PriMera Scientific Surgical
Research and Practice
Volume 5 Issue 5 May 2025
ISSN: 2836-0028

PriMera Scientific Publications

# Characterization of Fly Ash from Biomass Materials (Woods) commonly used for Domestic Cooking in Imo State, South East, Nigeria

**Type:** Research Article
**Received:** February 13, 2025
**Published:** April 28, 2025

**Citation:**
Onwujiariri CE., et al. "Characterization of Fly Ash from Biomass Materials (Woods) commonly used for Domestic Cooking in Imo State, South East, Nigeria". PriMera Scientific Surgical Research and Practice 5.5 (2025): 24-26.



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## Abstract

As a result of high cost of fossil fuel and upsurge use of wood as an alternative source of fuel for domestic cooking and growing concern about the health risk associated with this practice, warranted the combustion and harvest of fly ash from selected fire woods such as African Oil Bean (Ugba), African Velvet Tamarind (Icheku), African Mango (Ugiri), African Pear (Ube), Mango (Mangoro) and African Bread Fruit (Ukwa) commonly used in Oru Community, Ahiazu-Mbaise, Imo State, South East Nigeria. Characterization of their fly ashes was carried out in order to determine the woods that generate lesser pollutants into the atmosphere. The woods fly ash were generated and analyzed for Heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs), Morphology and Mineral contents. Heavy metals (Nickel, Zinc, Chromium, Manganese, Cadmium and Lead) were analyzed using Atomic Absorption Spectrophotometer (AAS), 16-priority PAHs were analyzed using Gas Chromatography-Mass Spectrometer (GC- MS), Minerals were determined using X-ray Diffractometer (XRD) and Scanning Electron Microscope (SEM) was used to determine the morphology of the fly ashes. The results obtained showed low concentrations of heavy metals in the fly ash of the woods, which were below W.H.O permissible limit (2.0mg/kg) except lead (Pb) and zinc (Zinc) that recorded high concentrations in all the fly ashes. PAHs concentrations across the fly ashes recorded an average value range from (0.02 mg/kg - 0.21 mg/kg) which was below USEPA permissible exposure limits (0.02 mg/kg - 0.5 mg/kg). Total PAHs concentrations recorded in woods fly ash were between (0.02 mg/kg and 4.63 mg/kg). Icheku wood fly ash recorded the highest total concentration of PAHs (4.63 mg/kg) while Ube wood fly ash, had the least (0.2 mg/kg). Highly carcinogenic PAHs such as Benzo (b) Fluoranthenene, Benzo (a) Pyrene, Benzo (k) Fluranthene, Chrysene, Dibenzo (G,h) anthracene and Indeno (1,2,3 c-d)were not detected in the woods fly ash. For minerals, mangoro fly ash recorded the most abundant essential mineral (24.97%) phosphorus content while Ugba fly ash recorded the lowest essential mineral (16.21%) sodium content. Aluminum and lithium, which are non- essential mineral elements, were found in the woods fly ash. SEM analysis in the woods fly ash recorded results of the range of particle sizes. Ugba (16 µm - 66 µm), Icheku (16 µm -200 µm) Ugiri (10 µm - 33 µm) Ube (36 µm -76 µm) Mangoro (20 µm - 60 µm) and Ukwa (33 µm - 86 µm). Icheku fly ash recorded the largest particle size range(16 µm - 200 µm) which is above the

USEPA threshold value range (10 μm - 100 μm) for woods fly ash inhalation while Ugiri fly ash recorded the lowest particle size range (10 μm - 33 μm). From the SEM results, constant exposure to the woods fly ash could possibly lead to lungs inflammation and other respiratory diseases especially that of Ugiri wood. The best woods in relation to Heavy metals concentrations, PAHs, Particle sizes and Minerals are Ugba and Mangoro wood and are recommended for wood fuel. Other woods like Ube, Ukwa and Ugiri are also recommended for usage but under strict regulation, while Icheku wood should be rarely used since it contains very high concentrations in all the parameters analyzed in this study.

