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IMPACT OF CLIMATE-SMART STOVES ON HOUSEHOLD AIR POLLUTION IN ASUOGYAMAN DISTRICT, EASTERN REGION, GHANA

BY

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DECLARATION

I hereby declare that there is no part of this thesis that has been submitted for a degree in any university. There is no part of this work that contains any material which has been published by another author without the author being duly acknowledged.

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ABSTRACT

The intense extraction of fuelwood and its use in Traditional Three-Stone Stoves (TTSS) for cooking by riparian communities along the Volta Lake is deemed to be linked with deforestation and the release of harmful gases that influence household air pollution and water level of the Volta Lake which is vital to hydropower generation. This study evaluated the impact of introduced improved local cookstoves christened “Climate-Smart Stoves” (CSS) on household air pollution, fuelwood consumption, cooking time and the health of residents of Asuogyaman District of Ghana. The study employed both purposive and simple random sampling procedures to select 20 cookstoves-comprising 10 CSS and 10 TTSS for controlled cooking to assess the performance of and emissions reduction by either stove. Landsat imagery for 2014, 2016 and 2018 was used to ascertain the extent of changes in forest cover which is tied to deforestation in the district. Records on Respiratory Tract Infections (RTI) were obtained from health facilities in the district. The results revealed that CSS was efficient at reducing carbon monoxide and particulate matter emissions ($PM_{2.5}$) but consumed 36% more fuelwood during cooking, and users spent 44% more time in cooking than TTSS users. Also, out of a total of 188,309 RTI cases reported at health facilities, 41.38% were males whiles 58.62% were females and the burden of RTI fell disproportionately on females between ages of 20-34 years and children between the ages of 1- 4 years. It is recommended that efforts should be made to provide CSS to all households in the district to reduce noxious emissions that harm respiratory health. However, a second look at the engineering of CSS should be taken to improve fuel consumption and saving cooking time.

DEDICATION

This study is dedicated to my parents and my sibling.

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LIST OF ABBREVIATIONS

CSIR – Council for Scientific and Industrial Research

CSS – Climate-Smart Stoves

GHGs – Greenhouse Gases

GSS – Ghana Statistical Service

MWRWH – Ministry of Water Resources Works and Housing

MOFEP – Ministry of Finance and Economic Planning

NGO – Non-Governmental Organisation

TTSS – Traditional Three-Stone Stove

VRA – Volta River Authority

DEFINITION OF TERMS

Banku – A local Ghanaian dish prepared by boiling a mixture of fermented corn and cassava dough in hot water.

Climate-Smart Stove – An improved clay stove that is meant to increase fuelwood and thermal efficiencies and reduce harmful emissions from cooking.

Controlled Cooking Test – A test conducted to assess the performance of an improved stove relative to a traditional stove.

Traditional Three-Stone Stove – A stove made of irregularly shaped stones placed on the ground to support a cooking pot over an open fire.

CHAPTER ONE

1.0 Introduction

1.1 Background to the Study

One of the prominent developments in human history is the use of fire. This has provided a means by which a wider variety of food could be processed through cooking to ensure food security and safety (Kumar, Kumar, & Tyagi, 2013; Staton & Harding, 2011). Cooking involves the use of both solid and non-solid fuels. Solid fuels used in cooking comprise wood, charcoal, coal, animal dung and residue from crops while non-solid fuels consist of gas, electricity and kerosene (Bruce *et al*., 2015; Desalu *et al*., 2012; Ubuoh & Nwajiobi, 2018; West *et al*., 2013).

The advancement in technology has caused a slow change from employing solid fuel use to fossil fuels and or electricity (Akintan, 2014; Staton and Harding, 2011). However, a greater part of the world's population still uses biomass in various forms for cooking meals (Dam, 2017). Biomass fuel represents about 90% of primary energy consumption in developing countries (Burke & Dundas, 2015). About three billion people worldwide are heavily reliant on biomass fuel and cook meals with it. Nearly three-quarters of biomass worldwide is consumed in mainly rural areas and impoverished urban zones (Kazzi, 2016; Preble *et al*., 2014; Yuntenwi, 2008).

According to Kazzi (2016) biomass, particularly fuelwood, is intensely used in sub-Saharan Africa for the preparation of meals and is usually burnt inefficiently in smoky stoves such as the traditional three-stone stove. These traditional stoves, though free and easy to construct, are very inefficient and require huge amounts of fuelwood for cooking. Although popular cooking equipment in Sub-Saharan Africa and other regions, the use of traditional three-stone stoves are known to have negative health, environmental and socioeconomic impacts (Hafner *et al*., 2018; Okello *et al*., 2013).

As a result of incomplete combustion of fuelwood in simple household stoves, a lot of dangerous gases and particles that cause harm to health are emitted into the atmosphere with other factors like poor ventilation of household cooking areas worsening it (Amegah *et al*., 2014; Chafe *et al*., 2014). Pollutants like carbon monoxide, particulate matter, and other harmful compounds such as smoke and soot are emitted into the environment (Sota *et al*., 2014). These pollutants are believed to be associated with serious health complications such as respiratory diseases, vision impairment, cancer and low birth weight.

Exposure to household pollution is found high among women and children due to the long hours they spend in the cooking area (Karimu *et al*., 2016). Globally, 3.5 million women and children mostly in developing countries die early due to the use of fuelwood annually (Ottinger & Bradbook, 2007; Rhodes *et al*., 2014). Out of this figure, about 1.5 million deaths recorded annually is attributed to acute respiratory infections in children alone (Devakumar *et al*., 2014).

According to Abigaba *et al.* (2016) and Sander *et al.* (2011) women and children particularly in rural areas, spend lengthy periods searching for and gathering fuelwood for household cooking and heating using these stoves. This reduces time spent in productive activities such as childcare, agricultural production, education and may fuel the insurgence of school dropout, non-attendance, child delinquency and reduction in productivity and finances. Financial constraints in most rural regions also prevent most households from using alternative cooking methods which are less reliant on forest resources (Kazzi, 2016). Also, the use of fuelwood in traditional inefficient stoves in rural areas is mainly because traditional stoves are cheaper to use (Birzer *et al*., 2014). Traditional three-stone stoves are easily moved to any place of choice (Burke & Dundas, 2015) and its smoke is deemed to have insect-repelling abilities (Pérez-Padilla *et al*., 2010).

The demand for biomass, especially fuelwood, exerts pressure on local forests and woodlands and contributes to deforestation. Environmental costs of deforestation include precipitation and temperature modifications in local and regional climates. It also results in silt build up in rivers and reservoirs due to increased effect from runoffs, a decline in carbon sequestration, noxious emissions from burning and loss of biodiversity (Yuntenwi, 2008). The need for fuelwood is often dire to the extent that reforestation attempts of degraded areas proved futile because even immature trees were quickly harvested for cooking or charcoal production and such is the case in the lower Volta basin.

The degradation of forests and woodlands in most developing countries is an immense contributor to global greenhouse gas emissions (Dresen *et al*., 2014; Pearson *et al*., 2017). Legal and illegal timber harvesting, fuelwood collection, farming, overgrazing and wild forest fires are causes of forest degradation which consequently leads to deforestation. This, in turn, increases the volume of greenhouse gases into the atmosphere (Bensch & Peters, 2015; Miettinen *et al.*, 2014; Panel, 2014; Pearson *et al*., 2017).

Fuelwood and its energy are very important for the sustenance of livelihood in Sub-Saharan regions (Dresen *et al*., 2014). Fuelwood collection for household meal preparation is deemed an important deforestation driver in most Sub-Saharan African developing countries. However, this situation is multifaceted in terms of measurement even with complex procedures (Odei, 2015). Also, the pollution of indoor air caused by using fuelwood in meal preparation results in numerous health issues. Thus, plans to reduce the consumption of fuelwood should help mitigate the change in climate, aid in forest conservation and make livelihoods better for individuals (Dresen *et al*., 2014).

Ghana is one of the West African countries with a high demand for fuelwood and the heavy dependence on fuelwood threatens environmental sustainability and wreaks a lot of health and environmental hazards (Aabeyir *et al*., 2011; Lusambo, 2016; Mensah & Adu, 2015; Obiri *et al*., 2015). In Ghana like in many parts of Africa, biomass is the primary source of cooking energy due to inadequate access to other energy sources in rural and urban households. It is the major energy source in rural regions for heating, cooking meals and provision of lighting as well as energy for rural and cottage industries (Duo *et al*., 2018; Obiri *et al*., 2015). According to Hallberg & Hallme, (2015) each person uses about 640kg of wood annually in Ghana. Again, 80% of households in Ghana are solely dependent on fuelwood for energy provision and this accounts for about 71% of primary household and small-scale industries energy consumption.

The improved cookstove has been described as a tool capable of reducing household air pollution, emission of greenhouse gases and deforestation and improving the health of individuals (Adem & Ambie, 2017). Many governments and Non-Governmental Organisations have thus promoted its wide-scale production, adoption, distribution and use (Thomas *et al*., 2015). There is the evidence that the provision of improved cookstove technology on a wide scale could help address the negative human health, energy and environmental consequences associated with solid fuel use (Urmee & Gyamfi, 2014).

Improved cookstoves have the potential to maximise thermal and fuel efficiency thereby reducing the expenditure on and consumption of fuelwood. They operate safely and minimise emissions such as carbon monoxide and particulate matter which cause household air pollution and other human health associated risks (Abasiryu *et al*., 2017; Urmee & Gyamfi, 2014).

The fuelwood crisis that links deforestation with fuelwood consumption has been discarded by many (Tesfaye *et al*., 2015) because fuelwood is often harvested from wood that has already fallen or from sources prepared for construction or land clearance hence rendering the link between deforestation and fuelwood use weak (Subedi *et al*., 2014). However, it is said that an increase in population and average national per capita income has caused a change in demand, consumption and choice of fuel. The surge in population has caused a rapid increase in fuelwood demand in developing countries since it serves as the primary cooking and heating energy source. This could have a huge impact on forest resources and the environment, and it is, therefore, paramount to re-visit issues on the impact of wood fuel consumption on deforestation (Ikurekong *et al*., 2009; Mhache, 2012; Subedi *et al*., 2014).

Although the efficiency benefits of improved cookstoves are known, their ability to reduce pollutant emissions, influence deforestation and alter the socio-economic status of users is not well-understood (Jackson, 2013). Also, issues regarding maintenance, acceptance and patronage of improved cookstoves are worth discussing. Thus, this study aimed at assessing the efficiency of climate-smart stoves in reducing harmful emissions that arise from cooking with fuelwood in the Asuogyaman District in the Eastern Region of Ghana.

1.2 Statement of Problem

Fuelwood extraction is one of the dominant activities carried out by inhabitants of the Volta Lake Basin (Ayivor, 2007; Gordon *et al*., 2013). These riparian communities are heavily dependent on fuelwood for household energy production leading to deforestation. Deforestation around water bodies increases evapotranspiration and leads to silt build-up thereby reducing the level of water found in them.

To reduce the heavy dependence on fuelwood for domestic cooking and heating and curb unregulated cutting down of trees by riparian communities along the Volta lake, the Volta River Authority partnered with the Fisheries Commission in the Asuogyaman Zonal Office to provide fuel-efficient and energy-saving stoves for these communities. These improved traditional cookstoves termed Climate-Smart Stoves (CSS) were provided to twenty (20) riparian communities in Asuogyaman, Biakoye, South Dayi and Kpando Municipalities (VRA, 2018) to help replace the Traditional Three-Stone Stoves (TTSS) which were dominantly used among riparian communities of the Volta Lake for heating and cooking (VRA, 2016).

The provision of climate-smart stoves was aimed at reducing Greenhouse Gas (GHGs) emissions and alleviating the adverse effects of climate change; as well as reducing forest degradation through reduced consumption of fuelwood and the protection of the health of households along the fringes of the Volta Lake. It was also to influence positively the socio-economic life of the inhabitants (VRA, 2016).

The Council for Scientific and Industrial Research (CSIR) of Ghana, tested the performance of both climate-smart stoves and traditional three-stone stove in a study using only a sample of each stove. The study revealed that climate-smart stoves were efficient than traditional three-stone stove in saving fuelwood (CSIR, 2017). However, there is a need to carry out a broader test involving different communities to confirm the actual performance of climate-smart stoves in households.

Aside from its efficiency in utilizing little fuelwood for energy and being a better cooking alternative than the traditional three-stone stove, the climate-smart stove was found to also reduce harmful gases, suspended particulates, volatile organic compounds and carbon monoxide (CO) among others emitted during use. These emissions are known to have negative health implication on humans as well as influence climatic conditions.

This present study is intended to evaluate the efficiency of the climate-smart stove in reducing fuelwood consumption, cooking time and emissions of carbon monoxide (CO), Particulate Matter of aerodynamic size less than 2.5 microns ($PM_{2.5}$) and Sulphur Dioxide (SO_2) which influence household air pollution in Asuogyaman District in the Eastern Region of Ghana. It further probed into the health implications associated with the use of the stoves. Also, it evaluated the changes in forest cover which are linked with deforestation in the district. The outcome of this study will be beneficial to all stakeholders and also inform policymaking concerning how cost-effective the use of climate-smart stoves has been in reducing the dangers associated with cooking with open fires and protecting the environs of the Akosombo dam which in turn will safeguard hydropower generation. The results from the study will also aid the Volta River Authority in evaluating how beneficial their watershed management activity was undertaken in 2016 has been.

1.3 Justification

Wood harvesting from riparian forests for domestic energy supply is a common activity carried out by residents of the Volta Lake basin (Ayivor, 2007; Gordon *et al*., 2013). About 85% of households in the Asuogyaman District use fuelwood and charcoal extracted from the riparian forest and this contributes to forest depletion. The Volta lake, created by the construction of the Akosombo Hydroelectric dam in the Volta basin, covers an expanse of $8500km^2$ and has a live storage capacity of $16,132m^3$. The lake stores water for hydropower generation, domestic water supply, agricultural and industrial activities, lake transport and tourism (Ghansah *et al*., 2016; Gordon & Amatekpor, 1999; Owusu *et al*., 2016). Deforestation around water bodies increases evapotranspiration and leads to silt build-up thereby reducing the level of water found in them. Thus, most water bodies including the Volta Lake are exposed to the vagaries of the weather accounting for the intermittent reduction in flow and drying up (Akpoti *et al*., 2016; Boateng, 2014; Breuning-Madsen *et al.*, 2012; MWRWH, 2011).

Also, burning fuelwood in inefficient traditional stoves for cooking is popular in this district and studies report that this act produces gases which affect climate (Aberilla *et al*., 2020; Bates *et* al., 2013; Fajola *et al*., 2014; Oguntoke *et al*., *2010;* VRA, 2016). Household air pollution produced by using fuelwood in cookstoves has been acknowledged to be the cause of most respiratory ailments and death worldwide (Baqir *et al*., 2019). Although climate-smart stoves have been disseminated among riparian communities in Asuogyaman District, its actual performance in households has not been assessed broadly.

Ergo, this study evaluated how efficient the introduced climate-smart stoves are in reducing Carbon Monoxide (CO), Sulphur Dioxide (SO_2) and Particulate Matter

($PM_{2.5}$) which are known to cause household air pollution in the Asuogyaman District in the Eastern Region of Ghana. Further, it assessed whether the use of the traditional three-stone stoves is linked with any health implication. Also, the decline in forest cover, an occurrence which is tied to intense fuelwood harvesting was evaluated in the fore mentioned district since this poses a threat to the Volta Lake and sustainable hydropower generation.

1.4 General Objective

The main objective of this study was to assess the effectiveness of Climate-Smart Stoves (CSS) in household air pollution in the Asuogyaman District.

1.5 Specific Objectives

The study specifically sought to:

i. Conduct a comparative test on the amount of Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2) produced by CSS and TTSS.

ii. Compare specific fuelwood consumption per meal cooked between CSS and TTSS in Asuogyaman District.

iii. Compare the total time spent on cooking meals between CSS and TTSS.

iv. Evaluate the changes in forest cover in the last five years.

v. Assess the health implications of stove use reported at health facilities in the Asuogyaman District.

1.6 Research questions

To achieve the specific objectives of the study, the following research questions were posed to guide the study:

i. Is there any difference in the amount of Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2) emitted by CSS and TTSS during use?

ii. What is the difference in specific fuelwood consumption per meal cooked between CSS and TTSS in Asuogyaman District?

iii. Is there any difference in the total time spent on cooking meals with CSS and TTSS?

iv. What are the changes in forest cover in Asuogyaman district in the last five years?

v. What is the health implication of stove use reported at health facilities in Asuogyaman district?

1.7 Hypotheses

The following hypotheses were tested in this study:

i. There is a difference between the amount of Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2) produced by CSS and TTSS.

ii. Climate-Smart Stoves (CSS) influence specific fuelwood consumption per meal cooked in the Asuogyaman District.

iii. There is a difference between the time spent on cooking with CSS and TTSS.

1.8 Significance of the Study

This study will help in ascertaining how efficient the introduction of climate-smart stoves by the Volta River Authority has been in reducing household air pollution associated with the use of fuelwood in traditional three-stone stoves.

Also, it will aid in assessing how cost-effective the use of climate-smart stoves has been concerning fuelwood consumption and dangers associated with cooking with open fires. The study will probe into how effective the use of climate-smart stoves has been in reducing fuelwood consumption per meal cooked and how much fuelwood is being harvested from riparian forests. The reduction in deforestation in the riparian forests along the Volta lake will help prevent erratic consequences in terms of the Lake's hydrological cycle and power generation ability of the Akosombo and Kpong Dams.

The results from the study will also aid the Volta River Authority in evaluating whether their Watershed Management Activity undertaken in 2016 is yielding a positive result. The Volta River Authority also intends to provide all riparian communities along the Volta Lake with climate-smart stoves. Thus, the results of the study will help in the realization of that intent. The study will also serve as secondary data to help inform future researchers.

1.9 Delimitations of the Study

According to Simon (2011) the delimitations of a study, which are in the researcher's control, refer to the features that limit the scope of a study and describe the boundaries of a study. The study is thus limited in scope by the following:

- The study focused on the inhabitants of the Asuogyaman District in the Eastern Region of Ghana although there are other districts along the Volta Lake to whom CSS was disseminated.
- The study focused on only three out of the numerous emissions derived from the use of fuelwood in cooking. The emissions considered are; Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2).

