LIFE CYCLE ASSESSMENT OF THE TRADITIONAL EARTHEN WARE POT: A COMPARATIVE STUDY OF MPRAESO AND VUME IN THE EASTERN AND VOLTA REGIONS RESPECTIVELY OF GHANA.

BY

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DECLARATION

I hereby declare that this submission is my own work towards the award of a Doctor of Philosophy (PhD) and that to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree in the University, except those that are referenced accordingly.

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ABSTRACT

The traditional production of earthenware bowls in Ghana, as any other production activity, generates environmental and health issues over its production cycle. Over the years, little attention has been paid to the impacts related to earthenware production and use in the country. A common and useful tool in evaluating the environmental impacts of a product and promote its sustainability is the Life Cycle Assessment (LCA) tool. This thesis presents a comparative study of the life cycle of traditional earthenware pots produced in Mpraeso and Vume, in Ghana. The LCA methodology employed considered the International Organization for Standardization (ISO) 14040 rules and data from the potters on the production cycle. The unit of analysis was 1kg of the product and the scope of the study was from cradle to grave to examine the stages of the earthenware pot, a commonly used product in Ghana. At the production stage of the cycle, several analyses were carried out on raw materials. Plasticity of raw materials including raw clays, mixed clays and clay additives were performed according to ASTM D4318-05 methodology to ascertain the plastic limit of the substances. Mineralogical analyses of raw materials and pots were ascertained by Scanning Electron Microscopy (SEM). Physio-chemical properties of the clay were also studied, likewise, heavy metals were measured using the Atomic Absorption Spectrometer (AAS). Possible leaching of heavy metals from pots into food through the processes of grinding, serving and storage of food at different temperatures at the use stage were also examined. Further, the human health risk impact of the production and usage of earthenware pots were assessed employing the USEPA health risk and the cancer risk models. Additionally, the pottery socio – cultural issues and perception on production methods and environmental impacts of the industry among the 2 communities were verified through the administration of questionnaire to the potters. The data was analyzed by Principal Component Analysis, Pearson coefficient of correlation and Analysis of Variance. Clay mineralogical and chemical composition showed that the clays of Mpraeso and Vume are composed mainly of Si, Al, Fe, smectite (montmorillonite), kaolinite, illite and quartz as major minerals, and the plasticity of the clays increases with the addition of a temper. There were gender and socio-cultural systems governing the pottery industry in the study areas. Indigenes were not happy with the mass destruction of the environment coupled with no plan of reclamation. Leaching and health risks analyses indicated that, food consumption and storage in unglazed pots is associated with metals of Fe, Co and Ni which were found to be above WHO/FAO recommended levels. More so, human contact during processing and inhalation during extraction over a long period could affect indigenes health. Further assessment of the environmental impact by ReCipe endpoint method in Simapro 7.1 software during the stages of extraction and firing using the traditional methods of production showed intense devastation. The results also demonstrated that energy used in the industry was the major contributor towards resource depletion, environmental and health impacts in the industry. There is the need therefore, for the regularization of the industry by National Board for Small Scale Industry, Environmental Protection Agency, Environment and Sanitation office for health, safety and environmental protection since there are some socio-economic and environmental implications of the pottery production cycle. Regulations and training will also ensure economic benefits to local assemblies and national government through taxation and foreign exchange earnings.

DEDICATION

This work is dedicated to my family.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
EDS	Energy dispersive system
EU	European Union
FAO	Food and Agricultural Organisation
ISO	International Organisation for Standardisation
LCA	Life Cycle Assessment
MFA	Material Flow Analysis
PCA	Principal Component Analysis
PPb	Parts per billion
SDG	Sustainable development goals
SEM	Scanning Electron Microscopy
SETAC	Society of Environmental Toxicology and Chemistry
USEPA	United States of Environmental Protection Agency
USFDA	United States Foods and Drugs Board
WHO	World Health Organisation

CHAPTER ONE

INTRODUCTION

1.0 Background

Clay as an industrial raw material may not be high on the radar of valuable minerals but affects life on earth in far reaching ways because of its use in pottery making and other products like bricks and tiles. From primeval time's people all over the world has used clay to mould pots, bowls, vases, floor tiles and a wide range of other products used on regular basis. According to De Guire (2014), as early as about 400 B. C. earthenware pottery was produced on a mass scale in many parts of the world. This wide, purposeful use of pottery supported the local agrarian community, and as such was heartily encouraged (Walsh & Friztlan, 2014).

Today the ceramic industry found under the manufacturing sector has a GDP of $23.86 billion worldwide. In addition, the ceramics market in a global context is expected to reach between $287 billion and 408 billion dollars from 2018 to 2022 respectively with China as a key player (Ceramic Industry, 2015). According to a recent report by Grand View Research Incorporation, funding for ceramic projects in developing countries like Indonesia and Malaysia has increased, because ceramics is contributing significantly to economic growth and raises both the technological stock and skills of a country towards national development (Rajesh, 2013).

In Africa, pottery has a long history as one of the oldest arts. The arts contribution to South Africa's GDP is 15.2% (Heritage Association of South Africa, 2013). It is speculated that the raw material for pottery production clay, abounds in the West African region (Adelabu, 2012). Studies in Sub-Saharan Africa have demonstrated the symbolic prominence of pottery making, its abundance as well as its durability. Archaeologists commonly find them during excavations providing a latent way of the human past evident and appreciated. The African traditional worships, socio-cultural events and traditions employ the services of the pot. Again, the pot plays significant roles in the preparation and storage of food and drinks and in ceremonies like naming of children, puberty, marriage and death rites (Mulaba-Bafubiandi *et al*., 2015). These have sustained the pottery industry to present.

In Ghana, the story remains unchanged as pottery making continues to be an integral part of many communities within the country. The wealth of clay minerals in Ghana supports its rich and historic traditional pottery industry that dates from the Stone Age (Boachie-Ansah, 2011). The procedures for making the craft vary in different communities of the country. Even though pottery plays a conspicuous part in the daily lives of the Ghanaian, the industry has not been given the needed attention hence its struggle to stay afloat in the nation (Nortey *et al*., 2017). This situation is threatening the survival of the indigenous pottery sector in Ghana.

In most Ghanaian cultures' pots are view as symbols of hospitality and generosity, a much-admired quality among Ghanaians. Thus, these pots are made to contain precious and sometimes scarce liquids (e.g., water) and food that are given freely to strangers and friends alike. Recent developments in art and culture, tourism and floral industry have revitalised pottery production in the country.

It is assumed by many that the influx of fridges and blenders from modern technology in Ghanaian homes may have replaced the unique services of the pots and that the conventional utility attached to the pots has reduced. There is also another school of thought that the patronage of the earthenware has decline dramatically owing to modernization and infiltration of other materials (plastic and metal utensils) which continually replace the handcrafted pottery. Again, there is the view that, potters currently are almost facing extinction because of changes in the society (Rajesh, 2013).

The advantages of these earthen and organic products over technological ones have dawn on most homes, hence the desire to go back to them (Ziaee *et al*., 2017). The indigenous production process and products of pottery in Mpraeso and Vume employed techniques in raw material extraction, processing, use and end of life which marks the beginning of another production cycle.

However, the production of these traditional earthenware products is multifaceted with pervasive health and environmental problems. In a traditional craft like pottery, compatibility with the natural environment does exist but aspects of the production cycle have not suited with the health and environmental protection. Various types of environmental pollution are generated in the ceramic industry resulting in environmental degradation and destruction including air, water, and soil to mention a few. The major of which is air pollution, which leads to several impacts on earth like, ozone layer depletion, global warming, acidification as well as eutrophication (Muthukannan *et al*., 2018)

In Ghana, no comprehensive studies have been carried out on the clay industry and the impacts thereon the environment, health of the potters and the communities. Therefore, this study for the first time, seeks to identify and quantify environmental and health impacts of pottery industry through a Life Cycle Assessment (LCA) of every stage of pottery production in the traditional set up.

1.1 Problem Statement

The unceasing existence and usage of earthenware pottery products calls for rigorous health safety and environmental protocols, as the production, usage and disposal of these products may be associated with health and environmental implications. These concerns are particularly heightened in developing countries like Ghana, where the production processes remain rudimentary and often go through several stages, resulting in various health and/or environmental consequences. As countries are increasingly mainstreaming issues of environmental sustainability and good health into governmental policies in line with the SDGs, there is the need to examine the residual impacts at the various stages of the production process.

The pottery industry, including bricks, tiles etc. generates impacts over its life cycle from extraction of resources until the final disposal of the waste ceramics (i.e from cradle to grave), with consumption of resources, water and energy, air emissions, emissions to water and soil environment, waste management etc.

At the extraction stage, mining of clay is very labour intensive as well as environmentally degrading resulting in the destruction of large tracts of lands, creation of sinkholes impacting on hydrologic ecosystems, dust production, etc (Suraj & Neelakantan 2014).

These sinkholes serve as breeding grounds for mosquitoes, death traps for humans and animals alike (Fayiah, 2020). Forests destroyed affects biodiversity, carbon sink stock and agricultural lands (Robertson, 2017; Asante-Kyei *et al*., 2014; Sarkodie *et al*., 2014).

In the case of processing as dry clay is mixed with water, particulate matter is then emitted into the atmosphere. Consequently, there has been frequent cases of respiratory diseases among potters emanating from the chronic inhalation of large amounts of free silica during clay mixing. This results in high susceptibility to respiratory tract infections (RTI) since the lungs become instinctively clogged (Smith, 2006).

Other associated health challenges include injury, skin diseases, respiratory infections (cold, flu, sneezing etc) (Sanjelet *et al*., 2016; Soewardi *et al*., 2016; Wanave *et al*., 2013).

There is also ergonomics which is the postural discomforts of workers in general. Since the traditional potters do a lot of specific tasks continually, they are susceptible to repetitive strain injuries (Mali *et al.*, 2016; Soewardi *et al.*, 2016). Additionally, due to lack of proper workstations, carrying and lifting of heavy working materials like bags of clay and glaze, causes back injury, shoulder disorders, fatigue and musculoskeletal related disorders among workers in the pottery industry (Wanave *et al*., 2013).

The traditional pottery processing also generally involves high temperatures which bring about emissions of greenhouse gases (carbon dioxides, nitrogen oxides, sulphur oxides), heavy metals, etc. to the air (Kharol *et al.*, 2020; Quinteiro *et al.*, 2012; Toledo *et al.*, 2004; Abrahao & Carvalho, 2017). The large amount of greenhouse gases (GHG) emitted contributes to global warming. In the final stage, pots are sorted out in the course by unloading from the bonfire or the kilns manually, packed and transported for sale.

In Ghana and around the world however, there is paucity of data or information on energy consumption, environmental implications as well as GHG emissions from pottery production.

The anticipated problems have led to a number of researches to be undertaken on the industry using the life cycle assessment especially in the developed world with some studies demonstrating the most important impact categories to global warming, human toxicity and acidification (Almeida *et al*., 2011; Bovea *et al*., 2007; Mahalle, 2010). In Ghana, the application of LCA to evaluate environmental loads and their health implications in the pottery industry is lacking. This comprehensive research assessed the relationships of production, pollution, and protection due to their inter-connectivity and apply this nexus to the traditional pottery industries in Mpraeso and Vume in Ghana. These 2 towns are well known for pottery making in Ghana. Also, some research has been conducted in some aspects of pottery activities as compared to other well known pottery making towns where no data on pottery activities is avaialable. This will enhance the data collction needed for this research. The application of one of the tools of industrial ecology which is the LCA is used to support and address the symbiosis of sustainability and development in humanity's unsustainable growth and developmental path.

1.2 Research Questions

The likely questions that can be raised are

1. What is the mineral composition and the plastic limit of the clay used for the pottery in the study areas?
2. What heavy metals can leach out of the finished pottery wares?
3. What are the health challenges associated with the traditional pottery industry?
4. What is the significance of traditional pottery in the socio- economic and cultural development of the people?

5. What are the impacts of traditional pottery production on the environment?

1.3 Aim

To apply the life cycle assessment model to study and analyse the environmental and health impacts of the traditional pottery industry to promote stewardship practices for policy formulation to help decision makers in the pottery industry.

1.4 Objectives

The overall objective was to investigate the environmental, socio-economic, and health impacts of the traditional pottery industry in other to promote its sustainability in the country. The study specifically sought to;

1. To determine the mineral composition and plastic limit of the clay used for traditional pottery.
2. To investigate the leachability of heavy metals from the finished products
3. To assess health implications in the pottery industry
4. Ascertain the socio- economic impacts and cultural perceptions of people in the pottery industry.
5. To obtain scientifically valid and objective reference values for the environmental loads of the traditional pottery production by performing a life cycle analysis

1.5 Hypothesis

1. H0: The impact of the pottery industry on the environment is negligible.

   H1: The impact of the pottery industry on the environment is not negligible

2. H0: There are significant concentrations of heavy metals in traditional pots

H1: Heavy metals concentrations in traditional pots are insignificant.

1.6 Justification

The two communities are characterised by large concentrations of these enterprises serving both local and foreign markets. This shows high degree of location inertia as a huge percentage of the total ceramic units of Ghana is found in these two communities. The two enclave sites have the potential of revealing interesting real scenario cases which has the needed quality that is associated with the pottery industry to enrich the study.

Mpraeso is an Akan dominated ethnic group town in Ghana and within the Birimian rock system while Vume is Ewe subjugated and within the Dahomeyan rock formations. The study will compare and reveal the different production cycle of the two distinct ethnic groups and their impact on environment and health related issues.

Many potteries industrial setups whether large or small are examining ways of mitigating environmental degradation and health effects of pottery production due to increase in public awareness. Presently, those that are being considered are greenhouse gases effect, photochemical smog and acidification, ecosystem degradation, etc. Thus, the case study of pottery industries of Vume and Mpraeso in Ghana becomes imperative with the belief of finding solutions to improve their environmental concerns in pottery production.

Again, the clays of the geological systems from the two communities will be compared to reveal mineralogical formations that may influence the quality of the clay material used for the earthenware products.

The life cycle assessment (LCA) more importantly will aid with the compilation and examination of the inputs and outputs of materials and energy and the associated environmental impacts from the production cycle of the two towns. As indicated earlier, their activities are resource depleting and environmentally degrading. Hence this research can be considered to provide information on the different production methods, which method and product is environmentally friendly.

The study will also serve as a baseline for other research to be done on the pottery industry as there is paucity of information in this particular sector. In addition, awareness of public health impact will aid the introduction of policies and regulations to significantly mitigate the problem. Researchers will appreciate this aspect of the manufacturing industry and design policies that will bridge the gaps in the ceramic industry.

1.7 Background of the study area

The two study areas (Mpraeso and Vume) are well known localities of traditional pottery industries. Mpraeso is the capital district of the Kwahu South district in the Eastern Region and has a population size of 11,190 as at 2013. It is on latitude 034’59988’’N and longitude 043’59.999 ‘’W). The altitude of Mpreaso is 308m with total area of 1462km^2 (Fig.1.1).

Vume is in the South Tongu District in the Volta Region with Sogakope as its capital. Vume is sited at the western bank of the Volta estuary and across to the eastern bank is the Sogakope. The South Tongu District lies between latitudes 6°10^{l} and 5°45^{l} North and longitudes 30°30^{l} and 0°45^{l} East. The South Tongu District was carved from Tongu District which was established prior to1988 (Ghana Statistical Service., 2014). According to the

2010 Population and Housing Census Report, South Tongu District had a population of 87,950. The population density is high in communities along the major roads and in few other communities where the road network is good. However, the population is sparse in the north-eastern and south-eastern parts of the district. The district is largely rural with majority of its population (87.1%) living in the rural localities.

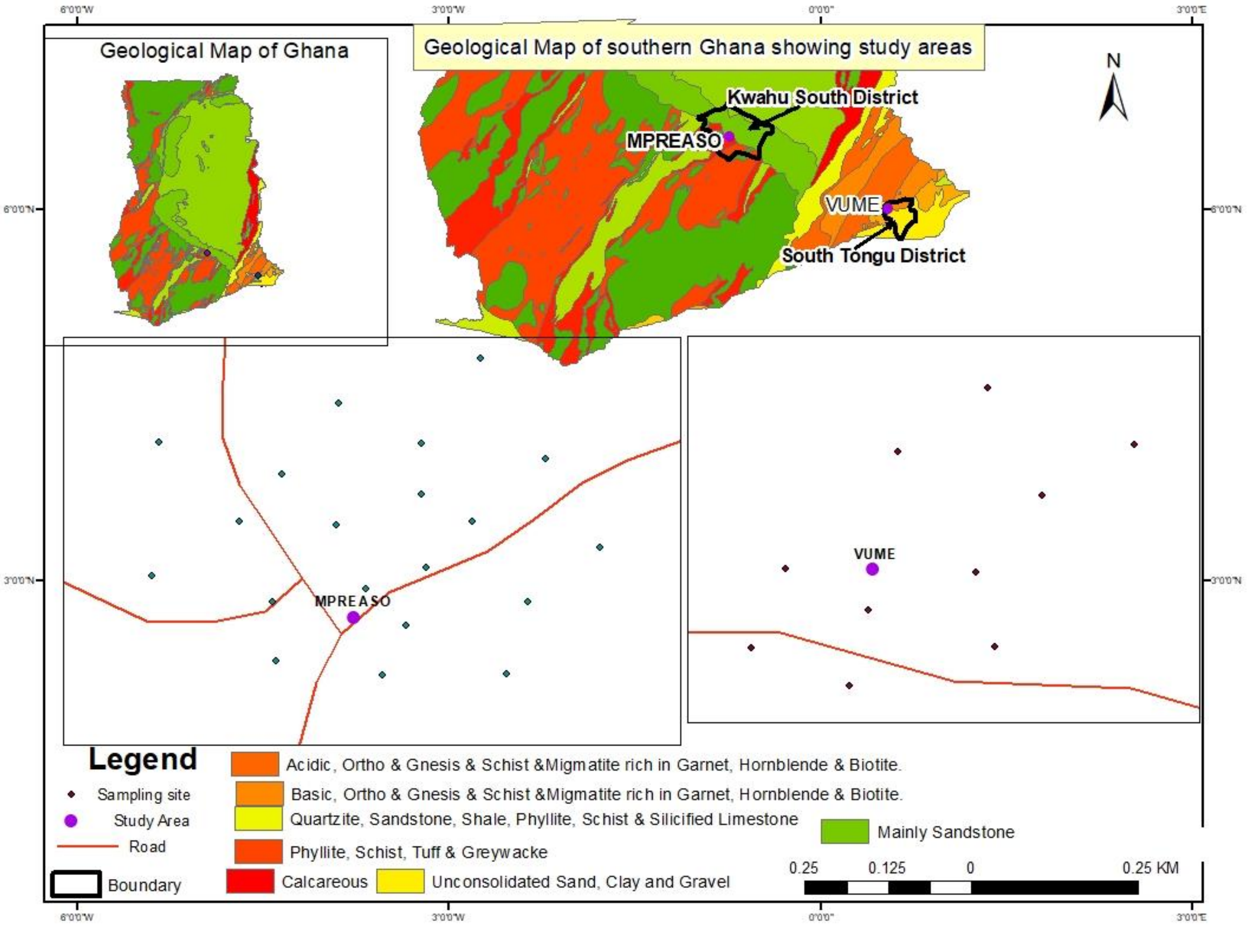


Figure 1. 1 Map of the study areas

The South Tongu District is in the southern part of the Lower Volta Basin and bounded to the north by the Central and North Tongu Districts, to the east by the Akatsi South District, to the west by the Ada East District of the Greater Accra Region and to the south by the Keta Municipality.

The South Tongu District occupies a total land area of 643.6 km^2. The district is generally low lying by virtue of its location within the coastal savannah plains but rises gradually to a height of 75m above sea level. The Volta River runs through the district to the Gulf of Guinea. Vume, Lolito, and Sokpoe are communities in the district endowed with large clay deposits which geologists have predicted to last for over 100 years if it is mined commercially and in a sustainable way (Fig.1.1). Though, the manufacture of brick and tiles from clays used in the construction industry has not been fully exploited, pottery products like earthenware, flowerpots and ornaments are produce on a medium to large scale in these communities. The geomorphological formation of the area dates back several years and lies within the lower Volta Basin. High mineral volume of clay deposits have been developed into paints and other chemical products (Asamoah *et al*., 2018).

1.7.1 Geology and soils of Mpraeso

The geology of Mpraeso is of Upper Voltaian sandstones type consisting of coarse and fine-grained massive sandstones that are thin bedded, flaggy, impure, ferruginous or feldspathic and locally inter-bedded with shales and mudstone (Fig.1.1). The sandstones are found along the boundary margins whiles shales and mudstones outcrop within the central part of the district from below the sandstone bed. Clays used in the Mpreaso pottery industry are however mined from Nkawkaw and Oframase whose soils are derived from weathered phyllites, schists, tuffs and greywackes of the Birimian system (Fig.1.2). The Birimian formation is rich in iron and most of the economically mined mineral resources of the country (Dickson & Benneh, 1995; Kesse, 1985).

1.7.2 Geology and soils of Vume

The underlying rocks in the district are metamorphic in origin. The major soils formed over these geological formations are the Ziwai-Zebe complex soils, Tondo-Motawme complex and Agawtaw-Pejeglo complex soils which are formed over the Dahomeyan acidic gneiss rocks (Figs.1.1). The district is endowed with large clay deposits at Lolito, Vume and Sokpoe communities, which are predicted by geologist to last for over 100 years if mined commercially in a sustainable way (Figs.1.2). Rocks of the Dahomeyen composed of quartz, feldspar, epidote, hornblende, garnet and mica minerals (Kesse, 1985).