***Keywords:*** Fly Ash; Biomass (wood); Oru; Ahiazu-Mbaise (Imo State)

## Introduction

Wood is known to be a fibrous structural and porous tissue, found within the roots and stems of trees and other woody plants. It could either be hard or soft wood (Emmons, 2013).

The growing concern about the use of woods as an alternative fuel for cooking as well as the health risk implications associated with its use, led to the combustion of some selected woods harvested from Oru community, Ahiazu Mbaise, Imo State, South East Nigeria for characterization of their fly ashes in order to determine the woods that does not generate high level of contaminants into the atmosphere and thus suitable for use in cooking. Wood has been put into use for several years, such uses includes for fuel, material for construction, tools, weapon making, furniture and paper (DeMiejer et al, 2004). In 1991, harvested woods were meant for furniture making and building construction (Hickey and King, 2001).

The health implication of biomass combustion on household cooking purposes in developing countries shows a very high level of public discomfort of indoor wood combustion annually due in these areas, which includes an approximate number of 1 to 2 million untimely deaths to inveterate obstructive pulmonary disease, tuberculosis, lung cancer and inveterate respiratory diseases (Smith and Liu, 2019).

The health impact of biomass fly ash intake have moreover been recorded in developing nations where women and in some cases, children spend numerous hours cooking over unvented indoor stoves (Griggs et al.., 2016). Studies carried out on biomass combustion products, indicated a continuous relationship between exposure and high level respiratory symptoms, increased risk of respiratory ailment and reduced lung function. These studies have primarily been centered on children, in spite of the fact that the few studies which assessed grown-ups appeared comparative (Rothman et al.., 2015).

Fly ash is a product of wood combustion. It is part of a set of products that makes up the most abundant waste materials worldwide (Pitman, 2006). Fly ash exists after combustion because ash adheres to wood, making up between 1-15 % of its weight. Fly ash is composed of tiny airborne particles and is thus considered to be a type of particulate matter or particle pollution (Sumner, 2010). Broadly speaking, fly ash is a pollutant and it contains acidic, toxic and radioactive matter. This ash contains lead, arsenic, mercury, cadmium and uranium (Fritze, 2001).

Wood contains trace levels of trace elements (such as arsenic, barium, lead, beryllium, boron, cadmium, thallium, selenium, molybdenum and mercury), many of which are highly toxic to humans and other life (Palviainen and Finer, 2012). The effect of fly ash on the environment can vary based on the combustion plant where it is produced as well as the proportion of fly ash to bottom ash in the waste product (Lattimore et al.., 2016).

There were numerous instances examples of high PAH presence in wood fly cinder, published by (Enell et al., 2008). A much reduced PAH content of 2.9ng/g dw, was quantified in bottom ash derived from wood waste and forest reduces, which were burned at temperature between 400 and 500°C (Haglund, 2018).

Wood ash contains most of the minerals that a tree will take up during its lifetime, be it in the farm of bottom or fly ash, but most especially, the fly ash. These comprises of two categories including macronutrients and micronutrients (Okmanis et al, 2016).

According to Jansen (1997), clearly states that, the fly ash content from the Norway Spruce Tree is totally different from other trees in Norway, going by the SEM analysis conducted.

## Materials and Methods

### *Sample Collection and Identification*

Six different plant branches with fresh leaves, flowers and fruits which includes African Oil Bean (Ugba), Black Velvet Tamarind (Icheku), African Mango (Ugiri), African Pear (Ube),

Mango (Mangoro) and African Bread Fruit (Ukwa) were randomly collected from different locations in a particular community called Oru, in Ahiazu Mbaise Local Government Area of Imo State, Nigeria and identified by a Taxonomist; by name, Dr. Ekeke. C, From the Department of Plant Science, University of Port Harcourt, Rivers State, Nigeria. Then, the dry logs of the different plants were later collected from same location and further dried under sun for combustion to generate fly ash.

### *Wood Sample Preparation*

Each of the six different wood samples were collected in dry logs and shredded using a machete, packed into bags, tied, labeled and further air dried.

### *Wood Sample Incineration*

Measured quantity (625g) of each of the shredded wood samples were put into aluminum pot, placed and ignited in the combustion chamber of the fly ash sampler incinerator for burning.

