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FACTORS INFLUENCING PERSONAL EXPOSURES TO FINE PARTICULATE MATTER, CARBON MONOXIDE AND URINARY HYDROXY-PAH LEVELS AMONG FEMALE FISH SMOKERS IN SOUTHERN GHANA

BY

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DECLARATION

I, **NANA YAA ASUAMA AFFUL**, do hereby declare that this dissertation is the result of my efforts under able supervision. I take full responsibility for this work. I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgement, the work presented is entirely my own.

………………………………………… 6th October, 2022

NANA YAA ASUAMA AFFUL Date

(Student)

…………………………………………….. 6th October, 2022

DR. REGINALD QUANSAH

(Supervisor)

DEDICATION

This work is dedicated to my family. I am truly grateful for your love and support.

ACKNOWLEDGEMENT

I would like to acknowledge the Almighty God for the strength he provided me during the course of my pursuance of this degree.

Am grateful to my supervisor, Dr Reginald Quansah, Department of Biological Environmental and Occupational Health, for his help and guidance in making this final work a success.

Much appreciation goes to my family for their love and support.

ABSTRACT

Background: Fish smoking is practiced by most households in Ghana but mostly on a large scale by women who live in and around fishing communities as a commercial activity. It is a good source of income for women in most fishing communities. However, this activity poses a great health risk to these women and their entire household due to the smoke emanating from the process. Biomass is the commonest type of fuel used by majority of the fish smokers in Ghana together with the Traditional cook stoves. Biomass as a fuel undergoes incomplete pyrolysis thus leading to the production of smoke rich in Particulate Matter, Carbon monoxide and other harmful air pollutants. Although chronic exposure to smoke has adverse health effects, very few studies have assessed the exposure of smoke produced from Biomass amongst fish smokers. This study seeks to estimate the levels of PM 2.5, CO and urinary PAH as well as factors that influence their levels among female fish smokers in twelve communities in Southern Ghana.

Objective: To determine the levels of fine Particulate Matter ($PM_{2.5}$) Carbon Monoxide (CO), and urine Polycyclic Aromatic Hydrocarbons (PAH) and its metabolites among fish smokers in Southern Ghana and the factors that influence the levels of these pollutants in fish smokers.

Methods: This is a Cross-sectional study which made use of the midline data obtained from the *Invisible Fishers* pilot study. 120 healthy female fish smokers between 15 and 49 years were sampled. The inclusion criteria were; women who were actively involved in fish smoking, not pregnant and women who were willing to remain in the community during the study period. The data used comprises of a background data, urine samples of 119 of the women and data on personal exposures to CO and $PM_{2.5}$ (air quality data). Structured questionnaires were used to collect data on the socioeconomic characteristics of the women and special monitors were used to take the air quality data. Urine samples were also taken from the participants for laboratory analysis for urinary PAH. Means (SD), T-test, pairwise correlations, appropriate transformation and multiple linear regression were done to determine the level of exposures, correlations between the compounds and factors associated with each compound.

Results: The mean of 48-hr levels of $PM_{2.5}$ was 156.95 ppm ± 149.81. The mean of 48-hr levels of CO was 9.25ppm± 10.96. The overall mean level of PAH level was 112.16 µg/l ± 219.16. Methylnaphthalene recorded the highest maximum levels of 815.02 µg/l with a mean of 40.85 µg/l ± 150.80. The mean levels of Hydroxypyrene (PAH metabolite) among fish smokers was 0.55 µg/l ± 0.93. There was a strong positive linear association between the levels of Carbon Monoxide (CO) and $PM_{2.5}$. There was a weak positive correlation between $PM_{2.5}$ and PAHs. Age, Region of residence, oven type, cooking frequency, time spent smoking fish, person who spends most time cooking at home and wealth index were factors that influenced the levels of compounds in the fish smokers.

Conclusion: Positive correlations were found between harmful compounds that emanate from the use of biomass as the primary source of fuel for fish smoking. Home characteristics such as cooking frequency and time spent cooking as well as Work characteristics such as Oven type were predictors of the levels of PAH and its metabolites like Hydroxypyrene, in the fish smokers. There is the need for a collaborative effort between the Ministries of Gender and fisheries to put in place measures to reduce the exposure levels of harmful smoke products to fish smokers. Steps should be taken to design and provide improved locally made ovens for fish smokers and their households.

LIST OF TABLES

LIST OF ABBREVIATION

OH	Hydroxyl
CO	Carbon monoxide
PAHs	Polycyclic Aromatic Hydrocarbons
$PM_{2.5}$	Particulate Matter 2.5µm

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The livelihood of an estimated 700 million people worldwide, more than 10% of the global population, is supported by fisheries and aquaculture. Fish smoking using biomass fuels and other preservation methods represent more than 15% of utilization of world fisheries production (Food and Agricultural Organisation, 2012). Fish smoking is a very popular preservation method of fish after harvest in Ghana mostly among women. Women are referred to as "invisible fishers" of this fisheries economy. These women are seldom directly involved in capturing. However, they dominate other facets of the fishery value chain including purchasing, processing and smoking, and retailing fish (Michael et al., 2019) making them significant actors in the fisheries economy. Yet, female fish smokers have to deal with inequality in terms of the access to social and economic resources (Fröcklin et al., 2013). Also, the biomass fuels they use generates large amounts of particulate matter (PM), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (PAHs) leading to personal exposure to $PM_{2.5}$ (particulate matter with aerodynamic diameter of 2.5 µm or less), CO and other toxins among these women. $PM_{2.5}$ and PAH are amongst the most dangerous constituents in smoke (Elzein et al., 2021; Kongpran et al., 2021). Fish smoking, a common occupation among women residing along the coastal towns of Ghana, has been associated with $PM_{2.5}$ and PAH emissions (Flintwood – Brace, 2016; Motorykin et al., 2015). Meanwhile, $PM_{2.5}$ and PAH, have been linked with increasing risk of chronic obstructive pulmonary disease, lung cancer, acute lower respiratory infections, cardiovascular events, adverse pregnancy outcomes, and all-cause mortality in adults and children (Amegah, Quansah & Jaakkola, 2014; Umoh, 2014**).**

1.2 Problem Statement

In a bid to earn foreign exchange, industrial fish smoking was introduced and is on the increase in recent times using high quality equipment with proper sanitary procedures that produce fish that meets international standards – smoke and PAH free (Asiedu et al., 2018). Notwithstanding, a large chunk of the fish smoked locally is done using traditional methods which exposes the fish smokers to smoke and its associated health hazards (Muntaka, 2020; Asiedu et al., 2018). Global reports show that chronic exposure to these constituent particles result in a number of respiratory and carcinogenic conditions such as chronic obstructive pulmonary disorder and lung cancer (Fuller et al., 2013; Turner et al., 2011; WHO, 2018). Some studies have also documented the occurrence of cardiovascular and ocular diseases, low birth weight and poor haematological indices among fish smokers and in fish smoking communities (Asiedu et al., 2018; Carter et al., 2017; Dadzie et al., 2019; Fuller et al., 2013; Motorykin et al., 2016; Purbayanti et al., 2020). Some new technologies in cook stoves helps reduce the amount of smoke produced during fish smoking (Agyekum, 2020). An example of such is the Ahotor oven.

Exposure assessment as a basis for measuring exposure–response relationships of household air pollution is essential for the formulation and implementation of effective stove-fuel interventions (Peel et al., 2015). There has been limited studies on the exposure to PM2.5 and PAH, among fish smokers. There have also been few studies on factors influencing the levels of PM 2.5 and PAH in fish smokers in Ghana. This study seeks to provide empirical evidence of levels of PM (2.5), CO and PAH as well as factors that influence their levels among fish smokers in southern Ghana.

Additionally, it will inform the introduction of effective interventions to reduce this harmful exposure and improve health among women who smoke fish is likely to increase earning potential of women in this industry and to preserve fisheries value chains in Ghana.

1.3 Research Questions

What factors influence exposure to personal 48-hr fine Particulate Matter ($PM_{2.5}$), Carbon Monoxide (CO) and urine PAH levels in female fish smokers in southern Ghana?

1.4 Objectives of the study

1.4.1 General Objectives

To measure the levels of the48-hr personal $PM_{2.5}$, Carbon Monoxide, urine PAH and their metabolites and establish their determinants in selected fishing communities in Southern Ghana.