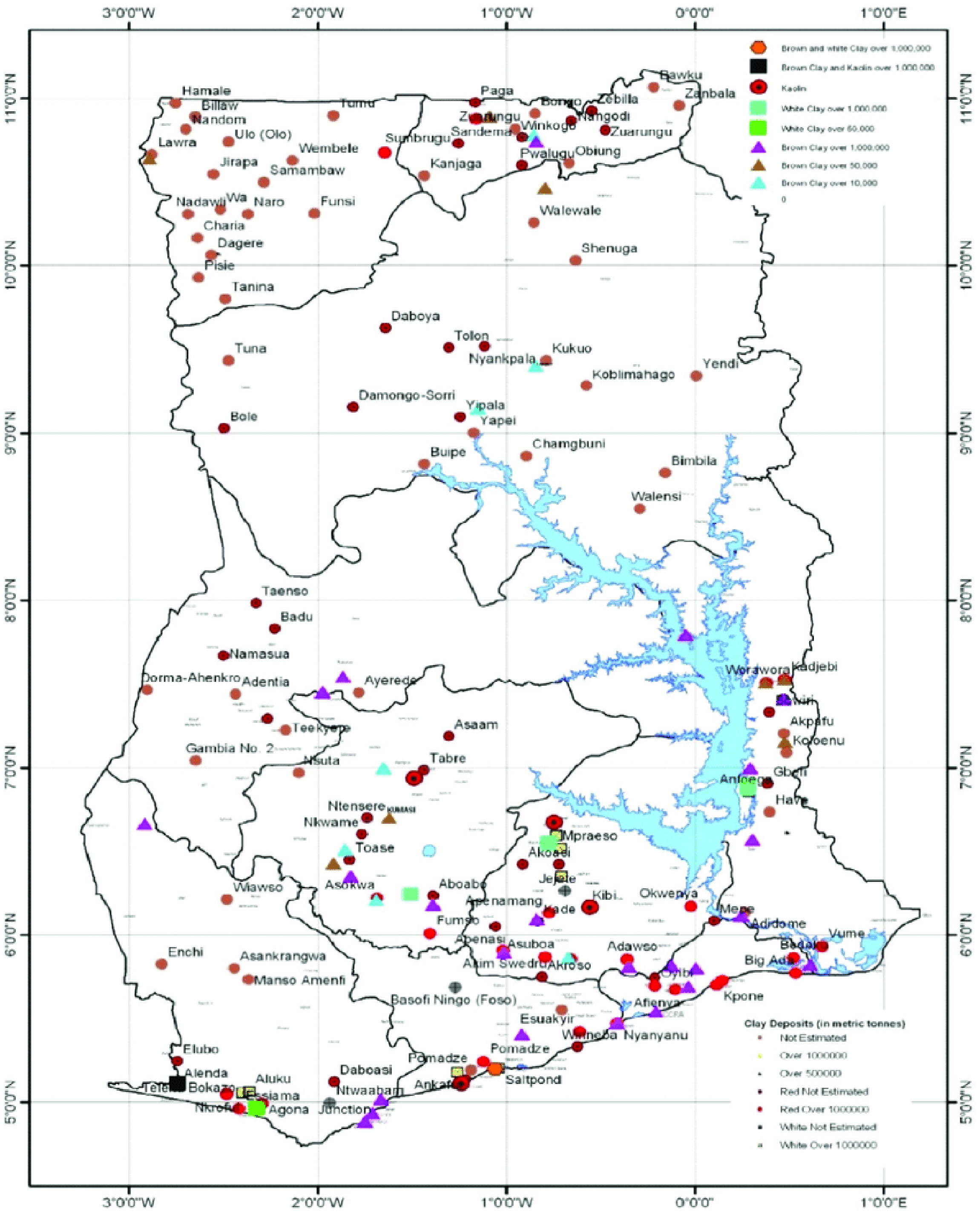


Figure 1. 2 A map of clay mineral deposits in Ghana. Source: Geological Survey Department

1.8 Structure of the thesis

The study is a comparative one and is organised into nine chapters.

- The first chapter gives the background information on the life cycle of the earthen ware pot and the underpinning environmental and health issues that are of interest to society. The chapter discusses the problem to be studied, questions that the study seeks to address and outlines the objective of the study. The chapter also gives a brief geographical background of the study areas.
- Chapter two reviews existing literature on Life Cycle Assessment (LCA), and its applications and studies in Ghana.
- Chapter three concerns the mineralogical, plastic limit and physiochemical analyses of the clay and pot materials.
- Chapter four is pottery production in the study area and its functional, socio-cultural and economic importance in societal dispensation.
- Chapter five is leachability of heavy metals from the finished products.
- Chapter six is the health implications of humans in the life cycle of the earthenware pot.
- Chapter seven gives insight of regulatory bodies responsible for the entire industry and chapter eight is the environmental load impact using the Simapro model.
- The last chapter, chapter nine dwells on the summary, limitation, and recommendations of the study. The entire presentation demonstrates the interpretation of the earthenware pot's Life cycle within the scientific, social, economic, health and environmental context.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The focus of this thesis is to use the Life Cycle Assessment (LCA) which is an environmental tool in the application of a specific case of the traditional pottery production industry in Ghana. The environmental criteria into decision making especially concerning the traditional pottery industry is essential. A sustainable approach considering the three pillars of sustainability thus social, economic and environmental issues were reviewed in this chapter. A review of existing literature suggested that information on the traditional pottery production is sparsely distributed and incomplete. The traditional pottery industry served as a test case for identifying stakeholders, quantifying economic and environmental issues.

The first section defined sustainability and its application in a conceptual framework by Ehrlich & Holden (1974). This followed a brief discussion on the energy usage in the pottery ceramic industry. After clearly describing sustainability and energy, the chapter presents brief history and review of LCA.

The second section discussed studies of clays and potteries in the study area, reviewed clay deposits and harvesting in Ghana and subsequently looked at the sociocultural and economic significance of the industry. This followed an assessment of environmental sustainability of the pottery industry, which considered land pollution, air pollution, and the health impacts of the pottery industry.

2.1 The Life Cycle Assessment (LCA)

2.1.1 The Concept of Sustainability in the LCA

Several environmental activities and concerns relate to the traditional pottery industry in developing countries like Ghana. These concerns include land degradation from clay extraction and forest degradation due to the dependence on biomass energy and air pollution from the emissions during firing of the pots. These issues raise several environmental concerns of sustainability which are embedded in the Life Cycle Assessment, hence the need to review the concept of sustainability regarding the environmental issues outlined above.

Industrial production and consumption culture are encountering dramatic changes due to pollution and waste problems; non-renewable resource consumption and rapid growth in the world population (Nahman & Lange 2009). This change in increased production and or consumption demands makes sustainability a strategic issue for discussion. Sustainability is the capacity to endure (Spreitzer *et al.*, 2012). It is an influential, but abstract concept that needs to be incorporated in products, processes, and systems to encourage minimization of environmental impacts (Maxwell *et al*., 2006)

In performing a holistic analysis of products, processes and systems from a sustainability perspective, there needs to be an integration of environmental, economic, and social factors in the design (de Jonge, 2012; Roseland, 2000; Weidema, 2006;). Sustainability according to the Brundtland Commission of the United Nations on March 20, 1987 is ‘development that meets the needs of the present without compromising the ability of future generation to meet their own needs’. This concept is to ensure that resources are always available. It answers the question of supplying society's needs from the environment or future generations' ability to meet their needs. Incorporating the sustainability concept into product, process or system is very important especially now that we have many options in meeting our demands. The onus therefore lies on us to choose the "best" option with respect to environmental concerns.

There are three pillars of sustainability as illustrated in Fig. 2.1, which are social, economic and environmental (Clune & Zehnder 2018).

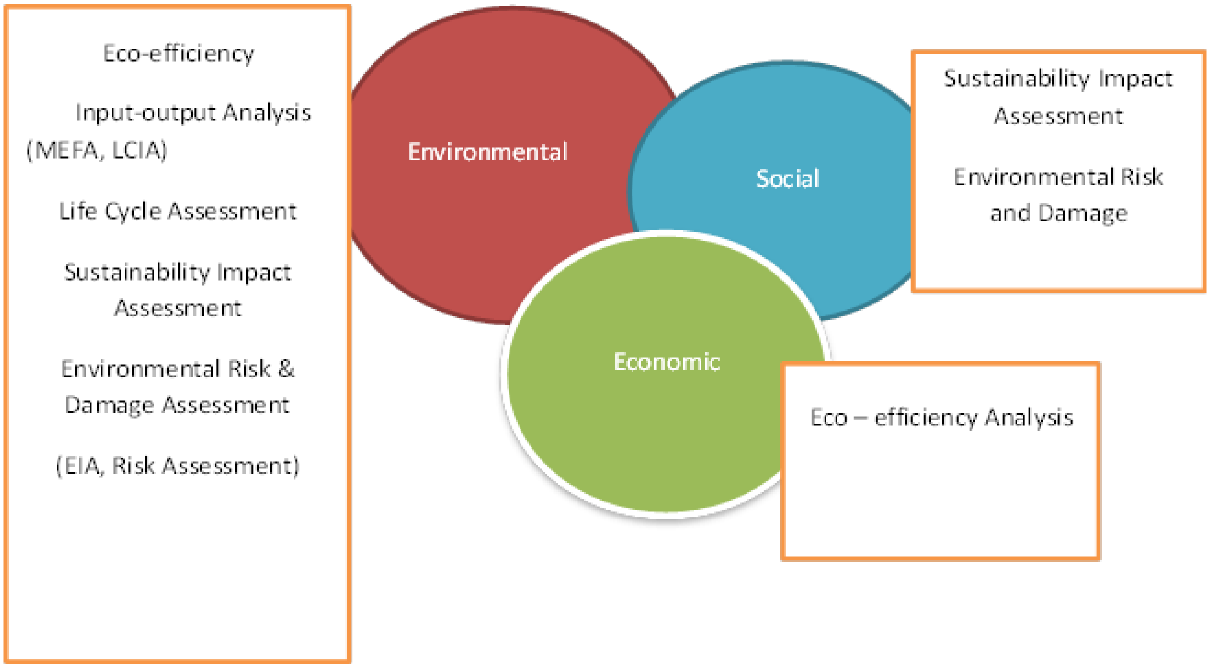


Figure 2. 1: The three pillars of sustainability.

The economically sustainable pillar ensures that goods and services are produce on a continuing basis, to maintain manageable levels of government and external debt, which prevents extreme sectoral imbalances that might damage agricultural or industrial production (Klöpffer, 2008). A socially sustainable system achieves distributional equity, adequate provision of social services including health and education, gender equity, and political accountability and participation. The environmental pillar guarantees the sustainability of production and consumption of goods and services (Heijungs & Guinée, 2010).

An integration of the three pillars in a design gives the overall sustainability without fluctuating environmental burdens (Figure 2.1). Clearly, these three elements of sustainability introduce many potential complications to the original simple definition. The goals articulated are multidimensional, raising the issue of how to balance objectives and how-to critic success or failure.

A little touch on economic and social pillars is employ in this study, for the evidence of a holistic approach but focus will mostly be on the environmental pillar. The reason is the growing global awareness of the importance of protecting the environment. A broader discussion of the social/societal responsibilities can be found in Alting (1995) and Saemann (1995) while that of economics is in Hunkeler *et al.,* 2008.

Technology together with advanced economy provide goods and or services in myriad ways giving us choices on productions and products (Hendrickson *et al.,* 2006). To make those choices more intelligently, society needs to know not only the market price of each alternative, but the associated health and environmental consequences. In understanding the magnitude of the pressures on resources in the environment, a conceptual framework by Ehrlich & Holden (1974) explained mathematically in terms of the relationship between human consumption, affluence and population growth.

The relationship indicates that Environmental impact (I) is because of population numbers (P), Affluence (A) and Technology (T). This concept as indicated in equation 1 quantifies the magnitude of the pressure on resources in the environment.

$$I = P*A*T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1.$$

Population growth has a marked influence on levels of consumption and the efficiency of resource use (Ehrlich & Holden 1974). If technology (T) can be null by ensuring clean technological processes, then there will be no environmental impacts (I).

In an official United Nations population estimate, the world population, which was 6.9 billion as of May 2009, increased to 7 billion early 2012 and will exceed 9 billion people by 2050. Most of the increase will be in developing countries whose population is projected to rise from 5.6 billion in 2009 to 7.9 billion in 2050. It is the combination of population increase in the developing world and unsustainable consumption levels in the developed world that poses a stark challenge to sustainability (Blanc, 2017; Perveen, 2004)

2.1.2 Energy consumption

Along the value chain of the pottery industry, quiet a huge amount of energy is consumed. During extraction through to the manufacturing stage especially when drying and firing, most environmental hotspots can be identified (Ibáñez-Forés *et al*., 2013). At the stage of firing, energy in the form of electricity, coal, thermal energy and fuelwood are often used.

In Ghana and particularly the study areas, fuelwood is the major source of energy consumed during pottery production. This source of energy is not strange as in a worldwide context, the use of fuelwood is more evident in developing countries and forms a vital component in the supply of primary energy, especially for domestic and industrial use.

In the ceramic pottery industry, a number of authors have researched into energy requirement and emissions (Almeida *et al*., 2010; Bovea *et al*., 2010; Goldoni *et al*., 2006; Koroneos & Dompros 2007; Nicoletti *et al*., 2002; Tikul & Srichandr 2010), consumption and efficiency improvement of the industry (Delpech *et al.*, 2018; Li *et al.*, 2018; Schwob, *et al.*, 2009; Zhao *et al.*, 2014). Ciacco et al., 2017 found that the firing and sintering stages of the ceramic tile industry recorded the highest level of energy consumption.

Quinteiro *et al*. (2012) also discovered that the manufacture stage uses about 90% of energy. However, Quinteiro *et al.*, (2012) also showed that energy consumption is strongly dependent on the dimensions of the earthenware ceramic pieces. Peng et al. (2012) evaluated the LC of the traditional pottery industry to estimate net energy consumption to identify the hotspots, improve the production process, and determine if solar energy is suitable as alternative energy source for production. It was realised that demand for energy during pottery production increases as the population upsurges.

2.1.3 Industrial Ecology

Industrial ecology is the study of material and energy flows through industrial systems Lowe (1993) defines industrial ecology as a recognised system designed for the environment in achieving a zero-waste principle. This industrial metabolism is viewed as a big approach used in materials and flows to manage the industries and natures interface. Graedel *et al* (1995), believes that Industrial Ecology is the science of sustainability as it optimizes energy and capital (human and monetary). Resources are also optimize thus ensuring less consumption and waste.

The industrial ecology framework for environmental management is aimed at identifying and implementing strategies that reduce environmental impact of industrial systems. This framework appreciates the interaction between society and its environment, and the impact industry has on the environment. Extracted raw materials and natural resources from the earth are transformed into products and services that meet the demands of the population. This makes the provision of goods and services rendered in an environmentally friendly way.

Industrial ecology promotes lower natural resources use and new discoveries for waste materials or by products. This makes systems more efficient and sustainable thus products are design to minimise adverse environmental impacts and maximise beneficial environmental impacts. Industrial ecology is therefore a multidisciplinary field that combines aspects of economics, engineering, sociology, technology, and environmental science.

Ehrenfeld et al. (1997) explained the principles of industrial ecology as improving the efficiency of industrial processes through redesigning of products, processes, equipment, and the reuse of materials to conserve resources. The use of less virgin materials and the energy sources that have less or no impact on the environment is encouraged in the study of industrial ecology. The ideology of doing more with less thereby increasing the efficiency of resources is enhanced and this promotes sustainability of resources. In encouraging new dispensations, environmental policies must be aligned with industrial ecology concepts, which is expected to encourage a more comprehensive index in measuring the nation's wealth.

2.2 Theories and concepts of industrial Ecology

2.2.1 Industrial ecology tools

Industrial ecology has grown swiftly in the last few decades and some authors argue that it is now a well established field of research (Ehrenfeld, 2004). Two industrial ecology tools are used in research, and they are Material Flow Analysis (MFA) and Life Cycle Analysis (LCA).

2.2.2 Material Flow Analysis (MFA)

Material Flow Analysis (MFA) is a method that categorizes and compiles all flows into and out of a system and their impact in the environment (Rincón *et al.*, 2013). This makes the method to establish an inventory for LCA hence LCA can be an impact assessment of MFA results. The tool uses its results as a basis for managing resources, the environment, and wastes.

Unlike the LCA that strives for completeness and can be applied to as many substances as possible, MFA strives for transparency and manageability limiting the number of substances to be analysed. This has made some environmental practitioner's critic the inappropriate use of MFA in comparative studies. Since the current study focuses on comparing the production processes of traditional pottery in Vume and Mpreaso, the appropriate tool to use within industrial ecology is the Life Cycle Analysis (LCA).

2.3 The Life Cycle Assessment tool

2.3.1 History of the life cycle Assessment

Wassily Leontief was the first to develop the LCA and did many works in the 1930s. Subsequent studies on life cycle aspects of products and materials continued from the late 60s and early 70s and focused on issues such as energy efficiency, the consumption of raw materials and, to some extent waste disposal. Prior to that, in 1969, the first multi- criteria study for Coca-Cola was conducted by Midwest Research Institute to make choices between glass and plastic for container, internal or external container productions and end of life options. This was under the supervision of the resource and environmental profile analysis (EMPA) of Coco-Cola (USA) as indicated in Figure 2.2. The results for this study, which was never published, was that plastic bottle was the best container.

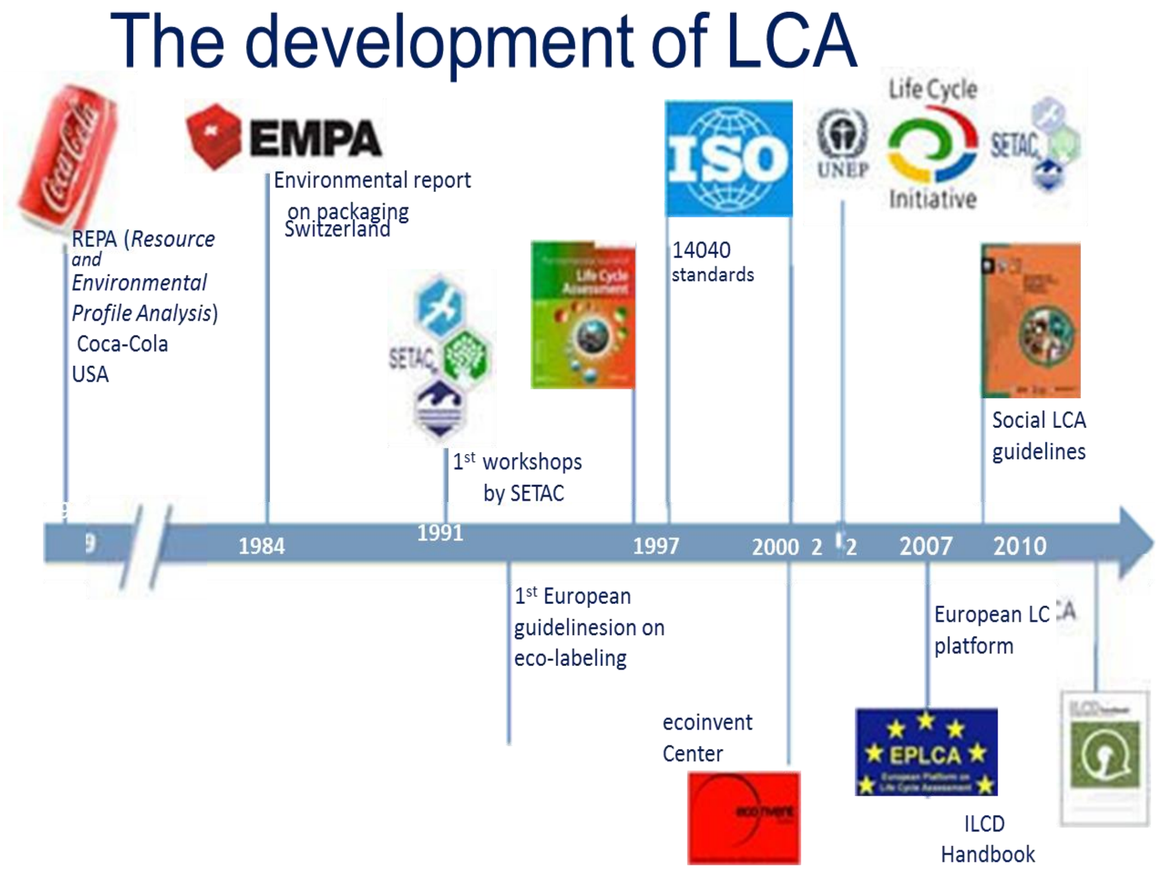


Figure 2. 2: LCA development from 1969 to 2010.

This was contrary to expectation and questions of validity then occurred which led to calls by the scientific community for standardisation process. Early independent studies were also piloted both in the United Kingdom for Schweppes by Ian Boustead and in Sweden for Tetra Pak by Gustav Sundström. Their studies spotlighted packaging and waste management.

However, from 1969 until 1984 not much activity or work on LCA was carried out (Meadows *et al*., 1972). The development of LCA became much more distinctive after 1984 with the surge of environmental interest. In 1984, a packaging organization in Switzerland came up with an environmental report on environmental issues and packaging using the Ecoinvent organization, which was widely criticised (Environmental Protection, 1984). It was not until the early 1990s that the term life cycle assessment came into general use as earlier studies were called Eco balances, resource and environmental profile analyses, or cradle- to-grave studies. Currently, Eco invent is the biggest database centre in the world in terms of life cycle inventory data analysis.

Then in 1991, SETAC (Society of Environmental Toxicology and Chemistry) got involved in LCA as well. SETAC is an international environmental professional's organisation with members from all over the world. They attempted to harmonise the methodological proceedings of LCA internationally. This yielded the first workshop in 1991 where a document consisting of the procedural framework for LCA was made available with regards to LCA.

Around the same time in 1992-1993 the first European guidelines were on ecolabelling which was followed closely in 1997 with the life cycle assessment journal as indicated in Figure 2.2. This is an international journal dedicated to publishing life cycle assessment papers. The initiation by SETAC to standardise the LCA process led to the well-known International Organisation for Standardisation (ISO) 14040+ 44 series.