### *Collection of Fly Ash Samples*

After the incineration of each wood, the fly ash was harvested from the fly ash tray above the chimney of the fly ash sampler incinerator, stored dried in the chemistry laboratory for preparation for analysis.

### *Preparation of Fly Ash Samples for Laboratory Analysis*

After collection of fly ash samples, 5g of each sample was weighed from the bulk sample into six separate containers for each of the woods and were sent to laboratories for analysis of listed parameters.

## Results

### *Heavy Metals Concentration in the Woods Fly Ash Samples*

The results of the mean concentrations of heavy metals in the six woods fly ash samples (Ugba, Ugiri, Icheku, Ube, Mangoro and Ukwa) are shown in Table 3.1.

| *Heavy Metals* | *Ugba* | *Ugiri* | *Icheku* | *Ube* | *Mangoro* | *Ukwa* | *W.H.O Limit* |
|---|---|---|---|---|---|---|---|
| Nickel (Ni) | 0.204±0.086 | 0.613±0.508 | 0.613±0.505 | 1.19±0.973 | 0.15±0.039 | 1.596±1.304 | 10mg/kg |
| Zinc (Zn) | 0.912± 0.044 | 1.501±1.227 | 0.533±0.436 | 1.634±0.436 | 2.296±1.875 | 1.988±1.624 | 0.60mg/kg |
| Chromium (Cr) | N.D | N.D | N.D | N.D | N.D | N.D | 1.30mg/kg |
| Manganese (Mn) | 3.606±2.945 | 3.606±2.944 | 5.847±4.774 | 7.506±6.128 | 2.754±2.248 | 2.933±2.395 | 11mg/kg |
| Calmium (Cd) | N.D | N.D | N.D | N.D | N.D | N.D | 0.02mg/kg |
| Lead (Pb) | 3.861±3.158 | 4.797±3.924 | 5.454±4.58 | 4.233±3.457 | 4.107±3.354 | 3.90±3.185 | 2.0mg/kg |
| Total | 8.583±6.233 | 10.517±8.603 | 12.447±10.295 | 15.536±12.079 | 9.307±7.516 | 10.417±8.508 | |

Values are means ± Standard Deviation (S.D) of three replicates, Not Detectable (N.D).

***Table 3.1:*** Concentration of Heavy Metals (mg/kg) in Fly Ash of six Woods commonly used in Oru, Ahiazu Mbaise, Imo State, Nigeria.

### *Polycyclic Aromatic Hydrocarbons (PAHs) Concentrations in the Fly Ashes of the Samples*

The result of PAHs concentrations from the fly ashes of the woods (Ugba, Icheku, Ugiri, Ube, Mangoro and Ukwa) are shown in Table 3.2.

| *PAHs* | *Ugba* | *Icheku* | *Ugiri* | *Ube* | *Mangoro* | *Ukwa* |
|---|---|---|---|---|---|---|
| NaP | N.D | N.D | N.D | N.D | N.D | 0.03 |
| Ace | N.D | N.D | 0.05 | N.D | N.D | 0.07 |
| Can | N.D | N.D | 0.05 | 0.05 | N.D | 0.05 |
| Flo | 0.14 | 0.08 | 0.06 | 0.05 | N.D | 0.02 |
| Ant | 0.21 | 0.07 | 0.03 | 0.04 | 0.04 | 0.03 |
| Phe | 0.13 | 0.11 | 0.03 | 0.06 | 0.16 | 3.25 |
| Flu | N.D | 0.86 | 3.22 | N.D | 2.88 | 0.18 |
| Pyr | N.D | 0.51 | 0.07 | N.D | 0.07 | N.D |
| BaA | N.D | N.D | 0.21 | N.D | 0.09 | N.D |
| Chr | N.D | N.D | N.D | N.D | N.D | N.D |
| Bbf | N.D | N.D | N.D | N.D | N.D | N.D |
| BkF | N.D | N.D | N.D | N.D | N.D | N.D |
| Bap | N.D | N.D | N.D | N.D | N.D | N.D |
| DbA | N.D | N.D | N.D | N.D | N.D | N.D |
| IdP | N.D | N.D | N.D | N.D | N.D | N.D |
| BgP | N.D | N.D | N.D | N.D | N.D | N.D |
| $\sum PAHs$ | 0.48 | 4.63 | 3.68 | 0.20 | 3.24 | 3.63 |

