kilns.
ii. Alternative Fuel Sources: Investigating and promoting the use of sustainable and cleaner fuel sources for brick production can significantly reduce the release of PAHs and other pollutants. Biomass, natural gas, and other less polluting fuels should be considered.
iii. Confinement and Zoning of Production Sites: There should be strategic planning to confine brick production to specific areas, away from residential and agricultural zones. This can help mitigate the spread of PAHs and protect the health of local communities and the environment.
iv. Soil Remediation Techniques: Further research is necessary to refine and implement effective soil remediation techniques, such as phytoremediation and bioremediation. These methods leverage plants and microorganisms to degrade PAHs in contaminated soils and should be tested for efficacy and feasibility in the context of burnt brick production sites.

v. Regulation and Policy Implementation: Policymakers should enforce stricter regulations on emissions from brick-making industries. Regular monitoring and assessment of soil quality around production sites should be mandated to ensure compliance and safeguard public health.

vi. Awareness and Education: It is crucial to raise awareness among brick producers and the local community about the environmental and health impacts of traditional brick-making practices. Educational programs can promote the adoption of cleaner technologies and sustainable practices.

vii. Long-term Environmental Monitoring: Establishing long-term environmental monitoring programs will help track the effectiveness of implemented remediation and pollution control strategies. Continuous data collection and analysis can inform policy adjustments and technological improvements.

viii. Socio-economic Studies: Future research should also consider the socio-economic aspects of transitioning to cleaner technologies. Understanding the economic implications for local brick producers and providing support for sustainable livelihoods can facilitate the adoption of environmentally friendly practices.

ix. Interdisciplinary Research: Collaboration between environmental scientists, engineers, policymakers, and local communities is essential to address the complex issue of PAH contamination from brick production. Interdisciplinary research can yield innovative solutions and ensure holistic approaches to environmental conservation and public health protection.

By addressing these future research areas, we can develop comprehensive strategies to mitigate the environmental impact of brick production, protect soil health, and safeguard the well-being of local communities. Continued efforts in these directions will contribute to creating a sustainable and healthier environment in Makurdi and similar regions globally.

Data Availability
The data will be available upon request

Conflict of Interest
The authors declare that they do not have any conflict of interest.

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Authors' Contributions
Ogbodo O. Juliana drafted the manuscript. Danduwa Emmanuel conducted the laboratory tests. Egbeneje O. Victor developed the methodology, and Otanwa E. Helen edited the manuscript. All authors approved the final version of the manuscript.

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