Thus between 1997 and 2000, the (ISO) 14040 defined Life Cycle Assessment, as the compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system during a product's lifetime. The United Nations Environmental Program (UNEP) in 2002 also got involved in LCA. Some members of the UNEP were also members of SETAC so there was a decision to merge the two.

Presently there is UNEP SETAC life cycle initiative with the aim of combining efforts to get the life cycle assessments done better round the globe. After outlining the history of LCA, subsequent write-ups introduced the present methodological framework of LCA (Fig.2.2), explaining the need for a whole system modelling approach. All these are to help build consensus as well as methodological robustness in LCA.

2.3.2 Types of LCAs

The rapid surge of interest in ‘cradle to grave’ assessments of materials and products is an indication of a groundswell of opinion that life-cycle assessment methodologies are among the most promising new tools for a wide range of environmental management responsibilities (Curran, 2008; Huang & Hunkeler 1995).

The Life Cycle Assessment applications is still developing, and several unresolved issues remain to be addressed. Many practitioners increasingly recommend LCA as an important decision-making aid in environmental system management (Azapagic, 1999; De Benedetto & Klemeš 2009). Since sustainability gained importance for decision making in policy, business and education cycles interested in sustainability assessment tools has expanded and different assessment tools have been developed (Hoogmartens *et al*., 2014). These tools were used to measure and compare environmental impacts of human activities for the provision of goods and services.

Within the widely applied sustainability tool of LCA, further sub methodologies that focus on different aspects of sustainability may be distinguished. An integrated framework in figure 2.3 indicates the various interactions between sustainability assessment tools. An environmental LCA (eLCA) is the conformist type of LCA that assesses environmental impacts such as materials, energy and waste flows of a product from cradle to grave (Hunt *et al.*, 1992). This comprehensive environmental scope of eLCA embraces greenhouse gases, water emissions, ecosystem quality natural resources and human health (Weidema *et al.*, 2008).

In performing a holistic analysis and improving sustainability two types of LCA; environmental LCA (eLCA) and social LCA (sLCA) are developed to be applied separately or in combination (Andrews, 2009; Jørgensen et al., 2008; O'Brien *et al.*, 1996; Tillman, 2000; Weidema *et al.*, 2008).

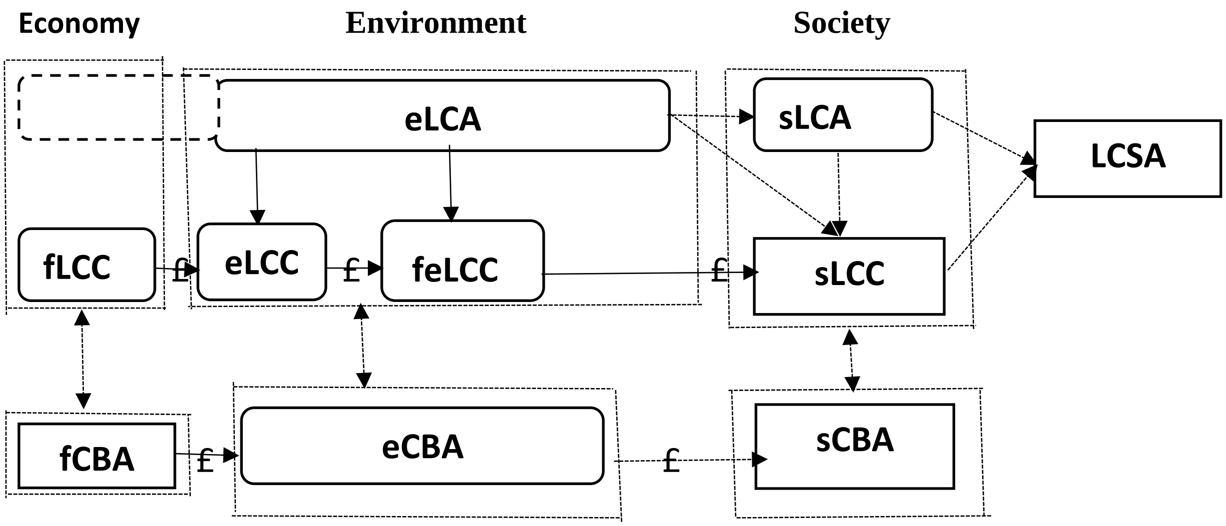


Figure 2. 3 Adopted from Hoogmartens et al., 2014: Interactions of different sub methodologies of sustainability within widely applied LCA tool.

KEY:_eLCA - Environmental Life Cycle Analysis, FeLCC - Full Environmental Life Cycle Costing,_sLCA - Social Life Cycle Analysis, sLCC - Social Life Cycle Costing, LCSA - Life Cycle Sustainability Assessment, fCBA - Financial Cost Benefit Analysis, fLCC - Financial Life Cycle Costing, eCBA - Environmental Cost Benefit Analysis, eLCC - Environmental Life Cycle Costing and sCBA - Social Cost Benefit Analysis.

Social LCA, an adolescent tool, is developed based on the already well-acquainted eLCA. This makes literature to propose different methodological alternatives for inventory analysis and impact assessment stages for sLCA. In this study, the eLCA procedure was applied to give an integral idea of trends and methods that the pottery industry can relate to during different stages of production. The pottery industry is perceived to be an industry that emits numerous greenhouse gases, destroys the ecosystem, and affects human health at various stages during production.

There are also attributional LCA (ALCA) and Consequential LCA (CLCA). The United Nations Environmental Program and SETAC (2011) define attributional studies as methods that provide information on what portion of global burdens can be associated with a product and its life cycle. Attributional LCA (ALCA) is applied to assess the environmental burden of a product assuming a *status quo* situation. The Attributional LCA describes the pollution and resource flows within a chosen system attributed to the delivery of a specified amount of the functional unit (Bamber et al., 2020; Ekvall, 2019; Hunkeler *et al.*, 2008). Tillman (2000) also described this approach of LCA as “accounting LCA”.

Consequential LCA (CLCA) on the other hand is used to assess environmental consequences of a change in demand. CLCA estimates how pollution and resource flows within a system change in response to a change in output of the functional unit (Ekvall, 2019; Hunkeler *et al.*, 2008; Weidema *et al.*, 2008) This approach uses marginal data for assessing the consequences of a system because of changes in decisions (Finnveden *et al.*, 2009). Ekvall et al (2005) is of the view that both ALCA and CLCA are used for the purposes of decision-making and learning.

Many authors argued that ALCA is more suitable and broadly applied when decisions are not going to be made by policy makers immediately to indicate models on consequences of decisions (Baitz, 2017; Yang, 2016; Tillman, 2000). This study therefore can be situated within the ALCA approach because of the environmental hotspots identification and the averages of data to be used, which reflects the actual physical flows of the system used. However, it is not clear what the effects of these choices are on outcomes (Thomassen *et al.*, 2008).

The popularity of LCA and related life-cycle approaches is growing rapidly globally. Industry, government, and non-governmental organisations are all applying the tool and exploring its possibilities. The industrial approach to holistic environmental management is to review products, processes, and activities. Most companies especially in developing countries do not use LCA daily. However, in countries where companies have group of employees working full time on LCA use, the results are used to identify hotspots in the production process for specific product. LCAs are also used to make comparative studies for different products or production processes.

2.4 Sectoral applications of LCA

The application of the Life Cycle Assessment tool in production cycles helps to inform our choices thereby appreciating the sustainability challenge in the world. Applications of LCA that have received a good deal of attention are comparisons of paper, plastic and ceramic cups, paper and cloth diapers, and paper, plastic, and durable shopping bag (Ahamed *et al*., 2021; Cordella *et al.*, 2015; de Haes, 1993; Foteinis, 2020; Jung *et al.*, 2011; Mattila *et al*., 2011; Potting & van der Harst 2015; van der Harst *et al*., 2014).

Currently there is no entire life cycle analysis research data available on traditional pottery industry worldwide. Those available focused on the construction industry where ceramics have been analysed in comparison with other materials (Han *et al*., 2015).

Two studies conducted by Quinteiro-Filho *et al*., (2012) and Quinteiro *et al*., (2012) on earthenware addressed the effects of emissions and energy. Comparative study of different traditional pottery production cycles and their impacts on the health of the potters are rarely conducted. Many other researchers applied the LCA to assess the environmental behaviour of different types of construction materials.

The literature review shows many examples of the application of LCA to the industrial ceramic sector. A tabulation of some works is represented in Table 2.1. Quinteiro et al., 2012 is the only work on LCA in traditional earthen ware. Other works have been on ceremic products like glazed tiles and marbles (e.g. Benveniste et al., 2010; Tikul, N., & Srichandr, 2010 etc see Table 2.1). Besides the tabulated works other studies have done a comparative analysis of different products.

Nicoletti et al. (2002) used the LCA method to compare flooring materials thus, ceramic and marble tiles. A better environmental profile was found for marble tiles. A better environmental profile was also observed for marble tiles by (Almeida *et al*., 2016; Bovea *et al*., 2007; Ros-Dosdá *et al*., 2018; Rydh et al., 2005). Asif et al. (2007) did analysis of construction materials typically used in dwelling homes: wood, aluminium, glass, concrete and ceramic tiles. Other LCA studies in the construction industry are by Bakhoum *et al*. (2015) and Dimitrokali *et al*. (2010) on eco-friendly and smart buildings, Koroneos, C., &

Dompros (2007) brick production, Traverso & Finkbeiner (2010) and Finkbeiner *et al*. (2010) on marble tiles.

Tikul & Srichandr (2010) researched on the environmental impact assessment of ceramic tile production in Thailand. In their research, the results showed that global warming impact on ceramic tile and human toxicity impact values were quite conspicuous and rather high compared with existing data in current literature. Indeed, the use of ceramics in our daily activities is projecting in our daily lives making consumers very particular with their choices.

Table 2. 1 Applications of LCA in the ceramic industry

Author	Ceramic Industry (TILE)	Pottery Earthen-ware	Title and country	ENVIRONMENTAL IMPACT STUDIED								
				GWP	OD	Acid	EU	PS	HTA	HTW	HTS	Energy
Nicoletti *et al.*, 2002	x		Comparative Life cycle Assessment of flooring materials: ceramic versus marble tile. Italy	x		x			x			x
Goldoni *et al.*, 2006			A case study about LCA of ceramic sector: application of life cycle analysis results to the environment management system adopted by the enterprise Italy									
Koroneos *et al.*, 2007	x		Environmental assessment of brick production in Greece	x		x						x
Ibáñez-Forés *et al.*, 2011	x		Life cycle assessment of ceramic tiles. Environmental and statistical analysis. Portugal	x	x	x	x	x	x	x	x	x
Benveniste *et al.*, 2010			Sectoral life cycle analysis of ceramic tile Spain	x	x	x	x	x				
Tikul *et al.*, 2010			Assessing the environmental impact of ceramic tile production in Thailand	x					x	x	x	
Cargnin et al (2012)	x		Case Study of the comparative Life cycle analysis (LCCA) of glazed porcelain tile and red body stone ware tile production Brazil	x					x	x	x	
Peng *et al.*, 2012)	x		Co2 emission calculation and reduction option in ceramic tile manufacture – the Foshan case China	x								
Mezquita *et al.*, 2012	x		Energy optimization in ceramic tile manufacture by using Thermal oil Spain									x
Quinteiro *et al.*, 2012		X	Allocation of energy consumption and greenhouse gas emissions in the production of earthen ware ceramic pieces. Portugal	x								x
Tikul, 2014.	x		Assessing environmental impact of small and medium ceramic tile, manufacturing enterprises in Thailand	x	x	x	x					x

Han et al., 2015		Life Cycle assessment of ceramic façade materials and its comparative analysis with three (3) other common Façade materials China	x	x	x	x	x	x	x	x
Ciacco et al., 2017		The energy consumption in the ceramic tile industry in Brazil	x							
Abrahao et al., 2017	x	Environmental Impacts of the red ceramic industry in North East Brazil	x					x	x	x

KEY

GWP – Global Warning Potential, EU – Eutrophication, OD – Ozone layer Depletion, HTA Human Toxicity Air HTS Human Toxicity Soil HTW Human Toxicity Water. PS Photochemical Smog -

Bovea *et al.* (2010) analysed the environmental performance of ceramic tiles and the possible improvements related to the productive cycle. The firing process was identified as the critical process in most of the impact categories of which proposals were put together to correct the situation. Mahalle (2010) conducted a comparative LCA to compare the environmental performance of hardwood flooring with some alternative flooring types: carpet, ceramic floor tiles, vinyl flooring, cork, and linoleum.

The study observed that Carpet flooring material had the highest negative environmental impact. There are a number of works in the construction industry (Han *et al*., 2015; Ibáñez-Forés *et al*., 2013) that identified sustainable and most appropriate best available technology (BAT). There is a huge environmental commitment highlighted in the industrial ceramics sector which cannot be found as yet among the artistic and traditional ceramics sector despite its economic, historical and artistic value and contribution in the productive sub-sector (Giudice *et al.*,2013).

Currently there is no literature on eLCA using ALCA approach in traditional pottery in Ghana. Afrane *et al*., (2011) worked on LCA on fuelwood as a source of energy for heating and evaluated the costs and life-cycle environmental impacts of energy used in Ghanaian households for the purpose of cooking and concluded that renewable sources of energy in Ghana must be improved. In addition, LCA on the cocoa industry in Ghana was conducted by Ntiamoah et al (2008); which demonstrated that the use of fertilizers and pesticides were major contributors to the impacts in the cocoa production stage. A few others including LCA in the timber sector (Eshun *et al*.,2011) and bamboo bicycle frames (Agyekum *et al*., 2017) have been conducted.

Apart from these publications, there is virtually no literature on eLCA using ALCA approach in traditional pottery in the world and Ghana especially. Most studies reported concentrate on literature on African Art and History of traditional pottery (Gosselain, 1999; Berns,1993; Berns, 2007).

2.5 Studies of clays and pottery in Mpreaso and Vume

Hilton et al. (1999) studied how two different methods of making pots coexisted in Vume. The study showed the difference in the methods and its contexts in history and culture. Sarkodie *et al*. (2014) examined the environmental impact of clay harvesting in Mpraeso. The results indicated that the nearness of the clay harvesting sites to river bodies contributed immensely to pollution of water bodies. More so, 90% of the respondents interviewed accepted that the degraded lands were not reclaimed.

In a separate study Samlafo *et al.* (2016) screened for potentially harmful heavy metals such as Pb, Cd, As and Hg in earthenware clay deposits at Vume. With the exception of As level, the quality of clay at Vume was generally good for the production of earthenware products. A summary of works done on the pottery industry in Ghana is presented in Table 2.2., and most studies focused on minerology and plasticity of the clays, socio-economic impacts, cultural perceptions, leachability of heavy metals, policy gaps and environmental impacts of the industry (e.g. Samlafo *et al.*, 2011; Usman *et al.*, 2004 etc) (Table 2.2).

Table 2. 2: Summary of works done in Ghana on clay and traditional pottery.

Author	Study area	Mineral composition & plastic limit of clay	Socio-economic impact	Cultural perception	Heavy metals leaching	Policy gaps	Environmental impact	Health impacts
Smith (1989)			x	x				
Haluska (1999)	Vume			x				
Speight et al (1999)			x	x				
Nsaih et al (2008)	Mfensi	x						
Nsaih et al (2011)	Aferi	x						
Samflo et al (2011)	Otsew	x			x			
Asante et al (2013)	Kpando		x	x				
Sarkodie et al (2014)	Mpreaso					x	x	
Wemegah (2014)	Sirigu		x	x				
Samflo et al (2017)	Volta & Central	x			x			

2.6 Clay deposits and harvesting in Ghana.

2.6.1 Clay deposits in Ghana

Clay is the common name for several fine-grained, earthy materials that exhibits plastic attributes when wet. It is a widely distributed and abundant mineral resource used for major industrial and economic variety of humongous usages, which are of importance to society (Mukherjee, 2013; Velde, 1992). The minerals have proven to be among the most essential industrial minerals because of their unique physicochemical properties and versatile applications within a wide range of fields including ceramics.

Archaeologists in Ghana date certain types of pottery back to the 13th century, with findings that include smoking pipes, pots for storing water and cooking, and other items (Anquandah, 1998; Stahl *et al*., 2008). This is not astonishing as research findings indicate that Ghana of land size 238,535km^2 has enough significant amount of clay reserves in commercial quantities deposited in all parts of the sixteen regions (Craven, 2007.)

In Ghana, clay deposits are found in all the regions as illustrated in Fig.1.2. Kaolin (China Clay) for instance is found in large deposits in Kibi in the Eastern Region and Abandze-Saltpond in the Central Region. In Ashanti Region, Mfensi clay is one of the most useful clay types. In view of its importance, a study was carried out to determine its characteristics to serve as a guide for local pottery ventures and ceramics industries (Nsiah, 2008).

2.6.2 Clay harvesting in Ghana

Clays are harvested in all the regions especially in communities where pottery activities are concentrated. Clay harvesting like illegal mining activity (galamsey) is done mostly using simple tools to gather for use. Depending on the demand some communities use heavy machines to extract the raw material thereby affecting the stream morphology, slope stability, smother organisms in streams and destroy the aesthetic view of the environment.

2.6.3 Clay mineralogy

Clays typically form over long periods from the gradual chemical weathering of rocks, (feldspars and micas) usually silicate-bearing, by low concentrations of carbonic acid and other diluted solvents (Eberl, 1984; Righi & Meunier, 1995). This occurs generally near the earth's surface with content of hydrogen and oxygen in the form of hydroxyl. The structures of the clay minerals are reasonably well-known to be phyllosilicate groups which are naturally found in all parts of the world (Sposito, *et al*., 1999; Velde, 2000).

Greater detail and more precision are needed if the properties of clays are to be fully understood especially in the study areas. The clay particles are of grain sizes less than 4 micrometres (µm) with its mineralogy different from sand and silt and few minerals like the micas (biotite and Muscovite) which are big enough and can be seen with the naked eyes. The varied properties of clay such as colour and cohesion are because of isomorphous substitution within the clay sheets. Clay impurities of Fe_2O_3, TiO_2, K_2O and Na_2O are found in clays in Ghana (Zelazny, 1986; Murray, 2006).

Presence of certain elements such as Fe in clay mineral framework bring about the colourization of the clay. Again, the influence of reactions between clay minerals and other organic compounds present in the environment influences the colour of the clay material. There are varying properties of these clay mineral and the structural factors that control these properties are not well understood (Murray, 1999).

The Scanning Electron Microscopy (SEM) analysis is urgently needed to divulge the structure and the characteristics of the clay minerals in the study area (Pittman, E. D., & Thomas, 1979).

2.6.4 Mineralogical study of clays

Clay mineralogical composition are analysed by destructive (Neutron Activation Analysis, Inductively Coupled Plasma-Optical Emission Spectrometry, Atomic Absorption Spectrometry) and non-destructive (Light Microscope, Portable X-ray fluorescence, Scanning Electron Microscopy etc) methods. The crystalline structure of polymeric aluminosilicate layer is observed through a scanning electron microscope.

The use of the SEM technique in the project is essential since it is uniquely suited for studying clays due to its magnified, three-dimensional view of the unmodified or natural clay surface with great depth of focus (Bohor & Hughes, 1971; Keller *et al*., 1986; Tite & Maniatis, 1975). This is because the use of electrons for imaging of samples gives out highly magnified images of the fine-grained minerals in clay compared to what is possible with a light microscope (Gillott, 1969).

The SEM instruments is equipped with energy dispersive X-ray spectrometers (EDS) for providing qualitative and quantitative elemental information on the major (bulk) elements of the raw materials that was used. SEM techniques will generally give information on what was used for making the wares and conditions of the elements present (Froh, 2004).

Elemental composition of the clay, the processed clay and the finished pottery product can then be successfully studied with corresponding elements at various stages of the production cycle of the earthenware. The mineralogical composition which can alter the plastic limit of the clay can be compared and common features identified from the clays of the two sites.

2.6.5 Plastic limit of clay minerals.

Plasticity limit is the minimum amount of water or moisture content in percentage at which the soil crumbles, when rolled into threads of 3 mm in diameter (Moreno-Maroto & Alonso-Azcárate, 2017; Sridharan & Nagaraj, 2005). The addition of water to dry clay increases the clays cohesion which tends to reach a maximum when the water nearly displaces all the air from the pores between the particles (Kemper & Rosenau, 1984). This is necessary to make the clay plastic and is referred to as the Plastic Limit of the clay.

The addition of more water into the pores induces the formation of a high yield-strength body that may crack or rupture when minimum force is applied to it. A plastic clay body can withstand the addition of considerable amounts of water, passing through a stage in which it remains dry to the fingers and is easily molded. Plastic limit is a parameter of Atterberg's limit which is determined using Casagrande method (ASTM 1991, ASTM D4318-05, ASTM, 2005).

The simple technique of plastic limit determination has been long criticized as it is not suitable for sandy soils and requires considerable judgement from the operator (Ishaque *et al.*, 2010). In characterizing a pottery system and optimizing the processing conditions, measurements of pottery materials and control of the plastic limits are needed (Andrade *et al.*, 2011).

2.6.6 Pottery production cycle

Pottery is the craft of making ceramic materials into pots or pottery wares using clay. It is one of the first synthetic material inventions ever created by humans originating before the Neolithic period to date (Violatti, 2014). The term pottery refers to objects made of clay mineral that have been fashioned into a desired shape, dried, and either fired at temperatures between 1100 and 1200°C or baked to fix their form. Major pottery wares are stoneware, porcelain and earthenware (pots).

The name pottery is sometimes use as a generic term for ceramics that contain clay but not used for structural, technical, or refractory purposes. In classification, the term 'ceramics' is divided into advance and traditional ceramics of which the latter has other branches like pottery and earthenware.

The traditional pottery earthenware ceramic products are used for inorganic materials with possibly some organic content, consisting of non-metallic compounds and made permanent by a firing process. There are some categories of ceramics products namely earthenware, stoneware, and fine ceramic. Ceramic production follows the process sequence of production involving extraction, processing, forming, drying, partial glazing/enamelling , firing, sorting/packing and transportation (Bozsin, 1966).