*Note*: ND = Not Detected, Nap = Naphthalene, Ace = Acenaphythylene, Acn = Acenaphthene, Flo = Fluorene, Ant = Anthracene, phe = Phenanthrene, Flu – Fluoranthene, Pyr = Pyrene, BaA = Benz (a) Anthracene, Chr = Chrysene, Bbf = Benzo (b) fluoranthene, BkF = Benzo (k) Fluranthene, Bap = Benzo (a) pyrene, I.dp = Indeno (1, 23 - cd) pyrene, Dba = Dibenzo (G, h) anthracene, Bgp = Benzo (ghi) perylene.

***Table 3.2:*** Concentration of PAHs (mg/kg) in Fly Ashes of the Woods.

### *Mineralogy Analysis of the Fly Ash Samples*

The result of the level of mineral contents in six different woods (Ugba, Icheku, Ugiri, Ube, Mangoro and Ukwa) fly ash is shown in Table 3.3.

| *Elements* | *Ugba* | *Icheku* | *Ugiri* | *Ube* | *Mangoro* | *Ukwa* |
|---|---|---|---|---|---|---|
| Lithium (Li) | 24.48 | 0.16 | 2.05 | | 51.60 | |
| Oxygen (O) | 21.10 | 36.41 | 47.59 | 44.40 | | 47.19 |
| Nitrogen (N) | 19.76 | | | 4.89 | | |
| Silicon (Si) | 16.22 | 31.96 | | 3.89 | | 35.86 |
| Sodium (Na) | 16.21 | | 9.38 | | | |
| Caesium (Cs) | 14.50 | | | | | |
| Germanium (Ge) | 3.96 | | | | | |
| Iron (Fe) | | | | | 0.40 | 14.75 |
| Zinc (Zn) | | | 0.15 | | | 0.64 |
| Terbium (Tb) | | | 0.37 | | | 1.56 |
| Phosphorus (P) | | 13.60 | 14.43 | 11.24 | 24.97 | |
| Aluminum (Al) | | | 12.57 | | 21.75 | |
| Fluorine (F) | | | | | 0.14 | |
| Barium (Ba) | | | | | 0.99 | |
| Cobalt (Co) | | | | 10.28 | | |
| Galium (Ga) | | | | 25.30 | | |
| Thulium (Tm) | | 7.77 | | | | |
| Chlorine (Cl) | | 1.13 | | | | |
| Hydrogen (H) | | 0.19 | | | | |
| Carbon (C) | | 1.13 | | | | |
| Sulphur (S) | | | | | 0.35 | |
| Zirconium (Zr) | | | 13.46 | | | |

***Table 3.3:*** Elemental Composition (%) of the Six Woods Fly Ashes.

### *Scanning Electron Microscope (SEM) Micrograph obtained from the Fly As samples*

The result of SEM shows the shapes and particle sizes of the six fly ash samples.