- The study did not delve into the consequences of fuelwood harvesting on the soil.

1.10 Limitations of the Study

The following factors were out of the control of the researcher and thus influenced the outcome of the study. Thus, the limitations of the study are:

- The study was limited to only a Controlled Cooking Test (CCT) to assess the efficiency of CSS in fuel-saving and emissions controlled. However, a Water Boiling Test (WBT) could also have been undertaken and the results of both tests would have significantly informed the outcome of the study.
- Due to the lack of equipment, other emissions such as Volatile Organic Compounds (VOCs) and Oxides of Nitrogen (NO_x) that are emitted during fuelwood burning and are also known to impact on both human health and climate were not assessed.
- The constraint of time and issue of inaccessible terrain limited the researcher's ability to visit all communities in the Asuogyaman District to whom CSS have been provided and to have further interactions with community members.
- Due to illiteracy of members of study communities visited by the researcher, questionnaires had to be read and interpreted to study participants before responses could be provided to them.
- The study was also limited in the fast receipt of information due to the absence of superiors in various health institutions at most times. This led to the inability of the researcher to receive data on recorded respiratory health cases quickly. Also, community members to whom the study applied were

going about their various economic activities thus accessing them for a response to questionnaires was tiresome.

- The study was limited to 20 cookstoves due to delay in procuring the necessary equipment to carry out the controlled cooking test.

CHAPTER TWO

Literature Review

2.0 Introduction

This phase of the study discusses literature related to the study. Thus, it examines the concept of the study within a theoretical framework of characters as reviewed from existing publications. The literature review discussed have the following themes:

- Human Alterations to Riparian Areas
- Management of the Volta Lake
- Greenhouse Emissions
- The Traditional Three-Stone Stove
- The Climate-Smart Stove

2.1 Human Alterations to Riparian Areas

There has been active research ongoing for the last two decades which is aimed at understanding the dynamic forces and administrative uses of riparian zones. Riparian is coined from the Latin word "*Riparius*" denoting "of the bank of a river". "It thus encompasses living communities on lands beside ponds, lakes, streams, rivers and some wetlands" (Naiman *et al.*, 2000).

Riparian zones are widely known to serve as important biological and ecological zones of transition for terrestrial and aquatic ecosystems. They develop along waterways with plentiful vegetation and play important roles in the maintenance of several ecosystem functions such as riverbanks stabilisation and protection and improve water quality (Davis & Smith, 2013; Hansen *et al.*, 2010).

According to Parkyn & Davies-Colley (2003) riparian zones are significant in cooling temperatures of banks of water bodies as well as that of the waterbody itself. They further assert that riparian zones also play the role of water purification, nutrient filtration and retention. Research undertaken by Méndez-Toribio *et al*. (2014) on riparian vegetation diversity in the Duero river watershed in Michoacán, Mexico further indicated that riparian zones ensure water quality maintenance, stabilises hydrologic cycle of water bodies, provide food and homes plants and animals. They also provide aesthetic, recreational and tourism opportunities.

In another study to find out the diversity of riparian plant species and their distribution to human disturbance in the Wami River, Mligo (2017) found out that riparian zones provide many hunting and breeding sites that aid the survival of a lot of wildlife and provide shade for migratory fish as well as maintaining moisture in riparian soils.

Regardless of their ecological imperativeness, a lot of riparian zones have been destroyed and water bodies found close to them have been altered by human activities through farming, damming for the provision of electricity and have been invaded by foreign species and heavily by pollutants (Klemas, 2014). He further asserted that riparian zones are faced with other impacts such as the conversion of zones to pasture, livestock grazing, cultivation, modification of the hydrological cycle, landscape fragmentation, bank erosion as well as destabilisation by livestock. This may be because riparian zones are equally spots of attraction for anthropogenic activities like agriculture, settlement building, grazing, mineral extraction and non-point source pollutions (Fu *et al*., 2017).

According to Mligo (2017) due to development for the establishment of homes, utility lines, roads and bridges many forest canopies have been removed. This interference by humans has all negatively influenced riparian areas and altered fluvial geomorphological attributes of these zones.

After a study conducted on riparian vegetation in temperate and sub-tropical regions, Richardson *et al*. (2007) stated that disturbances that are human-driven occur from local to large scales and influence riparian ecosystems. Hydrological changes caused by dam construction and river flow changes cause an alteration in constituents and extent of riparian habitats and the use of land immediately adjacent to water bodies such as in crop cultivation may buoy sediment deposition and eutrophication (Richardson *et al*., 2007).

Hughes (2016) in the assessment of the management of riparian zones and erosion along banks of streams in New Zealand found out that the continuous disturbance to catchment areas caused by humans led to increased erosion of bank of streams and deposition of sediments. According to him, the increase in rates of erosion may have been due to alterations in riparian zone hydrology due to removal of vegetative land cover and its subsequent yield to new flow regimes.

Méndez-Toribio *et al*. (2014) assessed the watershed of river Duero in Mexico and detected that agricultural activities and human settlement construction accounted for about 50% occupancy of the territory and this affected riparian vegetation directly through biomass removal and indirectly through water pollution.

A study conducted in Kenya on sustainable management of riparian areas established the fact that these areas have not been properly secured from ill human-related activities such as settlement establishment and tree cutting (Matunda, 2015).

Also, Lawal (2016) asserted that anthropogenic activities along the riverbanks in Ogun State have led to degradation, intense bank erosion, alteration in vegetation communities and distribution of wildlife along the banks. Also, commercial sand dredging and sugarcane farming take place along the banks.

The ongoing alteration of riparian habitats in Sahelian countries such as Burkina Faso is left with little or no attention given to adverse ecological and human cost that will arise from these modifications. Riparian forests are noted to be ecosystems that face extreme danger due to human activities and civil engineering processes (Sambaré *et al.*, 2011).

In Ghana, a lot of vegetative covers has been destroyed by anthropogenic activities. Unregulated wood extraction, mineral exploration and extraction, urbanisation and bad agricultural practices have consumed a greater proportion of forest cover. These acts coupled with poor un-sustained managerial undertaking are ridding the environment of its quality, dwindling the ecosystems' ability to provide goods and services and threatening the livelihood of natives around water bodies and riparian zones (Essegbey *et al.*, 2013). Most rivers and water bodies including the Volta lake are exposed to the vagaries of the weather. This accounts for the intermittent drying up of many water bodies which once were always flowing (MWRWH, 2011).

Many mitigating measures have been put in place over the years to protect basins, sustain river bodies and riparian zones in Ghana. One of the key mitigating interventions is the forming of Ghana's Water Resource Commission (WRC) (see Figure 1) through an Act of Parliament, Act 522 of 1996 (Gordon *et al.*, 2013; Mul *et al.*, 2015). According to this Act, WRC is the establishment solely charged with the duty of controlling water resources in Ghana as well as direct policies drawn by the Government of Ghana in line with them (Owusu *et al*., 2016).

The Water Resource Commission (WRC), Ghana, through its arms, have put a lot of measures in place aimed at protecting Ghana's water resources and to ensure inter and intragenerational equity in terms of water resource distribution and use in the country. Notable among them is the sensitisation of the populace through education and stakeholder training using the media and community durbars as means of reaching out to citizens to inform them about the need to protect these water resources (MWRWH, 2011). Also, field operations have been carried to control pollution from illegal mining activities and encroachment of water bodies (Owusu *et al*., 2016).

Figure 1: Institutions That Make Up the Water Resource Commission

Source: Owusu *et al.*, 2016

The dredging of rivers to quell flooding, running water quality monitoring, adopting programs like Integrated Water Resources Management (IWRM) and strengthening policies to safeguard groundwater resources for posterity are all activities carried out by the Water Resource Commission to protect water resources for the inhabitants of Ghana (MWRWH, 2011; Owusu *et al*., 2016).

The Riparian Buffer Zone Policy was launched in 2013 (Abeekpeng, 2018) as a means of managing freshwater resources in Ghana by regulating human activities along with freshwater bodies through sustainable practice as well as protecting the quality of open water bodies. The White Volta river system, which is key to this study, runs through Togo, Burkina Faso and Ghana. It constitutes about 43% of Ghana's total drainage area, contributes an annual 20% inflow into the Volta lake and thus, it is quite vital to the generation of hydropower in Ghana's hydropower generation stations namely; Akosombo hydroelectric dam and power station at Kpong (Owusu *et al*., 2016).

The protection of the Volta River and its environs is therefore very paramount due to the establishment of the Akosombo Hydroelectric dam in 1965. Also, the dam's construction caused the Volta Lake's creation and the lake constitute approximately 3.7% of Ghana's total landmass and serve a chiliad of purposes such as tourism, transportation and aquaculture (Ampomah, 2017).

The Volta River Authority, a representative arm of Ghana Water Resource Commission, through the construction of the Akosombo Hydroelectric dam and the consequent formation of Lake Volta is mandated to oversee the Volta River basin, manage the water resources of the Volta Lake and to ensure continuous hydropower generation (Mul *et al*., 2015).

2.2 Management of the Volta Lake

The Volta River Basin is found in West Africa and is a water resource shared by six countries namely: Burkina Faso, Ghana, Togo, Côte d'Ivoire, Mali and Benin. Forty-three per cent (43%) of the basin is in Burkina Faso; 42% in Ghana; 6% in Togo; 3% in Benin; 3% in Côte d'Ivoire; and 3% in Mali. The basin stretches over an expanse of 400,000km^2 and contains the Oti River, Lower Volta, Black and White Volta which form the four major sub-basins in Ghana. (Boubacar *et al.*, 2005; McCartney *et al.*, 2012; Van de Giesen *et al.*, 2010).

The Volta river basin plays an important role in riparian community members that inhabit it. The Lower Volta is made up of small rivers which are tributaries to the Volta Lake. The Volta Lake, the largest man-made reservoir, was formed in the lower Volta due to the creation of the Akosombo Hydroelectric dam of Ghana between 1961 and 1965 (Ofori *et al.*, 2010).

The lake covers an expanse of 8500km^2 and has a live storage capacity of 16,132m^3. The lake stores water for hydropower generation, domestic water supply, agricultural and industrial activities, lake transport and tourism (Ghansah *et al.*, 2016; Gordon & Amatekpor, 1999; Owusu *et al.*, 2016). The Akosombo dam generates hydroelectricity for consumption on both domestic and industrial levels as well as for neighbouring West African countries including Togo and Benin (Essays, 2013).

After independence, the Volta River Development Act was passed by the Parliament of Ghana in 1961 and it led to the establishment of the Volta River Authority (Miescher, 2012). Per the construction of the hydropower dam and creation of the Volta Lake, Volta River Authority (VRA) was charged with the duties to manage electricity generation, transmission and supply/distribution for industrial, commercial and domestic use in Ghana and its neighbouring countries, and the resettlement of residents (Eshun & Amoako-Tuffour, 2016).

Further instruction for the duties of Volta River Authority was stipulated in the Volta River Development Act; (Act 46) of 1961 (Cobbinah & Adams, 2018). This act enjoined Volta River Authority to manage the water resources of the Volta Lake to promote tourism, lake transport and agricultural activities such as irrigation, aquaculture and inland water fishery (Miescher, 2012; Mul *et al*, 2015).

The Volta River Authority since its establishment has undertaken many activities which are geared towards executing effectively their mandates as stipulated by the Volta River Development Act, act 46 of 1961. The Akosombo Dam after its construction in 1965 was producing 588MW of power. Rapid industrialisation which commenced after the establishment of the Akosombo dam peaked the demand for power. Due to this, additional generating units were commissioned to buoy Akosombo's power generating capacity (Eshun & Amoako-Tuffour, 2016; Gordon & Amatekpor, 1999; Miescher & Tsikata, 2009).

To improve upon power generation and aid the government to achieve strategies stated in the Renewable Energy Policy, Volta River Authority also developed a Renewable Energy Policy to develop and run renewable energy plants (10% of renewable energy sources) which are eco-friendly and cost-effective (VRA, 2018).

The Volta River Authority provides electricity for domestic and industrial purposes in Ghana. Among the establishments to which VRA provides electricity for their activities are AngloGold Ashanti, Newmont Ghana Gold Limited, Aluworks, Akosombo Textiles Limited, Diamond Cement Ghana Limited, TV3 Network

Services Limited, Volta Aluminium Company (VALCO) in Tema as well as Electricity Company of Ghana (ECG) which is the body responsible for electricity provision for household consumption in Ghana (VRA, 2004).

Volta River Authority exports power to Togo and Benin. Also, power exchanges by VRA with countries such as Cote d'Ivoire, Benin and Burkina Faso are done through Compagnie Ivoirienne d' Electricite' (CIE), Communaute' Electrique du Benin (CEB) and SONABELL respectively to provide neighbouring West African countries with electricity. These connections thus form part of the arrangement under the West Africa Power Pool (WAPP) (Asumadu-Sarkodie & Owusu, 2016; VRA, 2004; 2018).

The Volta River Authority is also involved in the undertaking of non-power activities to ensure the protection of the health and welfare of individuals in the Volta Basin (VRA, 2004). It is very much concerned with its responsibility to the society in the aspects of its operations. Thus, it continues to organise programmes geared towards the reduction of negative environmental impacts of its activities and seeing to the well-being of the communities of the Volta Basin (VRA, 2004).

The Volta River Authority together with the Government of Ghana established the Volta River Resettlement Trust Fund. The purpose of this fund is to aid in improving the lives of communities that were affected due to the construction of the Akosombo dam (Obimpeh, 2016). And Volta River Authority since 1996 has contributed US$500,000 every year to this fund to take on projects aimed at safeguarding the environment, public health, social welfare, providing education, electricity, potable water supply and ensuring sanitation. And in 2003, Volta River Authority started the Community Development Initiative to enhance the development of riparian communities in the Volta Basin. This was an investment into human capital and to develop socio-economic activities in all communities along the Volta Lake to boost development (VRA, 2004; 2018).

Volta River Authority gives utmost importance to the health of its workers and their families as well as the members of the communities in its operation areas. Provisions for health care has been made through the construction of the Volta River Authority hospital, clinics and health programmes (VRA, 2004).

The Authority organises programmes which are geared towards safeguarding environmental integrity. It takes on programmes such as dredging at the Volta River estuary to reduce the occurrence of bilharzia and schistosomiasis in communities along the Volta Lake and to return the ecosystem to its former state. The operation of the medical ship, Onipa Nua, on the Volta Lake is overseen by Volta River Authority to provide free medical services to riparian communities' members of the Volta Lake. For instance, the Volta River Authority helped in providing medical assistance to Mepe, Dambai, Akwamufie and other communities in the Volta Basin who suffered from Bilharzia infection. The ship undertook voyages to about 16 villages and communities and offered health care assistance in clinical issues, mass immunisation and treatment of Schistosomiasis (VRA, 2004).

The Authority has also taken pains in educating community members of the Volta fringe on sensitive issues such as lake transport challenges and security, the need to protect the Volta lake and oversees tourism-related activities in the basin (VRA, 2004). Also, afforestation projects are undertaken to restore the vegetative land cover on highlands along the fringes of the Lake Volta. And this is because of a collaboration between the Volta River Authority and Forestry Commission of Ghana (VRA, 2016).

The Volta River Authority is also mandated to fight deforestation, increase the benefits derived from agro-processing activities around the Volta Lake and its environs and provide a healthy and enabling environment for women entrepreneurs and households (CSIR, 2017).

The Volta River Authority in conjunction with Fisheries Commission, Akosombo zone, provided improved traditional clay stoves which they christened Climate-Smart Stoves (CSS) to twenty (20) riparian communities in Asuogyaman, Biakoye, South Dayi and Kpando Municipalities. This initiative was aimed at reducing Greenhouse Gas emissions (GHGs) and mitigate the ill effect of climate change as well as to reduce forest degradation through reduced consumption of fuelwood and ensure the health of households in fringe communities along the Volta Lake (VRA, 2016).

2.3 Greenhouse Emissions

The change in climate is associated with gases that trap the sun’s energy and reintroduce them into the earth’s atmosphere causing an elevation in atmospheric temperature (Aba, Ndukwe, Amu, & Baiyeri, 2017). These gases are termed Greenhouse Gases (GHGs) and they include Carbon Dioxide (CO_2), Nitrous Oxides (NO_x), Methane (CH_4), Water Vapour (H_2O), Ozone (O_3) and fluorinated gases. These gases enter the atmosphere through natural processes or anthropogenic activities (MacCarthy *et al*., 2018).

According to Upadhyaya (2016), volcanic eruptions contribute to 0.03% of CO_2 in the atmosphere. Other gases such as Sulphur Dioxide (SO_2), water vapour and dust are released into the atmosphere because of volcanic eruptions and these can trap most of the sun's energy in the earth's atmosphere which in turn causes an increase in the temperature of the earth and acid rain. The interaction between the ocean and the atmosphere is also a major source of CO_2, N_2O and water vapour. These gases can absorb radiation of the sun and contribute to the intense heating of the earth as well as changes in weather patterns over regions.

Human-caused emissions of GHGs have increased massively since the Industrial Revolution and continue to be the major contributor to the variation in weather patterns. The intense use of fossil fuels for power generation in vehicles, as well as wastes and effluents from industries, introduce GHGs into the atmosphere (Aba *et al*., 2017).

Fluorinated gases such as Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur Hexafluoride (SF_6) among others are almost exclusively man-made. They play a major role in industrial activities such as aluminium smelting, manufacturing of refrigerators and air-conditioners. These gases cause great changes in climate by inducing global warming (Höglund-Isaksson *et al*., 2006).

Huge quantities of greenhouse gas emissions are introduced into the atmosphere from transportation, commercial and residential buildings. The change in land use for development activities such as the construction of urban settlement and expansion of industrial infrastructure involves the removal of forests which hitherto served as sinks for some of these greenhouse gases and thus augment the saturation of these noxious gases in the atmosphere (Watcharaanantapong, 2016). Again, the combustion of fossil fuels in public transportation introduces large volumes of greenhouse gases into the atmosphere which can harm human health and cause high climatic fluctuations (Kalita, 2016).