A scientific research by Nsiah et *al.* (2011) categorised clays that are good for specific use. The research disclosed that the clays of the Ashanti Region of Ghana are suitable for earthenware pots, bricks and tiles hence good source of material for both the building and pottery industries. Moon *et al*. (2008) also revealed that Mfensi clay in the Central Region of Ghana was reasonably plastic and when fired at 1100^{o}C suitable for earthenware and stoneware but not suitable for bricks and tiles. This study seeks to divulge the suitability of clays used in pottery by potters of Mpraeso and Vume in Ghana.

2.7 Heavy metal Leachability from finished pots

Throughout the world, the health of consumers is of priority to public health nutritionist and allied stakeholders. Regulations concerning the leaching of toxic elements from food wares are controlled by studying the total diet through governmental institutions because certain food wares leach heavy metals into food stored in them. Food contacts with food wares should not impart flavour, colour, odour or toxicity to the nutritional characteristics of the food to be consumed (Rupp, 2003).

As stated in the EU regulation of 1935/2004 "all materials intended to be brought into contact with food must not, under normal or foreseeable conditions of use, transfer constituents to food in quantities, that could endanger human health; or bring about an unacceptable change in the composition of the food; or deteriorate the organoleptic characteristics (taste/odour) of the food" (Restuccia *et al*., 2010). The United States Food and Drug Administration (FDA) uses equal to or less than 0.5 ppb (parts per billion) dietary concentration as the level at which a substance is not considered a food additive (CFR170.39). The study therefore seeks to investigate toxic metals that leach from earthenware pots into food prepared, eaten, and stored in them.

Ijeoma *et al.* (2014) in their research on heavy metals in edible clays sold in Anambra State in Nigeria proved that Cd, Pb, Hg and As are toxic even in trace amount. Omolaoye *et al.* (2010) stated that all ceramics wares contain heavy metals in varying concentrations with nearly 60 % of ceramic wares having Pb concentration higher than 500 µgg-1 and that of cadmium levels generally been low.

Glazed clay pots are said to contain heavy metals like Pb and Cd (Anderson *et al*. (2017)) but the traditional clay pots are unglazed and therefore is expected to be free from these heavy metals (Nsengimana, *et al*., 2012). The possibility of trace metals leaching from these traditional clay grinding pots under various conditions such as pH, type of food, contact time of cooking and temperature when cooking or eating in them has gained great interest with less monitoring and less information reported on their presence in processed/cooked food (Boisa, N., & Bekee, D. 2017).

A study in Rwanda reported 1.092 mg/L, 0.196 mg/L and 57.99 mg/L of Pb, Cd, and Fe leachates respectively, in banana liquor of pH 4.7 as this alcoholic beverage was prepared in a traditional pot (Nsengimana, J., & Bishop, 2012). This work seek out potentially heavy metals in the clay material and their leaching from clay based food wares.

2.8 Potential Health risk and hazards of earthen ware users

Pottery wares leach metals which can be poisonous to humans at certain levels of concentration and period of exposure (Valadez-Vega *et al*., 2011). These health effects are generally not observed after a solitary exposure. For instance, trace quantities of Ni in humans affects the central nervous system, Anemia, gastrointestinal damage, and the association it has with alteration in genetic expressions (Al-Fartusie *et al*., 2017; Mishra et al., 2019).

The metal cadmium is ten times more toxic than Pb and is commonly exposed to humans due to its huge industrial use. Acute or chronic poisoning is caused to humans as they get expose to these heavy metals through the consumption of contaminated diet, alcohol and water and this has risen over the years (Duruibe *et al*., 2007).

Samlafo et al., (2016) worked on Cd, As, Pb and Hg levels in earthen ware clay deposits at Vume and found Cd, Pb, and Hg levels to be below detection limit of US EPA 1990 limit whiles Asernic levels was above the threshold. Again, Samlafo *et al.* (2011) researched into heavy metals in earthen ware clays in Otsew in the Gomoa West District of Central Region of Ghana and reported As concentration of 9.48ug/g which is also higher than the safe limits of 0.07ug/g by US EPA (1989) standards. A research on the risk associated with geophagia in Ghana by Kortei *et al*. (2020) indicated As levels of 0.6ug/g to 1.8ug/g in clay samples from Anfoega in the Volta Region of Ghana.

The risk and hazards of earthen ware users are increased at varied temperature and pH of food prepared or stored in them as well as the time duration of food cooked or store in these earthen wares (Bolle et al., 2012). These conditions are reputed to increase leaching of metals into the food substances to be consumed by humans.

There is little or no regulation put in place in Ghana for the manufacture of traditional earthen food ware products. These products are let free to flood the market with questionable quality and safety standards been compromised. Similar products in Europe has Directive 84/500/EC set by the European Union to monitor leaching of some metals like lead and cadmium leaching from ceramic food wares to have standard limit of 4.0 and 0.3 mg $L{-}1$ respectively (Demont et al., 2012).

Using the Standard Method of Test, (ASTM-C738-72) the FDA's maximum allowable concentration of leachable lead ranges from 0.5-3μg/mL for food wares used in food consumption. The International Organisation for Standardisation (ISO) also has limits for lead and cadmium release from glazed ceramic food wares (Mania, *et al*., 2018).

Due to increase in the use of grinding pots in Ghana, there is a critical need to estimate the risk to human health through consumption of food in a product of daily intake of metal and also estimate the daily oral exposure for human population, at non-lethal dosage during a lifetime (US EPA, 2010).

A number of publications (Mokhtar et al., 2014; Du *et al*., 2013; Pastoor *et al*., 2014) have used the health risk assessment models to estimate metal intake of humans through pathway exposures to evaluate human health. Other methods of assessing human health rely on a paradigm that depends heavily on animal testing to identify the dose response for adverse effects. Many thousands of chemicals are required in such assessment, resources are needed to undertake fully traditional testing and evaluation of these chemicals on these animals (Pastoor *et al*., 2014). Such resources are simply not available hence the use of the USEPA model which attempts to apply integrated approaches seems more applicable in this project.

Food consumed in the pot will be evaluated by the ratio of daily intake of metal (DIM) to the oral reference dose (RfDo) for relevant metals (US EPA, 2013). If the value of HRI is less than 1, then consumers who are the exposed local population are said to be safe.

On the other hand, if HRI is equivalent to or advanced than 1, then it is considered as not safe for human health. This implies the latent health risk occurring requires related interventions and defensive measurements to be taken (US EPA, 2013). Therefore, the role of this work is to use the health risk assessment models to estimate metal intake of humans through pathway exposures in evaluating human health throughout the life cycle of the traditional earthenware pot.

2.9 Environmental and health impacts of the pottery industry

Although environmental problems have been with us for many years, pollution has become a primary concern in recent times. Pollution is an indication of contaminants into an environment that causes instability, disorder, harm or discomfort to the living organisms (Kumar, *et al*., 2011). Results of thousands of measurements carried out by the Centro Ceramico of Bologna on most of the Italian ceramic factories, indicated that the ceramic industry is relatively clean, compared to other industries.

They further stated that though some environmental problems were found especially in areas where production was concentrated, the most significant of all was air pollutants such as fluorides, NO_X. and many more. However, other researchers are of the opinion that the pottery industry has numerous pollutions including noise pollution (Asante-Kyei, *et al*., 2016; Palmonari *et al*., 2012b; Sarkodie *et al.*, 2014). This research will use the life cycle assessment tool to identify the pollution associated with traditional pottery in Mpraeso and Vume in Ghana.

2.10 Land degradation

The pottery industry has attracted increasing attention of environmentalist worldwide to conserve the ecosystem and sustain the industry in the affected places (Baveye *et al*., 2016).Clay mineral in Ghana is extracted using open cast or strip-mining method. Unfortunately, this method of mining is more harmful as many geo-environmental disasters occur on larger tracts of land (Mkpuma *et al*., 2015). Vegetal cover is removed which could enhance the erosion of sediments into streams polluting the waterways. This sore fish, smother plant life downstream, and cause disfiguration of river channels and streams causing flooding sometimes (Hallusaka., 1999;).

After extraction, sinkholes are produced, and badly shaped land topography with numerous depressions of different shapes and depths left behind. This creates permanent scares on the landscape and the mining areas become severely threatened by soil erosion and land degradation (Asante-Kyei & Addae, 2016; Sarkodie et al., 2014).

When the forest is degraded, it directly or indirectly affects climate patterns as well. This is because deforestation destroys erstwhile carbon sinks increasing carbon dioxide levels in the atmosphere and the tree and plant cover, which compromised on, creates a steep imbalance in the rain cycle influencing many other factors. The reduced plant cover creates an imbalance in the atmosphere, subjecting the environment to various concerns like global warming, the greenhouse effect, irregular rainfall and flash floods among others (Aigbedion *et al*., 2007). Research indicates that, lands that are once converted into a degraded one, can never be fertile whatever the magnitude of measures taken to redeem its state are.

Most clay harvesters degrade the forest when they abandon the harvested site after their harvesting activities without any effort to reclaim it (Asante-Kyei & Addae, 2016; Sarkodie et al., 2014). The effects of this damage can persist for years after the clay mineral has been hauled out including the loss of flora and fauna or loss of habitats (Hallusaka., 1999).

2.10.1 Air pollution

Traditional manufacturing of grinding pots in Ghana involves firing of ceramics in the open environment and in kilns emitting high number of toxic particles into the environment. Air pollution arising out of ceramic production is eminent during the firing stage of production where clay mineral structure disintegrates as results of high temperatures (Palmonari *et al.*, 2012b) .

These airborne particles can be harmful to human health. For instance, gaseous fluorine compounds (hydrofluoric acid, fluorosilicic acid, silicon tetrafluoride, or even alkali fluorides) among other pollutants specifically So_x, No_x, Hcl and Voc are released at this stage due to use of fuelwood as source of energy. Inhalation of such poisonous air increases the chances of health problems of not only ceramic workers but also other citizens as well as micro urban climate (Anlar, *et al*., 2017; Bessa, *et al*., 2020; Rondon, *et al*., 2011).

According to Andres, *et al*., 2011, the annual global emissions of CO_2 into the atmosphere is estimated at 2,600 million tonnes, of which about 60% are from human activities and the rest from natural processes. The World Health Organization report May 2014 estimated that air pollution contributes to 7 million premature deaths each year globally, which may now exceed the burdens of malaria, tuberculosis and AIDS combined. China has also cited air pollution as the fourth biggest health threat in the country of which science and technology are been used to salvage the problem (Pope *et al*., 1995). The National Environmental Policy (2014) by UNEP in response to Resolution 7 of the UNEA 1 is also geared towards curbing air pollution.

The EPA Ghana in the State of Environment Report 2004 listed charcoal production and rudimentary kilns and stoves industries as the main issues related to air quality in the country. The National Environmental standards for ambient air under its specifically regulated activity indicated that for each kilogram of dry wood burnt, a discharge of not less than 1.5 gram of particles should occur. Thus, air pollution abatement has been a hot topic of debate and action around the world in recent times. Therefore, the role of this work is to investigate the contribution of particulate emissions into the environment during traditional pottery production.

2.11 Health risk and hazards of potters and citizenry.

Apart from environmental degradation in the pottery production process, there exist also health impacts. Human health concerns in the industry are quite numerous. Workers in the pottery industry encounter an array of health complications as studies have shown a positive correlation between ceramic production and deterioration in health (Kappos *et al*., 2004; Lee, *et al*., 2010; Levin, *et al*., 2008) . They include the following:

2.11.1 Malaria

The mining of clay is done in watery pits which are perfect breeding grounds for mosquitoes that spread malaria diseases. The proliferation of mosquito breeding sites contributes to malaria in these traditional pottery sites (Kayamba, K., & Kwesiga, P. 2016). Asante *et al*., (2011) conducted a research in the Ahafo mining area and report an overall malaria prevalence of 22.8% in 2006/2007, with ~98% generally in mining areas. According to the research this is not a situation only in Africa such as Ghana and South Africa but also in Asian countries like Papua New Guinea. These uncovered sinkholes apart from trapping rainwater also serve as death traps for children, strangers and animals alike who are not familiar with the terrain (Winde, F., & Stoch, E. 2010; Fearon *et al*., 2015).

2.11.2 Respiratory Tract Infection

Respiratory Tract Infection (RTI) is another prevalent health issue in clay production areas. The respiratory system is a series of organs that are responsible for breathing; the lungs are the primary organs of this system, which also include the nasal passage, oral cavity, pharynx, larynx, trachea, bronchi and bronchioles. Workers become vulnerable to RTI because of their exposure to hazards such as smoke and dust during the production process

(Chen, *et al*., 2012). Potters exposed to harmful dust particles become susceptible to multiple pulmonary complications, which affects their respiratory system.

Dehghan, *et al*., (2009) demonstrated that occupational exposure to ceramic and tile dust can harm workers' respiratory system. Several authours (Chen, *et al*., 2012; Hossein, *et al*., 2008; Halvani *et al*., 2008) observed that, potters exposed to dust particles had frequent respiratory symptoms and a significant relationship between them and duration of employment though a few (Saad et al., 2006; Bahrami, A., & Mahjub, H., 2003) could not find any significant relationship. Halvani *et al*., (2008) research further detected that, lung capacities in ceramic workers with symptoms were lower than in workers without the symptoms. In addition, the respiratory symptoms were more frequent in potters.

2.11.3 Heat

Various studies indicate that there is a range of heat related illness potters are exposed to. Increase in heat increases the vulnerability of persons with cardiovascular, respiratory, and/or cerebrovascular diseases (Nag *et al*., 2009). Studies have also shown that excess exposure to occupational heat result in increased health risks, low productivity and in turn reduced economic output (Dash, K., & Kjellstrom, T., 2011; Kjellstrom *et al*., 2009; Venugopal, *et al*., 2016; Krishnamurthy *et al*., 2017; Dutta, *et al*., 2015).

Working in environments of excessive ambient temperature above 35°C succumbs potters to severe physical and psychological stress which reduces productivity and increases health hazards (Oliveira, *et al*., 2015). Work-related skin diseases account for approximately 50 percent of occupational illnesses and are responsible for an estimated 25 percent of all lost workdays. These dermatoses are underreported because their association with the workplace is not recognized (Alfonso *et al*., 2015).

2.11.4 Ergonomics

Ergonomics from an Occupational Safety & Health (OSHA) perspective is the process of designing the job to fit the employee, rather than forcing the employee's body to fit the job. This was a hot topic for OSHA in the 1990s, with the agency issuing a standard for ergonomics in 2000, which quickly was repealed in 2001.

Recent data in 2013 from the Bureau of Labour Statistics (BLS) shows that ergonomics remains a costly issue for businesses. The BLS data further explains that employees suffering from ergonomics-related injuries required more time off the job than those with other types of workplace injuries and illnesses (a median of 11 days versus eight days).

In Brazil, many workers from the ceramic industry have left their jobs because of work related musculoskeletal disorders. The BLS data also specified that these types of injuries account for one-third of days-away-from-work cases (Gamperiene, M., & Stigum, 1999). Soewardi, H., & Rahmayani, (2016) found 38.5% prevalence of musculoskeletal pain in the ceramic industry. Bastos (2016), also revealed that brick and tile catchers offer a great potential for musculoskeletal risks to their workers.

Other researchers detected that pain in the lower limbs of pottery workers have been very common and related to working in standing positions for protracted periods without posture variations (Gamperiene & Stigum, 1999; Longen, *et al*., 2018). More studies have shown that prolonged standing is associated with discomfort and cardiovascular problems and have proposed the benefits of changing posture while working (Waters, R., & Dick, B., 2015; Adriana & Iguti 2010). Due to many specific tasks performed continuously by potters, they are susceptible to repetitive strain injuries and related ergonomic challenges in the industry. Wanave et al., (2013) explained in their research that due to lack of proper workstations potters experience back injury, shoulder disorders and fatigue among others. In a separate study conducted in India to analyse postures by potters, it was found that profound deviations from natural curvature of various body parts especially the waists and necks due to awkward body postures for prolonged time existed in workers. Neck, shoulder, muscle contraction of body and upper limb pain have been related to pottery activities which require holding the neck in a forward bent posture for a prolonged time, working with arms above shoulder level and repetitive movements of hands and wrists (Sanjel *et al*., 2016; Melzer, A & Iguti, A. 2010; Majumder, *et al*., 2016; Punnett *et al*., 2004; Soewardi *et al*., 2016). In Ghana, no studies have been done on the effects of the pottery industry on the health conditions of workers.

2.12 Socio-Cultural Significance of pottery

Many Ghanaian homes and tribes use the earthenware to perform several functions (Asante *et al*., 2015). The Ashantis in Ghana years ago position a variety of pots known as “abusua kuruwa”, a cooking pot and other outfits beside the grave of recent entombments. They indicated that the pots usually contained hair of all blood relatives of the dead person kept for ancestral cleansing. In some parts of Northern Ghana, a distinctive funeral pot containing locally brewed beer (pito), is place at the entrance of a deceased’s room during the funeral period. Guests are served with this beer to symbolise hospitality. Instances where the deceased were women, their eating bowls that represents their personality is crush collectively with other pots of hers to precis the end of the funeral rites. The pot used for this ritual is preserved to act as a link between the deceased woman, her family, and the earth.

In southern Ghana, the “Ga” tribe uses vessels made of earthenware (Ntaaso) for the preparation of their festive meal kpokpoi during Homowo festival. Pots play significant roles in invigorating, cleansing, and curing the Ga society. Gas also believes that palm wine and water taste better and remains fresh when stored in earthenware pots. Pots are used in Ghanaian shrines in most tribes to revere the ancestors, dispense medicines; burn incense and in performing several other rituals.

2.12.1 Gender and the pottery industry

Throughout the world and in Africa, pottery production has always been women’s work in almost every culture though a few men have made strides within the industry. Women have been making pottery wares in almost every region in Ghana. All the processes involved in traditional pottery production are controlled by women, ranging from clay winning and processing, forming, and firing for centuries now. Years ago, it is obligatory for a woman to learn the art of pottery among certain cultures in Ghana before she is recognized as a member of the society. This helps the women in managing their future homes as pots were bartered for food and women are generally responsible for that. Meanwhile Rattray *et al.* (1927) is of the opinion that pottery said to be lying entirely in the domain of women in Ghana can hardly be correct.

2.13 Socio - Economic Significance of Traditional pottery

In the past Ghana had a few ceramic industries like the Saltpond ceramic industry which used to employ about 200 people at the inception of the company in 1973. The plant had the capacity to produce about 50% of the total market demand for ceramic products in Ghana. However by the year 2003 only 40 workers were present and gradually deteriorated due to very taut competition from imported products among other factors

It is in view of this that in 2008 Miss Joyce R. Aryee former Chief Executive Officer of the Ghana Chamber of Mines suggested that the clay, marble and granite industries which have been ignored over the years, should engage the attention of policy makers without any further delay. She further explained that these three natural vital resources if properly harnessed could directly affect the economic development of the respective communities and earn foreign exchange for the country.

She advocated for the necessary policies to commence in bringing the clay, granite and marble industries into the main mining industry and for the sector to lead Ghana's economy in the next five years (Ghana News Agency, 2008). Table 2.3 and 2.4 shows clays and the amounts of reserves in tonnes for Eastern and Volta regions in Ghana respectively. In recent times, Government has established the multimillion-dollar ceramic factory at the Free Zone enclave in Sekondi in the Western Region.

The project was to produce floor tiles, toilet bowls and other ceramic products using local raw materials such as limestone, kaolin clay, fieldspar and silica deposits identified in the Western and Central regions. Another estimated $3.8 billion has been invested into the development of about 15 million metric tonnes of clay deposits on Bomigo Island in the Keta Municipal Area to turn it into a major industry (Ghana News Agency, 2008). The clay deposits are estimated to last for 50 years, and will produce hollow bricks, roofing tiles, dinner wares, and plumbing fixtures as well as create opportunities for porters.

Reports also indicate that clay deposits occurring in economic reserves at Apinamang in the Eastern Region have proved suitable for paint manufacturing. These deposits could be used industrially for the manufacture of tiles and household utensils, basic raw materials for the paper industry, insulators, powder and as filter in the manufacture of pharmaceutical products. Research has not indicated the quantity of clay reserve (tonnes) in the study areas (Mpraeso and Vume) but the general clay reserves in the regions are indicated in Table 2.3 and 2.4.

Table 2. 3: Clay deposits in Eastern Region of Ghana (Kesse, 1985)

Area	Location	Reserve (tonnes)	Area	Location	Reserve
Nkwakwa	Adihima/Asuoya	2,240,099	Asamankese	Asamankese	840,000
	Abepotia	7,614,793		Apinmang	2,801,250
Kibi	Framase	41,687	Akim Oda	Akim Swedru	33,173,335
Anyinam	Tamfoi	1,285,084		Akim Awisa	1,285,553
	Moseaso	444,000	Akwapim	Akim Abonase	4,561,000
	Abomosu	4,081,434	Somanya	Adawso	1,027,000

Source: *(Kesse, 1985)*

Though there are huge clay reserves in Ghana, the clay industry's production is limited to traditional pots, plates, and mugs hence the need for the study. Further Ghana, as a country, has not explored this opportunity compared to countries like India, China, Brazil, Italy, and others where the industry contributes immensely to their GDP.