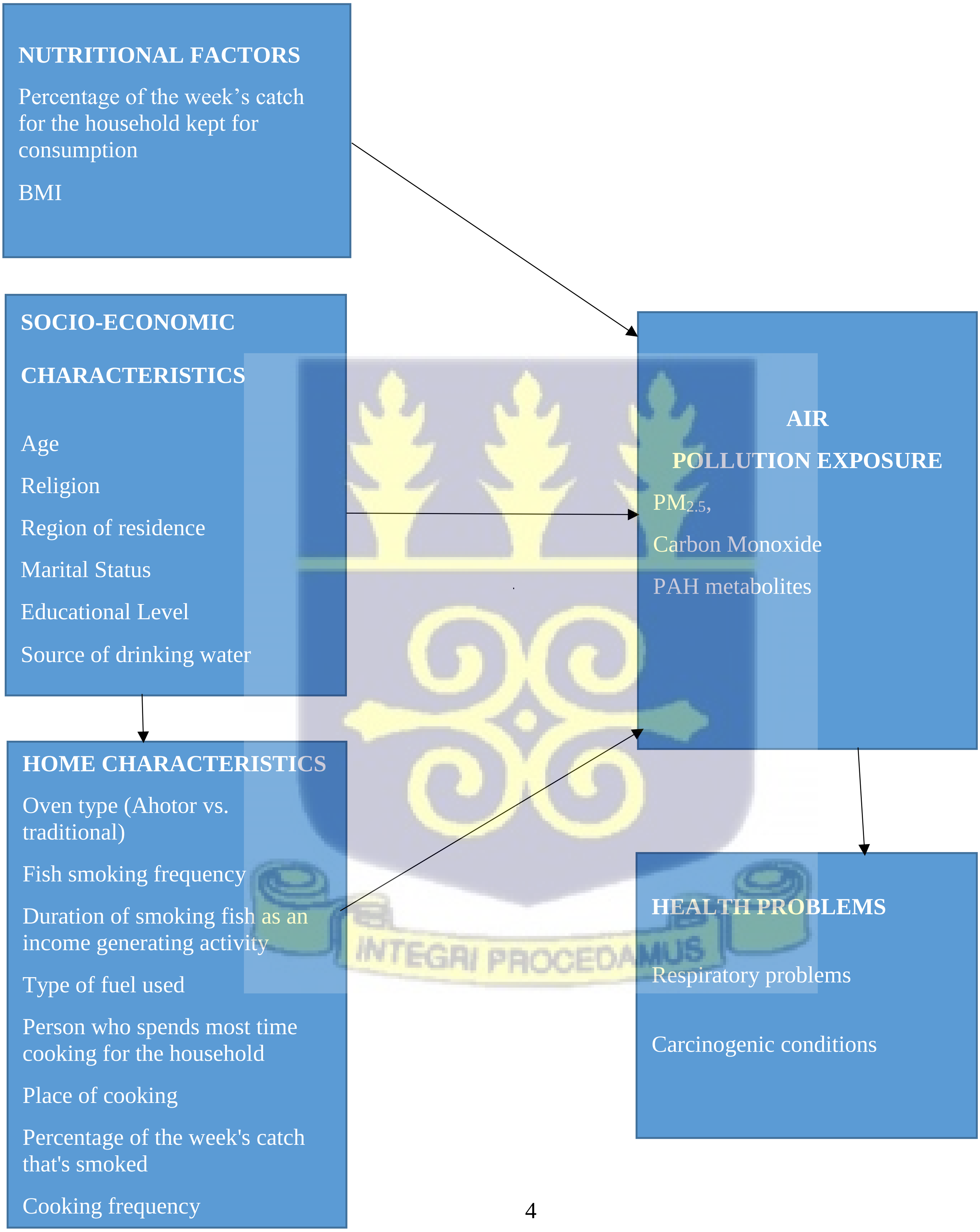
1.4.2 Specific Objectives

1. To measure the levels of $PM_{2.5}$, Carbon Monoxide and urine PAH and their metabolites among the fish smokers.
2. To find the correlation between the levels of $PM_{2.5}$, Carbon Monoxide and urine PAH and their metabolites in the fish smokers.
3. To identify the factors that influence the levels of $PM_{2.5}$, Carbon Monoxide and urine PAH and their metabolites in the fish smokers.

1.5 Justification

The aim of this study was to assess personal exposure to $PM_{2.5}$ and urinary PAH levels among fish smokers in Southern part of Ghana. The study measured the levels of $PM_{2.5}$ and PAH levels in fish smokers during fish-smoking periods. It also exposes factors that influence the levels $PM_{2.5}$, CO and PAH in fish smokers in southern Ghana. Findings from this study may provide information necessary to drive future decision-making concerning fish smoking in Ghana. Based on this study, relevant recommendations were made that when adopted by the appropriate authorities may reduce the dangers fish smokers face in their line of work. The study may also be a valuable addition to literature on fish smoking, $PM_{2.5}$, CO and PAH for future comparative study or new research.

1.6 Conceptual Framework of the Study



1.6.1 Narration of the conceptual Framework

The level of CO, $PM_{2.5}$, and urinary PAH among fish smokers may vary across socio-economic characteristics such as Age, Religion, Region of residence, Marital Status, Educational Level, BMI, Type of Toilet Facility, Wealth Quintile and Source of drinking water.

Besides these socio- economic factors, the determinants of exposure to CO, $PM_{2.5}$, and PAH among fish smokers may be influenced by household characteristics such as Oven type (Ahotor vs. traditional), Fish smoking frequency, Duration of smoking fish as an income generating activity, Type of fuel used, Person who spends most time cooking for the household, Place of cooking, Percentage of the week's catch that is smoked and cooking frequency. The level of emissions of CO, $PM_{2.5}$, and PAH may be less if an improved oven is used by a fish smoker as compared to a traditional oven. The length of time spent cooking and how long one has been involved the fish smoking business may influence the levels of PAH, CO and $PM_{2.5}$ that may be detected in a fish smoker. Biomass fuel is characterised by emission of smoke which emits these compounds. It is more likely for an individual who does their household cooking at the site of commercial fish smoking to have higher levels of the compounds under study due to prolong exposure to sm oke from the biomass fuel at the fish smoking site.

Dietary factors pertaining to percentage of the week's catch for the household that is smoked and kept for consumption may influence the level of exposure to PAH. However, these socio-economic factors, Dietary and household characteristics may confound or modify the effect that each factor especially oven type may have on the exposure to CO and $PM_{2.5}$, as well as the levels of urinary PAH among Fish Smokers.

Chronic exposure to PM 2.5, CO and PAH result in a number of respiratory and carcinogenic conditions such as chronic obstructive pulmonary disorder and lung cancer.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter contains a review of available literature relevant to this study. The chapter discusses and summarizes findings of previous studies based on the subject matter from various settings around the globe.

2.2 Particulate Matter ($PM_{2.5}$)

Particulate matter $_{2.5}$ are extremely dangerous smoke excipients produced during traditional fish smoking (Coulibaly et al., 2021). $PM_{2.5}$ have been linked to respiratory problems including wheezing, breathlessness, phlegm production and chronic cough among fish smokers (Flintwood – Brace, 2016). A cross-sectional study conducted in two towns at the Coastal parts of Ghana to explore differences in $PM_{2.5}$ exposure among women who were fish smokers (cases) and non-fish smokers (controls) (Weyant et al., 2022). Levels of $PM_{2.5}$ in both groups were found to be higher than the World Health Organization safe guideline (10 µg/m^3) though the $PM_{2.5}$ levels in the fish smokers were almost three times higher than that of the controls (Weyant et al., 2022). Air pollution caused by fish smoking was noted as a reason why non-fish smokers also had high $PM_{2.5}$ levels. In their study, high levels of $PM_{2.5}$ found in the fish smokers correlated with the severe respiratory symptoms experienced by the women (Weyant et al., 2022). Similarly, Coulibaly et al. (2021) found high levels of $PM_{2.5}$ in fish smokers and passers-by in urban Abidjan. $PM_{2.5}$ levels were higher than the WHO recommendation and varied slightly among these two groups with the fish smokers recording the highest concentrations (Coulibaly et al., 2021). Likewise, Antwi-Boasiako (2017) found high levels $PM_{2.5}$ three times above international guidelines among fish smokers and non-fish smokers along the coastal belt of Ghana. The study found a correlation between eye symptoms and PM

$_{2.5}$ levels among both groups even though the exposure levels of the fish smokers were higher than that of the non-fish smokers. (Antwi-Boasiako, 2017).