Hydroelectric dams are known to emit significant amounts of greenhouse gases. One of the major issues that contribute to the debate with regards to greenhouse gas emissions from hydroelectricity generation is the deficiency in approaches to quantify future GHGs emissions (De Faria *et al.*, 2015). Dams give off carbon dioxide and methane gas into the atmosphere which contributes significantly to the increase in atmospheric temperature (Fearnside, 2016).

Deforestation in developing countries is deemed to be a major contributory factor to global greenhouse gas emissions (Corbera, Estrada, & Brown, 2010). Forest degradation occurs when man directly causes a decline in forest canopy cover. It is the haphazard cutting of trees in the bid to satisfy man's immediate needs (Aba *et al.*, 2017). Drivers of forest degradation include agricultural activities, unregulated timber logging, fuelwood collection, forest fires and intense animal grazing in the forest (Dickinson *et al.*, 2015; Dresen *et al.*, 2014; Langbein, Peters, & Vance, 2017; Lewis & Pattanayak, 2012; Pearson *et al.*, 2017).

Agriculture is said to be a major contributor to GHGs emissions and about 13.5% of global anthropogenic greenhouse gas emissions in 2007 was emitted from agricultural production (Aba *et al.*, 2017; Jiang *et al.*, 2011). The major GHGs emitted from agricultural production are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). The clearing of forest for shifting cultivation, harvesting of fodder for livestock, emissions from rice paddies, ruminant animals, fertilizer application and land conversion all contribute to greenhouse gas emissions (Acquah, 2012; Bastami, 2016; Burney *et al.*, 2010; Marica & CorcheŞ, 2017)

The intense extraction of wood from forests contribute to greenhouse gas emissions. The unregulated logging of timber for construction and manufacture of furniture contribute to the removal of the forest trees which act as sinks for CO_2 (Lamb *et al*., 2016). The exploitation of forest for fuel production and other household uses are ways by which anthropogenic greenhouse gases are introduced into the atmosphere (Chidumayo & Gumbo, 2013; Njenga *et al*., 2013; Sjølie, 2012).

According to Buba, Abdu, Adamu, Jibir, and Usman (2017), about 3 billion people worldwide depend on solid fuels (fuelwood etc.) for cooking and heating and most of them reside in impoverished communities in developing countries. The use of wood fuel is very paramount in Sub-Saharan Africa and about 90% of its inhabitants, mostly located in rural areas depend heavily on charcoal and fuelwood for cooking.

Although biomass is largely used in Sub-Saharan Africa, there is a lack of improved technology to harness energy from biomass and aid in efficient use of wood. This inadvertently causes a lot of adverse effects to the environment, health and socio-economic status of inhabitants that dwell so much on biomass particularly fuelwood use (Iiyama *et al*., 2014). Household air pollution which occurs due to burning fuelwood in ineffective traditional and smoky household stoves in poorly ventilated conditions is the leading cause of death from respiratory ailments mostly in women and children (Jeuland & Pattanayak, 2012; Thompson, 2015).

The collection of wood fuel for cooking in most rural homes is time constraining especially for women engaged in income-generating activities and this restricts economic contribution (Van der Kroon, Brouwer, & Van Beukering, 2013). More time spent on looking for and collecting fuelwood reduces the time available for other productive activities (Mhache, 2014). It also causes a lot of health problems due to the carrying of heavy loads usually made of bundles of wood. Women and children are often spending time in cooking and collecting firewood and are at a greater risk of the ill implications of fuelwood use (Chen, 2018; Preston, 2012; Sole, 2016; Van der Kroon *et al*., 2013; Yash, 2016).

The search and gathering of fuelwood can be tiresome and associated with other negative effects like abduction, rape and snake bites (Chaigneau, 2013; Sander *et al*., 2011). Fuelwood collection among children in most rural areas is the major cause of child labour, school dropout, inconsistencies in school attendance, sexual violence and rape (Abigaba *et al*., 2016; Mwanza, 2014; Reddy & Nathan, 2013).

2.4 The Traditional Three-Stone Stove

About half the population of the world and majority (90%) of rural households in developing countries are heavily dependent on biomass particularly firewood for heating and cooking (Moturi, 2010). This is normally burnt in open fires or inefficient cooking stoves (see Plate 1) (Buba *et al*., 2017; Kees & Feldmann, 2011).

Sources of fuelwood become a major concern when one looks at its effects on the environment and the health of the individual. This becomes more worrying when the source is likely to affect vegetation meant to conserve a major water body such as the Volta lake. Different studies (Abasiryu *et al*., 2016; Berko, 2018; Malo, 2017) over the years have taken a close look at improving fuelwood consumption by cookstoves with little or no consideration to the damaging effect of fuelwood use to the conservation of water bodies.

Cooking with fuelwood in households is the leading source of huge amounts of smoke, carbon monoxide, particulate matter and other toxic pollutants (Oguntoke *et al*., *2010*). Inhaling these pollutants in households is known to be the cause of over 4 million deaths worldwide every year (Fajola *et al*., 2014). These pollutants when released into the environment cause adverse effects like a low birth weight in infants, chronic obstructive pulmonary disease, acute respiratory infections, cataracts and other forms of cancer (Igboanugo *et al*., *2015*; Ozoh *et al*., 2018; Sadoh *et al*., 2015; Tefera *et al*., 2016). Carbon monoxide and other emissions from wood fuel burning introduce greenhouse gases into the atmosphere which causes hydrological changes and global climatic alteration (Egeru *et al*., 2010).

Plate 1: Traditional Three-Stone Stove

Cooking is done using traditional three-stone stoves in impoverished areas in Sub-Saharan Africa (Adkins *et al.*, 2010). This is a common occurrence because the use of three stone stoves is the predominant method of meal preparation for a greater part of the population who are mostly poor (Wang *et al*., 2014). It is termed a three-stone stove because it is made of three irregular shaped stones placed on the ground to support a cooking utensil-usually a pot over an open and unvented fire (Gadgil *et al.*, 2013; Greco & Acerbi, 2016; Preble *et al*., 2014).

Traditional Three-Stone Stoves are cheaper to use because they are made from materials which are readily found in the local environment and they are also fuelled by these same materials thus its use is not economically stringent (Birzer *et al*., 2014). Also, they are easily moved to any place of choice, supports any pot size and wide fuel variety and its smoke is deemed to have insect-repelling abilities (Burke & Dundas, 2015; Pérez-Padilla *et al*., 2010). Although using traditional three-stone stoves comes with benefits, studies suggest that they are inefficient in fuelwood use compared to alternative improved cookstoves and thus is very inimical to forests which are already faced with farmland encroachment (Kazzi, 2016).

Employing traditional three-stone stove in cooking and heating is believed to be wrought with many dangers. Ibingira *et al*. (2016) in their study of the prevalence of child injuries in Eastern Uganda found out that most child injuries, particularly in rural areas, stemmed from burns from traditional stoves. Also, children and women received cuts from sharp razors and axes during wood splitting.

It was stated by Abigaba *et al*. (2016) while assessing how livelihoods are impacted on by fuelwood paucity in rural communities of Nyarubuye in South Western Uganda, that the search for fuelwood for use in traditional three-stone stoves results in accidents because fuelwood collectors climb traverse undulating topographies and dangerous terrains in search of fuelwood and end up falling off cliffs to their death or serious injury. Kazzi (2016) also stated that the flames of three stone stoves are often affected by wind. He went on further by saying that women and children get burnt due to stepping on exposed charcoal or having hot pot contents spilling over them. Additionally, charcoal and hot ash which are carried by the wind ignite dry straws in most rural kitchen areas and set them ablaze.

The use of traditional three-stone stoves poses a serious health risk to individuals especially women and children (Person *et al*., 2012). Household air pollution is the major cause of diseases and death especially in resource-poor communities and in women and children especially (Boadi & Kuitunen, 2006; Fajola *et al*., 2014; Iiyama *et al*., 2014; Kodros *et al.*, 2018; Negash *et al.*, 2017; Pratali *et al.*, 2019). About 4 million people die prematurely every year from diseases connected to solid fuel use and household air pollution from traditional three-stone stoves and of which, most are children (Asante *et al*., 2016; Atteridge & Weitz, 2017; Clark *et al*., 2013; Onyeneke *et al*., 2018; Seguin *et al*., 2018).

The inhalation of emissions from burning biomass causes diseases such as cardiovascular diseases, respiratory infections and lung cancer tuberculosis (Gordon *et al*, 2014). In addition to this, poverty, reduction in quality of life, environmental degradation and pollution are some resultant effects of the continued use of inefficient stoves for cooking (Owusu *et al*., 2015).

The development of improved cookstoves in developing countries that are heavily reliant on biomass has been a great challenge due to issues with finance (Fajola *et al*., 2014). Research, however, has been ongoing for the past four decades all in the bid to produce stoves that can reduce emissions and efficiently use fuelwood (Kshirsagar & Kalamkar, 2014).

Improved cookstoves have long been identified to have many advantages compared to traditional stoves. Improved cookstoves are efficient at saving fuelwood which consequently helps in forest conservation. They also impact positively on the health of users especially women and children by alleviating time spent in cooking areas due to their fast cooking ability and reducing emissions of air pollutants which usually poses a health threat (Oguntoke *et al.*, 2010; Okello *et al.*, 2013). Interventions for distributing energy-efficient cookstoves have been in existence for over 40 years and until recently were designed solely for maximising fuel efficiency, due to the surmised association between deforestation and household fuel use (Ruiz-Mercado *et al.*, 2011; Zube, 2010).

Other objectives of cookstove programs are to reduce fuelwood use, safeguard the health of users by reducing the emission of noxious gases, uplift the socioeconomic status of inhabitants of developing countries and reduce the ill effects of climate change through the reduction of greenhouse gases (Cundale *et al.*, 2017; Debbi *et al.*, 2014; Owusu *et al.*, 2015; Urmee & Gyamfi, 2014; Vose *et al.*, 2012).

Many of these initiatives also rally behind the Global Alliance for Clean Cookstoves (GACC)- an initiative which aims at aiding the provision of clean cookstoves and fuel to 100 million households by 2020 and pegging stoves fuel use and Particulate Matter ($PM_{2.5}$) at 70% and 90% respectively. These interventions aimed at reducing fuelwood use and emissions have the likelihood of reducing climate change, conserving forests and improving both the health and socio-economic status of individuals (Debbi *et al.*, 2014; Preble *et al.*, 2014; World Bank, 2011).

In Ghana, the energy sector is believed to need an intervention for the provision of modern cooking energy (Gyamfi *et al.*, 2015). This is due to the surge in the use of wood fuels as the principal cooking fuel. About 80% of households in Ghana lack ready access to clean cooking fuels and thus depend exceedingly on biomass fuel for household cooking. Although the impact of fuelwood use on deforestation is highly moot, the ill effect of smoke from cooking areas on the health of women and children is very evident (Kemausuor *et al*., 2015).

To ameliorate the mishap caused by the burning wood fuel in cooking and other energy-related issues, the Parliament of Ghana in 2011 enacted the Renewable Energy Law (Act 832), to make up for the provision and sustained use of renewable energy to generate electricity, aid in the transportation and residential fuel use in Ghana due to surge in energy demands expected in 2030 (Baffoe & Sarpong, 2016).

The Renewable Energy Act aims at promoting and supporting the increased use of improved cookstoves through the law, monetary motivations and other alluring packages. Its medium-term target is to ensure that rural communities have access to modern cooking fuels. The Government of Ghana aims at providing improved cookstoves to communities especially those in impoverished areas to reduce the demand for fuelwood and this forms part of the Sustainable Energy for All (SEA4ALL) Programme (Buah, 2014; Energy Commission, 2006; Hagan, 2015; Kemausuor *et al*., 2015).

Also, the reduction in fuelwood usage is part of Ghana's strategic energy plan (2006) and it is the sole aim of the Energy Commission of Ghana to make this a realisation (Asumadu-Sarkodie & Owusu, 2016). In line with this, institutions such as the Forestry Commission of Ghana, Environmental Protection Agency and the Volta River Authority are authorised to enforce appropriate laws, provide incentives and spear the effort in reducing fuelwood use in the energy sector (Kemausuor *et al*., 2015).

Thus, to fulfil its mandates, the Volta River Authority introduced climate-smart stoves to the Asuogyaman District to help reduce GHGs emissions, the total dependence on fuelwood for household cooking and consequently deforestation (VRA, 2016).

2.5 The Climate-Smart Stoves

In Ghana, about 2.2 million households especially those found in rural regions depend on fuelwood or charcoal for cooking (Obiri *et al*., 2015). The intense harvesting of wood for charcoal production and other energy needs has led to massive deforestation and other ill environmental effects (Amisah *et al.*,2009; Amoah *et al.*, 2015; Codjoe, 2007; Kusimi & Yiran, 2011). Efforts including the provision of improved cookstoves to rural areas have been used in reducing the use of wood fuel.

The introduction of cookstoves in Ghana started in 1990 with the ***Ahibenso cookstove programme*** which was a government initiative through the then Ministry of Mines and Energy in their pursuit to promote efficient cookstove. This initiative led to the dissemination of about 40,000 improved wood fuel stoves in 1993. This enterprise was later succeeded by a new cookstove called ***Gyapa*** which is found in most households in Ghana. Ghana is therefore populated with many cookstoves made of different materials (Edjekumhene *et al.*, 2001; Ribeiro *et al*., 2015).

The Energy Commission of Ghana in conjunction with Ghana Alliance for Clean Cookstoves (GHACCO) has put in place strategies to aid reduce the consumption of fuelwood, safeguard energy resources and proliferate improved cookstove use in Ghana. This has been done through public sensitisation, disseminating improved cookstoves and offering funding and technical expertise to stove producers (Ahiekpor, 2014). This enterprise is of utmost concern because of the damage the intense use of fuelwood has and still is causing to the environment.

A wider distribution of improved cookstoves will aid in subduing the intense fuelwood use in Ghana (Kemausuor *et al.*, 2015). The Energy Commission of Ghana in the bid to ensure that energy demands are met drew a plan known as the Strategic National Energy Plan (SNEP) which spans from 2006 – 2020. This was to aid in the provision of enough and viable energy services to boost economic growth in Ghana through plan formulation and notable among the institutions that participated in the development of this plan is the Volta River Authority (Energy Commission, 2006).

The Volta River Authority through the Environmental & Sustainable Development Department (E&SDD) has carried out a plethora of tasks to ensure the absolute protection of the Volta lake and its hydropower generation ability. These include organising environmental education and public awareness campaign in riparian communities every year. It has also carried out reforestation by establishing forest cover along the Volta Lake banks and some of its tributaries (VRA, 2016). Volta River Authority has also provided alternative sources of livelihood for members of riparian communities and has restricted activities such as felling of trees, draw-down farming, sand winning, cattle grazing and charcoal making which pose a threat to the Volta Gorge and its environs (VRA, 2018).

It became evident however those riparian communities along the Volta lake in carrying out income-earning activities continue to degrade the forest by harvesting trees for fuelwood or charcoal. About 85% of the population in the Volta Lake basin use fuelwood and charcoal in their households for cooking, heating and smoking fish in traditional mud stoves and three-stone stoves. This activity consumes a lot of fuelwood and emits copious amounts of smoke and greenhouse gases within the

Volta Lake basin which is deemed to impose climate change effects within the Volta lake basin by causing high-temperature rises and irregular rainfall patterns (VRA, 2018).

In protecting the Volta lake basin and the health of members of riparian communities from smoke originated diseases, Volta River Authority undertook community education in 2016 on improved traditional three-stone stoves - that which they termed as Climate Smart Stoves (CSS). Climate-smart stoves is given this cognizance because of its fuel use efficiency supported by the Council for Scientific and Industrial Research (CSIR) of Ghana (CSIR, 2017).

This campaign took place in riparian communities in Asuogyaman, South Dayi and Biakoye Districts and Kpando Municipality. This activity was carried out by a collaboration between the Fisheries Commission, Akosombo Zone and Environment & Sustainable Development Department (E&SDD) and Environment & Social Impact (ESI) department of VRA. Riparian communities were introduced to CSS by providing training on the construction, use and maintenance of the CSS. The ESI section undertook this activity between May and August 2016 in the districts (VRA, 2016).

Climate-smart stoves were provided by Volta River Authority to ameliorate greenhouse gas emission from the use of fuelwood and charcoal, reduce intense consumption of fuelwood which adversely impacts on the forest, mitigate climate change effects within the Volta Lake basin and protect the health of riparian community members along the Volta Lake by reducing exposure to extreme smoke and heat (CSIR, 2017; VRA, 2018;2016).

Climate-Smart Stoves were also introduced to reduce how much households spend on fuelwood and the time used in gathering fuelwood for domestic activities (VRA, 2018). It is also the focus of VRA to reach out to all riparian communities and enable them to adopt the patronage of CSS (VRA, 2016).

The Climate Smart Stove is built from clay, sand (0.5% of total volume) and water. It possesses an elevated chimney with 100 mm diameter which is fitted behind, and it rids the cooking area of smoke that is produced. Its long inner firepot, which is used in front loading of fuelwood is 920 x 310 mm and accommodates two cooking pots (Size 3 and Size 1½ weighing 1.711 kg and 1.132 kg respectively) at the same time. The support for the structure of the combustion chamber is composed of 6 pieces of iron rods with dimensions 12 x 600 mm (D x L) and the gap between the base of the pots to the floor of the firepot is 300 mm. The combustion chamber, which is devoid of lining has walls which are 220 mm thick. And the total measurement for the stove is (L x W x H) of 950 x720 x 330 mm (see Plate 2) (CSIR, 2017; VRA, 2018).