Table 2. 4: Clay deposits in Volta Region of Ghana (Kesse, 1985)

Area	Location	Reserve	Area	Location	Reserve
Ho	Adidome No 1	7,755,319	Bowiri	Kalakpa	501,440
Anfoega	Adidome No 1	469,800		Tuwotsive	1,944
	Tangidome	7,614		Amanfro/Anyinase	2,000,000
Gbefi-Hoeme	Nuzeme	10,083	Dayi	Dayi River Basin	997,900
	Toga	42,163	Ketekrachi	Woroto	7,027,707
	Kpetoe	29,160		Adankpe	2,273,361
	Aveyiboe	27,540	Hohoe	Adutor	35,854,085
Kudzra	Valexo	16,300		Kpoglo	9,413,582
	Aklamapata	6,318	Kadjebi	Kadjebi	97,742,979
	Have	6,430			
	Agbeditive	12,961			

Source: *(Kesse, 1985)*

This study therefore seeks to highlight on the importance of clay and its economic value to national development. Ceramics produced in these other countries are on a rather large scale in an organised mode. In Ghana, the ceramic industry operates under small-scale in an unorganized manner by individuals. Rajesh (2013) carried out a research in India and established that the unorganized sector accounts for 60% of total production of the industry.

Unfortunately, in Ghana, the unorganized state of the sector makes it impossible to ascertain the market size as establish in most developing countries. For instance, the Brazilian National Association of ceramics industry have approximately 6,900 ceramic industry that generates 293 direct jobs, 900 thousand indirect jobs and an annual income of US$9billion. The fact remains that ceramic product continue to be use in almost every Ghanaian home and even exported.

Countries that export ceramic or porcelain products have developed their skills to meet the international market, a challenge that confronts the industry in Ghana. According to Adu-Gyamfi *et al.* (2014), one of the major challenges is that indigenous potteries of Ghana lacked variety and has low standards of designs to meet diverse needs of advanced technological society. Ostensibly, researchers are of the opinion that the situation is because the potters' designs have remained static with no creativity, innovation and adaptability that are new to the users of the pots, especially when society is always craving for new things.

In addition, the finishing techniques used by the potters in Ghana often fall short of the aesthetic quality's requisite for contemporary lifestyle or taste. This situation is due to their inability to gain access to the appropriate knowledge and improve on their skills and technology. However, few individual potters are knowledgeable in crafting special artefact used by chiefs in our society. These individuals make the hallmark with the needed skills to retain certain aspects of Ghanaian culture and preserve cultural heritage as international personalities express interest in their art. The strategy required for the country's indigenous pottery sector to develop is predicated on the concept of modernization, restructuring, and repackaging towards meeting the demands of specific needs of society.

Boateng et al., (2015) emphasized in the Ghana Poverty Reduction Strategy Document (2003-2005), that strong economy, built on improved indigenous artefacts and accompanied by the right policy settings will boost national economic growth and reduce poverty; otherwise, indigenous products will continually lack the aptitude of revenue generation and environmental sustainability. The pottery industries in Vume and Mpreaso in Ghana had increased the tourist attraction to these towns although research indicated that at the local level, environmental impacts of the pottery industry are outweighed by the huge contribution it made to the socioeconomic wellbeing of the society. These expert potters dominantly women, play a vital role in the economic life of their community and the nation. Their products are of comprehensive base to society as it is used on daily indoor and outdoor errands. This study therefore seeks to investigate the environmental, socio-economic and health impacts of the traditional pottery industry to promote its sustainability in Ghana.

CHAPTER THREE

MINERALOGICAL COMPOSITION AND PLASTIC LIMIT OF CLAYS IN VUME AND MPREASO

3.0 Introduction

Potteries are household vessels used to process a variety of foods hence pottery like all other artifacts are a part of human activity. The principal function of these ceramic vessels is to transform the structure of edible foods by boiling or roasting, and for storing and serving particular types of food (Arthur, 2002). Accordingly, Ghana is no exception with regards to the above description. Ghanaians cook, store, serve, and transport their foods in low-fired earthenware pottery vessels locally called Ayiwa (Mpraeso) or Wegba (Vume) in the two study sites.

The increased usage of these earthenware pots has been major instruments of Ghanaian cultural heritage and preservation for centuries in our homes and eateries (Dores Cruz, 2011). This has initiated and directed investigations into the hub of pottery production in Ghana. The clays used for the pottery are mined from local neighboring areas and are seen to exhibit plasticity when mixed with water and additives at certain proportions which firm up when dried and fired into ceramic pots (Ekenyem, 2014; Scott, 1952; Velde, B., & Druc, I., 1999).

Occurrence of permanent physical and chemical changes in the mixed and fired clays (usually at temperatures higher than 1100°C) convert it into ceramic pots (Adu-Gyamfi *et al.*, 2014). The products are covered in sawdust (in Mpraeso) or iron slips are applied (in Vume) to provide generally a shiny, smooth surface and to seal the clay. A growing number of investigations carried on pottery worldwide has been based on archaeological artefacts and relics with great bulk of excavated artefactual material been silicate or carbonate based.

Mostly, the finished object has been the focus of study with emphasis on cultural, economic and social impacts of the pottery on society and not the raw material used (Costin, 1998; Gosselain,1992; Stark, et al., 2000). Likewise, in Ghana, not much attention has been given to the clay material used in pottery activities as well as comparative studies on them nor their finished products had been studied.

Recent investigations carried out in Ghana on the clay material characterized in the clay mineralogy for potteries from Mfensi, Aferi, Otsew and Vume (Samlafo *et al.*, 2011) as chemical analysis plays a vital role in the study of ceramics. Nonetheless there is scarcity of information on the elemental characterization on both the clays and its end product, the grinding pots (Arnold, *et al.*, 2000).

Clays mined from the local areas may differ in texture depending on the geochemistry and mineralogy of the raw materials (Harvey, C. & Murray, H. 1997; Stark, et al., 2000). Additionally, the chemical composition of pottery may be affected by production techniques like mixing of various clay materials. Similarly, the firing may differ from one community to the other. Hence the finished pot will reveal a characteristic chemical signature to uncover the class of chemical elements (LI *et al.*, 2010).

The clay and pot mineralogy were investigated using the scanning electron microscopy, a non-destructive method, which could give a good account of a complete life cycle of the clay material through to pots. The combination of high-quality imaging and analytical facilities offered by the SEM is predominantly valuable in this study. Fine-grained clay materials often contain phases associated with unacquainted situations which may or may not be part of the study. The analytical capability offered by the SEM allows direct clarification of these assemblages contributing significantly to petrological investigations. Substantial benefit towards the study of fine-grained sediments in Mpraeso and Vume was made.

Besides, these potteries were examined with atomic absorption spectrometry which is an added advantage as it offers measurement of an element at a time. These two techniques were used to analyze the samples from the two pottery production centres (Mpraeso and Vume) to see any distinctive chemical signatures. The raw materials used for pottery was considered, thus the clays and tempers (Mpraeso potters call their temper material *amodine* whereas the Vume potters give the name grog). Some clays are good for potting and are used straight whereas others must be mixed with tempers.

3.1 Methodology

3.1.1 Sampling sites

As indicated in chapter 1, the two study sites have raw materials used for pottery making with clay being the most dominant constituent. The clay is very plastic for shaping and chemically rich in hydrous aluminum silicates. Samples were taken from 20 sites in Mpraeso and 10 sites in Vume. Nonprobability sampling method specifically the convenience sampling method was applied. The sites were chosen based on potter’s availability and willingness to assist in the collection of the various data needed for the study (Fig.3.1) and geographically Mpraeso is of a bigger community with more potters compared to Vume community hence the varied numbers.

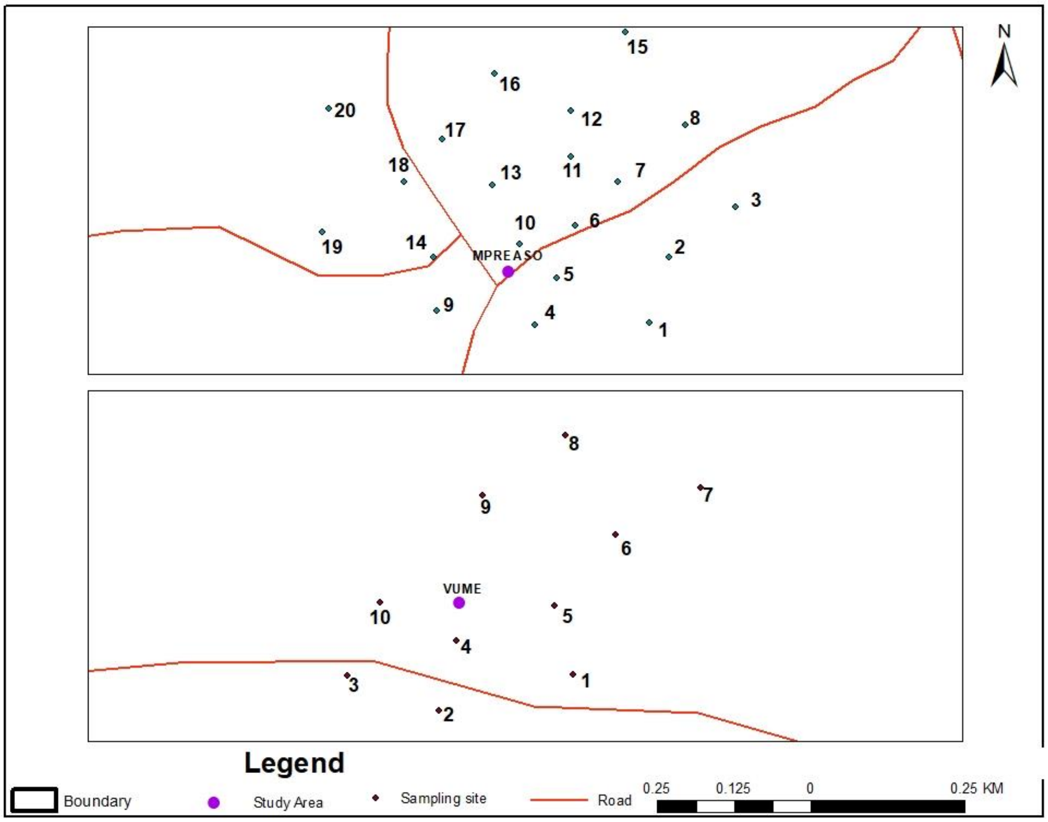


Figure 3. 1 Map of the sampling sites at Mpraeso and Vume in the Eastern and Volta Regions of Ghana respectively

3.1.2 Sample collection

Two clay samples one each from the respective study areas Mpraeso and Vume (Table 3.1) were collected at extraction sites. There is only one extraction pit in each community where all potters from respective study areas mine clay from making the clay samples involved here only two to be used for Scanning Electron Microscopy (SEM) analysis. Each clay sample from respective pit was collected using a wooden ladle and composited. Samples were put in ziplocks and placed in iced chest with a unique identity to the laboratory. Part of the collected samples were molded into grinding pots following procedures and protocols used in each study site by indigenes accordingly. Three pots were produced.

Table 3. 1 Clays sampled from Mpraeso and Vume for SEM Analysis

Site	Sample ID	Description of sample
Vume	V-site 8	Finished red pot from Vume
		Clay from extraction pit in Vume
Mpraeso	Site 11	Mpraeso extraction pit
		Finished red pot from Mpraeso
		Finished black pot from Mpraeso

One red pot for Vume, and two pots for Mpreaso (one red and one black) were also used for the SEM analysis (Table 3.1).

For plasticity, a total of 24 clay samples, 14 (7 raw clays and 7 mixed clays) from Mpreaso and 10 (5 raw clays and 5 mixed clays) from Vume were collected from potters for plastic limit determination (Tables 3.2 and 3.3). The samples consisted of raw clays, mixed clays and clay additives locally known as amodine (Mpreaso) and grog (Vume).

Also 57 samples of raw clays, mixed clays and clay additives were sampled from potters for physico-chemical analysis. Mpreaso samples were 33 consisting 11 samples each of raw clays, mixed clays, and clay additives (Tables 3.6, 3.7 and 3.8) whereas Vume samples were made up of 9 raw clays, 7 mixed clays and 8 clay additives making a total of 24 samples (Tables 3.9, 3.10 and 3.11). Sample numbers of mixed and clay additives were lesser than raw clays in Vume because potters did not have those clay samples at the time of sample collection.

3.1.3 Experimental

3.1.4 Plastic Limit Determination

Knowledge on the plastic limit of clays in the study sites is useful to aid potters in the reduction of production cost. The plastic limit which is a parameter of Atterberg's limit was determined using the Casagrande method. Two different test methods were experimented. Test method A used the mixed clays with additives traditionally made by potters for molding and Test method B used raw clays and added measured amounts of additives in the laboratory.

3.1.4.1 Test method A

100g of oven dried mixed-clay sample was measured and emptied into a plate according to ASTM D4318-05 methodology. A measured volume of distilled water was added until the soil becomes cohesive. This was rolled into a ball and then as a rule it was further rolled between the palms of the two hands which is a satisfactory and convenient procedure. Enough pressure was then applied to acquire a thread of diameter 3mm after which the soil was kneaded into an ellipsoidal shape and rolled out. This process was continued until the crumbling of the soil occurred. Care was taken to ensure that the threading was not broken up or crumbled by applying excessive pressure. A duplicate determination was carried out in precisely the same manner. The determination of plastic limit was express as the moisture content in percentage of the mass of the oven-dried soil and is calculated as follows:

$$\text{Plastic limit} = \frac{\text{Mass of water}}{\text{Mass of oven dried soil}} \times 100 \text{ ---------------------------------- } 3.1$$

3.1.4.2 Test method B

A test analysis of the plasticity of the clay was determined with varying amounts of clay additives (amodine and grog) on 5 raw clay samples of Mpreaso and 3 for Vume (Tables 3.4 and 3.5). 100g of raw clay was mixed with 20g, 40g, 60g, 80g and 100g of amodine/grog respectively for each sample. Water was added and rolled into a ball and the same procedure was followed according to ASTM D4318-05 methodology as done in test method A and plastic limit data determined.

3.1.5. Physico-chemical analysis

3.1.5.1 Sample treatment

Sample treatment involved the disaggregation and air drying for 7 days. The samples were pounded in a porcelain mortar and sieved with <40 mesh, homogenized, stored in labeled polythene bags and kept in the laboratory until analysis.

3.1.5.2 Digestion

The 57 samples were all digested by measuring and transferring 2g of samples in two replicates into a boiling test tube and treating with aqua regia (15ml HCl and 5ml HNO_3) (Horowitz, 1980). Samples were mixed and then heated on a hot plate in a fume chamber with gradual increment in temperature from 90^oC to 150^oC until decomposition was complete (red NO_2 fumes ceasing). The leachate became colorless, and the volume reduced through evaporation to about 5ml, transferred quantitatively to a 100ml volumetric flask and topped up to the mark with deionized water and filtered. The filtrate solution of samples was analyzed for Cd, Pb, As, Na, Mg, Fe, Zn, Co, Ni, Mn, Cr and Cu with the aid of Atomic Absorption Spectrophotometer (AAS). The AAS instrument uses a chosen lamp that produces a wavelength of light which is absorbed by an element of interest. Sample solutions were aspirated into the flame. If ions of the given element are present in the flame, they absorb the light produced by the lamp before it reaches the detector. The amount of light absorbed depends on the amount of the element present in the sample. Absorbance values for unknown samples were then compared to the calibrated curves prepared by running known samples.

3.1.5.3 Quality Assurance and Quality Control

For quality assurance and quality control, blanks were measured to evaluate their contributions to error in the measurements. For each extractant, a blank solution of that extractant and water free metals reagent was obtained in the same way as the leachate solution. Each experiment was run in duplicates, alongside with reference standards and materials to ensure reproducibility. Recoveries ranged from 85-100%.

3.1.6 Scanning Electron Microscopy (SEM)

In this study, the scanning electron microscope (SEM) method was used because it allows observation and investigation of very fine micro area in situ. It is also fast, accurate, non-destructive, and usually requires only a minimum of sample preparation. Multiple types of information about the geological samples, superficial microstructure, component analysis and crystal structure features can be sourced. The SEM uses energy-dispersive system (EDS) to assist in mineral identification and image analysis for morphological studies. Both quantitative and qualitative data analyses are obtained identifying the elemental makeup of the clay and finished pot samples. The SEMs broad applications include clays and pots offering mineral information at nanoscale level. This research used crude clays from in situ and finished pots produced in Mpraeso and Vume to establish divergent mineralogical constituent.

3.1.6.1 Sample preparation and analysis by SEM

Clay samples were prepared to withstand vacuum conditions and high energy beam electrons. The samples were solid, dry from moisture and free from any form of dust particles. Samples were iron filled to about 3mm in size to fit on the specimen stage. The solid dry sample was mounted on an aluminum stub with a carbon adhesive and placed in the sample cup holder and then into the phenom world SEM. An optical image was first produced then later an electronic image. Focusing, magnification, contrasting and brightness were all adjusted to produce a better image of high resolution. After which EDS analysis was carried out for elemental identification, distribution, and concentration. This was done using point elemental analysis.

3.1.7 Statistical analysis

The Principal Component Analysis, Pearson Coefficient of Correlation and ANOVA were applied to the clays to identify the source of heavy metal pollutants and the significant relationship between and among the heavy metals present.

3.2 Results and Discussions

3.2.1 Colour of Mpraeso clays

Clays in general are fine materials produced by the weathering of feldspathic and granitic rocks. The clays in Mpraeso were of hue between 2.5-5YR which is described as pale to light yellow colour by the Munsell colour chart. The grains were very fine of less than 2µm as indicated by Guggenheim *et al*., (1995). The poorly compacted clays could be due to clastic sedimentation in which there was poor sorting. This might also be as a result of less weight overlying the rock which was accompanied by reduced pore space.

3..2.2 Plasticity of Mpreaso clays

Table 3.2 shows the plasticity levels of Mpreaso samples; they were good, fairly good and bad per plasticity description. Out of 14 samples, 8 could be molded into balls, rods and coils without breakage/cracks. These samples were good with 58% plasticity. On the other hand, another 21% of the samples had plasticity being good and bad whereas the remaining set seemed good and fairly good. Site 2 raw clay was the least plastic as it could only be molded into a ball. Generally raw clays were more plastic (71%) than those with the additive (amodine clay) (43%). Moreover, the volume of water absorbed by raw clay samples was higher ranging between 37-53ml as compared to the amodine mixed samples (26-44ml) as shown in Table 3.3.

Table 3. 2: Plasticity of clay samples from Mpreaso

Sites		**Vol. of $H_2$0 added (ml)**	**Plasticity description**								
			Good			**Fairly good**			**Bad**		
			Ball	**Rod**	**Coil**	**Ball**	**Rod**	**Coil**	**Ball**	**Rod**	**Coil**
Raw	Site 2	37	√	-	-	-	√	-	-	-	√
	Site 3	45	√	√	√	-	-	-	-	-	-
	Site 6	47	√	√	√	-	-	-	-	-	-
	Site 7	53	√	√	√	-	-	-	-	-	-
	Site 9	48	√	√	√	-	-	-	-	-	-
	Site 10	53	√	√	√	-	-	-	-	-	-
	Site 17	42	√	√	-	-	-	-	-	-	√
Mixed	Site 2	26	√	√	-	-	-	-	-	-	√
	Site 3	32	√	√	√	-	-	-	-	-	-
	Site 6	32	√	√	-	-	-	√	-	-	-
	Site 7	40	√	√	√	-	-	-	-	-	-
	Site 9	35	√	√	-	-	-	√	-	-	-
	Site 10	44	√	√	√	-	-	-	-	-	-
	Site 17	30	√	√	-	-	-	-	-	-	√

NB: Weight of clay = 100g

Table 3.3 shows the plasticity test with varying amounts of the clay additive called amodine. Results show that the water absorption capacity of the clay mixture increases with increasing amount of amodine from 20 to 100g. Site-3, Site-7 and Site-8 exhibited fairly good and bad plasticity characteristics, whereas Site 2 and Site-6 had good plasticity at all the varying amodine mixture weighting. However, plasticity of the clay mixture decreased with increasing amount of amodine from a good to bad state. Twenty (20g) of amodine was the best clay mixture as three (60%) out of five samples could be moulded into rounded, rodded, or coiled state with the other two samples failing to be shaped into a coiled form. At 40g of amodine mixture 60% of samples could also be shaped into rounded, rodded, or coiled states but Site 3 sample exhibited fairly good and bad features when rounded and coiled (Table 3.3).

Table 3. 3: Plasticity test of clay samples from Mpreaso with amodine

Sample ID	**Weight of amodine added (g)**	**Vol. of H_20 added (ml)**	**Self-test of plastic limit (amodine) plasticity description**								
			Good			**Fairly good**			**Bad**		
			Round	**Rod**	**Coil**	**Round**	**Rod**	**Coil**	**Round**	**Rod**	**Coil**
Site 2	20g	52	√	√	√	-	-	-	-	-	-
	40g	59	√	√	√	-	-	-	-	-	-
	60g	63	√	√	√	-	-	-	-	-	-
	80g	65	√	√	√	-	-	-	-	-	-
	100g	68	√	√	√	-	-	-	-	-	-
Site 3	20g	45	√	√	√	-	-	-	-	-	-
	40g	45.1	√	-	-	√	-	-	-	-	√
	60g	55.1	√	√	-	-	-	√	-	-	-
	80g	69.1	√	√	-	-	-	√	-	-	-
	100g	79.1	-	-	-	√	√	-	-	-	√
Site 6	20g	48	√	√	-	-	-	√	-	-	-
	40g	52	√	√	√	-	-	-	-	-	-
	60g	70	√	√	√	-	-	-	-	-	-
	80g	80	√	√	√	-	-	-	-	-	-
	100g	100	√	√	√	-	-	-	-	-	-
Site 7	20g	42	√	√	-	-	-	-	-	-	√
	40g	51	√	√	-	-	-	√	-	-	-
	60g	59	√	√	-	-	-	-	-	-	√
	80g	65	√	√	-	-	-	√	-	-	-
	100g	66	√	√	-	-	-	-	-	-	√
Site 8	20g	53	√	√	√	-	-	-	-	-	-
	40g	56	√	√	√	-	-	-	-	-	-
	60g	60	√	√	√	-	-	-	-	-	-
	80g	68	√	√	√	-	-	-	-	-	-
	100g	72	√	√	-	-	-	-	-	-	√

NB: Weight of clay = 100g

3.2.3 Colour of Vume clays

Vume clays in general were produced by the weathering of the granitic acidic gneiss of the Dahomeyan rocks. The clays were of a hue between 7.5-10YR which is described as orange to dull yellowish orange colour by the Munsell colour chart. They were well compacted with very fine grains of about a size less than 2µm (Kostorz, 2016) similar to the Mpraeso type.