2.3 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are carcinogenic excipients derived from the incomplete combustion of organic materials (Huang et al., 2022). Traditional fish smoking is noted to be a major source of PAHs as the process requires the burning of wood which exposes fish smokers and the general public to PAHs through inhalation of smoke, dermal absorption and ingestion of the smoked fish (Huang et al., 2022; Tongo et al., 2017). Assessment of some smoked fishes commonly eaten (smoked Tilapia, Atlantic mackerel and catfish) across the West African region showed very high levels of PAHs beyond the acceptable range for human consumption (Tongo et al., 2017) – a threat to public health safety. In a Finnish study, the use of an indirect smoker, which employed distance between the fish and the smoke using an external chamber separated from the food revealed lower levels of PAHs compared to the direct smoking method where smoke is generated in the same chamber as the smoked fish (Hokkanen et al., 2018). A study conducted to ascertain the occurrence of PAHs in smoked Pacific mackerel bought from various markets in Ghana showed that the smoked fishes contain twenty different types of PAHs of low, medium and high molecular weight of carcinogenic potentials (Palm et al., 2011). Recent Ghanaian study comparing PAHs levels in fish smoked using the novel FAO-Thiaroye Technique (FTT) and the traditional oven showed PAH levels of 1.8 - 7.6 $\mu g\ kg^{-1}$ and 70 - 395 $\mu g\ kg^{-1}$ respectively (Bomfeh et al., 2019). PAH levels in FTT fishes were below European Union regulatory limits, whereas levels in the traditional oven fishes exceed such limits by up to 33-fold. The use of fire wood significantly increased the PAH levels in the fish compared to the use of charcoal (Bomfeh et al., 2019). In Indonesia, smoked catfish and Eurasian carp fish were analysed to determine changes in nutritional quality and PAHs content using two types of smoking methods – traditional ovens and metallic filter method (Tiwo et al., 2019). The latter requires the use of a metallic filter of 100 µm in diameter which is placed between the oven and the tray containing the fishes, allowing the fishes to be in contact with only the filtered smoke. Nutritional quality specifically protein and carbohydrate contents of the fishes had reduced and increased respectively with both methods while fat content using the traditional oven had increased. PAHs content was higher in fish smoked using traditional ovens compared to using the metallic filter (Tiwo et al., 2019). PAH in the human body is assessed by the use of a human metabolite, urinary 1-hydroxypyerene, found in urine of persons exposed to combustion or air pollution (Fan, 2014). The presence of 1-hydroxypyrene serves as a marker that shows that a person has been exposed to smoke containing PAH. The presence of 1-hydroxypyrene in the urine has been strongly linked with an increased risk of cancer (Fan, 2014).

2.4 Carbon Monoxide

Carbon monoxide is a colourless, odourless and flammable gas that is used in some food processing companies to package can fish and meat products in order to maintain the physical integrity or aesthetics of the fish or meat (Djenane & Roncales, 2018; Marrone et al., 2015). Though useful in some food industries, debates have been raised on the safety of CO since high levels are considered hazardous to workers and consumers (Djenane & Roncales, 2018). Using CO to maintain physical integrity has also been criticized and banned by the European Union over worry it may be used to mask contaminated or spoilt food items (Marrone et al., 2015). Fish smoking is a culprit in the excessive production of CO due to the combustion of fire wood as fuel (Antwi-Boasiako, 2017; Flintwood-Brace, 2016; Weyant et al., 2022). Flintwood-Brace (2016) monitored and measured personal exposures of female fish smokers in the Western Region. In the study, she found that majority of the women (65.57%) were exposed to CO levels above acceptable levels during the process of fish smoking. Along the coastal belt, fish smokers and non-fish smokers were again monitored for exposure to CO levels and found to be exposed to very high levels of CO whether they were engaged in fish smoking or not. Statistically, women who were engaged in fish smoking had higher exposure to CO when compared to the non-fish smokers (Antwi-Boasiako, 2017). Gari processors in Kintampo were also studied for CO exposure due to the use of fire wood in gari processing (Adeshina et al., 2020). During gari processing, the workers were exposed to CO levels ranging from 2.23 ppm - 32.47 ppm while CO levels ranged from 0.03 ppm - 32.48 ppm when they were either asleep or not processing gari (Adeshina et al., 2020). The average CO levels encountered by the workers during or after processing were above WHO safe guidelines posing risk to health. According to the researchers, though the workers knew the dangers in using fire wood, they still preferred to use it due to its cost-effective nature (Adeshina et al., 2020). CO sensors used to collect information on CO levels encountered by fish smokers revealed unacceptable levels of CO near the breathing zone of study participants (Weyant et al., 2022). CO levels were found to be above 2.6 times greater than safe levels. Symptoms experienced by the fish smokers including poor eyesight, headaches, burning eyes, and dizziness were all strongly correlated with CO exposure (Weyant et al., 2022).

2.5 Risk Factors

2.5.1 Duration and Frequency of Exposure

The duration and frequency of fish smoking has also been implicated in the level of hazardous excipients found in the smoked fish and the fish smokers (Flintwood – Brace, 2016; Hokkanen et al., 2018). According to Hokkanen et al. (2018), fish smoking duration and temperature in addition to the type of smoking method used influences the level of PAH formed in the fish. Flintwood – Brace (2016) also noted that majority of fish smokers who spent a median of ten years in the business of fish smoking had an increased risk of respiratory and cardiovascular symptoms. In her study, the average number of hours spent in the smokehouse showed an exposure-response relationship with symptoms of wheezing, breathlessness, chronic cough and phlegm production (Flintwood – Brace, 2016). Among artisanal fish smokers in the Western region, Obeng (2018) also found a strong positive association between the frequency of eye problems reported by the fish smokers and the number of years spent smoking fish

2.5.2 Oven type

The Traditional oven also known as the Chorkor oven has a single combustion chamber with the fish trays loosely placed on it allowing direct contact of the smoke and fish. The direct contact encourages the drippings of the fish unto the fire releasing high levels of PAH. The Chorkor stove is designed to hold a capacity of eight trays (Institute for Industrial Research-CSIR et al., 2016). However, the novel Ahotor oven has two separate combustion chambers which allows for the efficient burning of the wood while producing less smoke. Just as in the traditional oven, a number of wooden trays used to smoke the fish by stacking them on each other except this time the trays are of the exact same sizes to prevent smoke seepages. In order to reduce PAH emissions, a channel is created to collect and eliminate drippings from the fish. This oven holds twenty trays (Institute for Industrial Research- CSIR et al., 2016).

2.5.3 Amount of Smoked Fish Consumed

The amount of smoked fish consumed by fish smokers and general public have been raised as an issue of concern due to the introduction of dangerous smoke excipients into the fish during the process of smoking. Iko Afé et al. (2021) found heavy metals and compounds such as polycyclic aromatic hydrocarbons, heterocyclic amines, and nitrosamines in smoked fish sold in a market in Abidjan. Upon examination, these metals and compounds were found to exceed safe levels for humans – exhibiting risks of toxicity and carcinogenicity (Iko Afé et al., 2021). A Ghanaian comparative study on how exposure to fish smoking and consumption of smoked fish affect anaemia prevalence in fish smokers and non-fish smokers showed that even though fish smokers consumed more fish and other iron containing foods than the non-fish smokers, anaemia prevalence was significantly higher among the fish smokers (Armo-Annor et al., 2021). According to the researchers, the use of firewood for fish smoking may have contributed significantly to an increased risk and prevalence of anaemia among the fish smokers (Armo-Annor et al., 2021).

2.6. Summary

Particulate Matter $_{2.5}$, CO and urine PAH are extremely dangerous smoke excipients produced during traditional fish smoking. PM $_{2.5}$ have been linked to respiratory problems like wheezing and breathlessness among fish smokers (Flintwood – Brace, 2016). CO though useful in some food industries, debates have been raised on the safety of CO since high levels are considered hazardous to workers and consumers (Djenane & Roncales, 2018).

Some factors have been found to influence the extent of exposure to these pollulants. Some of them are; the duration and frequency of fish smoking, type of oven used and the number of fish that is smoked and consumed.

The duration and frequency of fish smoking has been implicated in the level of hazardous excipients found in the smoked fish and the fish smokers (Flintwood – Brace, 2016; Hokkanen et al., 2018). Obeng (2018) found a strong positive association between the frequency of eye problems reported by the fish smokers and the number of years spent smoking fish among artisanal fish smokers in the Western region.

According to the Institute for Industrial Research in 2016, the design of a smoke oven can help reduce the amount of smoke produced from burning wood fuel an example of such oven is the Ahotor oven.

The number of smoked fish consumed by fish smokers and general public have been raised as an issue of concern due to the introduction of dangerous smoke excipients into the fish during the process of smoking. According to the researchers, the use of firewood for fish smoking may have contributed significantly to an increased risk and prevalence of anaemia among the fish smokers (Armo-Annor et al., 2021).

CHAPTER THREE

METHODS

3.1 Study Design

This cross-sectional study was conducted as part of a midline assessment of the Invisible Fishers Pilot (IVF) Project. The IVF Project was conducted by the University of Michigan in collaboration with the University of Ghana and Innovation for Poverty Action-Ghana (IPA). The study was titled "The Invisible Fishers: Empowering and safeguarding women in fisheries value chains in Ghana to reduce anaemia. The main objective of the study was to develop, adopt, and pilot test a set of interventions into fishers' value chains in Ghana in order to mitigate anaemia among women. Three sets of interventions (Treatment arms) were instituted and pilot tested. The first treatment arm was; a multisector behaviour change intervention, focused on promoting anaemia mitigating behaviour. The second treatment arm was; an intervention aimed at strengthening women fish processors' entrepreneurial skills and improving market linkages for their processed fish products. The third and last treatment arm was; an intervention introducing improved fish smoking technology to women fish processors in the first two treatment arms. In the third treatment arm, there was an introduction and promotion of a recently developed fish smoking oven known as the "Ahotor "that was explicitly designed to reduce emissions from biomass fuel combustion, decrease PAH levels of smoked fish and increase fuel efficiency. The focus was to pilot test the promotion, uptake and more importantly the impact of the improved oven among women beneficiaries in the communities. It was from this third treatment arm that data was obtained and used for this cross-sectional study.