In comparison with climate-smart stoves, Traditional Three-Stone Stove (TTSS) is made of three stones obtained from a riverbank. The distances between the stones are set so it can accommodate an aluminium pot size of 3 weighing 1.711 kg and space between the base of the pot to the floor of the aluminium pot is 300 mm like that of the CSS (see plate 2) (CSIR, 2017). Also, in 2017, CSIR undertook a comparative evaluation for fuel efficiency and carbon savings between the climate-smart stove and traditional three-stone stove. The Council for Scientific and Industrial Research (CSIR) of Ghana stated after their observation that Climate Smart Stove consumed fuelwood efficiently with fuel savings of 51.45% and fuel processing rate of 76.6% and this was deemed appropriate for both domestic and industrial use. Volta River Authority desires to make climate-smart stove available to all forty (40) riparian communities participating in the ongoing reforestation programme (CSIR, 2017; VRA, 2018).

This intervention by Volta River Authority aims to lessen GHG emissions, alleviate climate change impacts, protect the health of inhabitants in the Asuogyaman District and to reduce deforestation by cutting down fuelwood use (VRA, 2016). However, the extent to which these goals have been met is not known with certainty. The present research fills that gap. Thus, this study takes a critical look at how effective Climate-Smart Stoves (CSS) have been in reducing the emission of carbon monoxide, particulate matter and sulphur dioxide compared with traditional three - stone stoves which is known to affect the health of households that employ the use of fuelwood in cooking. It will also probe into how effective climate-smart stove have been in reducing fuelwood use and increasing cooking efficiency.

Plate 2: Climate-Smart Stove

CHAPTER THREE

Materials and Methods

This chapter describes the study area concerning climatic conditions, location and topography of the area, vegetation characteristics and soil type. Demographic features such as population structure and economic activities are also included in this chapter.

Furthermore, details of the research design, as well as appropriate methods and procedures used in collecting data to determine applicable outcomes and other information relevant to the study, are also highlighted in this section of the study.

3.1 Description of Study Area

3.1.1 Background of the Study Area

The Asuogyaman District Assembly which has Atimpoku as its capital forms part of the 26 Municipal and District Assemblies in the Eastern Region of Ghana. It was created from the defunct Kaoga District, which had Somanya as the capital under local government instrument L.I. (1431) of 1988 as a result of Ghana Government re-demarcation of Metropolitan, Municipal and District Assemblies exercise carried out to operationalize decentralization programme in the country (MOFEP, 2018; Oduro-Yeboah *et al*., 2018).

3.1.2 Location and Topography

The Asuogyaman district as shown in Figure 2 is located between latitudes 6^{o} 34^{o} N and 6^{o} 10^{o} N and longitudes 0^{o} 1^{o} W and 0^{o}14E. It is about 120m above Mean Sea Level (MSL) and covers a total estimated surface area of 1,507 km^2, constituting 5.7% of the total area of the Eastern Region of Ghana. The district shares its northern border with Afram Plains South District and the Upper and Lower Manya

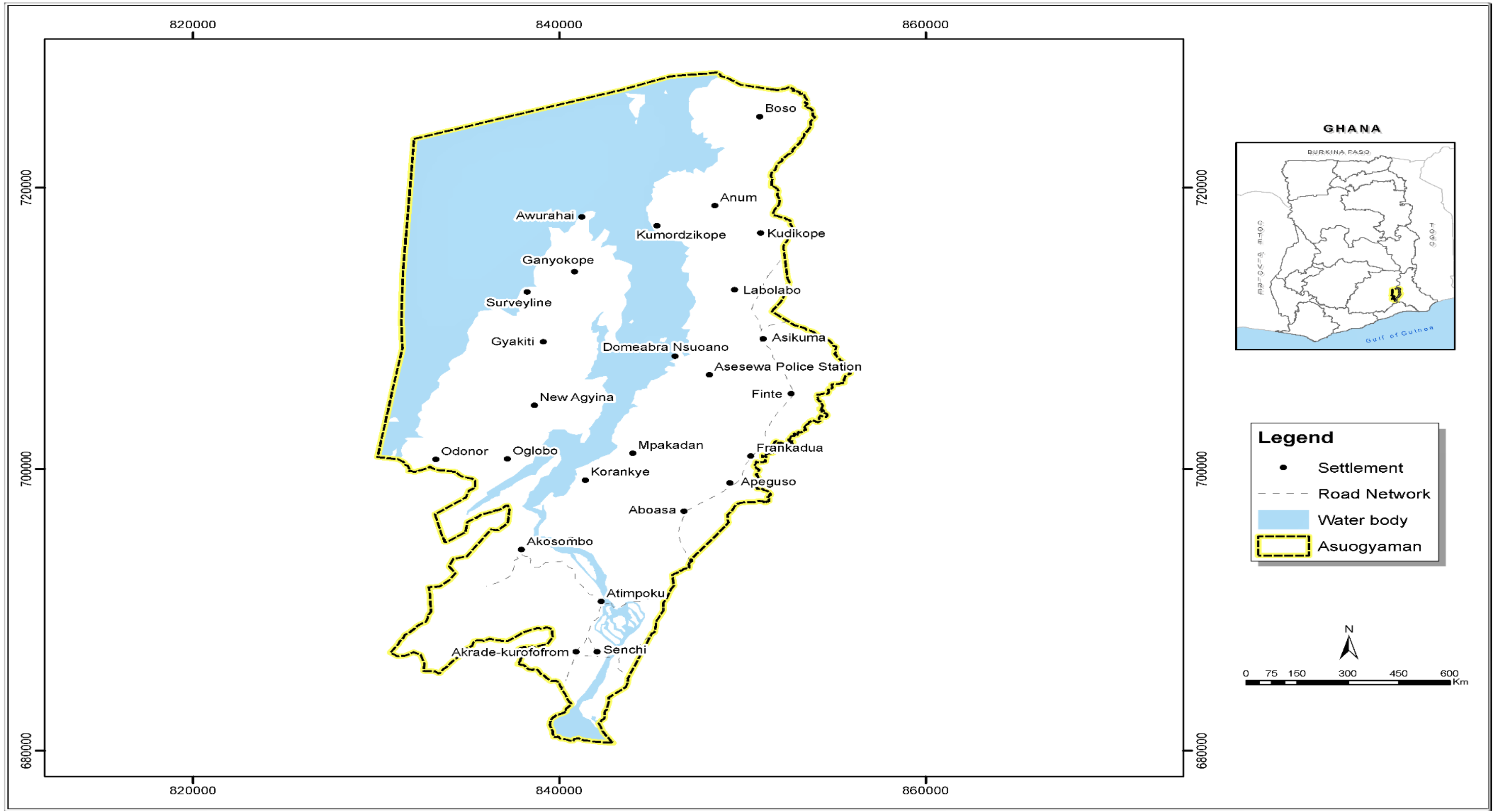


Figure 2: District Map of Asuogyaman

districts to its South and West respectively. Further its eastern border is shared with Kpando, North Dayi, Ho and the North Tongu Districts of the Volta Region.

The district's topography is generally undulating. It is mountainous and interspersed with low lying plains to the west and the east. The Volta River cuts through such ridges to create a gorge where the Volta Dam at Akosombo is located. On average, the highest of the peaks in the District ranges between 700 – 800m above sea level" (GSS, 2014).

3.1.3 Geophysical and Environmental Characteristics

3.1.3.1 Climate

The Asuogyaman District is located within the Dry Equatorial Climate Zone and it experiences a double maxima rainfall which is experienced by the district peaks amid May and July. Its minor season also occurs between September and November. Yearly rainfall with amounts between 670mm^3 and 1130mm^3 usually begins in April, reaches its zenith in June and ends in November. The dry season occurs between November and December and ends in March. However, it is usually warm over the entire year with a maximum monthly mean of 37.2ºC and a minimum of 21.0ºC (Obimpeh, 2016). Relative humidity ranges between 98% and 31% between June and 31% January (GSS, 2014).

3.1.3.2 Vegetation

The vegetation of the Asuogyaman District is characterised as belonging to the semi/ Deciduous Rain Forest and the coastal savannah zone of Ghana. The vegetation found there are mainly dry semi-deciduous forest and savannah woodland and regrowth. Timber resources are negligible. Predominant tree types in the district include oil palm, mango, silk cotton, Neem and Cassia. The main food crops grown in the district include cassava, maize, plantain and vegetables. Banana, pineapples and mango are also cultivated as cash crops (Kumah, 2014). The natural biophysical milieu looks slightly vulnerable due to different forms of environmental vagaries because a greater portion of the natural forests has been destroyed due to lumbering, ill farming practices, bush burning and short fallow periods (Ampofo *et al*., 2016; Obimpeh, 2016).

3.1.3.3 Soil

The main soil type found in the district is the heavy Akuse series with sandy and sandy loams in certain areas (Nartey, 2011).

3.2 Population Structure

The Asuogyaman District has a population of 98,046 comprising 48% males and 52% females. This forms 3.7% of the population of the Eastern Region. The district's inhabitants are predominantly young with 64% of the populace below the age of 30 and children between the ages of 0 and 14 years constitute 37.4%. About 71% of the population is found in rural areas of the district. The population of the district presents diverse scenarios for the future and therefore require policy attention with special emphasis on youth development (GSS, 2014; MOFEP, 2018).

3.3 Economic Activities

About 69% of the population aged 15 years and older are economically active while 31.2% are not. Also, 93.0% of this economically active population is employed and 7% unemployed. The main reason for not being economically active for both sexes is full-time education (64.3% of males and 35.7% of females). Majority of the employed population are engaged as skilled agricultural, forestry and fishery workers and service and sales personnel. Approximately 81% of the population are into agricultural activities and it is the main source of livelihood to members of the district. Livestock farming, food cropping, cash cropping and fishing are the prominent types of agricultural activities in the district (GSS, 2014; Obimpeh, 2016).

The most predominant of these is food cropping with more than 78% of farmers in the district involved in this activity. The major food crops produced are maize, cassava, plantain, yam and vegetable. Livestock farming is carried out on a limited scale employing only about 8% of farmers. Fishing in the Volta Lake also forms part of the agricultural activities of the district (GSS, 2014).

The Asuogyaman District is very popular with tourism in the country as it has tourists sites such as the Volta Lake, Akosombo Dam, Adomi Bridge, traditional fetish and religious shrines which attract tourists to the district and thus, serves as a mode of income generation (Ayerakwa, 2012; MOFEP, 2018).

3.4 Research Design

The study employed the use of a mixed research approach which according to Creswell (2014) involves the collection, analyses and fusion of both qualitative and quantitative research into a study. This approach was chosen because it gives a holistic understanding of the problem under study than either a qualitative or quantitative method alone.

3.5 Population

The population for the study was the inhabitants of Asuogyaman District in the Eastern Region of Ghana to whom the study applies. The target population was all households who use the Climate-Smart Stoves (CSS) or who adhered to the use of the Traditional Three-Stone Stove (TTSS) in the twelve communities in the

Asuogyaman District namely Surveyline, Kudikope, Ampanawu, Old Apaaso, Nyameben, Adjena Dornor, Dodi Asantekrom, Mapakadan, Klegekorpe, Abume. Kokonte Kpedzi and Labolabo Tornu. The population of communities like Adjena Dornu, Old Apaaso, Abume, Mpakadan, Kokonte Kpedzi, Surveyline, Kudikope, Klegekope, Ampanawu and Dodi Asantekrom were used due to easy accessibility. Members of the other two communities, Klegekorpe and Labolabo Tornu, had migrated to other communities for a fishing expedition.

3.6 Sampling Procedure

Purposive and snowball sampling methods were employed during questionnaire administration. The purposive sampling procedure was used to select households that use CSS in the preparation of meals in the 10 selected communities because the exact households that use CSS were known.

Since little was known about the households that use TTSS, snowball sampling was used. This procedure was utilised because it is one of the efficient procedures of identifying units to be included in a study sample when little is known about the required units (Sharma, 2017). For the controlled cooking test in the 4 selected communities, simple random and purposive sampling methods were used to select TTSS and CSS respectively.

3.7. Data Collection Procedure

3.7.1 Survey on Households that Use CSS and TTSS

Structured questionnaires and open-ended questions were used to gather information on households that use CSS (Appendix I) and TTSS (Appendix II). It was also to investigate whether there were any health implications associated with the use of the stoves. The questionnaires administered extracted information which was categorised into four groups namely (1) socio-demographic characteristics (2) use of CSS and TTSS (3) health implications of stoves use and (4) perception of CSS and TTSS (see Table 1).

Table 1: Overview of Questions from Questionnaires

S/N	Data Group	Description
1	Socio-demographic characteristics	Sex, age, marital status, level of education, occupation, number of persons per household and monthly income
2	Use of CSS and TTSS	Type of cooking fuel used, how cooking fuel is attained, types of food cooked, the quantity of food cooked, time used in cooking, method of stove ignition, how often stoves are used and whether other stoves are used in addition to CSS and TTSS.
3	Health implications of stove use	Health problems experienced while using stoves and how long health problems have been experienced
4	Perception of CSS and TTSS	Why cooking with CSS or TTSS is preferred and recommendation for improvement in the design of CSS and TTSS, adoption and sustained use

Questionnaires were self-administered to all the communities covered by this study. The respondents were required to fill them in English. However, translation into local and easily understandable languages was done for the illiterates. Out of a total of 100 questionnaires administered to households using CSS, 52 were filled successfully and collected giving a retrieval rate of 52% while a 100% retrieval rate was achieved for the 120 questionnaires shared in households using TTSS.

3.7.2 Controlled Cooking Test (CCT)

The controlled cooking test which is considered as one of the most appropriate tests in assessing the efficiency of CSS compared to TTSS was performed in the selected households within the communities, following the protocol stated by Bailis (2007).

This test was carried out in both households that use CSS and TTSS. Traditional Three-Stone Stoves were selected using simple random sampling while climate-smart stoves were sampled used purposive sampling. A controlled cooking test involves a chef preparing a selected standardised meal on a traditional cookstove and improved cookstove three times each. Twenty (20) cookstoves comprising 10 CSS and 10 TTSS each were selected for the test. Ten (10) functional CSS in Adjena Dornu, Kokonte Kpedzi, Mpakadan and Surveyline were selected as well as, an equal number of TTSS (10) to have a basis for the comparison of the performance of CSS and TTSS.

The test was conducted in homes with participants who volunteered. Users of the various stoves were asked to operate the stoves as they normally did during cooking. The test required participatory chefs to cook a traditional standardised meal under standard conditions. For this study, females in households who participated were made to cook “Banku” because a survey conducted earlier showed that it is the staple meal eaten by the inhabitants of the study communities. “Banku” is made from boiling a mixture of fermented cassava and corn dough until a thick paste is formed and this is often accompanied with a sauce. Also, fuelwood for the controlled cooking test was purchased from local community suppliers a week before the test and stored under sheds in respective communities. This was done to avoid delay because transporting fuelwood to the various test communities would be time and labour demanding.

3.7.2.1 Procedure for Controlled Cooking Test

The standard cooking protocol of Bailis (2007) was adopted while conducting the controlled cooking test and all recordings were made on a data sheet (see Appendix XIII). Details of the procedure are provided below:

Before cooking:

- The average dimension of wood used was taken using a 120cm measuring tape and recorded as 100.52± 25.76 x 8.66 ± 3.31 cm (L×D).
- An average hardwood typical of the study area, with a moisture content of approximately 20.95% (dry basis) was used. This was measured using moisture meter Voltcraft FM-300 (Conrad Electronics SE, Hirschau) whose measurement was in dry basis (see Plate 4). Three (3) pieces of wood fuel were selected randomly from a pile of fuelwood obtained from the community. The moisture contents were taken at different locations on each of the fuelwood selected from the pile of fuelwood. Average moisture content was found and used in the calculations.
- The average weight of 1163g of corn dough which costs GHS 2.00 and cassava dough of an average weight of 971g priced at GHS 1.00 were mixed with an average of 750ml of water in a cooking pot of size “3” weighing 1738g
- The average weight of 1163g of “corn dough” which costs GHS 2.00 and “cassava dough” of an average weight of 971g priced at GHS 1.00 (made by fermenting milled corn and cassava respectively for 3 days) were mixed with an average of 750ml of water in a size “3” cooking pot weighing an average of 1738g.

- Fuelwood of average weight 13000g was used to set fire and after which the pot with the cassava and corn dough mixture was put on the fire to begin the cooking of "Banku".
- Fuel ignition was carried out by using a small piece of black polythene lighted with the strike of a match. This was a common practice among the households visited.
- Pollutant emissions of CO, $PM_{2.5}$ and SO_2 were at the same time measured during the cooking events. The recording of emission data started immediately the cooking pot was put on the cookstove with the cooking time noted.
- The weight of all materials required to undertake the controlled cooking test was measured using a constant electronic digital scale (ISO 9001:2008 certified by Standard Global Services) which has a capacity of 600kg.
- An average baseline cooking time of 45minutes was utilized in the test because that was the average time for "banku" to get cooked stated by households surveyed earlier.

After cooking:

- The weight of the food cooked and the cooking pot was measured and recorded.
- Also, the charcoal at the tip of the unburnt fuelwood after cooking was knocked off and the weight of the fuelwood was weighed and recorded.
- The char that remained in the stove after cooking and the ones knocked off were collected into a char container and weighed.

- As a standard testing protocol, three (3) repeated tests were conducted for each stove.

The calculations for the indicators of stove performance shown below were used and these can be found in Bailis (2007).

- **Total Weight of Food Cooked (g)** $(W_f) = \sum_{J=1}^{3} (Pj_f - Pj)$,

  Where:

  J = Index for Each Empty Cooking Pot Used (Up to Three).