3.2.3.1 Plasticity of Vume clays

The plasticity of Vume clays are shown in Table 3.4. Sixty-percent (60%) of samples' had plasticity were good with about 30% having bad plastic properties as they could only be shaped into coil-like shapes. Site 7 mixed sample was the least plastic clay material. Like Mpreaso, raw clays were more plastic (67%) than clays with grog (33%). However, the water holding capacity of raw clays was lower (26 – 33ml) compared to mixed clays (26 – 47ml). Generally, raw clays of both study areas were more plastic than clays mixed with other materials of pottery.

Table 3. 4 Plasticity of clay samples from Vume

Sites		**Vol. of $H_2$0 added (ml)**	**Plasticity description for Vume**								
			Good			**Fairly good**			**Bad**		
			Ball	**Rod**	**Coil**	**Ball**	**Rod**	**Coil**	**Ball**	**Rod**	**Coil**
Raw	Site 6	33	√	√	√	-	-	-	-	-	-
	Site 7	26	√	√	√	-	-	-	-	-	-
	Site 8	26	√	√	√	-	-	-	-	-	-
	Site 9	28	√	√	√	-	-	-	-	-	-
	Site 10	33	√	√	-	-	-	√	-	-	-
Mixed	Site 6	26	√	√	√	-	-	-	-	-	-
	Site 7	33	-	-	-	√	√	-	-	-	√
	Site 8	30	√	-	-	-	√	-	-	-	√
	Site 9	40	√	√	-	-	-	-	-	-	√
	Site 10	47	√	√	√	-	-	-	-	-	-

NB: Weight of clay = 100g

Plasticity test of varying grog content in the clay mixture of Vume are presented in Table 3.5. Unlike Mpreaso clays, the water absorption of Vume clay fluctuated with increasing grog content in the clay mixture. It increased from 20-40g, decreased at 60g and increased again from 80-100g of grog content (Table 3.5). Likewise, plasticity of samples decreased with increasing grog content in the clay mixture. At 20g the plasticity of all samples was good; being shaped into rounded, rodded or coiled forms.

Table 3. 5: Plasticity test of clay samples from Vume with grog

Sample ID	**Weight of grog added (g)**	**Vol. of H$_2$0 added**	**Vume self-test of plastic limit (Grog)**								
			Good			**Fairly good**			**Bad**		
			Round	**Rod**	**Coil**	**Round**	**Rod**	**Coil**	**Round**	**Rod**	**Coil**
V-Site 6	20g	36	√	√	√	-	-	-	-	-	-
	40g	48	√	√	-	-	-	-	-	-	√
	60g	40	√	√	√	-	-	-	-	-	-
	80g	46	√	√	-	-	-	-	-	-	√
	100g	50	√	√	-	-	-	√	-	-	-
V.Site 7	20g	40	√	√	√	-	-	-	-	-	-
	40g	49	√	√	√	-	-	-	-	-	-
	60g	35	√	√	√	-	-	-	-	-	-
	80g	53	√	-	-	-	√	-	-	-	√
	100g	59	-	-	-	√	√	-	-	-	√
VSite 8	20g	28	√	√	√	-	-	-	-	-	-
	40g	53	√	√	√	-	-	-	-	-	-
	60g	32	√	√		-	-	√	-	-	-
	80g	40	√	√	√	-	-	-	-	-	-
	100g	52	√	√	-	-	-	√	-	-	-

NB: Weight of clay = 100g

At 40g grog content 67% of samples could be molded into the three forms: round, rod and coil with only sample V-site 6 failing the coil test. From 60-100g grog content V-site 8 sample still had good plasticity except 60g and 100g addition that had fairly good at the coil test. On the other hand, V-site 6 and V-site 7 pit plasticity were fairly good and bad. Thus, 20g addition of grog was the best mixture of plasticity of Vume clays. From the simulated clay mixture results, plasticity of the clays increased by addition of additives (amodine and grog) and the best ratio was to add one-fifth (1/5) of the weight of the clay.

3.2.4 Physico-chemical results and discussions of Mpreaso clays

The physico-chemical quality of Mpreaso clays is given in Tables 3.6 - 3.8. The electrical conductivity (EC) of Mpreaso samples ranged from 2 to 598 µS/cm for raw clays, 70-653 µS/cm for clay additives (amodine), and 26-316 µS/cm for mixed clays.

The pH of the clays from Mpraeso, depending on the type whether mixed, raw or additive clay (amodine) varied between 5.3-8.8 (raw, Table 3.6), 5.2-8.3 (amodine,Table 3.7) and 5.5-7.4 (mixed, Table 3.8). Generally Cd and As were not present in all the three types of clays from Mpraeso. However in all the three types, Co and Pb were not found in most sites (Tables 3.6-3.8). Iron was detected in large quantities in all the sites which could be attributed to the geology. Likewise Zn, Mn, Ni and Cr were found in the raw and mixed clays. The concentration of some (Mn, Zn) of these metals were within permissible limits of soils by WHO, FAO and EU (Table 3.6-3.8).

Table 3. 6: Concentration of elements in raw clays of Mpreaso

Sample ID	**pH (H_2O)**	**EC µS/cm**	**------------------------------Elements, (mg/kg)------------------------------**									
			Cd	**Co**	**Zn**	**Mn**	**Ni**	**Pb**	**Fe**	**Cr**	**Cu**	**As**
Site 2	5.4	2.2	BD	BD	16.5	15.6	98.8	10.3	2585.0	36.9	18.6	BD
Site 3	7.1	2.81	BD	BD	17.3	8.0	64.7	0.2	952.0	18.7	19.6	BD
Site 4	6.7	306.0	BD	BD	40.8	31.0	54.4	BD	1444.0	41.0	10.9	BD
Site 5	8.1	184.3	BD	BD	12.7	30.3	79.4	BD	1358.0	38.1	2.4	BD
Site 6	6.5	2.71	BD	0.5	14.3	30.9	70.4	BD	2371.0	34.2	22.8	BD
Site 7	5.3	407.0	BD	BD	27.0	68.2	101.3	BD	2885.0	26.4	BD	BD
Site 8	6.6	598.0	BD	9.2	12.4	13.2	68.8	BD	1617.0	33.4	1.6	BD
Site 9	6.9	187.2	BD	19.5	72.0	85.4	61.9	BD	2283.0	58.6	71.3	BD
Site 10	8.4	120.9	BD	10.8	25.8	17.7	5.7	BD	583.0	16.8	7.8	BD
Site 11	7.3	61.7	BD	23.9	23.8	34.2	43	BD	941.0	64.9	8.9	BD
Site 12	8.8	152.1	BD	BD	23.5	22.1	34.8	BD	986.0	32.0	10.4	BD
Mean	7.0	184.1	BD	5.8	26.0	32.4	65.7	0.95	1636.8	36.5	15.9	BD
SD	1.1	188.3	BD	9.2	17.4	23.8	27.7	7.1	775.6	14.7	20.2	BD
Limits (FAO/WHO)			**3**	**50**	**300**	**2000**	**50**	**100**	**50,000**	**100**	**100**	**20**
Limits (EU)			**3**	**N.A**	**300**	**N.A**	**75**	**300**	**N.A**	**150**	**140**	**N.A**

BD – below detection; N.A – not available

Table 3. 7: Concentration of elements in Amodine clays of Mpreaso

Sample	**pH**	**EC**	------------------------------ **Elements, (mg/kg)**									--------------------------------
	(H_2O)	**µS/cm**	**Cd**	**Co**	**Zn**	**Mn**	**Ni**	**Pb**	**Fe**	**Cr**	**Cu**	**As**
Site 2	5.3	70.8	BD	BD	1.2	2.6	80.4	43.9	1201.0	BD	BD	BD
Site 3	7.1	70.8	BD	BD	BD	BD	72.7	BD	557.0	BD	BD	BD
Site 4	8.2	280	BD	BD	13.0	91.1	57.1	BD	140.0	23.2	2.1	BD
Site 5	6.3	190.8	BD	BD	7.8	27.5	75.3	BD	610.0	2.3	BD	BD
Site 6	7.1	510.0	BD	BD	2.8	BD	50.4	BD	134.0	19.9	5.0	BD
Site 7	8.1	158.0	BD	BD	34.5	72.1	46.3	BD	371.0	8.5	31.0	BD
Site 8	7.3	153.2	BD	BD	17.0	36.9	47.8	BD	160.0	13.5	1.7	BD
Site 9	7.2	158.8	BD	29.7	17.8	61.3	52.7	BD	96.2	11.2	BD	BD
Site 10	8.3	653.0	BD	BD	14.1	28.3	45.3	BD	670.0	11.5	BD	BD
Site 11	5.2	201.0	BD	12.8	16.0	19.4	89.0	BD	1465.0	12.7	BD	BD
Site 12	6.2	122.0	BD	BD	13.8	63.5	74.6	BD	817.0	9.9	BD	BD
Mean	6.9	233.5	BD	3.9	12.5	36.6	62.9	3.9	565.6	10.3	3.6	BD
SD	1.1	184.5	BD	11.9	9.3	28.7	15.8	BD	455.9	6.1	14.1	BD
Limits ((FAO/WHO),			**3**	**50**	**300**	**2000**	**50**	**100**	**50,000**	**100**	**100**	**20**
Limits (EU)			**3**	**N.A**	**300**	**N.A**	**75**	**300**	**N.A**	**150**	**140**	**N.A**

BD – below detection; N.A – not available

Table 3. 8: Concentration of elements in mixed clays of Mpreaso

Sample	**pH**	**EC**	----------------------------**Elements, (mg/kg)**									-------------------------------
	(H_2O)	**µS/cm**	**Cd**	**Co**	**Zn**	**Mn**	**Ni**	**Pb**	**Fe**	**Cr**	**Cu**	**As**
Site 2	5.5	278.0	BD	BD	17.2	45.1	115	20.9	1707.0	18.2	21.7	BD
Site 3	6.2	26.4	BD	BD	12.4	26.1	44.9	32.0	757.0	20.4	12.1	BD
Site 4	5.7	219.2	BD	BD	45.0	141.5	73.1	16.3	1793.0	56.8	48.9	BD
Site 5	6.1	77.6	BD	BD	11.8	29.7	62.0	13.1	1493.0	30.0	BD	BD
Site 6	5.9	316	BD	10.5	25.0	86.6	59.5	BD	1313.0	21.7	10.3	BD
Site 7	6.2	78.2	BD	BD	1.4	5.1	54.9	BD	1050.0	35.1	BD	BD
Site 8	5.8	97.0	BD	13.6	31.6	27.6	55.2	BD	1316.0	27.7	2.4	BD
Site 9	7.4	101.4	BD	12.6	17.5	44.9	57.0	28.4	633.0	25.2	9.0	BD
Site 10	6.2	211.0	BD	5.4	27.7	22.8	32.5	BD	1073.0	31.3	BD	BD
Site 11	5.7	119.0	BD	6.7	24.7	32.0	97.0	BD	1085.0	19.7	11.0	BD
Site 12	7.3	94.2	BD	17.3	26.4	63.9	55.1	BD	271.0	42.0	17.6	BD
Mean	6.2	147.1	BD	6.0	21.9	47.8	64.2	10.1	1135.6	29.8	12.1	BD
SD	0.6	93.4	BD	4.5	11.6	38.0	23.3	8.0	459.1	11.5	14.2	BD
Limits ((FAO/WHO			**3**	**50**	**300**	**2000**	**50**	**100**	**50,000**	**100**	**100**	**20**
Limits (EU)			**3**	**N.A**	**300**	**N.A**	**75**	**300**	**N.A**	**150**	**140**	**N.A**

BD – below detection; N.A – not available

3.2.5 Physico-chemical results and discussions of Vume clays

The elements measured for Vume clay samples are illustrated in Tables 3.9 – 3.11. Most samples were slightly acidic with pH ranging; raw (5.2 -8.9, Table 3.9), grog (5.3 - 7.3, Table 3.10) and mixed (5.2 -7.4, Table 3.11). Electrical conductivity of raw clays varied between 7 and 399 for raw clays (Table 3.9), 78 and 514 for grog clays (Table 3.10) and 16 and 416 for mixed clays (Table 3.11) of Vume.

Table 3. 9 Concentration of elements in raw clays of Vume

Samples	**pH**	**EC**	**----------------------------Elements, (mg/kg) -----------------------------**									
	(H_2O)	**µS/cm**	**Zn**	**Mn**	**Ni**	**Cu**	**Fe**	**Cd**	**Pb**	**As**	**Cr**	**Co**
Site 2	5.2	7.0	142.6	184.3	93.3	5.7	19350.0	6.5	64.8	BD	BD	BD
Site 3	6.3	195.9	BD	37.9	66.7	BD	15370.0	8.9	31.0	BD	BD	1.4
Site 4	5.5	86.3	9.4	37.4	87.2	4.1	7359.0	7.3	86.3	BD	BD	6.3
Site 5	5.8	399.0	BD	45.7	81.8	6.8	9109.0	7.5	59.9	BD	BD	3.2
Site 6	6.7	43.0	BD	101.6	69.1	12.0	3103.0	8.0	53.8	BD	BD	6.7
Site 7	7.1	323.0	BD	24.8	69.3	3.9	1634.0	7.5	24.8	BD	BD	BD
Site 8	6.4	44.1	BD	37.8	81.4	5.3	2635.0	9.5	BD	BD	BD	BD
Site 9	6.4	66.9	BD	36.5	76.5	7.2	3994.0	11.2	21	BD	BD	12.8
Site 10	8.9	114.5	BD	32.7	81.4	2.8	12210.0	8.6	74.2	BD	BD	8.2
Mean	6.5	142.2	16.9	59.9	78.5	5.3	8307.1	8.3	46.2	BD	BD	4.3
SD	1.1	136.4	79.8	51.7	8.9	2.9	6234.9	1.4	24.0	BD	BD	4.3
Limits ((FAO/WHO)			**300**	**2000**	**50**	**100**	**50,000**	**3**	**100**	**20**	**100**	**50**
Limits (EU)			**300**	**N.A**	**75**	**140**	**N.A**	**3**	**300**	**N.A**	**150**	**N.A**

BD – below detection; N.A – not available

Table 3. 10: Concentration of elements in grog clays of Vume

Samples	**pH**	**EC**	**-------------------------------Elements, (mg/kg)-----------------------------**									
	(H_2O)	**µS/cm**	**Zn**	**Mn**	**Ni**	**Cu**	**Fe**	**Cd**	**Pb**	**As**	**Cr**	**Co**
Site 2	7.3	301.0	28.5	74.4	73.2	9.1	3703.0	4.4	90.9	BD	BD	5.7
Site 3	5.3	510.0	41.5	70.0	74.9	BD	9901.0	8.6	BD	BD	BD	BD
Site 4	6.0	268.0	9.3	29.7	63.4	BD	1386.0	5.7	66.6	BD	BD	6.3
Site 5	7.1	514.0	BD	34.9	65.5	0.7	2327.0	8.7	87.6	BD	BD	BD
Site 6	6.4	79.4	2.9	36.2	65.8	4.9	2917.0	4.7	BD	BD	BD	BD
Site 7	5.9	201.0	BD	30.1	75.2	3.5	3679.0	9.6	74.9	BD	BD	4.8
Site 8	5.7	78.3	BD	35.6	83.6	0.3	2816.0	7.3	71.3	BD	BD	7.1
Mean	6.2	278.8	11.7	44.4	71.7	2.6	3818.4	7.0	55.9	BD	BD	3.4
SD	0.7	180.5	17.7	19.2	7.2	3.6	2798.5	2.1	10.5	BD	BD	1.0
Limits ((FAO/WHO)			**300**	**2000**	**50**	**100**	**50,000**	**3**	**100**	**20**	**100**	**50**
Limits (EU)			**300**	**N.A**	**75**	**140**	**N.A**	**3**	**300**	**N.A**	**150**	**N.A**

BD – below detection; N.A – not available

Interestingly unlike Mpreaso samples, As and Cr were the only elements that were not found in the Vume clays. Cadmium (Cd) was detected in all clay samples from Vume. However, Pb was not observed in site 8 (raw clays), site 3, site 6 (grog clays) and site 6 (mixed clays). With reference to Mn and Ni all the clay samples of Vume were rich in these elements just like in Mpraeso clay type except for site 3 that was not found. Zn was not observed in most sites at Vume eg. 7 sites (raw clays) had concentration lower than detection limit). Overall, all the elements studied had concentrations lower than the specification by international bodies with the exception of Ni

Table 3. 11: Concentration of elements in mixed clays of Vume

Samples	**pH (H$_2$O)**	**EC µS/cm**	**--------------------------------Elements, (mg/kg)------------------------------**									
			Zn	**Mn**	**Ni**	**Cu**	**Fe**	**Cd**	**Pb**	**As**	**Cr**	**Co**
Site 2	5.2	392.0	103.0	111.3	82.8	7.3	2870.0	8.2	87.7	BD	BD	9.3
Site 3	6.0	16.0	BD	44.9	78.2	BD	8098.0	7.6	41.3	BD	BD	3.9
Site 4	5.4	119.0	6.9	92.9	70.7	0.7	1617.0	7.4	95.0	BD	BD	BD
Site 5	5.4	70.4	3.1	45.8	61.4	13.5	3536.0	10.8	40.2	BD	BD	BD
Site 6	5.5	416.0	BD	26.1	72.9	2.2	2547.0	7.6	BD	BD	BD	0.8
Site 7	6.4	78.2	BD	33.3	67.3	5.2	5069.0	8.4	29.6	BD	BD	7.4
Site 8	5.8	87.0	13.1	45.6	79.5	6.5	6900.0	7.6	67.5	BD	BD	1.5
Site 9	7.4	100.1	5.1	54.3	77.0	2.8	7932.0	8.8	100.3	BD	BD	7.4
Mean	5.9	159.8	16.4	56.8	73.7	4.8	8049.9	8.3	57.7	BD	BD	3.8
SD	0.7	153.7	43.1	29.7	7.1	4.3	2554.9	1.1	29.1	BD	BD	3.5
Limits ((FAO/WHO)			**300**	**2000**	**50**	**100**	**50,000**	**3**	**100**	**20**	**100**	**50**
Limits (EU)			**300**	**N.A**	**75**	**140**	**N.A**	**3**	**300**	**N.A**	**150**	**N.A**

BD – below detection N.A – not available

Although mineral ions are essential elements in living organisms, there has been much concern about the increasing toxicity of some of these elements in the environment. Naturally soils contain mineral ions dissolved from rocks as the water travels along mineral surfaces in the soil (Kusimi & Kusimi, 2012). Thus, depending on the extent of exposure of these minerals, they could be in higher concentrations or vice versa. Results of AAS determination show that Fe concentration in all the clay samples were quite high and indicative of high Fe content in the geology of the study sites (Mpraeso and Vume). Ferralitic parent material may have weathered into the clay material with the presence of Oxide minerals of haematite (αFe_2O_3) and goethite ($\alpha FeOOH$) in the study sites. The clay extraction pits were open and had water which can facilitate oxidation of Fe elements in the clay. Other times Ti and Fe elements form mixed Ti-Fe oxide minerals of ilmenite and pseudo rutile (Fritsch *et al.*, 2005). Human activities also explain the toxicity levels of certain elements in the environment.

The pH values of samples ranged from 5.2 to 8.9. The oxidation of iron in the soil could explain the pH levels in some clays because lower pH is mostly associated with higher iron concentrations in samples (Tables 3.6-3.11). Rocks of the Dahomeyen are impregnated with iron: epodote [Ca2(Fe,Al)Al2(SiO4)(Si2O7)O(OH)] and hornblende [(Ca,Na)2(Mg,Fe,Al)5(Al,Si)8O22 (OH)2] (Kesse, 1985). The Birimian formation is also reach in iron (Kesse, 1985). Deep chemical weathering under tropical conditions mobilizes iron in the soils which justifies the high concentration of iron in clay samples in both localities.

Other chemical elements that exceeded WHO/ FAO and EU guidelines in soils are Cd and Ni. Nickel levels were high in some samples of both Mpreaso and Vume whiles Cd was found to be higher in certain samples in Vume clays. Naturally, cadmium exists in the earth's crust in zinc, lead and copper sulphide ores, thus enters the environment through weathering (US EPA, 2012). It is anthropogenically introduced into the environment when it is unrecovered from the industrial extraction of the ores or the disposal of cadmium rechargeable batteries or cadmium bearing electronic gadgets. Zinc, lead, and copper sulphide ores are not found in the geology accounting for the low levels of these metals, therefore the possible source of high Cd levels in Vume clays could be from industrial waste of cadmium. The clay is mined in a valley in the town where domestic waste is dumped, and it is also the drainage system for the southern part of the town. Leachate from industrial wastes leaches into the soils increasing Cd levels from electronic equipment. Clays of Mpreaso are mined outside the towns which is not within the reach of waste from households hence the absence of Cd in Mpreaso clays.

Nickel is the fifth most common element on the earth and in soils it is associated geochemically with iron and cobalt (Harasim *et al.*, 2015). This metal has widespread distribution in the environment, as there are almost 100 minerals of which it is an essential constituent and which have many industrial and commercial uses (Cempel et al., 2006). In soils it occurs mostly in minerals such as pentlandite, garnierite, millerite, niccolite and ullmannite.

Nickel is commonly present in two principal ore types: sulphide or laterite (Harasim *et al.*, 2015). Rock phosphate, which is used as a raw material for phosphatic fertilizers, is known to contain Ni ranging between 16.8 to 50.4 mg kg-1 and triple super phosphate may also contain 15.6 to 25.2 ppm (Chauhan, *et al.*, 2008; Rop, 2019). Anthropogenic sources include fertilizers like ammonium nitrate (<0.20 ppm) and manure from dairy, poultry and swine (Harasim *et al.*, 2015).