3.2 Study Site

The study was between May 2018 and August 2019 in the Volta and Central regions of Ghana. Twelve communities, six from the Volta region and six from the Central region were used for the study. The communities from the Volta region were; Torpor, Dafortornu, Gborfe (Kpando District), Kpevetornu, Fantikorfe, Agordeke (South Dayie District). The six communities in the Central region were Abandze, Nankesedo, Briwa (Mfantseman District), Ammisano, Ekumfi Narkwa, Edumafa (Ekumfi District). These twelve communities have some of similarities some of which are, their strong dependence on local fisheries for livelihoods, the dominance of smoked fish in fisheries value chains and the core relevance of women as active fish processors within the fish processing industry.

Mfantseman Municipal is sited along the Atlantic coastline of the Central Region of Ghana. It stretches approximately 21 kilometres along the coastline and about 13 kilometres inland constituting an area of 300.662 square kilometres. The proportion of land area of the municipality to that of the region is 3.1percent (Ghana Statistical Service, 2021). The municipality has rich fishing grounds along the coast and has made fishing a major activity along the coastal towns and villages notable among which are Biriwa, Anomabo, Abandze, Ankaful and Kormantse.

The Ekumfi District is located along the Atlantic coastline of the Central Region of Ghana. The District is bounded to the West by the Mfantsiman Municipality, to the North by the Ajumako -Enyan–Essiam District, to the East by the Gomoa West District and to the South by the Gulf of Guinea. It occupies a total land area of 276.65 square kilometres or 0.12 percent of Ghana's land area, making it the fifth smallest among the twenty districts in 83 the Central Region. Fishing is a major economic activity carried out by the people, especially along the coastal areas (Ghana Statistical Service, 2021).

The South Dayi District lies within latitudes 3020'N and 3.5005'N and on longitude 0017and 0027'E. It shares boundaries with North Dayi and Afadzato South Districts to the north, Ho West District to the east and Asougyaman District in the south, while the Volta Lake forms the western boundary. The District covers a total land area of358.3square kilometers, which is 1.7 percent of the total land area of the Volta Region with about 20 percent of its land covered by the Volta Lake (Ghana Statistical Service, 2021) Fish farming was introduced in 2006 and has become very popular over the years. Lake fishing accounts for the bulk of fish landed in the district. Fishermen who supply about 20% of the district daily requirement of fish carry out most of the inland fishing in the Volta Lake along the 80km lake shore of the district.

3.3 Study population

Hundred and twenty participants were selected from twelve communities in the Volta and Central regions. The participants were women who were inhabitants of these communities. They were non pregnant women between ages of 15 and 49 and were actively involved in fish smoking.

3.4 Sampling and Sample Size

The Invisible Fishers Project was a pilot study and applied a purposively sampling strategy. This sampling strategy was done to maximize heterogeneity among characteristics that were hypothesized to influence implementation of the interventions, its uptake and its impact on the population. No attempt was made to compute sample size because, the sample size for this study was not intended to be powered to detect statistically significant differences in the primary outcome of interest (IVF Pilot Study, 2019). Thus, a total of 120 healthy female fish smokers were recruited from 12 local communities: 6 in the Volta Region and 6 from the Central Region. 10 participants were then selected from each of the 12 communities.

3.5 Inclusion criteria and exclusion criteria

Participants selected for the study were females from the ages of 15-49 years of age, who were not pregnant, had no intensions of moving from the community during the study period and engaged in fish processing as a primary source of livelihood.

3.6 Data Collection

The purpose of the study as well as the variables being measured were verbally explained to the participants who gave their informed consent either written for the participants who could read and write or verbal for the participants who could not read and write. The data for the study were collected using Structured Questionnaires, Time Activity Dairies, Personal Air Quality monitoring (PM2.5 and CO) and Urine Sample collection. The University of Michigan Health Sciences and Behavioural Sciences Institutional Review Board (HUM00138934) and the University of Ghana Institutional review Board (ECBAS 0033/17-18) gave ethical clearance prior to data collection.

3.6.1 Questionnaire

The Invisible Fishers Project used a Quantitative approach in a form of a field survey with the use of a structured questionnaire. Participants were given pretested household questionnaire by trained enumerators. The questionnaire explored variables which included Socioeconomic characteristics such as Age, Marital status and educational level, Dietary characteristics such as Percentage of week's catch for the household that was kept for consumption and home characteristics such as Fish smoking and cooking frequency, distance of oven from the home and Type of fuel used for Cooking in the home

3.6.2 Time Activity Diary

Participants were each given a Time-Activity Diary for recording their hourly daily activities within the monitoring period. Participants only recorded the first 24 hours of the 48-hour monitoring period. Trained field personnel guided the study participants on how to record their activities in the diary. Also, literate members of the household were also made to guide participants who could not read and write. Trained field personnel were also sent to the various households to observe and record the hourly activities of the study participants. This was done during 4 to 6 hours of the first 24 hours of the monitoring period. The findings of the personnel were corroborated with the activity time diary and were recorded in observation guides. These observation guides included all of the activities recorded in the time-activity diary, allowing for direct comparison and validation of the time-activity data. When a participant engaged in a given activity, the field staff recorded the times at which the participant began and ended that activity. Observation guides also included information about the fish-smoking environment and the number of individuals involved in the fish-smoking activities and their particular roles. The observation guide helped established whether fish smokers adhere to any safety measures and use personal protective equipment and apparels when smoking fish. Place of cooking and person who spends most time cooking were also assessed to see if it had any

.

3.6.3 Personal $PM_{2.5}$ and Carbon Monoxide exposure measurement

For 48 hours, each of the study participant was made to wear a Lascar EL-USB-CO monitor (Lascar Electronics, Erie, PA, USA) and enhanced children's MicroPEM Monitor (ECM) (ECM, RTI International, Raleigh, NC). All monitors were calibrated before use. The Lascar EL-USB-CO was programmed to measure the concentration of CO in parts per million [ppm]) every five minutes. The monitors were secured in a breast pocket of a specially designed apron and were proximate to the breathing space of the participants, this allowed their inhaled CO to be estimated and recorded. Low- cost air quality monitors were mounted in the various smokehouses to measure temperature, CO and $PM_{2.5}$ in the smoke houses for 24 hours. There were constant regular checks on the monitors to ensure that they were always functional.

Demographic data and occupational history were also obtained from the participants using a structured questionnaire.

3.6.4 Urine sample collection

One hundred and nineteen (119) urine samples (60 from Central and 59 from the Volta regions) were collected from fish smokers. The women were given metal free sterile plastic containers. The participants were taught to carefully wash their hands with water and soap before collecting the urine samples. The urine sample was collected midstream to avoid contamination of the sample. The samples were carefully sealed labelled and kept in cold boxes before pickup. 15-20mls of urine was collected from each participant. The storage temperature was 4-8° C (cold boxes with ice packs). The samples were transported to laboratory at the Department of Chemistry at the Cape Coast University for analysis.

3.7 Urine sample preparation

The method that was employed was AOAC method 2007, QUECHERS Q110 En (Restek, www.restek.com). A 4 mL urine sample was pipetted into 10 mL centrifuge tube and 4 mL acetonitrile added followed by adding 1.625g of QUECHERS salt and vortexed for 5 minutes. The resulting mixture was centrifuged for 15 minutes at 3500 rounds per minutes. The supernatant was decanted into another tube containing primary secondary amine (PSA) and MgSO4 for cleaning up and drying respectively. The cleaned-up sample was then centrifuged for 15 minutes at 3500 rpm and collected into 1.5mL glass sample vials for GC-MS analysis (AOAC method 2007). The reagents and standards used were of high purity. The 8270 Mega mix standards (#31850), SV internal standards (6 components; 31206), B/N Surrogates mix (4/89 SOW, #31062) and GCMS tuning mixture (benzidine; DFTPP; 4,4′-DDT and pentachlorophenol, #31615) used were all purchased 90 from Restek. GC grade Hexane (≥ 99.8 %) and dichloromethane (≥99.8 %, # K4799165633) solvents were purchased from Millipore Corporation, Germany; Silica gel (60−120 mesh) was from BDH Chemicals Limited

Poole, England and anhydrous Na2SO4 (99.0 %, #7630-4405), Acetonitrile 99% analytical grade and Acetone 99% analytical grade were purchased from DAEJUNG chemical and metal Co. Ltd. QUECHERS salt containing 1g NaCl, 4g MgSO4, 1g trisodium citrate dihydrate, 0.5g disodium Hydrogencitrate for extraction was also obtained from Restek. QUECHERS pouch containing PSA (primary secondary amine) and magnesium sulphate for clean-up and drying respectively (4mL packed in 10ml centrifuge tube) was obtained from Restek. Preparation of standard and operational conditions for GC-MS Standard solution analytes of 10, 20, 50, 100 500 ppb were prepared from 1000 ppm standard. The Shumazu GC-MS model 2020 was used to analyse the analytes in the urine samples. The EPA method 8270 (SIM) with slight modification to improve selectivity and sensitivity was employed for the GC/MS analysis. A Shimadzu GCMS QP2020 system, equipped with AOC 20i auto injector was used for the analysis. The dimension of capillary column used was 30.0m (length) × 0.25mm (ID) × 0.25 µm (thickness) Rtx-5 ms fused capillary column. Helium (purity: 99.9995) gas was used as the carrier gas. The injection port temperature was set at 265.0 °C and the column oven temperature was initially set at 70.0 °C. Temperature programming was used for GC operations. Here the temperature was initially set at 70 °C and held for 2.0 min. it was then ramp at a rate of 20 °C/min to 90 °C and ramp again at 10 91 °C/min to 250 °C. The temperature was further ramped at 5.0 °C/min to 300 °C and held for 3.0 min. A total program time of 32.00 min was used. The injection volume was 1.0µL. The linear velocity flow control mode was used: the linear velocity was 42.3 cm/sec for a column flow of 1.33 mL/min, and a total flow of 8.7 mL/min.