  Pj_f = Weight of Pot After Cooking

- **Weight of Char Left After Cooking (g)** $(\Delta C_c) = C_c - k$,

  Where:

  C_c = Weight of Char Container and Charcoal (g)

  k = Weight of Char Container (g)

- **Equivalent Dry Fuelwood Consumed (g)**

  $(f_d) = (f_f - f_i) * \{1 - (1.2 * m)\} - 1.5 * \Delta C_c$,

  Where:

  f_f =Final Weight of Fuelwood (g)

  f_i =Initial Weight of Fuelwood (g)

  m = Wood Moisture Content (% Wet Basis)

  ΔC_c = Weight of Char Left After Cooking (g)

- **Specific Fuel Consumption (g/kg)** $(SC) = \frac{f_d}{W_f} * 1000$

- **Total Cooking Time (Mins)** $(\Delta t) = t_f - t_i$

  Where:

  t_f = Final Cooking Time (Mins)

  t_i = Initial Cooking Time (Mins)

- **Moisture Content in Wet Basis** (%) $M_w = \frac{M_d}{100+M_d}$

  Where:

  M_w = Moisture Content on Wet Basis

  M_d = Moisture Content on Dry Basis

3.7.3. Assessment of Gas Emissions During Controlled Cooking Test

Emission concentrations of CO and SO_2 were recorded using Aeroqual Series 500 (S500) gas monitors (manufactured by Aeroqual Limited; Auckland, New Zealand) and $PM_{2.5}$ by Haz-dust Environmental Particulate Air Monitor (EPAM-7500). These gas monitors with the right sensor heads were positioned in the cooking area before the cooking and were also used to record weather conditions such as temperature and relative humidity. The average temperature of 34^oC and relative humidity of 60.6% were recorded during the cooking tests. Kitchens found in the study area are generally made from mud with iron roofing sheets, have little ventilation and are constructed as stand-alone structures. Thus, the measurement of gaseous emissions was not affected by outside airflow. They were operational once the fire was set for the preparation of the meal and all measurements units were taken in milligram per cubic meter (mg/m^3) (see Plate 7). The sensors listed were used in the assessment of air pollutants in households because they can access gas concentration directly.

The Aeroqual S500 gas monitors and EPAM 7500 were programmed to log at an interval of one (1) minute. The monitors, therefore, recorded average pollutant concentrations and weather data – temperature and relative humidity continuously at 1-minute interval during the cooking of "Banku" in households that participated in the study. Studies showed that monitors should be placed between 1m to 1.5m above the floor level (Agyekum, 2017). The monitors were placed one meter away from the cookstove and one meter above the floor. The distance of a meter away from the cookstove was considered during monitoring of emissions to prevent the knocking off monitors by cooks which can damage them. This distance was considered as well to prevent them from extreme temperatures from the cooking area which could also affect their performance. Also, monitors were mounted a meter high above the floor during the assessment of air pollutants to obtain gas concentration directly in the air.

The sampling time, which was dependent on the time the "Banku" was cooked began from the setting of the fire in the stove and ended when the "Banku" was cooked. The data logged on the memory of the Aeroqual S500 gas monitor was downloaded unto a laptop computer with the aid of the Aeroqual S500 gas monitor software version S500 V6.5. The data on Particulate Matter ($PM_{2.5}$) was logged unto the EPAM 7500 and was translated into spreadsheet ASCII text files using DustCom Series 7 software on a laptop computer. Table 2 indicates the gases monitored, type of sensors used and sensor range.

3.7.4 Secondary Data

Secondary data for this study were obtained from published articles, journals, books, policy documents by government and internet sources. Data on population was also gained from the Ghana Statistical Service District Analytical Report (GSS, 2014).

Table 2: Sensor specification for Aeroqual Ambient Sensor and Haz-Dust EPAM 7500

Air Pollutant Monitor	Pollutant	Sensor Type	Sensor Range (mg/m3)
Aeroqual Series 500	CO	Gas Sensitive Electrochemical	0 – 123
	SO_2	Gas Sensitive Electrochemical	0 – 28
Haz-Dust EPAM 7500	$PM_{2.5}$	Optical Sensor	0.01-200

Gas Monitor   Gas Sensors   Temperature and Relative Humidity Sensor

Plate 3: Aeroqual S500 Gas monitor, Gas Sensor Heads and Temperature and Relative Humidity Sensor

Haz-Dust Environmental Particulate Air Monitor (EPAM-7500)

Voltcraft FM-300 (Wood Moisture Meter)

Plate 4: Haz-Dust Environmental Particulate Air Monitor (EPAM-7500) and Voltcraft FM-300 (Wood Moisture Meter)

Plate 5: Assessment of Fuelwood Moisture Using Wood Moisture Meter

Plate 6: Measurement of Fuelwood Dimensions Using a Tape Measure

Plate 7: Assessment of Emissions Using EPAM 7500 and Aeroqual S500 Gas Monitor During the Controlled Cooking Test.

3.7.5 Land Cover Classification and Accuracy Assessment

Three Landsat satellite images dated 22/03/2014, 23/01/2016 and 12/01/2018 were obtained from the United States Geographical Surveys (USGS) to evaluate forest cover changes which are tied to deforestation in the Asuogyaman District. The surface reflectance toolbox in ArcGIS was used to convert the top of the atmosphere (TOA) 81 into visible spectral features. Thirty training samples for each land class name; the built/bare area, dense cover, open cover and water areas were selected and supervised classification was performed using the Random Forest Classifier in Sentinels Application Platform (SNAP). The vegetation classes identified comprised of dense cover forest, open cover forest, farmlands and bare lands. The estimation of the pixel accuracy for each land cover type was done using the formulae below:

$$\frac{30\text{ m x }30\text{ m}}{1{,}000{,}000\text{ km}^2}$$

3.7.6 Health Implications of the Use of Stoves

The use of these stoves results in gas emissions. To evaluate this, respiratory health data recorded between 2014 and 2018 were obtained from the Volta River Authority Hospital and Asuogyaman District Health Directorate.

3.8 Data Analysis

The data collected from the field obtained through questionnaire administration and conducting the controlled cooking test were thoroughly examined to ensure fullness and correctness. Results from data analysed were presented using descriptive statistical techniques such as tables, graphs, frequencies and charts after processing it using the Statistical Package for Social Sciences (SPSS), version 25.0.

3.8.1 Hypothesis Testing

- There is a difference between the amount of CO, $PM_{2.5}$ and SO_2 produced by CSS and TTSS – To test this hypothesis, an independent sample t-test was conducted to ascertain if any significant difference existed between the amount of the fore-mentioned emissions from CSS and TTSS. Also, a one-way ANOVA using Tukey's Honestly Significant Difference (HSD) post hoc test was employed to determine whether any significant difference existed in the amount of CO, SO_2 and $PM_{2.5}$ emitted by CSS and TTSS with regards to the communities in which the cooking test was undertaken.
- Climate-Smart Stoves (CSS) influence specific fuelwood consumption per meal cooked in Asuogyaman District – This was tested with an independent sample t-test analyses to investigate whether CSS consumed less fuelwood per kilogram of food cooked.
- There is a difference between the time spent in cooking with CSS and TTSS – An independent sample t-test was carried out to test this hypothesis and to find out if there was a significant difference in time used for cooking by using either CSS or TTSS.

A significance level of 5% was considered for all the statistical tests carried out.

3.9 Ethical Consideration

Ethical clearance for this study was obtained from the Ethics Committee for Basic and Applied Science (ECBAS), University of Ghana to satisfy conditions for the protection of the privacy of respondents. This was to ensure that the research posed no harm to the health and rights of respondents. To fulfil aspects of this, the aim, objectives and procedures for the study were thoroughly explained to the respondents. It was made known to respondents that they were not under coercion to take part in the study and any respondent who had problems with the study was at liberty to withdraw from it at any point without any consequence.

In the completion of the questionnaires, respondents were made aware that the exercise would solely serve an academic purpose. They were assured that any information about the study will be highly confidential and anonymous as neither names nor contacts of respondents would be revealed at any time.

CHAPTER FOUR

Results

4.1 Socio-Demographic Profile of Respondents

Table 3 summarises the socio-demographic characteristics of the respondents. Out of the 172 respondents who were sampled from the 10 communities, 29 representing 16.86% were males and majority, 143 representing 83.14% were females.

The results show that 151 respondents representing 87.79% were married and 13 representing 7.56% were widowed, while 6 respondents representing 3.49% are single and 1.16% out of 172 of the respondents were divorced.

For formal education in the Asuogyaman district, majority, (54.07%) of the respondents had none whiles 23.84% and 18.60% had respectively, primary school and junior high school education. Respondents who had had senior high school education formed 3.49% of the respondents.

Generally, the majority (93.6%) of the respondents that participated in the study earn below GHS 400. Other results obtained showed that 34.30% of the respondents sampled earned between GHS 50 – GHS 100 followed by 30.23% who earn between GHS100 – GHS 150. It was also realised that 18.60% of the respondents earn between GHS 150 – GHS 200 whiles 10.47% had an income between GHS 200 – GHS 300. It was further revealed that while 2.91% earned between GHS 400 – GHS 500, a marginal 1.16% earn above GHS 500. This goes to prove that majority of the respondents are low-income earners.

Table 3: A Summary of Socio-Demographic Profile of Respondents

Variable	Category	Frequency	Per cent
Sex of Respondents	Male	29	16.86
	Female	143	83.14
Age of Respondents	21 – 30	39	22.67
	31 – 40	65	37.80
	41 – 50	45	26.16
	51 – 60	16	9.30
	61 – 70	4	2.33
	71 and Above	3	1.74
Marital Status of Respondents	Single	6	3.49
	Married	151	87.79
	Divorced	2	1.16
	Widowed	13	7.56
Educational Level of Respondents	No Formal Schooling	93	54.07
	Primary School	41	23.84
	Junior High School	32	18.60
	Senior High School	6	3.49
Occupation of Respondents	Farming	74	37.19
	Fishing	24	12.06
	Trader	54	27.14
	Public/Civil Servant	2	1.00
	Others	45	22.61
Number of Persons Per Family	Below 3	5	2.91
	3 – 5	62	36.05
	6 – 8	63	36.62
	Above 8	42	24.42
Monthly Income of Respondents	GHS 50 - GHS 100	59	34.30
	GHS 100 - GHS 150	52	30.23
	GHS 150 - GHS 200	32	18.60
	GHS 200 - GHS 300	18	10.47
	GHS 300 - GHS 400	4	2.33
	GHS 400 - GHS 500	5	2.91
	Above GHS 500	2	1.16

4.2 Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2) produced by CSS and TTSS

The concentrations of pollutant emissions of CO, $PM_{2.5}$ and SO_2 recorded in this field study is shown in Figure 3. It can be seen from Figure 3 that the mean CO emission concentration from households that used CSS was 7.56±11.845mg/m^3 and that from households that used TTSS was 16.36±16.07 mg/m^3. There was a statistically significant difference (p=0.001) between the means of carbon monoxide emissions from both stoves (see Appendix III).

Sulphur dioxide emissions recorded an average of 0.18±0.01mg/m^3 in households that used CSS and 0.18±0.02 mg/m^3 in households that prepared meals with TTSS. Thus, no statistically significant difference (p=0.965) exists between the averages of sulphur dioxide emissions from CSS and TTSS (see Appendix IV).

In comparing the means of $PM_{2.5}$ emissions, households that used CSS recorded a lower concentration of 0.82±0.10 mg/m^3 while households that employ the use of TTSS recorded 1.14± 0.07 mg/m^3. A p-value of 0.024 suggests that a statistically significant difference exists between the concentrations of $PM_{2.5}$ from CSS and TTSS (see Appendix V). The results, therefore, portray that apart from SO_2, there is a general statistically significant difference in the amount of CO and $PM_{2.5}$ between CSS and TTSS. Thus, based on the results, we do not reject the hypothesis that "there is a difference between the amount of CO, $PM_{2.5}$ and SO_2 produced by CSS and TTSS".

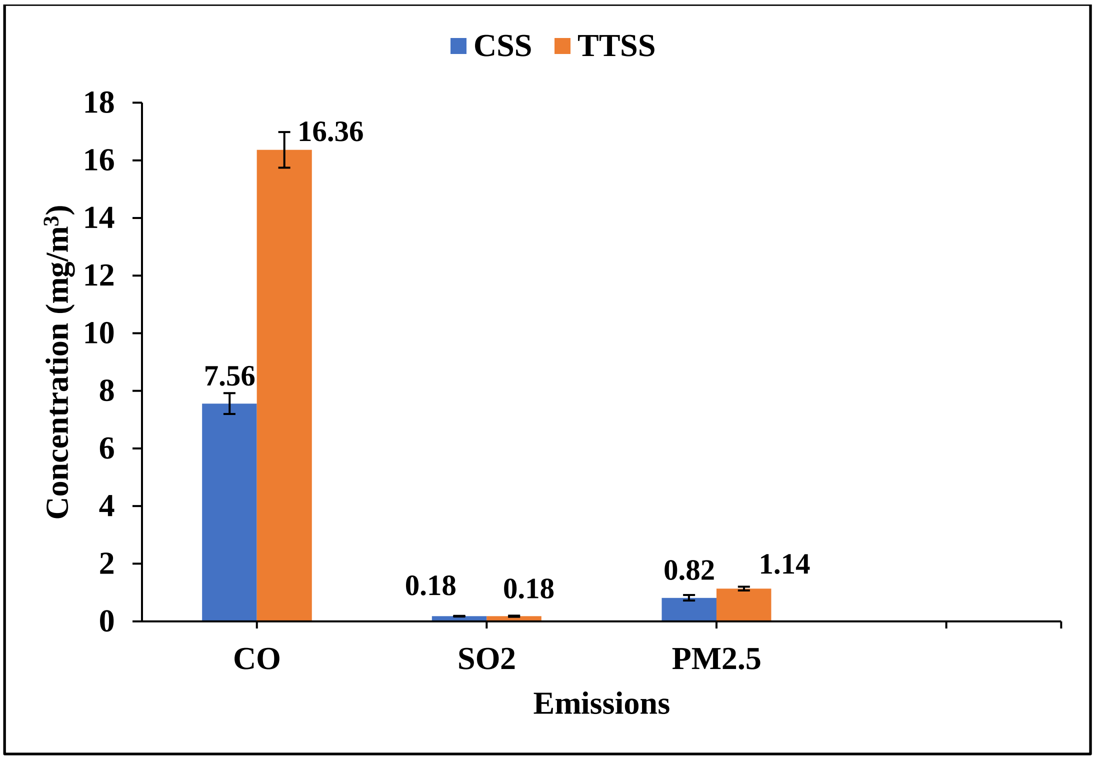


Figure 3: Concentrations of CO, $PM_{2.5}$, SO_2 Emitted from the Use of CSS and TTSS.

4.2.1 Differences in Gas Emissions Among Communities

The study further investigated the difference in CO, SO_2 and $PM_{2.5}$ from both CSS and TTSS among the communities the results are presented in Figures 4, 5 and 6.

4.2.1.1 Comparison of CO Emissions from Stoves Among Communities

Figure 4 shows that levels of CO emissions for CSS were between 2.80mg/m^3 and 11.84mg/m^3. Generally, there was a statistically significant difference ($p<0.001$) between CO levels for the communities. Post-hoc test indicated that there were statistically significant differences between all the communities except between Adjena Dornu and Kokonte Kpedzi (see Appendix VI).

Also, CO levels emitted from TTSS among the communities were between 13.46mg/m^3 and 20.76mg/m^3 and presented in Figure 4. There was generally a statistically significant difference in CO levels among the communities ($p<0.001$). Statistically significant differences made evident by post-hoc test was between Adjena Dornu and Surveyline and Kokonte Kpedzi and Surveyline. (see Appendix VII)

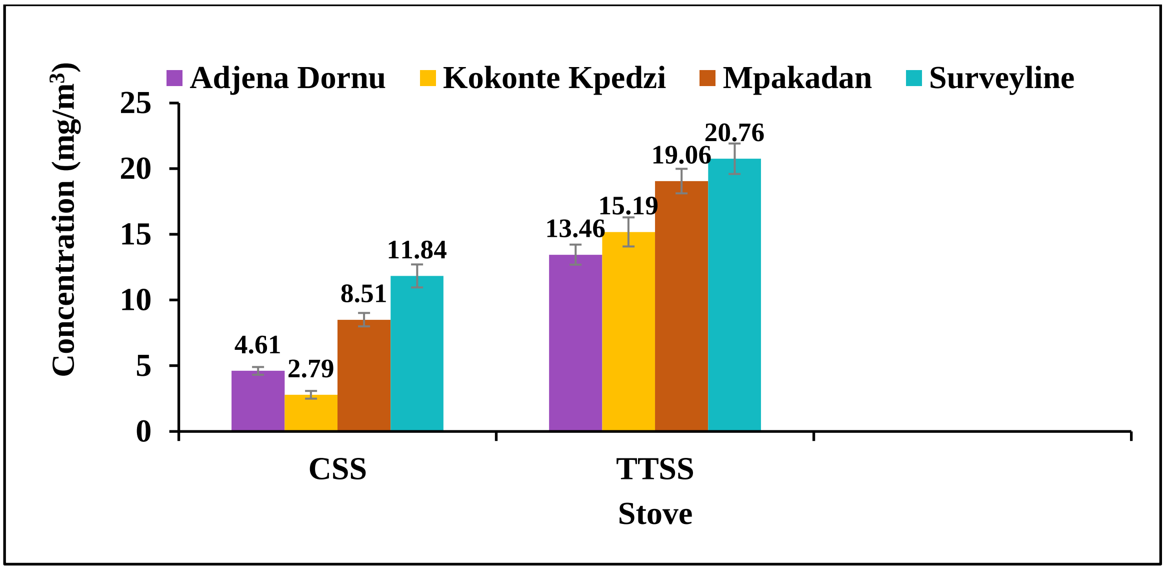


Figure 4: Comparison of CO Emissions from CSS and TTSS Among Communities

4.2.1.2 Comparison of $PM_{2.5}$ Emissions from Stoves Among Communities

The emissions of $PM_{2.5}$ from CSS, presented in Figure 5, were between 0.32mg/m^3 and 1.44 mg/m^3. A statistically significant difference existed generally between the communities ($p<0.001$). The Post hoc test further showed that the discrepancies in $PM_{2.5}$ levels were in Adjena Dornu and Surveyline, Kokonte Kpedzi and Surveyline and Mpakadan and Surveyline (see Appendix VIII).

The Traditional Three-Stone Stoves (TTSS) sampled in the communities emitted $PM_{2.5}$ levels between 0.74mg/m^3 and 1.70mg/m^3 as presented in Figure 5. Generally, there was a statistically significant difference ($p<0.001$) between $PM_{2.5}$ levels from the communities. The statistically significant differences made evident by post hoc test were between all the communities except between Adjena Dornu and Mpakadan (see Appendix IX).