Since much of the anthropogenic sources of Ni do not occur in the study areas, Ni in soils is attributable to rock weathering. The mobility of nickel in soil is site-specific, depending mainly on the soil type and pH. The mobility of nickel in soil is increased at low pH. As shown in Tables 3.6 – 3.11, higher Ni concentrations are associated with lower pH or slightly acidic soil conditions. The sulphate concentration and the surface area of soil iron oxides are also key factors affecting nickel adsorption (Richter *et al.*, 1980). In most soils, Ni is bound to ion exchange sites, and it is specifically adsorbed or coprecipitated with aluminum and iron oxyhydroxides. These are the dominant processes in neutral to alkaline soils. In acidic, organic-rich soils, where fulvic and humic acids are formed by the decomposition of organic material, Ni may be quite mobile, possibly because of complexation by these ligands (Kabata-Pendias *et al.*, 2001).

Many harmful effects of nickel are due to the interference with the metabolism of essential metals, such as Fe (II), Mn (II), Ca (II), Zn (II), Cu (II) or Mg (II), which can suppress or modify the toxic and carcinogenic effects of nickel (Coogan et al., 1989; Singare et al., 2012).

3.4 Analyses of Mpraeso clays by SEM

A scanning electron microscope (SEM) analysis of clays and pots was performed to see how the clay minerals diverged from one sample to another. For each sample, the electron beam focused on four divergent spots. The results of the mean and standard deviation (sd) of the elemental weight percentages of mineral constituents and their chemical composition are presented in Tables 3.12 and 3.13, respectively. The elements, Cd, Pb, As, Co, Ni, Cr and Cu were below detection limits so are not presented in the Tables.

3.4.1 Mpraeso raw clays

The ED spectrum results of site 11 at the extraction pit in Mpraeso showed the elemental weight percentages of the various elements contained in the clays to have concentrations of Si, Fe and Al to be high of 29.52%, 16.57 % and 6.86% respectively, Table 3.12. Meanwhile the concentration of Ca, Mg, Na, K and Ti were very low of (2.56%, 2.27%, 1.15%, 1.01% and 0.44%) respectively, Table 3.12. The chemical composition of the clay included SiO_2 (60%), Fe_2O_3 (25%), Al_2O_3 (14%), CaO (5%) and MgO (5%) with trace oxides of K_2O (3%), Na_2O_3 (2%) and TiO_2 (1%) (Table 3.13).

Table 3. 12: Average elemental weight composition of raw clays and pots from Mpraeso and Vume (%)

Sample ID			--						**Element Weight (%)**						--
	Sites		**O**	**Si**	**Fe**	**Al**	**Mg**	**Ca**	**K**	**Cl**	**Zi**	**Ti**	**Na**	**Mn**	**S**
Red Pot	**V-site 8**	Min	51.41	18.68	2.73	5.63	0.34	0.26	0.5	0.92	BD	0	0	BD	0
		Max	62.354	34.55	26.92	11.35	0.92	1.74	2.08	1.56	BD	0.71	2.27	BD	1.17
		Mean	57.72	24.25	9.69	8.09	0.60	0.91	1.09	1.24	BD	0.71	1.424	BD	1.17
		Sd	4.0	6.9	10.2	2.2	0.22	0.58	0.59	0.45	BD	0.36	0.94	BD	0.53
Raw Clay	**V-site 8**	Min	46.26	17.12	13.716	6.246	0.7	0	0.65	BD	BD	19.31	BD	0	BD
		Max	60.206	24.094	23.4525	10.324	0.88	0.24	5.17	BD	BD	29.38	BD	0.57	BD
		Mean	52.12	21.27	19.44	8.45	0.77	0.24	2.37	BD	BD	16.23	BD	0.57	BD
		Sd	7.2	3.6	5.0	2.06	0.09	0.13	2.47	BD	BD	7.1	BD	0.3	BD
Raw Clay	**Site-11**	Min	47.026	20.186	3.7175	4.07	0.88	0.32	0.88	BD	BD	0	0.95	BD	BD
		Max	57.958	36.884	32.658	11.84	3.38	5.17	1.15	BD	BD	0.44	1.32	BD	BD
		Mean	52.37	29.52	16.57	6.86	2.27	2.56	1.01	BD	BD	0.44	1.15	BD	BD
		Sd	4.60	7.9	12.6	3.43	1.0	2.4	0.18	BD	BD	0.22	0.18	BD	BD
Red Pot	**Site-11**	Min	48.05	21.24	9.05	9.32	2.87	0	0.9	0.69	0	0	0.32	BD	0
		Max	58.78	38.1	32.61	12.92	4.24	0.42	5.54	6.59	21.56	1.24	2.1	BD	21.56
		Mean	54.47	32.3	16.30	11.34	1.03	3.62	2.47	0.42	21.56	3.56	1.24	BD	21.56
		Sd	4.8	7.6	11.0	1.6	0.96	0.29	2.7	4.2	0.05	0.87	0.79	BD	15.2
Black Pot	**Site-11**	Min	54.06	21.55	14.51	6.87	0	0.85	1.04	1.59	BD	0	0.29	BD	0
		Max	62.743	26.8	26.68	10.58	0.25	9.29	8.67	5.49	BD	2.33	1.56	BD	0.68
		Mean	56.51	23.43	20.88	9.23	0.86	3.54	4.04	0.68	BD	2.32	4.10	BD	BD
		Sd	3.55	2.31	5.74	1.49	0.11	3.34	3.65	2.75	BD	1.03	0.53	BD	BD

BD – below detection

Table 3. 13: Average chemical composition of clays and pots from Mpraeso and Vume (%)

Sample ID	**Sites**	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**MgO**	**K_2O**	**TiO_2**	**Na_2O_3**	**CaO**	**Cl**	**Zi**	**SO**
Vume	**Red pot**	56.13	14.52	19.62	1.89	2.58	1.14	3.51	<0.01	3.13	<0.01	3.96
	V-site8	51.57	28.84	19.80	1.80	5.11	54.58	< 0.01	0.57	<0.01	<0.01	<0.01
Mpraeso	**Site 11**	60.34	25.25	14.23	5.17	2.80	1.07	2.42	5.42	<0.01	<0.01	<0.01
	Red pot	70.50	34.41	23.01	1.66	12.36	6.49	2.05	7.30	0.8	44.77	<0.01
	Black Pot	55.79	39.08	21.30	1.89	9.13	5.06	10.31	7.85	<0.01	<0.01	0.51

The Scanning Electron micrographs revealed some morphological structures (Plate 3) with Si/Al ratio of about 4.3. General morphology of the clay in Plate **{3.1I}** had some irregular **[c]** and angular **[f]** shaped quartz minerals while the euhedral shaped quartz minerals **[e]** were in face edge contact. Through weathering of feldspars and micas, silica was released which sourced the cementation of the quartz minerals (Fadil – Djenabou et al 2018). The micrite cementation of minerals observed among the detrital grains of quartz seem to have undergone some crystallization with some etched plates **[b]**. There was fibrous textural morphology **[a]** which is usually associated with illites (Güven, 2001). Incomplete to complete change or recrystallisation of the kaolinite and smectite minerals forms illites (Lanson, 1991) . Quartz minerals are dominant filling the intergranular pores with some Fe impurities in the clays of the extracted pit. Present also were Fe stains **[d]** which did not seem to have any orientation. But the dominant clay minerals were the illite - smectite with the abundance of Si, Fe and additional evidence characteristically displayed by the general Ca-Mg smectite phase. In plate **{3.1II}** the clay is made up of coarse-grained clast of quartz minerals having euhedral **[e]** and subhedral shapes **[g]**. Smectite minerals weathering into illite minerals (I-S) was seen. Presence of Na in the mineralogy is because of the precipitation of feldspars in the rock which replaces the silicon minerals. Na smectite minerals were present with quartz cementation reducing rock porosity but not its permeability.

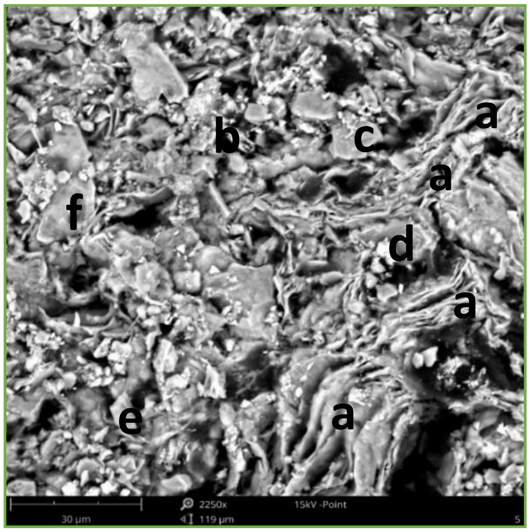


Plate 3.1I: Fibrous textural morphology

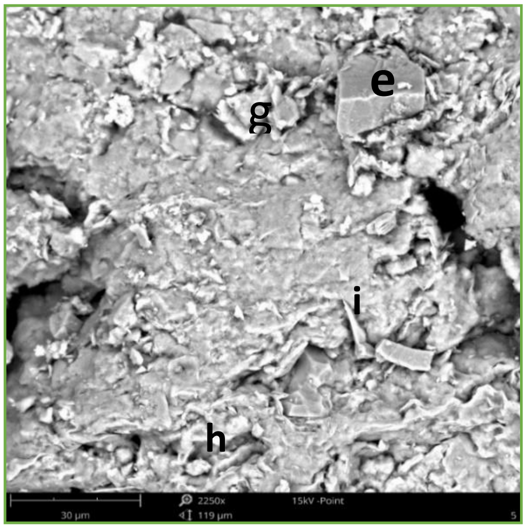


Plate 3.1II**:** Clast of quartz minerals

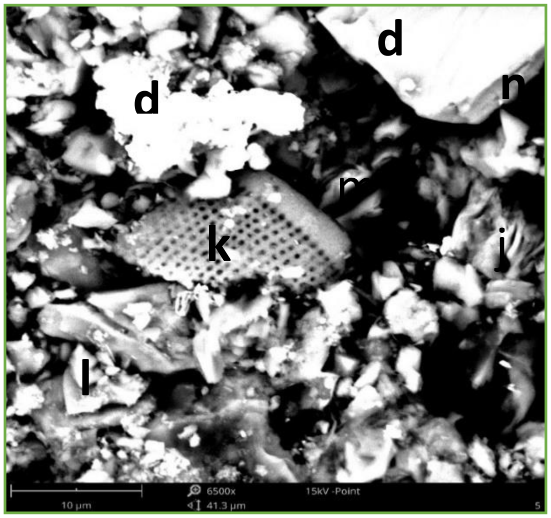


Plate 3.1III*:* Fe patches impurities

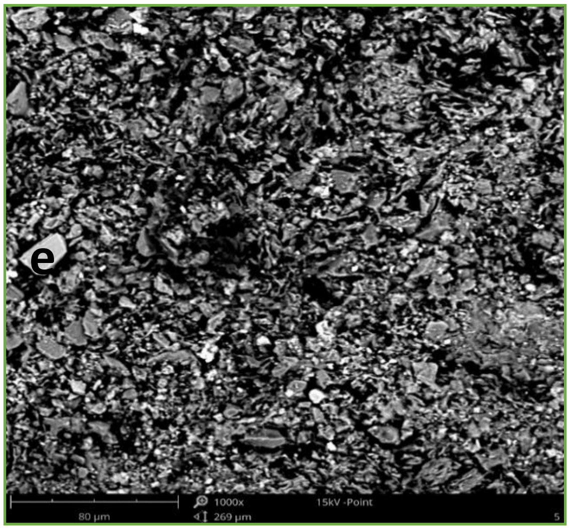


Plate 3.1IV*:* Euhedral shaped quartz mineral

Plate 3. 1 SEM micrographs of Mpraeso extracted clay.

a - Fibrous texture, **b** - Etched Plates, **c** – irregular shape, **d** – Fe stain, **e** - Euhedral shape, **f** - angular shape, **g** - subhedral shape, **h** - minerals interlocking, **i** - halloysite penetrating **j** – book page kaolinite **k** - koalinites, **l** - quartz flakes, **m** - dark space, **n** - hexagonal shaped quartz

Kaolinite minerals were dominant with Mg as trace elements. These kaolinites are poorly recrystalising to smectite minerals with halloysite rod penetrating them as represented in Plate **{3.1II}**. Few of the kaolinite were seen interlocking each other with face to edge contacts.

In Plate **{3.1III}** hexagonal shaped quartz **[n]** mineral was specified with patches of Fe impurities **[d]**. The book page kaolinite was also seen with agglomerates of smectite and illite minerals. The formation of illite minerals requires pore fluid and space as its growth medium is increased with amounts in potassium (K), silica (Si) and aluminum (Al) compositions. The minerals in Plate **{3.1III}** also showed dark spaces enclosed between the minerals which may augment porosity in the rock and encourage the formation of illite minerals under appropriate conditions (Baiyegunhi et al 2017). The ratio of Si/Al at point **[k]** was 2.4 signifying minimal weathering of the quartz minerals in the rock. Quartz flakes **[l]** or platelets was also detected with detrital quartz flattening demonstrating quartz saturation. The grain morphology and mineral composition in spot **[k]** is granular quartz with elements of Al, Mg, Ca, Na, K and Ti. This is a characteristic of a mixture of smectite and titanium oxide. Plate **{3.1IV}** showed euhedral shaped **[e]** quartz minerals with quartz flakes as well. The chemical composition of the clays in site 11 showed high SiO_2 (60.34%), Fe_2O_3 (25.25%) and Al_2O_3 (14.23%) respectively while CaO, MgO, K_2O, Na_2O_3 and TiO_2 were of trace concentrations. General presence of Fe_2O, TiO_2, MgO and CaO are minerals that were nearly always present as impurities in kaolinites. The occurrence of 2.80% K_2O can be explained by the presence of illite minerals in the clay.

3.4.2 Mpraeso pots

The finished pots in Mpraeso comes in two colors, black pots, and red pots respectively. Both pot types were subjected to the SEM/EDS studies to know the variations in mineralogy and chemical composition.

The weight percentages of the elements of the black Mpraeso pot had concentration of Si, Fe and Al to be high of 23%, 20.9% and 9% respectively (Table 3.12). However, concentrations of Na, K, Ca and Ti were noted to be 4%, 4%, 3.5% and 2% respectively (Table 3.12). In Plate **{3.2I}** the massive, compact, crystalline black pot of site 11 had fine-grained morphology with polymineralic coexistence. Needle-like minerals of quartz containing halloysite **[i]** of low crystallinity and Fe **[d]** clast in the center as an impurity which could leach out was observed. The elongated minerals of halloysites occurred because of fluid interactions with carbonates in conjunction with pressure and temperature. Illite-smectite minerals with flakes of quartz cemented in silica were prominently observed in Plate **{3.2II}**. Trace elements of Mg and Cl was identified with reduced occurrence of kaolinite book pages **[j]**. This can be explained as high temperatures transformed the kaolinites into metakaolinite. Images observed in Plate **{3.2III}** which is the finished red pot from Mpraeso site 11 showed euhedral shaped quartz **[e]** with a compact texture. Silicate minerals have cemented the kaolinite minerals occurring as large, thick, flat flakes with book pages (vermicular stacks). The weight percentages of elements in finished red pot recorded concentrations of Si (32.3%), S (21.6), Zn (21.6), Fe (16.3) and Al (11.3%) to be high.

Plate 3.2I: Fe clast mineral in sample

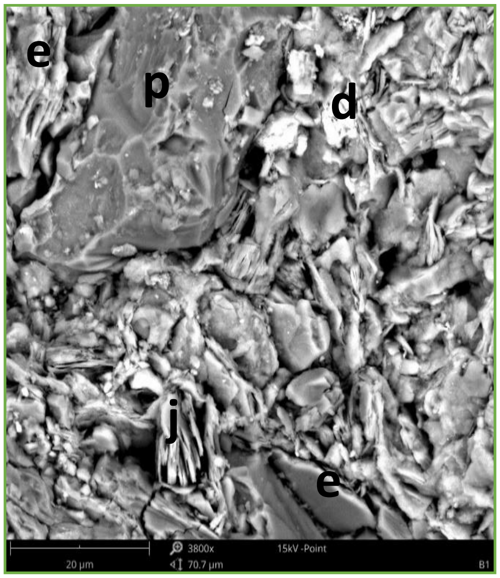


Plate 3.2II: kaolinite book pages

Plate 3.2III**:** Euhedral shaped quartz

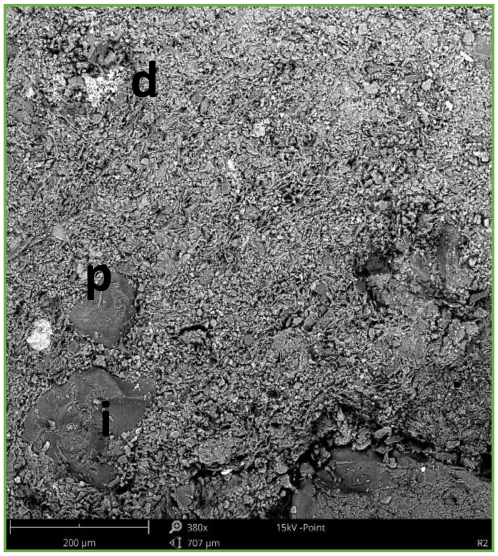


Plate 3.2IV: Fe patches in halloysite

Plate 3. 2 : SEM micrographs of Mpreaso black and red pots. [**O -**illite -smectite, **P-** clast of quartz, **j** – book page kaolinite, **l**-quartz flakes]

While Ca (3.6%), Ti (3.6%), K (2.5%), Na (1.2%), Mg (1%) were found to be of lower concentrations. The elemental composition of Si/Al at spot **[e]** was 2 which is a characteristic of smectite mineral mixture. Plate **{3.2IV}** had Fe patches present in the fine grained halloysite **[i]** minerals with a cryptocrystalline texture having few quartz clast **[p]** images in them. Ti, Mg, Ca and K were also established.

Kaolin, illite and smectite are referred to as standard clay minerals according to Keller *et al*., (1986) and these were the minerals present in the analyzed samples. The raw clay sample from site 11, finished black and red pot from Mpraeso all had mineral compositions of Si, Fe and Al with higher concentration values. These pots were molded from raw clay sample from site 11 and were seen to have similar elements with varied concentrations. The black pot sample had increased concentrations in Fe>Al>Na>K>Ca>Ti while the red pot sample had Si>Zn>S> Fe>Al> Ca>Ti>K>Na also increasing in concentrations. The raw clay sample and the black finished pot sample had no sulphur (S) but red pot sample had high concentrations of sulphur (S) and zirconium (Zi). The additives added to the raw clay sample could be the reason for the increased concentrations in Si and the presence of S and Zi in the red pot sample.

The SEM/EDS images identified quartz in high amount. The general rock morphology looked massive and had high concentration of quartz grains as silica minerals. Alteration of Ca and Mg is an indication of smectite textured material which is dominant in the extraction pit clay. The mineralogical composition of the clays could be in accordance with that of kaolin clay using the chemical formula $2SiO_2 \cdot Al_2O_3 \cdot 2H_2O$.

Kaolinites are noted for high concentrations of Al and K with alkaline conditions recrystallizing and favoring formation of Illite. Si, Fe and Al are the major elements in the finished pots (Gani *et al*., 2015). Varied amounts of Mg, K with trace elements Na, Ca and Ti could be detected in the samples (Demont *et al*., 2012). They are mainly fused in the quartz and kaolinite mineralogies.

The traditional firing of the pot in Mpraeso is done in the open where the temperatures may not be too high enough to induce major mineralogical changes (Grifa *et al*., 2017; Rasmussen *et al.*, 2012). Though some changes might occur, it must be noted that quartz is stable even at high temperatures (Broekmans, 2004). Kaolinite minerals undergo certain transformation when temperatures are applied to them.

The heat applied released hydroxyl ions in the form of water which turns the kaolinites to metakaolins (McConville, J., & Lee, E., 2005). At high temperatures metakaolins are transformed into free silica which are cristobalites and have chemical composition formula SiO_2 and mullites with chemical composition formula $3Al_2O_3.SiO_2$ (Ekenyem, 2014). The clay materials in the study area have a mineralogical composition which is useful in the manufacture of earthenware (Kabre, *et al*., 1998).

SEM samples of black pot and red pot from Mpraeso exhibited these mineral compositions with silica as the major mineral component. Clay minerals of kaolinite, illite and smectite are formed from both the dissolution of potassium feldspars and through the recrystallization of fine sediments. Clay mineral of both kaolinite and smectite can be recrystallized into illite and sericite (Baiyegunhi *et al.*, 2017).

The presence of K_2O content in kaolin may be used to determine the degree of alteration of Si-Al minerals with high values corresponding to high alterations. The values obtained were between 2 to 2.8 which is an indication of smectite - illite alteration of clay minerals (Fadil-Djenabou *et al.*, 2014). Potassium (K), occurred in all the samples which is an indication of illite content in them.

3.5 Analyses of Vume clays by Scanning Electron Microscopy

The results of SEM for extracted clays and pots of Vume are presented in Tables 3.12 and 3.13 and Plates 5 and 6.

3.5.1 Vume extracted clays.

The crude clay from site 8 in Vume showed weight percentages of elements with concentrations of Si (21.3%), Fe (19.4%), Ti (16.2%) and Al (8.5%) to be high. Nonetheless, K, Mg, Mn and Ca were in lower concentrations of (2.4%, 0.8%, 0.6% and 0.2%) [Table 3.12]. The chemical composition exhibited high concentrations in TiO_2 (54.6%), SiO_2 (51.6%), Fe_2O_3 (28.8%) and Al_2O_3 (19.8%) [Table 3.13].