3.8 Operational Conditions of Mass Spectrometer

The electron impact ionization source was used and quantitative data were collected using Selected Ion Monitoring (SIM) mode with ≥ 2 ions monitored for each compound. The temperatures of the ion source and the interface were set at 230 °C and 280 °C respectively.

3.9 Quality Control

Internal standard quantitative method was employed in this study. A five-point calibration curve for 8270 standards ranging from 0.01 to 0.5 mg/L, for which 50.0 µL of 5.0 mg/L internal standard (ISTD) has been added to each, was used for quantification. Surrogates standards (S) were also added to each standard (0.30–3.0 mg/L of S) and sample to check for method recovery (EPA method 8270). Initial calibration standards (ICVs) at 0.2 mg/L were ran and also CCVs at 0.5 mg/L were also ran to validate the GCMS method for each 10 continuous sample runs. Method reagent blank spiked with ISTD and surrogates were first analysed for each batch of sample analysis. Using the GCMS tuning mixture, manual tuning was conducted for every 12 hours in conformity to criteria for method 8270 E/D. Data obtained from questionnaire was checked in order to correct for discrepancies.

3.10 Study Variables

Dependent variables include 48-hour personal levels of CO, $PM_{2.5}$ and Urinary PAH and OH-PAH (Hydroxypyrene) levels

Independent variables include Socio-economic characteristics such as age , religion, marital Status, language, educational level, weight, height, BMI, type of toilet facility, wealth quantile and source of drinking water; Dietary Factors such as percentage of weeks' catch smoked for the household consumption,; Home characteristics such as cooking frequency, place of cooking, person who spends most time cooking for the household and type of fuel used for cooking at home; Work characteristics such as and percentage of week's catch that is smoked, fish smoking frequency, location of oven in the household, duration of smoking fish as an income generating activity

Treatment (type of oven), fish smoking frequency, cooking frequency, percentage of the week's catch that is smoked, person who spends most time cooking for the household, time spent cooking, time spent smoking fish, duration of smoking fish as an income generating activity, measure put in place to ensure oven is in good condition, measure put in place to reduce fish smokers' exposure to smoke and measure put in place to reduce smoke generated during fish smoking

3.11 Statistical Analysis

Primary objectives of this study are to determine factors associated with personal $PM_{2.5}$ and PAH exposure levels with oven type as the main independent variable (comparing women who use the distinct treatment arm / improved oven ("Ahotor" oven) and women who use the traditional oven (also known as the "Chorkor Oven")). Data analysis was done using the STATA 15. Two sample t-test/ ANOVA was used to test for variance in means of exposure levels in the different treatment arms and across other background variables with statistical significance set at $p < 0.05$. However, emphasis was not placed on the t-test since there were theoretically

actors such as fish smoking frequency, cooking frequency, percentage of the week's catch that's smoked, person who spends most time cooking for the household, time spent cooking, time spent smoking fish, and duration of smoking fish as an income generating activity. Exposures were averaged over the corresponding fish-smoking duration (Primary exposure) and non-fish smoking duration (Secondary exposure). Filter-corrected real-time concentrations were used to evaluate personal exposures to fine particles during fish-smoking. CO, $PM_{2.5}$ and PAH concentrations were tested for normality using Shapiro Wilk's test of normality and skewness and kurtosis test. Appropriate transformation was done if personal exposures to pollutants were skewed (Log transformation for phenols, inverse square transformation for Hydrooxypyrene, square root transformation primary and secondary CO, and primaryPM2.5; inverse cubic transformation secondary $PM_{2.5}$). Transformation was confirmed with quintile-quintile test (Q-Q test). To adjust for other variables, multiple linear regression model was fitted difference in mean exposure level of each pollutant between the treatment arms this was done by applying a forward step-wise regression approach by adding significant covariates and relevant covariates (age of respondents, treatment(type of oven), fish smoking frequency, cooking frequency, percentage of the week's catch that's smoked, wealth quintile, BMI, region, person who spends most time cooking for the household, time spent cooking, time spent smoking fish, duration of smoking fish as an income generating activity, measure put in place to ensure oven is in good condition, measure put in place to reduce fish smokers exposure to smoke and measure put in place to reduce smoke generated during fish smoking) for each normal transformation of the pollutants (p-value < 0.05).

CHAPTER FOUR

4.0 RESULTS

4.1 Individual characteristics of respondents

The mean age of fish smokers in this study was 38.9 years ± 6.7. Christians formed majority of the fish smokers (86.6%). Most fish smokers (71.7%) were married. More than half of the respondents (67.5%) had had formal education as compared to those who have had no formal education (32.5%). More than half of the fish smokers were overweight (54.3%). Less than half (42.5%) of fish smokers have improved toilet facilities. Thirty three percent of fish smokers belonged to the middle wealth index. Nearly ninety three percent (92.7%) of the fish smokers revealed that they do not keep all of the week's catch for household consumption where as 15.9% smoke all of the week's catch. Majority of the respondents (64.2%) cook daily or nearly every day with 29.9% (23/77) using Ahotor ovens and 70.1% (54/77) using traditional ovens. Out of the 120 respondents, 80.8% smoke fish in their households at most 5 times a week. More than half of the respondents (59.2%) have been smoking fish as an income generating activity for at most 15 years. Majority of the fish smokers (80.8%) indicated that they spend most of their time cooking for their households. Also, 58.3% of the fish smokers use LPG as their source of fuel in their households.

Table 4.1: Participants, Work and Household Characteristics (n=120)

	Total	
	n(%)	**Mean (SD)**
Socio-Economic Characteristics		
Age (Mean ± SD)		38.9 ± 6.7
Religion		
Christian	104(86.6)	
Non-Christians	16(13.3)	
Language		
Fante	55(45.8)	
Ewe	48(40.0)	
Ga-Adangbe	17(14.2)	
Marital Status		
Married	86(71.7)	
Non-Married	34(28.3)	
Educational Level		
No formal education	39(32.5)	
Formal education	81(67.5)	
Weight		66.55 ± 13.71
Height		1.59 ± 0.06
BMI		25.97 ± 5.03
BMI		
Underweight	4(3.3)	
Normal	51(42.5)	
Overweight	65(54.2)	
^Type of Toilet Facility		
Improved	51(42.5)	
Not Improved	69(57.5)	
Wealth index		
Lowest	58(48.3)	
Middle	40(33.3)	
Highest	22(18.3)	
***Source of drinking water**		
Improved	81(67.5)	
Non-improved	39(32.5)	
Dietary factors		
Percentage of the week's catch for the household kept for Consumption (n = 69)		
All of the catch	5(7.3)	
Not all of the catch	64(92.7)	

Work Characteristics	
Percentage of the week's catch that's smoked (n = 69)	
All of the catch	11(15.9)
Not all of the catch	58(84.1)
Duration of smoking fish as an income generating activity	
≤ 15 years	71(59.2)
> 15 years	49(40.8)
Fish smoking frequency	
≤ 5 times a week	
daily or nearly every day	
Home characteristics	
Cooking Frequency at home	
≤ 5 times a week	43(35.8)
daily or nearly every day	77(64.2)
Location of oven in household	
On household premises	94(78.3)
Elsewhere in the community	26(21.7)
Place of cooking	
In the house	90(75.0)
Outdoors	30(25.0)
Person who spends most time cooking for the household	
Respondent (index woman)	97(80.8)
Another household member	23(19.2)
Type of fuel used for home cooking	
LPG	70(58.3)
Wood or charcoal	50(41.7)

^Improved toilets are facilities designed to hygienically separate human excreta from human contact and non-improved toilet are facilities which allow some form of contact between human excreta and humans.

*Improved water sources are those that are likely to be protected from outside contamination and from faecal matter in particular. Non-improved water sources are those that are likely to be contaminated from the outside environment.