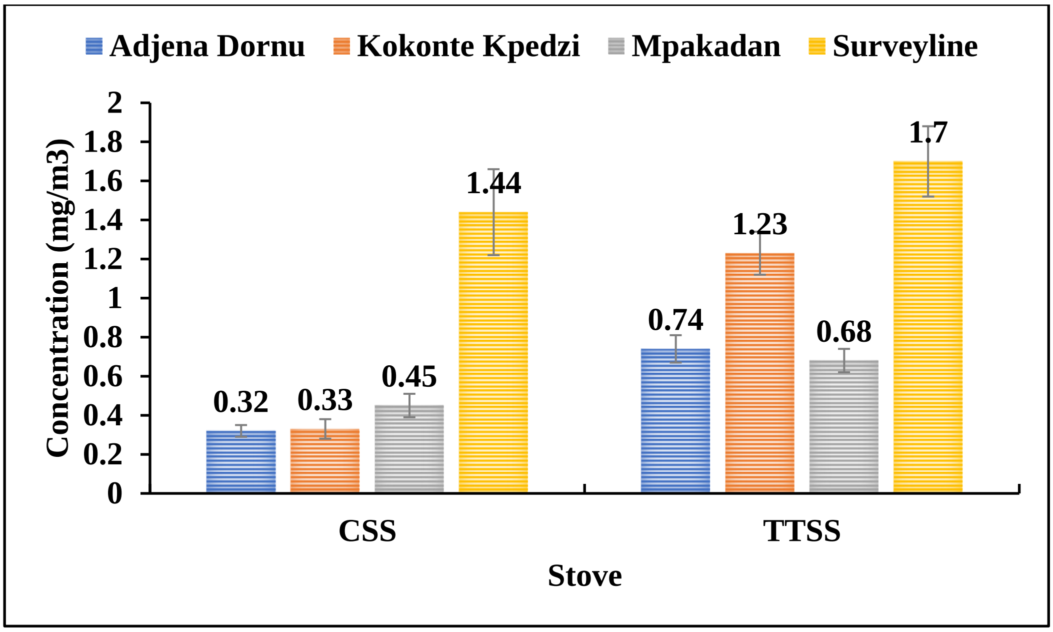


Figure 5: Comparison of $PM_{2.5}$ Emissions from CSS and TTSS Among Communities

4.3 Specific Fuelwood Consumption Per Meal Cooked Between CSS and TTSS

The results in Figure 6 show that households that used CSS in meal preparation recorded an average fuelwood consumption of 328.47±129.44g/kg of food cooked while households that prepared meals with TTSS recorded 209.70±212.24g/kg of fuelwood consumption. Thus, there is a statistically significant difference ($p=0.011$) between specific fuelwood consumption in CSS and TTSS. (see Appendix X). Based on findings from the study, we do not have enough evidence to reject the hypothesis that "Climate-Smart Stoves (CSS) influence specific fuelwood consumption compared with Traditional Three-Stone Stove in Asuogyaman District".

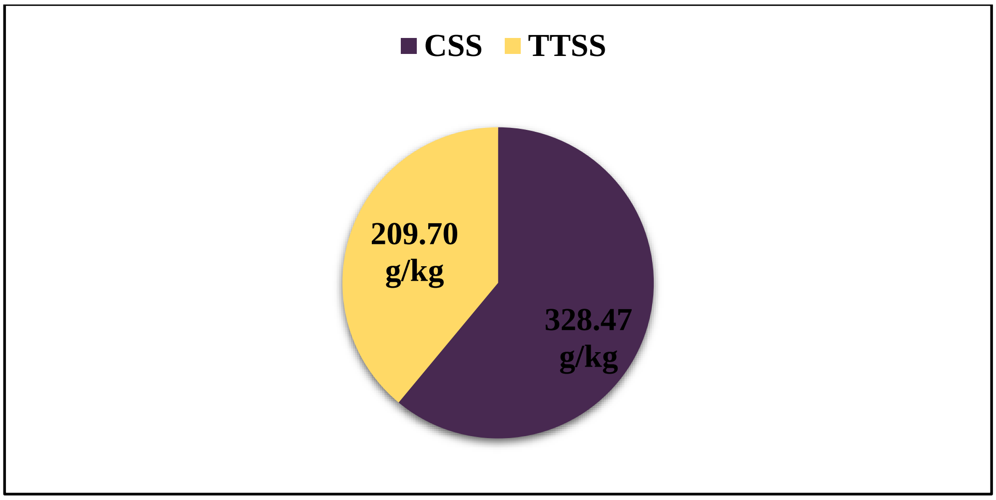


Figure 6: A Pie Chart Showing a Comparison of Specific Fuelwood Consumption Per Meal Cooked Between CSS and TTSS (g/kg).

4.4. Average Time Spent Cooking with CSS and TTSS

The average total cooking time for CSS and TTSS was compared by conducting an independent sample t-test. It can be inferred from Table 4 that households that used CSS in cooking used an average total cooking time of 37.30±13.91mins while households that prepared meals with TTSS used 20.93±5.42 mins. The significant statistical difference between the averages for the total cooking time was evident ($p<0.001$) (see Appendix XI). We do have not enough evidence from this study to reject the hypothesis that “there is a difference in the time spent in cooking with CSS and TTSS”.

Table 4: Average Time Spent in Cooking with CSS and TTSS

Type of Stove	N	Mean	SD	SE Mean
CSS	10	37.30	13.91	2.54
TTSS	10	20.93	5.42	0.99
Total	20	58.23	19.33	3.53

4.5 Land Cover Changes in Asuogyaman District in the Last Five Years

Changes in land cover in Asuogyaman district was analysed using satellite images. The result is represented in two sections. The initial section is on the land cover accuracy classification of the satellite images acquired while the other section focused on classification and changes in land cover types in the Asuogyaman district. The results are represented in Tables 5, 6 and 7.

4.5.1 Land Cover Accuracy Classification

Table 5 which shows the results for accuracy assessment indicate an overall accuracy of 97% and 100% with Kappa coefficients between 0.953 and 0.996. The highest producer accuracy which is 100% was recorded for built/bare area, dense forest cover and water in 2014, 2016 and 2018, while the lowest producer accuracy was recorded in 2014 for open cover. In assessing user accuracy, results in Table 4 shows that the highest,100%, was recorded for open cover and water sources represented by the Volta lake in 2014, 2016 and 2018. The lowest user accuracy of 93% was recorded in 2014 and 2016 for dense cover.

4.5.2 Land Cover Classification and Changes

Plate 8, Tables 6 and 7 describe land cover changes in Asuogyaman district with highlights of the details in four land cover classifications for years 2014, 2016 and 2018. It is evident that from the period of 2014 – 2018, the state of built/bare land area in the Asuogyaman district, has been increasing consistently from 2014, causing a decrease in the area for dense and open cover and water.

Table 5: Percentage Land Cover Accuracy Classification in Asuogyaman District (2014 – 2018)

Land Cover Types	2014		2016		2018	
	Producer's	User's	Producer's	User's	Producer's	User's
Bare/Built	100	94	100	98	100	100
Dense Cover	100	93	100	93	100	98
Open Cover	86	100	90	100	98	100
Water	100	100	100	100	100	100
Overall Accuracy	0.965		0.975		0.995	
Kappa Coefficient	*0.953*		*0.967*		*0.996*	

Table 6: Area of Land Cover Types (Km^2) in Asuogyaman District (2014 – 2018)

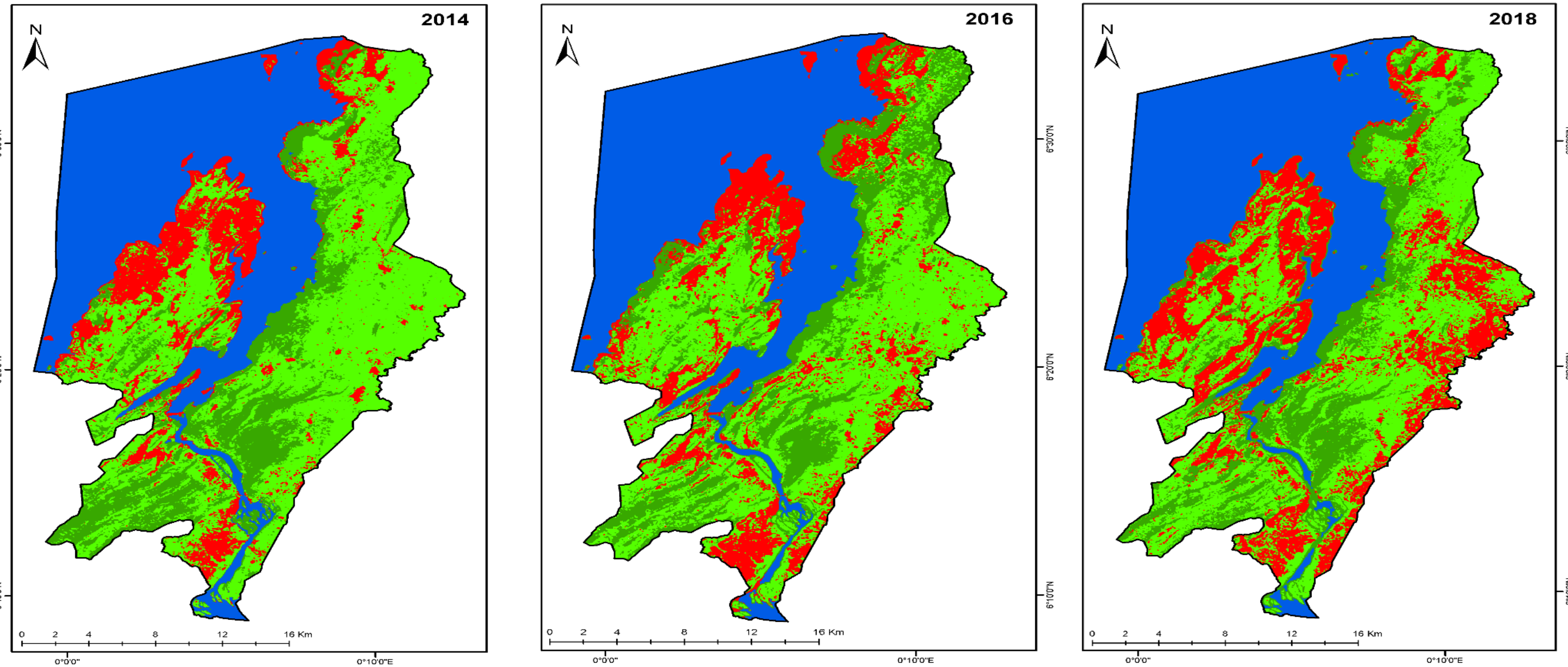
Land Cover Type	Year		
	2014	2016	2018
Bare/Built	99.39	117.47	150.57
Dense Cover	116.79	126.09	115.99
Open Cover	287.18	262.77	248.81
Water	266.79	263.84	257.67

Table 7: Land Cover Changes (Km^2) (2014 – 2018)

Land Cover Type	Years		
	2014 – 2016	2016	2018
Bare/Built	18.09	33.10	51.18
Dense Cover	9.29	-10.10	-0.80
Open Cover	-24.41	-13.95	-38.37
Water	-2.94	-6.18	-9.12

4.6 Health Implications of Stove Use in the Asuogyaman District

The trend in respiratory tract infection in the Asuogyaman District covering the period of 2014 to 2018 was recorded and the result is represented in Table 8. A total of 181,667 respiratory tract infections, that is upper and lower acute respiratory tract infections were recorded in Asuogyaman District from the year 2014 to 2018. Out of this, 75,042 representing 41.31%, were male reported cases whiles 106,625 constituting 58.69% of the cases were reported by females. It can also be inferred from Table 8 that collectively; respiratory tract infections are highest in females between ages of 20-34 years and in both male and female children between the ages of 1- 4 years.



Legend

- Boundary
- Built/Bare
- Dense Cover
- Open Cover
- Water

	Area in sqkm		
	2014	2016	2018
Built/Bare	99.39	117.47	150.57
Dense Cover	116.79	126.09	115.99
Open Cover	287.18	262.77	248.81
Water	266.79	263.84	257.67

	Land Use Land Cover Change (sqkm)		
	2014-2016	2016-2018	2014-2018
Built/Bare	18.09	33.10	51.18
Dense Cover	9.29	-10.10	-0.80
Open Cover	-24.41	-13.95	-38.37
Water	-2.94	-6.18	-9.12

Plate 8: Classified Landsat Imagery of Asuogyaman District Showing Changes in Forest Cover (2014 – 2018)

Table 8: Trends in Respiratory Tract Infections in Asuogyaman District (2014 – 2018)

Age	< 1Yr	1- 4	5-9	10-14	15-17	18-19	20-34	35-49	50-59	60-69	70 and Above	Total
Male	7460	*25108*	10153	5853	3890	1854	6590	5511	3183	2588	2852	75042 (41.31%)
Female	6367	*22532*	11190	6980	5034	3180	*16297*	14326	8738	5500	6481	106625 (58.69%)
Total	13827	47640	21343	12833	8924	5034	22887	19837	11921	8088	9333	181667

Sources: Asuogyaman District Health Directorate and Volta River Authority Hospital

CHAPTER FIVE

Discussion

This thesis reports on a study conducted in the Asuogyaman District in the Eastern Region of Ghana with the general objective to assess the effectiveness of climate-smart stoves in reducing deforestation and household air pollution. Results from the study generally indicated that climate-smart stoves were efficient at reducing CO and $PM_{2.5}$ but proved inefficient at reducing total time spent in cooking. Details of the results as they relate to the achievement of the study objectives are discussed in this chapter.

5.1 Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2) produced by CSS and TTSS

Improved cookstoves over the years have been acknowledged as being efficient at reducing high levels of emissions that are associated with the use of fuelwood in households cooking compared to traditional open fire stoves (Mitchell *et al*., 2019; Okello *et al*., 2013). Findings from this present study showed CSS was effective at reducing emissions (CO and $PM_{2.5}$) than TTSS. Climate-smart stoves yielded 54% lower levels of carbon monoxide than their traditional counterparts. This result obtained from the study affirms the assertion made by Baqir *et al.*, (2019). In his study, improved chulha stoves could reduce 51% of carbon monoxide emissions relative to the traditional chulha stoves. Berko (2018), Singh *et al.* (2012) and Smith *et al.* (2010) also made similar discoveries when newly designed stoves were tested using controlled cooking test and emissions test in their studies.

Particulate matter ($PM_{2.5}$) levels from the results also shows a 28% decline in $PM_{2.5}$ from CSS compared with TTSS. And this result agrees with a study carried out by

Pennise *et al*. (2009) in the city of Addis Ababa, Bonga and Kebribeyah Refugee Camps and Accra. It was found that $PM_{2.5}$ levels in households reduced by 26% after the introduction of an improved cookstove. Also, the findings of this field test conform with that of Jagger *et al*. (2017) when air pollutant concentrations of wood-burning in traditional three-stone and improved cooking stoves in Malawi were tested using a water boiling test. They discovered that the locally improved clay cookstove which burned fuelwood was able to reduce $PM_{2.5}$ emissions by 50%. Studies by Coffey *et al.* (2017) and Oguntoke *et al.*, (2010) confirm that cooking with inefficient stoves is the lead source of high levels of indoor air pollutants such as particulate matter and carbon monoxide.

The results from the study show that both CSS and TTSS produced the same levels of SO_2. According to Baker (1982) and Jiang *et al.* (2017), sulphur in wood is generally less than 0.1 per cent. This might account for the result obtained from the study. Also, previous measurements of SO_2 emission obtained from the electrochemical sensor and diffusion dosimeter colourimetric tubes gave a paucity of information on the relative contribution of sulphur emissions arising from combustion fuelwood (Habib *et al*., 2004). Due to absence of detailed information on sulphur dioxide emissions from fuelwood (Jiang *et al.*, 2017), it is difficult to explain the factors contributing to the emission of same concentrations of SO_2 from both CSS and TTSS.

5.2 Specific Fuelwood Consumption Per Meal Cooked Between CSS and TTSS in Asuogyaman District

Fuelwood is heavily depended on in sub-Saharan African countries especially in rural areas for cooking (Arthur *et al*., 2011; Buba *et al*., 2017; Gyamfi *et* al., 2015). In the Asuogyaman District, about 83% of households use fuelwood and charcoal as their main source of cooking fuel (GSS, 2014). Qualitative data from the study showed that 84.30% of all households covered used fuelwood and charcoal as the main source of cooking fuel (see Appendix XI). Dresen *et al*. (2014) asserted that improved cookstoves burn fuelwood more efficiently than traditional cookstoves and thus consume less fuelwood. This statement was made when they tested fuelwood consumption of injera and traditional three-stone stove using a controlled cooking test in Ethiopia. It was found that the injera (improved local cookstove) saved 40% more fuelwood when used in baking compared to the traditional three-stone fire. Also, Hafner *et al*. (2018) found that improved cookstoves reduced specific fuelwood consumption by 34.1% than their traditional counterparts did. However, this present field study recorded a 36% increase in specific fuelwood consumption in CSS than in TTSS and thus, contradicts this claim.

This observation could be due to the slow rate of adoption and use of CSS in the Asuogyaman District. The adoption rate and usage of improved cookstoves as reported by Bilsback *et* al. (2019), Johnson *et* al. (2019), Lewis & Pattanayak (2012), Ocheing *et al.* (2013) and Mamuye *et al.* (2018) can affect their fuel consumption. Also, users of traditional three-stone stoves in this present field study proved to be very skilled at tending the fire while cooking and thus maximised the energy from the fuel. The difference in fire tending habits of stove users affect fuel use during cooking (Kar & Zeriff, 2018; Moses & MacCarty, 2019; Ventrella & MacCarty, 2019) and this could explain the finding of this study. The findings of this present field study, therefore, defeats some of the intended objectives for the use of the CSS. This is because unsustainable harvesting of fuelwood for cooking can cause local environmental impact such as forest degradation (Bzugu *et al*., 2019; Pailman *et al*., 2018).