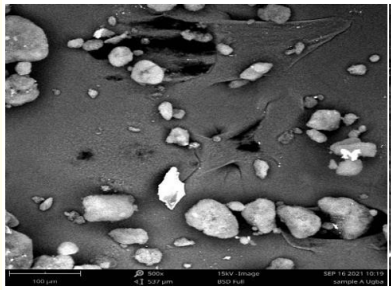

***Figure 3.1:*** Ugba.

***Figure 3.2:*** Icheku.

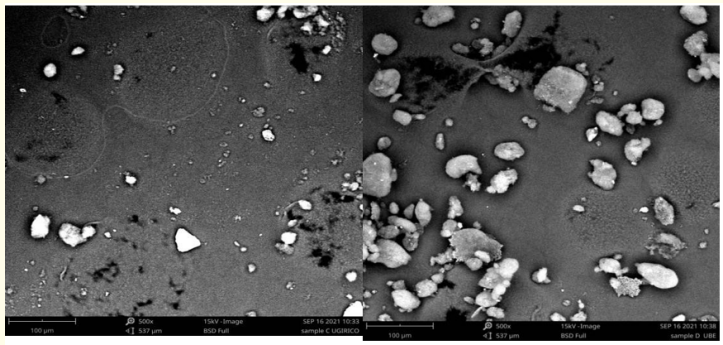

***Figure 3.3:*** Ugiri. ***Figure 3.4:*** Ube.

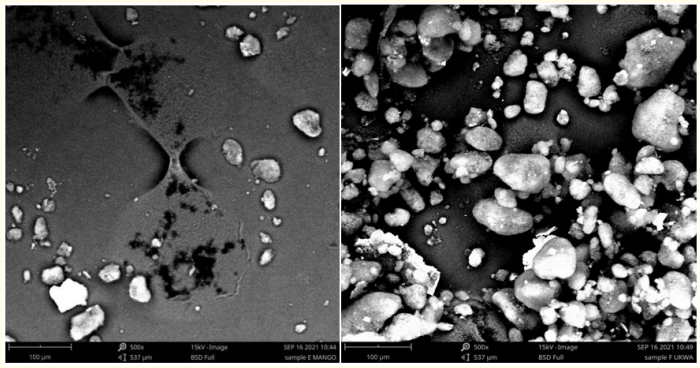

***Figure 3.5:*** Mangoro. ***Figure 3.6:*** Ukwa.

## Discussion

### *Concentration of Heavy Metals in the Woods Fly Ash Samples*

The result in Table 3.1 shows the mean concentrations of heavy metals in the fly ash samples.

The highest concentration of Nickel (Ni) was found in Ukwa wood fly ash (1.596±1.304mg/kg), while the lowest concentration was found in Mangoro wood fly ash (0.15±0.039mg/kg).

The study however, found higher concentration of Zinc (Zn) which falls within the range of 0.533-2.296mg/kg. The highest concentration of Zinc was found in Mangoro wood fly ash sample (2.296±1.875mg/kg), while the lowest concentration was found in Icheku wood fly ash sample (0.533±0.436mg/kg).

Result of Manganese (Mn) on the woods fly ash shows highest concentrations in Ube wood fly ash as (7.506±6.128mg/kg). The result further indicated concentrations on a high scale on Ugba wood fly ash as (3.606±2.945mg/kg) and Ugiri wood fly ash as (3.606±2.944mg/kg).

The highest concentration of Lead (Pb) in the fly ash samples was found in Icheku (5.454±4.58mg/kg), while the lowest concentration was found in Ugba wood fly ash samples (3.861±3.158mg/kg). The lead (pb) content of other woods fly ash samples increased in this order; Ugiri wood fly ash (4.797±3.924mg/kg) > Ube wood fly ash (4.233±3.457mg/kg) > mango fly ash (4.107±3.354mg/kg)>Ukwa wood fly ash (3.90± 3.185mg/kg).

A study by Onwuka (2014), reported concentrations of heavy metals in the fly ash of some woods like Icheku, Ugba and Ukwa, in Owerri municipal, Imo State, Nigeria, with value ranged from (0.201mg/kg - 6.342mg/kg) across the woods, which is below the value range of this study.

***Concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in the Woods Fly Ash Samples***

Table 3.2 shows the results of the concentrations of 16 priority PAHs in six fly ash samples. The result indicated that, Ukwa wood fly ash recorded the highest concentration of individual PAHs (Phenathrene – 3.25mg/kg) while the lowest concentration of individual PAHs was also found in Ukwa (Fluorene – 0.02mg/kg). The highest total PAHs concentrations was recorded in Icheku (4.63mg/kg) while the lowest total PAHs concentrations was recorded in Ube (0.2mg/kg). The total PAHs concentrations of other woods fly ash increased in this order; Ugiri (3.68mg/kg) > Ukwa (3.63mg/kg) > Mangoro (3.24mg/kg) > Ugba (0.48mg/kg).