4.2 Mean levels of PM 2.5, CO, PAH and its metabolites and Hydroxypyrene among fish smokers

The mean of 48-hr level of $PM_{2.5}$ was 156.95 ug/l ± 149.81SD.

The mean of 48-hr exposure to CO is 9.25ppm± 10.96SD.

The Polycyclic Aromatic Hydrocarbons (PAHs) identified among the fish smokers includes; Naphthalene, Acenaphthylene, Flourene, Anthracene, Phenanthrene, Pyrene, Benzo[a]anthracene, Chrysene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Indeno123cdpyrene, Dibenzahanthracene, Benzog[h]iperylene, Methylnaphthalene, 2 – Methylnaphthalene and Chloronaphthalene. Of these, Methylnaphthalene recorded the highest maximum levels of 815.02 µg/l with a mean of 40.85 µg/l ± 150.80SD. The overall mean level of PAH exposure was 112.16 µg/l ± 219.16SD.

The mean level of Hydroxypyrene among fish smokers was 0.55 µg/l ± 0.93SD.

	Min	Max	Mean	SD
Household Pollutants				
Personal 48-hr PM2.5 (ug/l)	2.00	757	156,95	149.81
Personal 48-hr CO (ppm)	<LOD	60	9.26	10.96
PAH exposure (ug/l)				
Naphthalene	<LOD	40.77	2.40	7.40
Acenaphthylene	<LOD	2.88	0.14	0.44
Flourene	<LOD	483.66	12.10	67.61
Anthracene	<LOD	0.45	0.03	0.07
Phenanthrene	<LOD	5.00	0.52	1.51
Pyrene	<LOD	63.65	13.39	25.69
Benza[a]anthracene	<LOD	5.00	1.17	2.10
Chrysene	<LOD	1.15	0.05	0.17
Benzo[b]fluoranthene	<LOD	0.51	0.04	0.12
Benzo[k]fluoranthene	<LOD	0.34	0.02	0.05
Benzo[a]pyrene	<LOD	5.00	1.15	2.10
Indeno[123-cd]pyrene	<LOD	0.32	0.01	0.03
Dibenz[ah]anthracene	<LOD	5.00	0.52	1.52
Benzo[ghi]perylene	<LOD	0.33	0.01	0.04
Methylnaphthalene	<LOD	815.02	40.85	150.80
2 - methylnaphthalene	<LOD	740.55	36.25	123.60
Chloronaphthalene	<LOD	317.66	3.57	29.73
∑ **PAH**	<LOD	996.72	111.61	219.24
Hydroxypyrene	0.25	6.21	0.55	0.93

LOD –LIMIT OF DETECTION

4.3 Correlation between household pollutants among fish smokers

From table 3, there is a strong positive linear association between the levels of Carbon Monoxide (CO) and $PM_{2.5}$ at (r = 0.61). This correlation is statistically significant

There is also a weak positive correlation between the exposure to $PM_{2.5}$ and PAHs (r = 0.26) and this is statistically significant.

Table 4.3 Correlation coefficients between household pollutants among fish smokers

	Carbon Monoxide exposure	$PM_{2.5}$ exposure	Total PAH	OH-PAH METABOLITE
Carbon monoxide exposure		**0.61***	0.02	0.07
$PM_{2.5}$ exposure			**0.26***	0.01
Total PAH				-0.08
OH-PAH METABOLITE				

* Statistically significant ($p \leq 0.05$)

4.4 Factors associated with levels of Carbon Monoxide among fish smokers

A multiple linear regression of factors associated with levels of Carbon Monoxide among fish smokers is illustrated in table 4.4. The model adjusted for age of respondents, treatment(type of oven), fish smoking frequency, cooking frequency, percentage of the week's catch that is smoked, wealth quintile, BMI, region, person who spends most time cooking for the household, time spent cooking, time spent smoking fish, duration of smoking fish as an income generating activity, measure put in place to ensure oven is in good condition, measure put in place to reduce fish smokers exposure to smoke and measure put in place to reduce smoke generated during fish smoking. A one-year increase in the age of fish smokers significantly reduced their exposure to Carbon Monoxide by 0.10ppm (mean diff = - 0.10; 95% CI = - 0.16 - - 0.04; p = 0.002).

Fish smokers in the Volta region had a significant increase in their exposure to primary carbon monoxide by 1.20ppm as compared to fish smokers in the Central region (mean diff = 1.20; 95% CI = 0.27 – 2.13; p = 0.013).

Table 4.4 Factors associated with levels of carbon monoxide among fish smokers

Variables	Adjusted mean difference	95% CI	p-value
Socio Economic Characteristics			
Age of respondents	**-0.10**	**(-0.16 - -0.04)**	**0.002***
Wealth index			
Lowest	0.00		
Middle	0.68	(-0.30 – 1.66)	0.168
Highest	0.44	(-0.77 – 1.64)	0.469
BMI			
Normal	0.00		
Overweight	0.41	(-0.50 - 1.33)	0.364
Region			
Central	0.00		
Volta	**1.20**	**(0.27 – 2.13)**	**0.013***
Home Characteristics			
Cooking frequency			
≤ 5 times a week	0.00		

daily or nearly every day	0.15	(-0.75 – 1.05)	0.737
Person who spends most time cooking for the household			
Another household member	0.00		
Respondent (index woman)	0.54	(-0.28 – 1.36)	0.189
Work Characteristics			
Fish smoking frequency			
≤ 5 times a week	0.00		
daily or nearly every day	-0.12	(-1.17 – 0.94)	0.821
Oven type			
Traditional oven	0.00		
Ahotor oven	-0.90	(-1.94 – 0.14)	0.089
Time spent cooking	-0.15	(-0.65 – 0.36)	0.557
Time spent smoking fish	-0.26	(-0.92 – 0.39)	0.421
Duration of smoking fish as an income generating activity	0.57	(-0.29 – 1.43)	0.187
Measure put in place to ensure oven is in good condition			
No	0.00		
Yes	-1.43	(-3.15 – 0.30)	0.103
Measure put in place to reduce fish smokers' exposure to smoke			
No	0.00		
Yes	-0.42	(-2.29 – 1.45)	0.654
Measure put in place to reduce smoke generated during fish smoking			
No	0.00		
Yes	0.46	(-1.13 – 2.05)	0.561
Dietary characteristics			
Percentage of the week's catch that's smoked			
All of the catch	0.00		
Not all of the catch	0.10	(-1.38 - 1.59)	0.890

*(statistically significant, p≤0.05)

4.5 Factors associated with levels of $PM_{2.5}$ exposure among fish smokers

As shown in table 4.5, fish smokers who use the Ahotor oven had significantly lower exposure to $PM_{2.5}$ as compared to fish smokers who use the traditional ovens (mean diff = - 4.03; 95% CI = - 7.02 - - 1.04; p = 0.009).

Table 4.5 Factors associated with levels of $PM_{2.5}$ among fish smokers

Variables	Adjusted mean difference	95% CI	p-value
Socioeconomic Characteristics			
Age of Respondents			
Wealth index			
Lowest	0.00		
Middle	1.67	(-1.39 – 4.73)	0.279
Highest	0.28	(-4.51 – 5.06)	0.908
BMI			
Normal	0.00		
Overweight	-0.56	(-3.50 – 2.37)	0.702
Region			
Central	0.00		
Volta	2.52	(-0.31 – 5.35)	0.080
Home Characteristics			
Cooking frequency			
≤ 5 times a week	0.00		
Daily or nearly every day	-0.24	(-4.05 – 3.57)	0.900
Person who spends most time cooking for the household			
Another household member	0.00		
Respondent (index woman)	2.38	(-1.53 – 6.29)	0.227
Time spent cooking	-0.04	(-1.92 – 1.84)	0.966
Work Characteristics			
Oven type			
Traditional oven	0.00		
Ahotor oven	**-4.03**	**(-7.02 - 1.04)**	**0.009***
Fish smoking frequency			
≤ 5 times a week			
Daily or nearly every day			
Time spent smoking fish	-0.01	(-2.44 – 2.44)	0.997
Duration of smoking fish as an income generating activity	2.49	(-0.42 – 5.41)	0.092
Measure put in place to ensure oven is in good condition			
No	1.00		
Yes	-3.46	(-8.45 – 1.53)	0.170
Measure put in place to reduce fish smokers' exposure to smoke			
No	1.00		
Yes	1.91	(-4.52 – 8.34)	0.553
Measure put in place to reduce smoke generated during fish smoking			
No	1.00		

Yes	-1.58	(-9.67 – 6.50)	0.696
Dietary Characteristics			
Percentage of the week's catch that's smoked			
All of the catch	1.00		
Not all of the catch	-0.11	(-5.63 – 5.42)	0.969

*(statistically significant, p≤0.05)

4.6 Factors associated with levels of PAH among fish smokers

From table 4.6, a one-year increase in the age of fish smokers significantly reduced their exposure to PAH by 8.24 (mean diff = - 8.24; 95% CI = - 14.53 - - 1.95; p = 0.011).