5.3 Average Time Spent in Cooking with CSS and TTSS

Improved cookstoves are adept at saving cooking time in the household as found in studies by Manoa *et al.* (2017) and Jeuland *et al.* (2015). Results from this study, however, show that CSS spent 44% more time in cooking than TTSS and this does not agree with the findings of CSIR (2017) suggesting that CSS reduced total time for cooking by 5%. This deviation could be attributed to the difference in the number of cookstoves used in the two studies. While CSIR used two cookstoves, this study, on the other hand, employed 20 cookstoves. According to Creswell (2014), the sample size has a direct influence on the results of a study. The result from the study agrees with a study conducted on cookstoves under field conditions in rural sub-Saharan Africa (Adkins *et al.*, 2010). According to their study, the traditional three-stone stove required approximately 17 minutes to cook a traditional meal while improved stoves showed a statistically significant increase in cooking time of 27% over the traditional stone stove (22min).

Kazzi (2016) in studying the performance, adoption and dissemination of improved clay cookstoves in rural Senegal found out that improved clay cookstoves showed a slight difference in mean cooking time relative to traditional three-stone stoves. The findings go to buttress the fact that the TTSS can be unexpectedly efficient if cautiously used (Zube, 2010). Its popularity for not being efficient is mainly due to a few errors in design. An example of these flaws is the loss of radiative energy from the fire to the environs. One more flaw, according to Ballard-Tremeer & Jawurek (1996), is the absence of a restricted current pathway for the fire vapours which leads to too much integration of cooler air from the surroundings.

According to Zube (2010), one benefit of the TTSS is the leeway to keep the cooking pot in proximity to the fire to increase the transfer of radiative heat. The non-existence of any close material also avoids the loss of heat that is meant to make the pot hot. Taking into consideration these downsides and advantages to TTSS, its average efficiency to transfer heat is deemed to be to roughly 14%.

Improved cookstoves have benefits over TTSS although they can from time to time prove inefficient if they are not designed properly (Ballard-Tremer & Jawurek 1996; L'orange *et al*., 2012; Samal *et* al., 2019; Shan *et* al., 2017; Tryner, 2016). By building a wall that engulfs the fire, it limits the quantity of fuelwood that can be fed into the fire at a time, by this means restricting the use of fuelwood. Another benefit from CSS is the extra enclosed gas pathway the walls create, and this restricts the inflow of surrounding air. This aids the cook to use the stove at an extra ideal air to fuel ratio while increasing the transfer of heat to the cooking pot. Thus, the variation in the cooking time of the stoves could be ascribed to the type of material used, the distance between the stove and the cooking pot.

5.4 Land Cover Changes in Asuogyaman District

The findings from the study revealed that the size of bare land has increased compared with that of the other land cover types in the Asuogyaman District. Results from the classified satellite images show that bare land area has increased by 51.18 square kilometres between 2014 and 2018 from a baseline of 18.09 square kilometres in 2014. Also, it can be seen from the results that dense forest and open forest in the study area have also reduced by 0.7% and 13.4% respectively since 2014. The Asuogyaman district has a population of 98,046 and 80% of them use charcoal and fuelwood as a source of household energy. Seventy-one per cent (71%) of households in this district are in the rural areas and majority, 92.4% are involved in crop farming (GSS, 2014). The increase in the size of bare land areas and its consequent decrease in dense forest and open forest sizes presented in this study may be as a result of a surge in the human population, thus the need to build homes, farms and find cooking fuel (Fu *et al.*, 2017; Mligo, 2017).

The reduction in the size of the Volta Lake in the study area agrees with the findings of Ayivor (2007) and Ghansah *et al*. (2016) where a reduction in water levels of the Volta Lake was attributed to deforestation and sediment transport. Gordon *et al.* (2017) while studying water resource vulnerability in the Volta basin also reported that inhabitants of the Volta basin practice intense tree harvesting causing the degradation of large areas of land. This has resulted in irregular rainfall patterns and the recession of the water table.

The provision of CSS was, therefore, the mitigating strategy meant to reduce over-dependence on the forest for fuelwood. It is, therefore, a matter of concern since the study reveals the inefficiency of CSS in reducing fuelwood consumption and cooking time.

The reduction in emission of gaseous pollutants which includes CO and $PM_{2.5}$ is, however, a good attribute of CSS since these gases which would have otherwise had an adverse effect on forest cover, the hydrological cycle of the Volta lake and hydroelectricity generation and climate are reduced (Bhojvaid *et al*, 2014; Brooks *et al*, 2016; Egeru *et al*., 2010).

5.5 Health Implications of Stove Use in Asuogyaman District

Improved cookstoves are capable of reducing household air pollution and improving the well-being of individuals (Adem & Ambie, 2017). Results from the study showed that respiratory tract infections were predominant in women and children below the age of five (5) years. This finding conforms with studies conducted by Chen (2018), Lewis & Pattanayak (2012), Preston (2012), Van der

Kroon *et al*. (2013) and Yash (2016) in regions where fuelwood was heavily relied on for household energy provision. Qualitative data from the study show that there was a perception of respiratory tract infections among respondents (97.67%) with the highest occurring among those who used TTSS (see Appendix XIV).

Record on respiratory tract infections was collected from diverse sources. However, evidence of respiratory tract infections among inhabitants of Asuogyaman District suggested that cooking with TTSS emitted high amounts of air pollutants which were associated with respiratory health infections and cancers (Bates *et al*., 2013; Igboanugo *et al*., 2015; Mortimer *et al*., 2017; Sadoh *et al*., 2015; Tefera *et al*., 2016). The efficiency of the CSS in the emission of fewer air pollutants as recorded by the study makes it ideal for cooking among rural folks who depend heavily on fuelwood. Thus, the provision of improved cookstove technology on a wide scale could help address the negative human health, energy and environmental consequences associated with solid fuel use (Urmee & Gyamfi, 2014).

CHAPTER SIX

Summary, Conclusions and Recommendations

6.0 Introduction

The study to assess the impact of climate-smart stoves on deforestation and household air pollution was conducted in the Asuogyaman District in the Eastern region of Ghana. A summary of the major findings of the research, the implications and conclusions are presented, in addition to recommendations and suggestions for further research on the study.

6.1 Summary of Findings of the Study

For this study, three hypotheses were stated and tested while two objectives were given. The results related to them are presented in brief in Table 9. It is important to note that the findings of the study state that the climate-smart stove was efficient at reducing carbon monoxide and particulate matter emissions which are related to cooking with fuelwood in households. However, not enough evidence existed to support the similarity that existed between sulphur dioxide emission from climate-smart stoves and traditional three-stone stoves. Also, the traditional three-stone stove consumed 36% less fuelwood during cooking than the climate-smart stove. The study again found out that the total time for cooking varied greatly between the climate-smart stove and traditional three-stone stove. The climate-smart stove spent 44% more time in cooking than the traditional three-stone stove.

Apart from the expansion of built/bare areas by 51.18km^2, there has been a reduction in the areas for dense forest cover, open forest cover and water in the Asuogyaman District between 2014 and 2018. Findings from the occurrence of respiratory tract infections (upper and lower acute) recorded in Asuogyaman

District between 2014 and 2018 showed that a total of 188,309 respiratory tract infections were recorded. And out of this record, 41.38% were males whiles 58.62% were females. Also, the burden of respiratory tract infections fell disproportionately on females between the ages of 20-34 years and children between the ages of 1- 4 years.

Table 9: Summarised Findings of Tested Hypothesis and Objectives of the Study

Hypotheses	Not Rejected	Rejected	Comments
1. There is a difference between the amount of Carbon Monoxide (CO), Particulate Matter ($PM_{2.5}$) and Sulphur Dioxide (SO_2) produced by CSS and TTSS.	✕		CSS was effective at reducing CO and $PM_{2.5}$ but not SO_2.
2. Climate-Smart Stoves (CSS) influence specific fuelwood consumption per meal cooked in the Asuogyaman District.	✕		The amount of fuelwood used per meal was higher in CSS than that used in TTSS.
3. There is a difference between the time spent on cooking with CSS and TTSS.	✕		Although CSS was meant to reduce the time spent on cooking, it appeared to be defective in that.
Objective	**Findings**		**Comments**
4. To evaluate the changes in forest cover in the last five years	Aside built/bare areas, the sizes of dense forest, open forest and the Volta Lake have reduced considerably since 2014.		The heavy reliance on fuelwood for cooking coupled with its intense extraction by inhabitants of the study area are the

		likely reasons for this finding.
5. To evaluate the health implications of the use of stoves in the Asuogyaman District.	Both upper and lower acute respiratory tract infections were recorded at higher levels among the inhabitants. The infection was mostly high among women between 20 – 34 years and in children below 5 years.	The use of fuelwood in inefficient smoky stoves such as the TTSS by a majority of the inhabitants might be the likely cause of the high level of respiratory tract infection. Women between 20 - 34 years and children are the most affected since women do most of the cooking with their children beside them.

6.2 Conclusion

Based on the findings of the study, the following conclusions were drawn:

i. The study established that climate-smart stoves are efficient in reducing carbon monoxide and particulate matter emissions that emanated from cooking with fuelwood in households.

ii. Climate-smart stoves were not efficient in reducing fuelwood consumption during meal preparation.

iii. Traditional three-stone stoves were more efficient in saving cooking time than climate-smart stoves.

iv. Forest degradation, an issue associated with intense fuelwood extraction and other human activities, was evident in Asuogyaman District.

v. Respiratory tract infections which may be attributed to the use of fuelwood in cooking was prevalent among inhabitants of Asuogyaman District, particularly in women and children.

6.3 Recommendation

Based on the findings and conclusion drawn from this study, the following recommendations are made:

- Due to the efficiency of the climate-smart stove in reducing carbon monoxide and particulate matter emissions that emanated from cooking with fuelwood in households, efforts should be made to supply all households with the climate-smart stoves in Asuogyaman District. Incentives could be provided by the Volta River Authority for communities to aid in the mass adoption and use of climate-smart stoves.
- Since there was not enough evidence to prove that climate-smart stoves were not efficient in reducing fuelwood consumption during meal preparation, there is the need for the Volta River Authority to have a second look at its engineering in terms of the material used for the construction, venting, and cooking pot - fire distance since these have been identified as factors affecting fuelwood consumption in smart stoves.
- There was little evidence to prove the fact that the traditional three-stone stoves are more efficient in saving cooking time than climate-smart stoves. Thus, it is required that the design and construction of climate-smart stoves be assessed by the Volta River Authority to improve its thermal efficiency.
- The evidence of forest degradation in Asuogyaman District calls for the education of the inhabitants of the various riparian communities on the consequences of forest depletion on the environment. Community woodlots

should be established by the Volta River Authority to serve as a source of fuelwood to prevent further destruction of the forest.

- Efforts should be made by the Volta River Authority to replace traditional three-stone stoves in riparian communities with climate-smart stoves since they have proven to be efficient in reducing emissions that could lead to respiratory tract infections. The stoves could also be used in well-ventilated structures to reduce significantly any emission.
- Further studies into the subject area could assess a larger number of cookstoves using both water boiling and controlled cooking tests to enable a more vivid conclusion to be made about the performance of the stoves.

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APPENDICES

Appendix I: Questionnaire for Climate-Smart Stove Users

University of Ghana

Institute for Environment and Sanitation Studies

My name is Mawusi Sylvester Kosi. This questionnaire aims to interview households that use climate-smart stoves to ascertain their efficiency and health impact. This activity is meant for an academic purpose. Thus, you are assured of strict confidentiality of all information given in this study. Thank you.

Please write selected response code(s) in the space(s) provided.

Background Information

Name of Community			
Respondent Number			
S/N	**Variable**	**Response**	**Response Code**
1	Sex	**1** = Male **2** = Female	
2	Age	**1** = Less than 20 **2** = 21 – 30 **3** = 31 – 40 **4** = 41 – 50 **5 =** 51 – 60 **6** = 61 – 70 **7** = 71 and Above	
3	Occupation	**1** = Farming **2** = Fishing **4** = Public/Civil Servant **5** = Trader **6** = ***Other(s) specify*** **…………………………………………………………**	
4	How many persons are in your household?	**1** = Below 3 **2** = 3 – 5 **3** = 6 – 8 **4** = Above 8	

5	What is the marital status of Stove user?	**1** = Single **2** = Married **3** = Divorced **4** = Widowed **5** = Separated	
6	What is the highest formal education level attained by household head?	**1** = No Formal Schooling **2** = Primary School **3** = Junior High School **4** = Senior High School **5** = Tech/Vocational **6** = Tertiary	
7	What is the highest formal education level attained by wife/stove user?	**1** = No Formal Schooling **2** = Primary School **3** = Junior High School **4** = Senior High School **5** = Tech/Vocational **6** = Tertiary	
8	What is the estimated monthly income of household?	**1** = GHS 50 – GHS 100 **2** = GHS 100 – GHS 150 **3** = GHS 150 – GHS 200 **4** = GHS 200 – GHS 300 **5** = GHS 300 – GHS 400 **6 =** GHS 400 – GHS 500 **7** = Above GHS 500	
Information on Fuel Use			
9	Which of the following cooking fuels do you use? ***(Multiple answers are accepted)***	**1** = Fuelwood **2** = Charcoal **3** = Both **4** = ***Other(s), please specify*** **…………………………..** **………………………**	
10	***If firewood is used*:** How do you acquire it?	**1** = Gather **2** = Buy **3** = Both	
11	***If firewood is gathered:*** Where do you get your firewood? ***(Multiple answers are accepted)***	**1** = From the Farm **2** = From the Forest **3** = Woodlot **4 = *Elsewhere, please specify*** **…………………………..** **……………………………..** **.**	
12	Who normally gets the firewood?	**1** = Girls **2** = Boys **3** = Husband **4** = Wife	

13	How long does it take you to acquire firewood?	**1** = Less than 20 minutes **2** = 20 - 30 minutes **3** = 30 minutes to 1 hour **4 =** More than 1 hour	
14	***If firewood is bought:*** How much money do you spend per week on firewood when using CSS?	**1** = Less than GHS 10 **2** = GHS 10 - GHS 20 **3** = GHS 20 - GHS 30 **4** = GHS 30 - GHS 40 **5** = GHS 40 - GHS 50 **6** = More than GHS 50	
15	Do you cut down trees from the forest?	**1** = Yes **2** = No	
16	If **Yes**, why do you cut down trees? ***(Multiple answers are accepted)***	**1** = To farm **2** = To sell to others **3** = To get fuelwood for cooking **3** = To make charcoal **4** = To make cooking implement **5** = ***Other(s), please specify*** **…………………………………………………………**	
17	Does the use of CSS prevent you from excessive cutting down of trees?	**1** = Yes **2** = No **3** = Indifference	
Information on Stove			
18	How did you know about the CSS? ***(Multiple answers are accepted)***	**1** = Neighbours, Family, Friends **2** = Public Meeting **3** = Installers **4** = O***ther(s), please specify*** **………………………………………………………**	
19	Which type of stove were you using before you got the CSS?	**1** = Metal fuelwood stove **2** = Coal pot **3** = Traditional-Three Stone Stove **4** = Gas stove **5** = ***Other(s), please specify*** **…………………………………………………………**	
20	When did you acquire your CSS?	**1** = 2016 **2** = 2017	

		3 = 2018	
21	Why did you decide to acquire CSS?	**1** = Appearance **2** = Fast cooking **3** = Low fuel use **4** = Less smoke **5** = Everyone is getting it. **6 = *Other(s), please specify* **………………………… ………………………….**	
22	At what rate do you cook with CSS?	**1** = Daily **2** = Once a week **3** = Twice a week **4** = Three times a week **5** = More than three times a week	
23	Do you prepare all meals using CSS?	**1** = Yes **2** = No	
24	If **No,** please give reasons.	**1** = Can't cook some meals with it **2** = Pot chamber is not large enough to cook a large meal **3** = Not used to CSS **4. *Other(s), please specify* **………………………… ………………………….**	
25	**If No,** which other type of stove do you use?	**1** = Metal firewood stove **2** = Coal pot **3** = Traditional-Three Stone Stove **4** = Gas stove **5** = ***Other(s), please specify*** **………………………… ………**	
26	Why do you use another stove in addition to CSS?	**1** = CSS is cumbersome to use **2** = CSS delays cooking **3** = Food loses its traditional taste **4** = CSS is uncomfortable to use **5** = ***Other(s), please specify***	

		………………………… …………………………..	
27	What do you like about using the CSS? ***(Multiple answers are accepted)***	**1** = Fuel saving **2** = Cooks fast **3** = Reduced smoke / soot **4** = Clean kitchen **5** = Less burns / accidents **6** = Less eye irritation **7** = More comfortable **8** = Better taste of food **9** = Saves money **10** = Less respiratory issues **11**= ***Other(s), please specify*** ………………………… ………………………… ……	
28	Do you have any problem with the use of CSS?	**1** = Yes **2** = No	
29	If **yes,** what is/are the problem(s) associated with using CSS? ***(Multiple answers are accepted)***	**1** = Cooking food with it takes longer **2** = It cannot be moved around **3** = It cannot cook certain meals **4** = It cannot cook with certain cook wares **5** = Its maintenance is difficult **6** = It does not last **7** = Uses too much fuel **8** = ***Other(s) please specify*** ………………………… ………………………… ……	
30	Have you ever replaced or repaired your CSS?	**1** = Yes **2** = No	
31	If **yes** what type of repair work did you undertake? ***(Multiple answers are accepted)***	**1** = Chimney fixing **2** = Cracks **3** = Pot area **4** = ***Others, please specify***	

		…………………………… …………………………… …..	
32	Did you receive training on the use of CSS?	**1** = Yes **2** = No	
33	If **yes**, in which aspect?	**1** = Fuel use **2** = Maintenance **3** = Construction of stove **4** = ***Others, Please Specify*** …………………………… …………………………… ……	
34	How do you perceive someone who uses CSS?	**1** = Cares about his health **2** = Cares about the environment **3** = Rich/affluent **4** = Shows off / flaunts	
35	How would you rate the general performance of the CSS in relation to TTSS?	**1** = No difference **2** = Worse **3** = Better	
Information on Health			
36	Do you use TTSS or have you ever used TTSS?	**1** = Yes **2** = No	
37	Did you face any health challenges in the course of using TTSS?	**1** = Yes **2** = No	
38	If **Yes**, what were some of the health problem(s) you faced while using the TTSS? ***(Multiple answers are accepted)***	**1** = Pain in eyes **2** = Coughing **3** = Headache **4** = Respiratory Diseases. **5** = Heat in the cooking area **6** = Smoke enters the eyes **7** = Burns **8** = ***Others, please specify*** …………………………… …………………………… ….	
39	Does the use of CSS affect your health?	**1** = Yes **2** = No	

40	**If Yes,** how are you affected?	**1** = Pain in eyes **2** = Coughing **3** = Headache **4** = Respiratory diseases. **5** = Heat in the cooking area **6** = Smoke enters the eyes **7** = Burns **8** = ***Other(s) please specify*** **……………………………………………………….…**	
41	If **No,** why do you think CSS does not affect your health?	**1** = No open fire **2** = Chimney collects smoke **3** = No headache from smoke **4** = No eyes irritation from smoke **5** = Less coughing ***6 = Other(s) please specify*** **……………………………………………………….…**	
42	Is there any recommendation/suggestion you would offer to improve CSS?	**………………………………………………………………………………………………** **………………………………………………………………………………………………** **………………………………………………………………………………………………** **………………………………………………………………………………………………**	

Thank You.