Udonwu et al. (2011) reported the occurrence of PAHs in some woods fly ash in Abakiliki, Nigeria with average value at 3.26mg/kg, which is above this very study.

Emoyan et al. (2019), worked on the fly ashes of some woods around Imo, Benin and Rivers had value ranges from 1.06 - 3.68mg/kg, which is higher than the value range in this work.

***Mineral Contents in the Woods Fly Ash Samples***

The result of mineralogy analysis in table 3.3 revealed that the fly ash from the woods contained various concentrations of minerals. The major essential minerals found in the woods fly ash were Nitrogen, Phosphorus, Sulphur, Iron, Sodium. Other major elements identified were zinc, caesium, carbon, lithium. In general, the mineral concentrations include Na, P, Zn, Cs of the fly ashes in this study were higher than those reported by (Huang et al., 1992) and lower than those reported by (Etiegni et al., 1991).

***Scanning Electron Microscope (SEM) Micrograph Analysis of the Woods Fly Ash Samples***

From the SEM results, Icheku wood fly ash has the biggest particle size (200μm) among the woods fly ashes. The smallest particle size from the woods fly ash is Ugiri wood fly ash (33μm). Other particle sizes of the fly ashes came in this order; Ukwa (86μm) >Ube (76μm) > Ugba (66μm) > Mangoro (60μm).

A study by Agiriga (2019), showed the SEM images of the fly ashes of some woods collected from Okigwe, Imo State, Nigeria, showed particles within the same size range similar to this study.

## Conclusion

The sole aim of this research work was to investigate the possible risk of heavy metals, PAHs, minerals and particle/ grain sizes of the fly ash in six woods (Ugba, Icheku, Ugiri, Ube, Mangoro and Ukwa) commonly used in Oru Community, Ahiazu Mbaise, Imo State, South East, Nigeria.

The mean and standard deviations of the concentrations of heavy metals in the fly ash samples gave concentrations below W.H.O permissible limits with the exception of lead and zinc which exceeded the permissible limit. However, high concentrations of lead and zinc in the fly ashes for this study and long term exposure can lead to nausea, vomiting and diarrhea.

The concentrations of the sixteen (16) priority Polycyclic Aromatic Hydrocarbons (PAHs) differed in level across the fly ashes. The low molecular weight PAHs like NaP, Ace, Acn, Flo, Ant and Phe dominated the woods fly ash while most of the high molecular weight PAHs like BaA, Chr, BbF, BKF, BaP, DbA, IdP and BgP were not detected. The resulting trend indicates that PAHs that exceeded EPA limit in the woods are capable causing nausea to the immediate users of the woods.

Elemental composition (%) of minerals in the fly ash of the various woods varied across the woods. Lithium had the highest percentage composition and was seen in Mangoro fly ash (51.60%) while the lowest elemental composition was found in Lithium (0.16%) for Icheku wood fly ash. The presence of minerals was more in Ugba and Icheku woods fly ashes, than the rest fly ashes. Essential mineral elements like phosphorus, sulphur, sodium, Iron, Nitrogen and non-essential mineral elements like Lithium and Aluminum were detected.

The result of the SEM images on the woods fly ash showed that, Icheku wood fly ash recorded the biggest particle size of fly ash (200µm), while Ugiri wood ash recorded the smallest particle size of fly ash (33µm). The particle sizes of the woods fly ash followed in the order; Icheku (200µm) >Ukwa (86µm) >Ube (76µm) > Ugba (66µm)> Mangoro (60µm)>Ugiri (33µm). Big sizes of fly ash particles like Icheku and Ugba wood fly ash, when inhaled, can become lodged in the deepest part of the lungs where they trigger asthma, inflammation and possibly lead to death.

The best woods in relation to Heavy metals concentrations, PAHs, Particle sizes and Minerals are Ugba and Mangoro wood and are recommended for wood fuel. Other woods like Ube, Ukwa and Ugiri are also recommended for usage but under strict regulation, while Icheku wood should be rarely used since it contains very high concentrations in all the parameters analyzed in this study.

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