Fish smokers in the middle wealth index had significantly reduced exposure to PAH as compared to those in the lowest index of wealth (mean diff = -93.05; 95% CI = -177.99 - - 8.41; p = 0.032).

Respondents in the Volta region had a significantly higher exposure risk to PAHs when smoking fish as compared to those from the Central region (mean diff = 126.53; 95% CI = 14.66 – 238.40; p = 0.027).

Cooking daily or nearly every day significantly increased fish smoker's exposure to PAHs as compared to those whose cooking frequency was at most 5 times a week (mean diff = 139.65; 95% CI = 16.99 – 262.32; p = 0.027).

Fish smokers who spent of their time cooking for their household had a significantly lower exposure to PAHs compared to other household members who spend most of their time cooking for the household (mean diff = -186.63; 95% CI = -295.33 - - 77.94; p = 0.001).

Furthermore, an hour increase in time spent smoking fish resulted in a significant increase in exposure to PAHs among fish smokers (mean diff = 100.65; 95% CI = 8.08 – 193.23; p = 0.034).

Table 4.6 Factors associated with levels of PAH among fish smokers

Variables	Adjusted mean difference	95% CI	p-value
Socioeconomic Characteristics			
Age of Respondents			
Wealth Index			
Lowest	0.00		
Middle	**-93.05**	**(-177.69 - -8.41)**	**0.032***
Highest	-36.16	(-136.84 – 64.53)	0.474
BMI			
Normal	0.00		
Overweight	8.00	(-88.66 – 104.66)	0.869
Region			
Central	0.00		
Volta	**126.53**	**(14.66 – 238.40)**	**0.027***
Home Characteristics			
Cooking frequency			
≤ 5 times a week	0.00		
Daily or nearly every day	**139.65**	**(16.99 – 262.32)**	**0.027***
Person who spends most time cooking for the household			
Another household member	0.00		
Respondent (index woman)	**-186.63**	**(-295.33 - -77.94)**	**0.001***
Time spent cooking	-56.93	(-117.85 – 3.99)	0.066
Work Characteristics			
Fish smoking frequency			
≤ 5 times a week	0.00		
Daily or nearly every day	2.56	(-105.13 – 110.25)	0.962
Oven type			
Traditional oven	0.00		
Ahotor oven	-56.77	(-169.58 – 56.05)	0.317
Time spent smoking fish	**100.65**	**(8.08 – 193.23)**	**0.034***
Duration of smoking fish as an income generating activity	71.49	(-39.48 – 182.48)	0.201
Measure put in place to ensure oven is in good condition			
No	0.00		
Yes	-90.95	(-226.78 – 44.87)	0.184

Measure put in place to reduce fish smokers' exposure to smoke			
No	0.00		
Yes	-2.75	(-158.26 – 152.77)	0.972
Measure put in place to reduce smoke generated during fish smoking			
No	0.00		
Yes	120.53	(-69.67 – 310.73)	0.209
Dietary Characteristics			
Percentage of the week's catch that's smoked			
All of the catch	0.00		
Not all	82.98	(-63.45 – 229.42)	0.260

*(statistically significant, p≤0.05)

4.7 Factors associated with levels of Hydroxypyrene (PAH Metabolite) among fish smokers

Fish smokers in the highest wealth index had significantly reduced exposure to OH-PAH metabolite as compared to those in the lowest quintile of wealth (mean diff = -0.92; 95% CI = -1.76 - - 0.80; p = 0.032) as shown in table 4.7.

The likelihood of being exposed to OH-PAH metabolite was significantly lower among fish smokers using Ahotor ovens compared to fish smokers using traditional stoves (mean diff = 0.84; 95% CI = 0.33 – 1.36; p = 0.002).

Table 4.7 Factors associated with levels of Hydroxypyrenee (PAH Metabolite) among fish smokers

Variables	Adjusted mean difference	95% CI	p-value
Socioeconomic Characteristics			
Age of respondents	0.01	(-0.04 – 0.06)	0.672
Wealth index			
Lowest	0.00		
Middle	0.14	(-0.51 – 0.79)	0.669
Highest	**-0.92**	**(-1.76 - - 0.80)**	**0.032***

BMI			
Normal	0.00		
Overweight	0.15	(-0.42 – 0.72)	0.599
Region			
Central	0.00		
Volta	0.37	(-0.30 – 1.03)	0.270
Home Characteristics			
Cooking frequency			
≤ 5 times a week	0.00		
Daily or nearly every day	-0.38	(-0.91 – 0.15)	0.152
Person who spends most time cooking for the household			
Another household member	0.00		
Respondent (index woman)	0.47	(-0.20 – 1.44)	0.166
Time spent cooking	-0.01	(-0.35 – 0.34)	0.975
Work Characteristics			
Oven type			
Traditional oven	0.00		
Ahotor oven	0.84	**(0.33 – 1.36)**	**0.002***
Fish smoking frequency			
≤ 5 times a week	0.00		
Daily or nearly every day	-0.04	(-0.74 – 0.66)	0.907
Time spent smoking fish	-0.05	(-0.71 – 0.62)	0.884
Duration of smoking fish as an income generating activity	-0.02	(-0.61 – 0.57)	0.953
Measure put in place to ensure oven is in good condition			
No	0.00		
Yes	0.39	(-0.24 – 1.03)	0.214
Measure put in place to reduce fish smokers' exposure to smoke			
No	0.00		
Yes	0.24	(-0.71 – 1.18)	0.615
Measure put in place to reduce smoke generated during fish smoking			
No	0.00		
Yes	-0.68	(-1.68 – 0.31)	0.173
Dietary characteristics			
Percentage of the week's catch that's smoked			
All of the catch	0.00		
Not all	-0.37	(-1.38 – 0.65)	0.473

*(statistically significant, p≤0.05)

CHAPTER FIVE

5.0 DISCUSSION

The mean of 48-hr level of $PM_{2.5}$ was 156.95 ug/l ± 149.81SD. The mean of 48-hr level of CO is 9.25ppm± 10.96SD. The overall mean level of PAH exposure was 112.16 µg/l ± 219.16SD. Of the various PAHs measured, Methylnaphthalene recorded the highest maximum levels of 815.02 µg/l with a mean of 40.85 µg/l ± 150.80SD. The mean level of Hydroxypyrene (OH-PAH metabolite) among fish smokers was 0.55 µg/l ± 0.93SD

Ahotor oven was found to reduce the levels of exposure to OH-PAH metabolite among fish smokers. Also, fish smokers in the fourth quintile of wealth had significantly reduced exposure to OH-PAH metabolite as compared to those in the lowest quintile of wealth

There was a strong positive linear association between the levels of Carbon Monoxide and $PM_{2.5}$ levels. Also, a weak positive correlation between the levels of $PM_{2.5}$ and PAHs and these were statistically significant.

Increase in age of fish smokers was found to significantly reduce their levels of Carbon Monoxide. Fish smokers in the Volta region had a significant increase in their exposure to Carbon Monoxide as compared to fish smokers in the Central region.

Fish smokers who use the Ahotor oven had significantly lower exposure to $PM_{2.5}$ as compared to fish smokers who use the Traditional ovens. Fish smokers who cooked daily or nearly every day had a significantly higher exposure to PAHs as compared to those whose cooking frequency was at most 5 times a week.

Being in the Volta region significantly increased the levels of PAHs as compared to those from the Central region. An hour increase in time spent smoking fish resulted in a significant increase in exposure to PAHs among fish smokers.

Fish smokers who spent less of their time cooking for their household had a significantly lower exposure to PAHs compared to other household members who spend most of their time cooking for the household. The cooking frequency was a significant predictor of exposure to PAHs. Fish smokers who cooked daily or nearly every day had significantly higher exposure to PAHs as compared to fish smokers whose cooking frequency was at most 5 times a week. Fish smokers in the middle wealth index had significantly reduced exposure to PAH as compared to those in the lowest index of wealth (mean diff = -93.05; 95% CI = -177.99 - -8.41; p = 0.032).

5.1 Mean Levels of $PM_{2.5}$, Carbon Monoxide and PAH's among the Fish Smokers

Among fish smokers who use the Ahotor oven, the mean 24-hr levels of $PM_{2.5}$ was 108.73 ppm ± 97.16 whilst those who used traditional ovens had a mean 24-hr levels of $PM_{2.5}$ of 181.37 ppm ± 165.64. The difference in exposure levels implies that, there is a lower exposure to PM2.5 when using the Ahotor oven. The mean of 24-hr levels of CO was 9.25ppm± 10.96 among fish smokers who use the traditional oven whereas there was a mean level of 7.28ppm ± 9.34 24-hr Carbon Monoxide level among users of the Ahotor ovens. The overall mean level of PAH was 112.16 µg/l ± 219.16. Of the various PAHs measured, Methylnaphthalene recorded the highest maximum levels of 815.02 µg/l with a mean of 40.85 µg/l ± 150.80. The mean OH-PAH metabolite level among fish smokers was 0.55 µg/l ± 0.93. For fish smokers who use the traditional oven, the mean Hydroxypyrene level was 0.68 ± 1.12 whilst the mean Hydroxypyrene lrvel for the Ahotor oven was 0.29 µg/l ± 0.03SD. This finding supports claims that women who use the novel Ahotor oven suffer a lower exposure to PAH as compared to the users of the traditional oven (Institute for Industrial Research- CSIR et al., 2016; Seyram, 2020). Similarly, Bomfeh et al. (2019) comparing PAHs levels using the novel FAO-Thiaroye Technique (FTT) and the traditional oven found PAH levels in FTT fishes to be below European Union regulatory limits, whereas levels from the traditional oven exceeded limits by up to 33-fold (Bomfeh et al., 2019). In Finland, lower levels of PAHs were generated by an indirect fish smoking method compared to the traditional direct smoking method (Hokkanen et al., 2018).