Appendix II: Questionnaire for Traditional Three-Stone Stove Users

University of Ghana

Institute for Environment and Sanitation Studies

My name is Mawusi Sylvester Kosi. This questionnaire aims to interview households that use traditional three-stone stoves to ascertain their efficiency and health impact. This activity is meant for an academic purpose. Thus, you are assured of strict confidentiality of all information given in this study. Thank you.

Please write selected response code(s) in the space(s) provided

Background Information

Name of Community	
Respondent Number	

S/N	**Variable**	**Response**	**Response Code**
1	Sex	**1** = Male **2** = Female	
2	Age	**1** = Less than 20 **2** = 21 – 30 **3** = 31 – 40 **4** = 41 – 50 **5 =** 51 – 60 **6** = 61 – 70 **7** = 71 and Above	
3	Occupation	**1** = Farming **2** = Fishing **4** = Public/Civil Servant **5** = Trader **6** = ***Other(s) specify*** ………………………………………… …………………	
4	How many persons are in your household?	**1** = Below 3 **2** = 3 – 5 **3** = 6 – 8 **4** = Above 8	
5	What is the marital status of Stove user?	**1** = Single **2** = Married **3** = Divorced **4** = Widowed	

		5 = Separated	
6	What is the highest formal education level attained by household head?	**1** = No Formal Schooling **2** = Primary School **3** = Junior High School **4** = Senior High School **5** = Tech/Vocational **6** = Tertiary	
7	What is the highest formal education level attained by wife/stove user?	**1** = No Formal Schooling **2** = Primary School **3** = Junior High School **4** = Senior High School **5** = Tech/Vocational **6** = Tertiary	
8	What is the estimated monthly income of household?	**1** = GHS 50 – GHS 100 **2** = GHS 100 – GHS 150 **3** = GHS 150 – GHS 200 **4** = GHS 200 – GHS 300 **5** = GHS 300 – GHS 400 **6 =** GHS 400 – GHS 500 **7** = Above GHS 500	
Information on Fuel Use			
9	Which of the following cooking fuels do you use? ***(Multiple answers are accepted)***	**1** = Fuelwood **2** = Charcoal **3** = Both **4** = ***Other(s), please specify*** **……………………………………………………**	
10	***If firewood is used*:** How do you acquire it?	**1** = Gather **2** = Buy **3** = Both	
11	***If firewood is gathered:*** Where do you get your firewood? ***(Multiple answers are accepted)***	**1** = From the Farm **2** = From the Forest **3** = Woodlot **4 =** ***Elsewhere, please specify*** **………………………………………………………...**	
12	Who normally gets the firewood?	**1** = Girls **2** = Boys **3** = Husband **4** = Wife	
13	How long does it take you to acquire firewood?	**1** = Less than 20 minutes **2** = 20 - 30 minutes **3** = 30 minutes to 1 hour **4 =** More than 1 hour	
14	***If firewood is bought:***	**1** = Less than GHS 10 **2** = GHS 10 - GHS 20 **3** = GHS 20 - GHS 30	

	How much money do you spend per week on firewood when using CSS?	**4** = GHS 30 - GHS 40 **5** = GHS 40 - GHS 50 **6** = More than GHS 50	
15	Do you cut down trees from the forest?	**1** = Yes **2** = No	
16	If **Yes**, why do you cut down trees? ***(Multiple answers are accepted)***	**1** = To farm **2** = To sell to others **3** = To get fuelwood for cooking **3** = To make charcoal **4** = To make cooking implement **5** = ***Other(s), please specify*** **……………………………………………………………**	
17	Does the use of TTSS prevent you from excessive cutting down of trees?	**1** = Yes **2** = No	
Information on Stove			
18	Why do you prefer cooking with TTSS?	**1** = Food tastes good **2** = It is easily accessible **3** = It is convenient for most meals (culture) **4** = It is easy to repair **5** = ***Other(s) please specify*** **……………………………………………………………**	
19	At what rate do you cook with the TTSS?	**1** = Daily **2** = Once a week **3** = Twice a week **4** = Three times a week **5** = More than three times a week	
20	Do you prepare all meals using TTSS?	**1** = Yes **2** = No	
21	If **No,** give reasons.	**1** = Cooking food with it takes longer **2** = It cannot cook certain meals **3** = It cannot cook with certain cook wares **4** = It uses too much fuel **5** = It does not last	

		6 = *Other(s) please specify* **………………………………………… ………………..**	
22	Do you cook with TTSS alone?	**1** = Yes **2** = No	
23	**If No,** which other type of stove do you use?	**1** = Metal firewood stove **2** = Coal pot **3** = Gas stove **4 = *Other(s) please specify*** **………………………………………… ………………..**	
24	Why do you use another stove in addition to TTSS?	**1** = To prepare specific meals **2** = Warm water /food **3** = To change cooking method **4** = ***Others, please specify*** ………………………………………… …………………	
25	Do you have any problem with TTSS?	**1** = Yes **2** = No	
26	If **Yes,** what are the problem(s) associated with using TTSS?	**1** = Cooking food with it takes longer **2** = It cannot be moved around **3** = It cannot cook certain meals **4** = It cannot cook with certain cookware **5** = Maintenance is difficult **6** = It does not last **7** = It uses too much fuel **8** = ***Other, please specify*** ………………………………………… …………………	
27	Have you heard of CSS?	**1** = Yes **2** = No	
28	If **Yes,** how did you know about CSS? ***(Multiple answers are accepted)***	**1** = Neighbours, Family, Friends **2** = Public Meeting **3** = Installers **4** = ***Others, please specify***	

		……………………………………… ………………	
29	Apart from TTSS, do you use CSS?	**1** = Yes **2** = No	
30	If **No,** why are you not using it?	**1** = It is expensive to get **2** = It is slow in cooking **3** = It has high cost of maintenance **4** = It is not convenient for most meals (culture) **5** = It cooks two meals at a go	
31	Do you think the use of CSS is associated with social status?	**1** = Yes **2** = No	
32	If **Yes,** give reasons.	**1** = It is for the rich **2** = Only the educated use it **3 = *Other(s) please specify*** ……………………………………… …………………	
33	Do you face any health challenges in the course of using TTSS?	**1** = Yes **2** = No	
34	If **Yes**, what were some of the health problems you face while using the TTSS?	**1** = Pain in eyes **2** = Coughing **3** = Headache **4** = Respiratory Diseases **5** = Heat in the cooking area **6** = Burns **7** = O***ther(s) please specify*** **………………………………………** **………………………...**	
35	If CSS was given to you, would you use it?	**1** = Yes **2** = No **3** = Maybe **4** = I cannot tell	
36	If **Yes,** why would you use it?	***Please specify*** **……………………………………………………** **……………………………………………………** **……………………………………………………**	

37	If **No,** why would you not use it?	***Please specify*** ……………………………………………………… ……………………..……………………………… …………………………………………………

Thank You.

Appendix III: Results of Independent Sample T-Test for Carbon Monoxide Emission Between CSS and TTSS

Group Statistics					
	Type of Stove	N	Mean	Std. Deviation	Std. Error Mean
CO	CSS	1073	7.5590	11.84617	.36164
	TTSS	675	16.3625	16.07042	.61855

Where "N" refers to the number of loggings taken during the Controlled Cooking Test

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
CO	Equal variances assumed	151.337	.000	-13.145	1746	.000	-8.80356	.66974	-10.11714	-7.48999
	Equal variances not assumed			-12.287	1130.486	.000	-8.80356	.71651	-10.20940	-7.39772

Appendix IV: Results for Independent Samples T-Test for Sulphur Dioxide Emission Between CSS and TTSS

Group Statistics					
	Type of Stove	N	Mean	Std. Deviation	Std. Error Mean
Sulphur Dioxide	CSS	406	.1795	.24178	.01200
	TTSS	240	.1785	.31237	.02016

Where "N" refers to the number of loggings taken during the Controlled Cooking Test

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Sulphur Dioxide	Equal variances assumed	9.086	.003	.047	644	.962	.00104	.02200	-.04215	.04423
	Equal variances not assumed			.044	408.058	.965	.00104	.02346	-.04509	.04716

Appendix V: Results for Independent Samples T-Test for Particulate Matter Between CSS and TTSS

Group Statistics					
	Type of Stove	N	Mean	Std. Deviation	Std. Error Mean
Particulate Matter	CSS	1214	.8192	3.33806	.09580
	TTSS	626	1.1379	1.63743	.06544

Where "N" refers to the number of loggings taken during the Controlled Cooking Test

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Particulate Matter	Equal variances assumed	.144	.704	-2.253	1838	.024	-.31870	.14146	-.59615	-.04126
	Equal variances not assumed			-2.747	1834.089	.006	-.31870	.11602	-.54626	-.09115

Appendix VI: Comparison of CO Emission from CSS Among Communities

ANOVA					
CO					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14872.385	3	4957.462	39.093	.000
Within Groups	135563.261	1069	126.813		
Total	150435.645	1072			

Multiple Comparisons						
Dependent Variable: CO						
Tukey HSD						
					95% Confidence Interval	
(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Adjena Dornu	Kokonte Kpedzi	1.81490	1.02803	.291	-.8303	4.4601
	Mpakadan	-3.89812*	1.07305	.002	-6.6592	-1.1371
	Surveyline	-7.23450*	.92718	.000	-9.6202	-4.8488
Kokonte Kpedzi	Adjena Dornu	-1.81490	1.02803	.291	-4.4601	.8303
	Mpakadan	-5.71302*	1.06894	.000	-8.4635	-2.9626
	Surveyline	-9.04939*	.92242	.000	-11.4229	-6.6759
Mpakadan	Adjena Dornu	3.89812*	1.07305	.002	1.1371	6.6592
	Kokonte Kpedzi	5.71302*	1.06894	.000	2.9626	8.4635
	Surveyline	-3.33637*	.97234	.003	-5.8383	-.8345
Surveyline	Adjena Dornu	7.23450*	.92718	.000	4.8488	9.6202
	Kokonte Kpedzi	9.04939*	.92242	.000	6.6759	11.4229
	Mpakadan	3.33637*	.97234	.003	.8345	5.8383
*. The mean difference is significant at the 0.05 level.						

Appendix VII: Comparison of CO Emission from TTSS Among Communities

ANOVA					
CO					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	4789.470	3	1596.490	6.328	.000
Within Groups	169276.587	671	252.275		
Total	174066.058	674			

Multiple Comparisons						
Dependent Variable: CO						
Tukey HSD						
					95% Confidence Interval	
(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Adjena Dornu	Kokonte Kpedzi	-1.73376	1.59850	.699	-5.8507	2.3831
	Mpakadan	-5.60470	2.27721	.067	-11.4696	.2602
	Surveyline	-7.29972*	1.90926	.001	-12.2170	-2.3824
Kokonte Kpedzi	Adjena Dornu	1.73376	1.59850	.699	-2.3831	5.8507
	Mpakadan	-3.87094	2.04640	.233	-9.1414	1.3995
	Surveyline	-5.56595*	1.62706	.004	-9.7564	-1.3755
Mpakadan	Adjena Dornu	5.60470	2.27721	.067	-.2602	11.4696

Appendix VIII: Comparison of PM2.5 Emission in CSS Among Communities

ANOVA					
Community					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	869.029	429	2.026	1.992	.000
Within Groups	797.298	784	1.017		
Total	1666.327	1213			

Multiple Comparisons						
Dependent Variable: Particulate Matter						
Tukey HSD						
					95% Confidence Interval	
(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Adjena Dornu	Kokonte Kpedzi	-.01431	.29638	1.000	-.7768	.7482
	Mpakadan	-.12510	.32016	.980	-.9487	.6985
	Surveyline	-1.11769*	.26188	.000	-1.7914	-.4440
Kokonte Kpedzi	Adjena Dornu	.01431	.29638	1.000	-.7482	.7768
	Mpakadan	-.11079	.30868	.984	-.9049	.6833
	Surveyline	-1.10338*	.24772	.000	-1.7407	-.4661
Mpakadan	Adjena Dornu	.12510	.32016	.980	-.6985	.9487
	Kokonte Kpedzi	.11079	.30868	.984	-.6833	.9049
	Surveyline	-.99258*	.27572	.002	-1.7019	-.2833
Surveyline	Adjena Dornu	1.11769*	.26188	.000	.4440	1.7914
	Kokonte Kpedzi	1.10338*	.24772	.000	.4661	1.7407
	Mpakadan	.99258*	.27572	.002	.2833	1.7019
*. The mean difference is significant at the 0.05 level.						

Appendix IX: Comparison of $PM_{2.5}$ Emission in TTSS Among Communities

ANOVA					
Particulate Matter					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	79.770	3	26.590	10.363	.000
Within Groups	1595.958	622	2.566		
Total	1675.728	625			

Multiple Comparisons						
Dependent Variable: Particulate Matter						
Tukey HSD						
					95% Confidence Interval	
(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Adjena Dornu	Kokonte Kpedzi	-.49166*	.16198	.013	-.9089	-.0744
	Mpakadan	.06249	.22653	.993	-.5211	.6460
	Surveyline	-.95807*	.19618	.000	-1.4634	-.4527
Kokonte Kpedzi	Adjena Dornu	.49166*	.16198	.013	.0744	.9089
	Mpakadan	.55414*	.20819	.040	.0179	1.0904
	Surveyline	-.46641*	.17468	.039	-.9164	-.0164
Mpakadan	Adjena Dornu	-.06249	.22653	.993	-.6460	.5211
	Kokonte Kpedzi	-.55414*	.20819	.040	-1.0904	-.0179
	Surveyline	-1.02056*	.23578	.000	-1.6279	-.4132
Surveyline	Adjena Dornu	.95807*	.19618	.000	.4527	1.4634
	Kokonte Kpedzi	.46641*	.17468	.039	.0164	.9164
	Mpakadan	1.02056*	.23578	.000	.4132	1.6279
*. The mean difference is significant at the 0.05 level.						

Appendix X: Results for Independent Sample T-Test for Fuelwood Consumption Per Meal Cooked

Group Statistics

	Stove	N	Mean	Std. Deviation	Std. Error Mean
Specific Fuelwood Consumption Per Meal Cooked	CSS	10	328.4667	129.44437	23.63320
	TTSS	10	209.7000	212.23802	38.74918

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Specific Fuelwood Consumption Per Meal Cooked	Equal variances assumed	.218	.642	2.617	58	.011	118.76667	45.38752	27.91367	209.61967
	Equal variances not assumed			2.617	47.952	.012	118.76667	45.38752	27.50659	210.02674

Appendix XI: Independent Sample T-Test for Total Time Spent in Cooking with CSS and TTSS

Group Statistics

	Stove	N	Mean	Std. Deviation	Std. Error Mean
Total Cooking Time	CSS	10	37.3000	13.91390	2.54032
	TTSS	10	20.9333	5.41984	.98952

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Total Cooking Time	Equal variances assumed	11.983	.001	6.003	58	.000	16.36667	2.72624	10.90951	21.82383
	Equal variances not assumed			6.003	37.602	.000	16.36667	2.72624	10.84577	21.88756

Appendix XII: Source of Cooking Fuel for Participants

Table 10: Main Source of Cooking Fuel for Respondents

Cooking Fuel	Frequency	Percentage
Only Fuelwood	27	15.70
Only Charcoal	0	0.00
Fuelwood and Charcoal	145	84.30
Others	0	0.00
Total	**172**	**100**

Appendix XIII: Data Recording Sheet for Controlled Cooking Test

Name of Community: …………………… Cooking Area Number: ……………………………
Type of Stove: ………………………… Date: ……………………… Time: ………………………

Environmental Variables	**Test I**	**Test II**	**Test III**
Wind Conditions **(No Wind, Light Breeze, Moderate Wind, Strong Wind, Very Strong Wind)**			
Physical Test Parameters			
Fuel Wood Type			
Wood Moisture Content (%)			
Average Fuelwood Dimension (LxBxH) (cm^3)			
Weight of Heat Pad (g)			
Weight of Fuel Wood (g)			
Weight of Char Container (g)			
Weight of Empty Pot Before Cooking (g)			
Weight of Cassava Dough (g)			
Weight of Corn Dough (g)			
Weight of Water (g)			
Initial Cooking Time (T_1) (Mins)			
Final Cooking Time (T_2) (Mins)			
Weight of Pot + Food After Cooking (g)			
Weight of Fuelwood after cooking (g)			
Weight of Char Container + Char (g)			

Description of Stove (Indicate the Construction Material of the Stove, the Way that the Pot(S) Fits in the Stove, and the Presence of Insulation, Chimney, Workspace, Etc):			
Comments About Cooking Process (smokiness, ease of use etc)			

Appendix XIV: Respiratory Health Challenges Among TTSS Users

Table 11: Perception of Respiratory Health Challenges Among TTSS Users

Response	Frequency	Per cent
Yes	168	97.67
No	4	2.33
Total	**172**	**100**