5.2 Correlation between the Various Compounds in the Fish Smokers

Analysis showed a strong positive linear association between the levels of Carbon Monoxide and $PM_{2.5}$ exposures. However, Klasen et al. (2015) described the relationship between $PM_{2.5}$ and CO concentrations in 128 households in Peru, Nepal, and Kenya as low to moderate (0.59 - 0.83). They stated that the weak correlation may be setting (structure, stove and fuel) specific as settings with low concentrations are likely to depict weak correlations and vice versa (Klasen et al., 2015). Previous study among households in Guatamala also noted that in settings where there is excessive burning of biofuel, stronger correlations can be found between CO and $PM_{2.5}$ (McCracken et al., 2013).

In this same study, there was a weak positive correlation between $PM_{2.5}$ and PAHs. These positive correlations are suggestive of the fact that any intervention to reduce exposure levels of a particular pollutant may likely reduce exposure other pollutants that they have a linear association with. Further studies on the correlation between such pollutants should be carried out to establish stronger linear association to inform intervention that will curb emission and/or exposure to such pollutants among fish smokers

5.3 Factors that Influence the Levels of the Compounds in the Fish Smokers

A one-year increase in the age of fish smokers significantly reduced their levels of Carbon Monoxide by 0.10ppm and PAH by 8.24. Also, fish smokers in the Middle Wealth Index had significantly reduced exposure to PAH as compared to those in the lowest wealth index while fish smokers in the Highest Wealth Index had significantly reduced levels of OH-PAH metabolite as compared to those in the Lowest Wealth Index. As fish smokers age or accrue wealth, they are most likely to assume supervisory roles in the business of fish smoking. These supervisory roles may lead to a reduction in time spent in the smokehouses since they may not be directly involved in smoking fish thereby reducing their exposure to the various compounds (Hokkanen et al., 2018).

Fish smokers in the Volta region had a significant increase in their exposure to Carbon Monoxide by 1.22ppm as compared to fish smokers in the Central region. Respondents in the Volta region had a significantly higher exposure risk to PAHs when smoking fish as compared to those from the Central region. A study by Dobraca et al. (2018) among girls in Northern California also noted region of residence as a significant factor in PAH concentrations. They stated that for all metabolites of PAH except 2-naphthol, being resident in San Francisco was associated with higher exposures, while being resident in Marin was associated with lower exposure. They noted the difference in exposures to be due to the more urban nature of San Francisco along with its heavy population, numerous buildings, high traffic emissions and the oldest homes as compared to Marin (Dobraca et al., 2018). Hence, a difference in geographic location, urban and commercial activity may be responsible for the difference in CO and PAH exposure risks in the Volta and Central Regions.

The cooking frequency was a significant predictor of exposure to PAHs. Fish smokers who cooked daily or nearly every day had significantly higher exposure to PAHs as compared to fish smokers whose cooking frequency was at most 5 times a week. Also, an hour increase in time spent smoking fish resulted in a significant increase in exposure to PAHs among fish smokers. Time spent smoking fish in addition to the type of smoking method used influences the PAH exposure (Hokkanen et al., 2018). An exposure-response relationship was also noted such that spending long hours smoking fish was synonymous with respiratory problems such as wheezing, breathlessness, chronic cough and phlegm production (Flintwood – Brace, 2016) as well as eye problems (Obeng et al., 2018). Fish smokers who spent of their time cooking for their household had a significantly lower exposure to PAHs compared to other household members who spend most of their time cooking for the household. Considering the earlier result concerning frequency and exposure, one would expect that the fish smokers would record higher exposure compared to the household cooks. In spite of the discordance, Lee et al. (2019) also notes that household cooks who are not fish smokers may experience higher levels of exposure than normal from cooking due to the fact that fish smoking pollutes the immediate environment increasing the baseline exposure of non-fish smokers

5.4 Strengths & Limitation

The association found in this study cannot be deemed as causal since it is a cross sectional study design. Purposive sampling which is a non-probability sampling technique was used in this study thus making it difficult to know how well the population is being represented. However, majority of the women in the selected communities were engaged in fish smoking thus it is safe to assume a fair representation of the population. Dietary characteristics such as number of fish smoked for household use may not be enough to predict levels of PAH as there may be other meals other than fish which are also smoked for home consumption. Generalizing findings may be a limitation due to the sample size. However, the study employed robust quantitative analytical techniques such as Multiple Linear Regression to determine factors that influence the exposure levels of CO, PM 2.5 and PAH among fish smokers.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The mean of 48-hr level of $PM_{2.5}$ was 156.95 ug/l ± 149.81SD.The mean of 48-hr level of CO is 9.25ppm± 10.96SD. The overall mean level of PAH exposure was 112.16 µg/l ± 219.16SD. The mean level of Hydroxypyrene (OH-PAH metabolite) among fish smokers was 0.55 µg/l ± 0.93SD

There was a strong positive linear association between the levels of Carbon Monoxide and $PM_{2.5}$ exposures.There was a weak positive significant correlation between secondary CO exposure and Hydroxypyrene (OH-PAH metabolite). Also, a weak positive correlation between the exposure to $PM_{2.5}$ and PAHs and these were is statistically significant.

Increase in age of fish smokers was found to significantly reduce their levels of Carbon Monoxide. Fish smokers in the Volta region had a significant increase in their exposure to Carbon Monoxide as compared to fish smokers in the Central region.

Fish smokers who use the Ahotor oven had significantly lower exposure to $PM_{2.5}$ as compared to fish smokers who use the Traditional ovens. Fish smokers who cooked daily or nearly every day had a significantly higher exposure to PAHs as compared to those whose cooking frequency was at most 5 times a week.

Being in the Volta region significantly increased the levels of PAHs as compared to those from the Central region. An hour increase in time spent smoking fish resulted in a significant increase in exposure to PAHs among fish smokers.

Fish smokers who spent less of their time cooking for their household had a significantly lower exposure to PAHs compared to other household members who spend most of their time cooking for the household. The cooking frequency was a significant predictor of exposure to PAHs. Fish smokers who cooked daily or nearly every day had significantly higher exposure to PAHs as compared to fish smokers whose cooking frequency was at most 5 times a week.

Fish smokers in the middle wealth index had significantly reduced exposure to PAH as compared to those in the lowest index of wealth (mean diff = -93.05; 95% CI = -177.99 - -8.41; p = 0.032).

Ahotor oven was found to reduce the levels of exposure to OH-PAH metabolite among fish smokers. Also, fish smokers in the fourth quintile of wealth had significantly reduced exposure to OH-PAH metabolite as compared to those in the lowest quintile of wealth

6.2 Recommendation

1.Ahotor oven from the study was noted to reduce the levels of Hydroxypyrene (PAH metabolite) thus the Ministries of Gender and fisheries as well as various NGO's including benevolent individuals in the communities should take steps to design and subsidise the cost of improved locally made ovens like the Ahotor oven for fish smokers and their households

2. The Government through community leaders and women groups in fishing communities should organise educational workshops to educate the fish smokers on how to efficiently maintain their ovens by regularly cleaning the holding trays to reduce smoke emissions from the seepage of fat from the fish into the fire.

3. It was noted from the study that Fish smokers who spent less of their time cooking for their household had a significantly lower exposure to PAHs compared to other household members who spend most of their time cooking for the household. There is therefore the need for the Ministries of Gender and fisheries to sensitize fish smokers to do household cooking and fish smoking on rotational basis for other members of the households to take turns in order to reduce prolong exposure to pollutants by one person

4. Younger fish smokers recorded a higher level of CO as compared to the older folks and this is most likely due to the fact that younger fish smokers are often employees of the older fish smokers and are therefore the ones who spend more time in the smoke houses smoking fish. A shift system as well as occasional breaks should be instituted by the employers of these young fish smokers so that they are not overly exposed to smoke from the smoke houses.

5. From this study, fish smokers from the Volta region had significantly higher levels of PAH as compared to fish smokers from the Central region. Hence, further research into fish smoking activities that account for regional differences in exposure levels to pollutants must be done.

6. There is a need for further research into correlation of between exposures to various pollutant to help inform interventions that can deal with many pollutants at the same time.

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