Minor concentration of K_2O (5.1%), MgO (1.8%) and CaO (0.6%) were detected as well. The occurrence of MgO and CaO which involved the substitution of the octahedral positions of Mg^{2+} and Ca^{2+} for Al^{3+} could explain the presence of smectite minerals in the sample. The SEM showed spherical Fe mineral in spot **[d]** of both Plates **{3.3I}** and **{3.3II}** along with micro fractures of kaolinite minerals that had flaky particles **[l]** in texture. Dissolved trace elements of Mg, Ca, and K in addition to Si occurred in high concentrations and filled the voids which cemented the coarse-grained kaolinite minerals. Intergrowth of illite smectite minerals in the voids were also present. The sediment gravity flow sorted the kaolinite minerals in decreasing grain size as seen from the image of Plate **{3.3I}** along **[r]**.

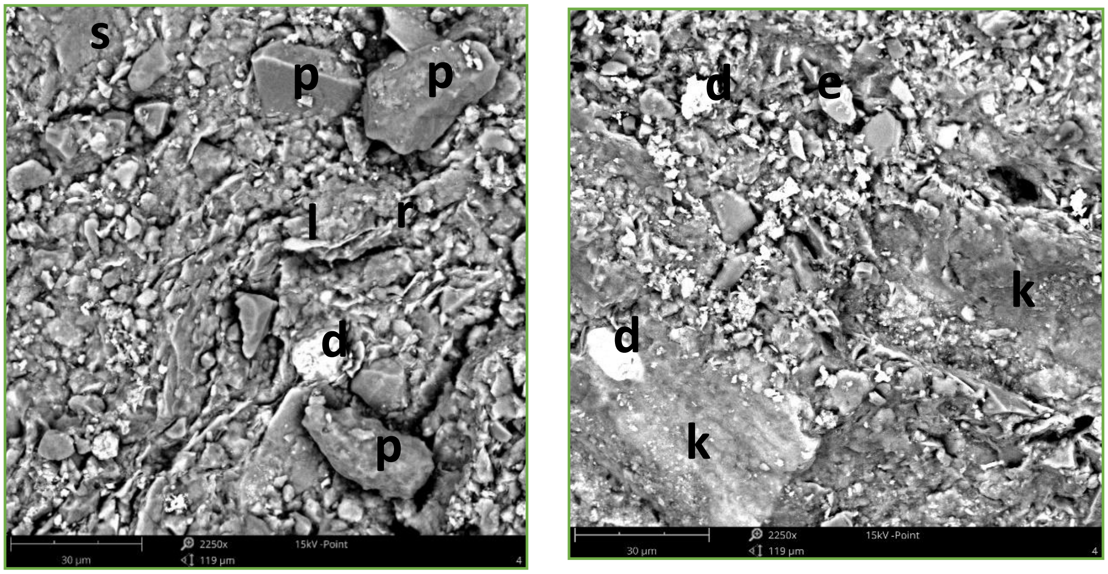


Plate 3.3I: Gravity flow along [r].

Plate 3.3II: flakes of kaolinites

Plate 3. 3**:** SEM micrographs of Vume extracted clays.

d-Fe stain, **P**- clast of quartz, **r** -gravity sorted minerals, **s**-parallel lamellae, **l**- flakes of kaolinite, **e**-Euhedral shape, **k**-kaolinites.

In addition, dissolution of feldspar and silica minerals filled the voids and cemented the kaolinite minerals. Parallel lamellae feature **[s]** in Plate **{3.3I}** on kaolinite mineral was realized. Plate **{3.3II}** had similar morphology as discussed in Plate **{3.3I}** with blocks of sharp edge kaolinite **[k]** cemented in flakes of Si, Fe and feldspars. There are high alterations of the kaolinites into illite - smectite minerals as low concentrations of K and Mg elements were observed. Other elements having minor concentration in accumulation were Mn and Ca. The chemical compositions suggest illite-smectite minerals with flakes of kaolinites in Plate **{3.3II}**.

3.5.2 Vume red pot

The finished pots in Vume comes only in one colour, red. The red Vume pot sample from site 8 SEM/EDS analysis showed some mineralogical and chemical variations. The weight percentage of elements had high concentrations in Si (24.3%), Fe (9.7%) and Al (8.1%). Lower concentrations were in Na (1.4%), Cl (1.2%), S (1.2%), K (1.1%), Ca (0.9%), Ti (0.7%) and Mg (0.6%) (Table 3.12).

Plate **{3.4I}** exhibits thermal treatment of kaolinite which does not only cause loss of water with the formation of meta kaolinites but also carbon reduction especially in the presence of charcoal. Spot **[d]** had high concentration of Fe with compact and massive structure of Al-Si elements forming structures of honeycombs **[u].** Also identified were kaolinites and smectites with filamentous **[t]** illite minerals. Patches of Fe **[d]** minerals with trace metals of Ca and Mg which formed the smectite minerals filled the pores and cemented the kaolinite minerals. Thermal application enhanced the experiential processes. Plate **{3.4II}** showed kaolinite mineralogy with some elements forming smectite -illite minerals having halloysite structures [**i**]. Vermiculites (Fe, Mg, Al and Si) were equally identified as thermal applications were prominent.

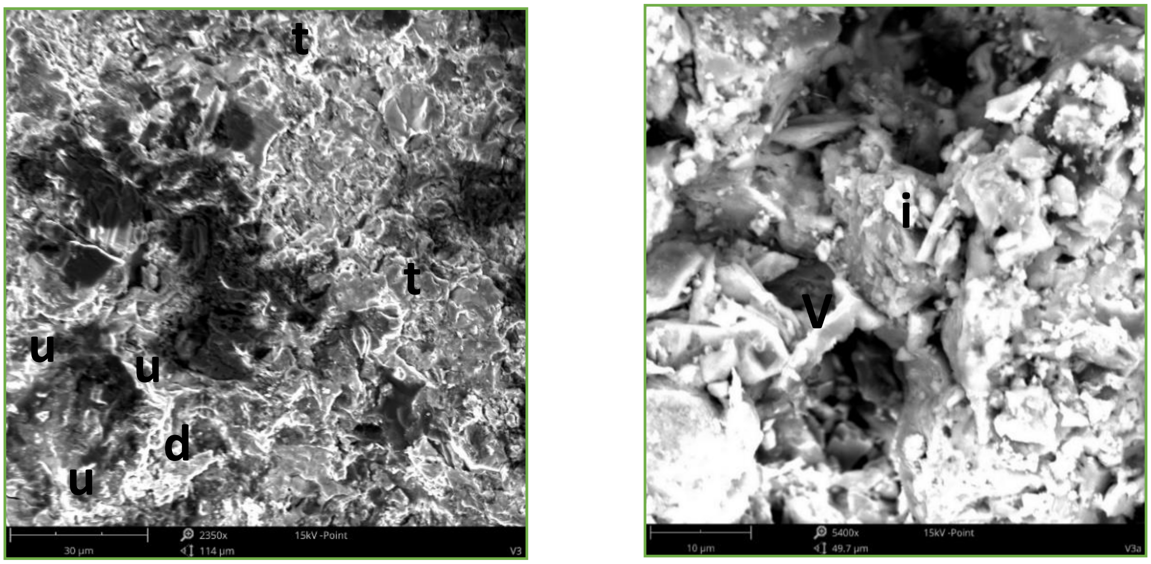


Plate 3.4I: Honeycomb structure

Plate 3.4II: halloysite structures

Plate 3. 4: SEM micrographs of Vume pots

The thermal influence on the silicates transformed them into cristobalites. Major elements of Na, Cl and Ca was recognized occurring in addition.

Vume crude clay mineralogy was observed to contain high concentrations of silica (quartz) with Fe and Ti as contaminant. The Vume clay may be kaolinites since they usually have the already mentioned mineralogy. Minerals of smectite, illite-smectite and quartz precipitated as intergranular pore filling cement. The finished Vume pot showed irregularities in shape and changes in the morphology of the minerals due to thermal applications.

High concentration of carbon elements in sample V-site 8 indicates thermal processes in the presence of charcoal. Fe concentrations in the finished red pot in Vume was high. Clay slips used as colorant on the pottery wares have Fe content hence a contributing factor for the high Fe concentrations observed.

3.6. Statistical Analysis

3.6.1 Principal Component Analysis of Geology in Study area.

The Principal Component Analysis was applied to identify sources of heavy metals in clay samples by applying varimax rotation with Kaiser Normalization to SEM results of the study areas. By extracting the eigenvalues and eigenvectors from the correlation matrix, the number of significant factors and the percent of variance explained by each of them were calculated.

Table 3. 14: Varimax rotated PC loading for Vume and Mpraeso clay (loadings >0.4 are shown in bold)

Element	Components			Communalities
	1	2	3	
Fe	**-0.740**	-0.104	0.242	0.617
O	**0.735**	0.307	-0.315	0.733
Si	-0.010	**0.647**	0.264	0.496
Al	**0.615**	-0.017	**0.638**	0.789
K	0.021	**-0.619**	**0.612**	0.759
Mn	**0.726**	-0.035	-0.072	0.534
Mg	-0.220	**0.578**	**0.660**	0.817
Ti	-0.208	**-0.721**	-0.069	0.588
Ca	**-0.708**	-0.308	-0.300	0.687
Eigen value	2.595	1.856	1.544	
% of variance explained	28.832	20.625	17.157	
% of cumulative	28.832	49.458	66.614	

Extraction method: principal component analysis. Rotation method: varimax with Kaiser Normalization. Rotation converged in six iterations.

Table 3.14 shows the results of the factor loadings with a varimax rotation, as well as the eigenvalues and communalities. The results indicate that three eigenvalues were higher than one (1) and that these three factors explained 66.6 % of the total variance. The first factor explained 28.8% of the total variance and loads heavily on Fe, O, Al, Mn, and Ca. Factor 2, dominated by Si, K, Mg, and Ti, accounted for 20.6% of the total variance. Factor 3 is loaded primarily by Al, K, and Mg, accounting for 17.2% of the total variance.

3.6.2 Statistical analysis of Physico- chemical analysis of clays

3.6.2.1 Mpraeso clays

PCA was applied to identify sources of heavy metals in Mpreaso clay samples through the application varimax rotation with Kaiser Normalization. Table 3.15a shows the results of the factor loadings with a varimax rotation, as well as the eigenvalues and communalities. The results indicated that two eigenvalues were higher than one (1) and that these two factors explained 76.97 % of the total variance. The first factor explained 46.7% of the total variance and loads heavily on Co, Zn, Mn, Cr, and Cu. Factor 2, dominated by Co, Ni and Fe accounted for 30.3% of the total variance.

Table 3. 15a Varimax rotated PC loading for Mpraeso clay (loadings >0.4 are shown in bold)

Elements	Components		Communalities
	1	2	
Co	**0.623**	**-0.597**	0.745
Zn	**0.882**	-0.141	0.798
Mn	**0.856**	0.269	0.804
Ni	0.073	**0.932**	0.873
Fe	0.384	**0.880**	0.923
Cr	**0.736**	-0.163	0.568
Cu	**0.822**	-0.023	0.676
Eigen value	3.269	2.119	
% of Variance explain	46.703	30.272	
% of Cumulative	46.703	76.974	

Extraction method: principal component analysis. Rotation method: varimax with Kaiser Normalization. Rotation converged in six iterations

Meanwhile the temper (additive) samples indicated three eigenvalues that were higher than one (1). These three factors explained 75.6 % of the total variance with the first factor explaining 43.3% of the total variance and loading heavily on Zn, Mn, Ni, Pb, Fe, Cr and

Cu. Factor 2, dominated by Zn, Fe, Cr and Cu accounted for 17.2% of the total variance. Factor 3 was loaded by Co accounting for 15.1% of the total variance as seen in Table 3.15b in Appendix A.

On the other hand, when the clay was mixed with the temper the results indicated three eigenvalues higher than one (1). These three factors explained 78.7% of the total variance with the first factor explaining 39.8% of the total variance and loading heavily on Zn, Mn, Fe, Cr and Cu. Factor 2, dominated by Co, Zn, Ni, Pb, Fe and Cr accounted for 25.3% of the total variance. Factor 3 was loaded by Ni, Pb and Fe accounting for 13.7% of the total variance as represented in Table 3.15c in Appendix A.

The clarification to this according to Franco-Uría *et al*., (2009) and Rodríguez-Seijo *et al*., (2017) is that the association of the heavy metals could be indicative of their common origins from anthropogenic or natural sources (geogenic and pedogenic sources). The highest loading of heavy metals (Co, Zn, Mn, Cr, and Cu) suggested that these heavy metals could be primarily ascribed to anthropogenic inputs. Anthropogenic activities such as pesticide application, fertilization, hunting, and atmospheric deposition, might generate a strong impact on the accumulation of heavy metals in the clay samples.

3.6.2.2 Vume clays

Likewise, PCA was applied to Vume clay samples to identify sources of heavy metals in them by applying varimax rotation with Kaiser Normalization. Table 3.16a shows the results of the factor loadings with a varimax rotation, as well as the eigenvalues and communalities. The results indicated three eigenvalues that were higher than one (1) and these three factors explained 80.3% of the total variance. The first factor explains 45.5%

of the total variance and loads heavily on Zn, Mn, Ni, Fe, Cd and Pb. Factor 2 dominated by Cu and Co accounts for 19.4% of the total variance. Factor 3 is loaded by Cu, Pb and Co accounting for 15.4% of the total variance.

Table 3. 16a: Varimax rotated PC loadings for Vume clay (loadings >0.4 are shown in bold)

Element	**Components**			**Communalities**
	1	**2**	**3**	
Zn	**0.903**	0.041	-0.222	0.867
Mn	**0.821**	0.302	-0.380	0.911
Ni	**0.705**	0.204	0.227	0.590
Cu	-0.036	**0.868**	**-0.451**	0.958
Fe	**0.758**	-0.307	0.325	0.774
Cd	**-0.756**	0.109	0.083	0.590
Pb	**0.594**	0.307	**0.613**	0.823
Co	-0.388	**0.683**	**0.543**	0.912
Eigen Value	3.638	1.554	1.232	
% of Variance explained	45.471	19.421	15.405	
% of communalities	45.471	64.893	80.297	

Extraction method: principal component analysis. Rotation method: varimax with Kaiser Normalization. Rotation converged in six iterations.

The temper (additive) samples applied varimax rotation with Kaiser Normalization extracting the eigenvalues and eigenvectors from the correlation matrix. The number of significant factors and the percent of variance explained by each of them were equally calculated. Table 3.16b (Appendix A) shows the results of the factor loadings with a varimax rotation, as well as the eigenvalues and communalities. The results indicated that two eigenvalues were higher than one (1) and that these three factors explained 83.8% of the total variance. The first factor explained 38.2% of the total variance and loads heavily on Zn, Mn, Pb and Co. Factor 2, dominated by Mn, Cu, Cd and Co accounts for 24.9% of the total variance. Factor 3 is loaded by Ni, Cd, Pb and Co accounting for 20.6% of the total variance. Finally, heavy metals in clay mixed with additive samples were also calculated for and Table 3.16c in (Appendix A) showed the results of the factor loadings with a varimax rotation, as well as the eigenvalues and communalities. The results indicated that two eigenvalues were higher than one (1) and that these two factors explained 74.9 of the total variances. The first factor explained 48.4% of the total variance and loads heavily on Zn, Mn, Ni, Fe, Pb and Co. Factor 2, dominated by Ni, Cu and Cd accounts for 26.4% of the total variance.

3.6.3 Statistical analysis using ANOVA

3.6.3.1 Clay in Mpraeso

In finding relationship between metals in clays, tempers and clay mixed with temper, one-way ANOVA test was applied to study this variance. A $p<0.05$ or lower was measured as significant.

3.6.3.1.1 Iron (Fe) and Chromium (Cr)

Fe and Cr varied between clays, tempers and clays mixed with tempers and within these sample types in Mpraeso. These metals were highly significant in all the three types of samples at 0.05 level using one-way Tukey HSD ANOVA test.

3.6.3.2 Clays in Vume

There was no significant relationship between and among sample types in Vume. This is because clays and tempers are dug less than 50m away from each other and so they are basically the same sample type hence the non-significance relationship.

3.6.4 Pearson coefficient of correlation on the Geology of the study area

Pearson correlation for existing minerals in the clays from Mpraeso and Vume were computed statistically. The coefficient of correlation provided a general assessment of minerals with specific ones in the suite of samples as represented in Table 3.17. For correlation significance, the criteria values of probabilities ($p<0.05$) was used. From Table 3.17 there is positive strong correlation between Mn/O ($r=0.882$, $p< 0.05$), K/O ($r=0.090$, $p<0.05$), Al/Si ($r=0.566$ $p<0.05$), Mg/Si ($r=0.844$, $p<0.05$), K/Al ($r=0.661$, $p<0.05$), Mg/Al ($r=0.539$, $p<0.05$) and Mn/K ($r=0.501$, $p<0.05$). However negative coefficient of correlation was recorded between Fe/O ($r= -0.690$, $p<0.05$), Mn/Fe ($r= -0.521$, $p<0.05$), Ti/O ($r= -0.541$, $p<0.05$), Ca/O ($r= -0.079$, $p< 0.05$), Ti/Si ($r= -0.661$, $p< 0.05$) and Ca/Si ($r= -0.057$, $p<0.05$) respectively.

Table 3. 17 Pearson coefficient of Correlation among metals at Mpraeso and Vume

	Fe	*O*	*Si*	*Al*	*K*	*Mn*	*Mg*	*Ti*	*Ca*
Fe	1								
O	-0.690	1							
Si	-0.184	0.031	1						
Al	0.257	0.030	0.566	1					
K	0.393	0.090	-0.240	0.661	1				
Mn	-0.521	0.882^*	0.030	0.382	0.501	1			
Mg	0.289	-0.496	0.844	0.539	-0.178	-0.418	1		
Ti	0.285	-0.541	-0.661	-0.227	0.302	-0.302	-0.317	1	
Ca	0.372	-0.079	-0.057	-0.373	-0.419	-0.421	0.041	-0.459	1

*****Correlation is significant at the 0.05 level (2-tailed).

Statistically there were strong correlation between Al and K at $p = 0.661 > 0.05$ among Mpraeso clays. There was also significant correlation between K/O at $p=0.090 >0.05$ and Mn/K ($r=0.501$, $p<0.05$) in Mpraeso clays.

However, there was negative correlation in Fe from the clay deposits in the two study areas at p= -0.690 >0.05 for Fe/O and p= -0.521 > 0.05 for Mn/Fe respectively while significant at 0.05 level using one-way Tukey HSD ANOVA test. Oxides of rutile and anatase (TiO_2) could be formed with Ti elements though observed in low concentrations in all the Mpraeso samples and is supported statistically by the negative coefficient of correlation of Ti/O at p = -0.541>0.05. The raw clay sample in Vume had the concentration of Ti to be very high (16.2%) and may combine with Fe to form oxide minerals through the negative correlation at Ti/O at p = -0.541>0.05.

3.7 Conclusion

From the analyses, it can be inferred that the clay mineral constituent in Mpraeso and Vume are kaolin clays with kaolinite minerals which are good for pottery works. Montmorillonite, kaolins and "common clays" are clay types used in industrial applications. 'Common clays' often contain illite–smectite mixed-layer minerals, and are largely used for ceramic (Bergaya, 2013).

Clays in Mpraeso have elements of Fe, Cu, Cr, Ni, Mn, Zn and elements of Cd, Co, As and Pb were below detection levels. On the other hand, in Vume elements of Mn, Ni, Fe, Cu, Cd, Pb Co were in varying concentrations while elements of As, Cr and Zn were below detection level.

CHAPTER FOUR

POTTERY PRODUCTION, SOCIO-CULTURAL AND ECONOMIC IMPORTANCE OF THE INDUSTRY

4.0 Introduction

Pottery are part of human activity that is produced and used in societal settings as it is a petty commodity (Stark, 1995). In the study communities (Mpreaso and Vume), pottery depicted the evolutional history of cultures around which their societies evolved. The art is a highly valued artistic profession which provided livelihood for the people living in these towns (Arthur, 2013). Accounts of pottery in the two study areas revealed the existing ethno-linguistic characteristics of pots (Stark, 1991). These pots from the local people are a representation of their cultural heritage which has exceptional contribution towards self-actualization of who they are. It is for these reasons and many more that potters in the study sites are capitalizing on to stay in business.

The present chapter is concerned exclusively with the socio-economic impacts and cultural perceptions of the people doing unglazed earthen ware pottery made from low-refractory clays of melting point ranging from 1100-1200°C (Tite, 1999). According to Asante, Opoku-Asare, and Wemegah (2015), traditional pottery promotes the education, conservation, and transmission of the cultures and norms of a people. Pottery plays a very important role in the indigenous culture of most ethnic groups in Ghana (Asante, Adjei, and Opoku-Asare 2013).

The research strategy is to follow the cycle of the pot from production to its use and through to the discard of the sherds otherwise end of use. The reproduction of another pot in replacement of the old one is the beginning of a new cycle. The chapter also related the socio-economic impact and cultural perception of the craft with the people.

The varied phases were interrelated in a specific way that contributed to the earthenware assemblage. Of the main discussion, the analysis of production practices was limited to that of Mpraeso and Vume to critique the relationships between the technology of manufacturing, the taxonomies for the function, the social and cultural significance and the actual use practices of earthenware pots were the focus of this chapter. This was accessed through observation, participatory and detailed photographic exploration of the production processes involved in Mpraeso and Vume. This indicated how potting traditions are related in two different ethnic groups (Akans and Ewes) and the evolution of these traditions over the years. The current study modelled all the processes, series of phases and adoptions by the potters. Basic groups of variables involved in the earthenware pot manufacturing process which plays an essential role in the cycles of pottery is also confined in the model (Figure 4.1). This process contains the life cycle of pottery which can make a valuable contribution to research in social science. All the varied phases in production which were the inputs were associated with the vessel image which was the product of interest.

Results of the study regarding the unglazed traditional production processes, socio-economic and cultural importance of the pottery industry were interpreted using SPSS. The chapter revealed that almost all the processes and taboos were the same and the changes that evolved from the two dynamic societies echoed.

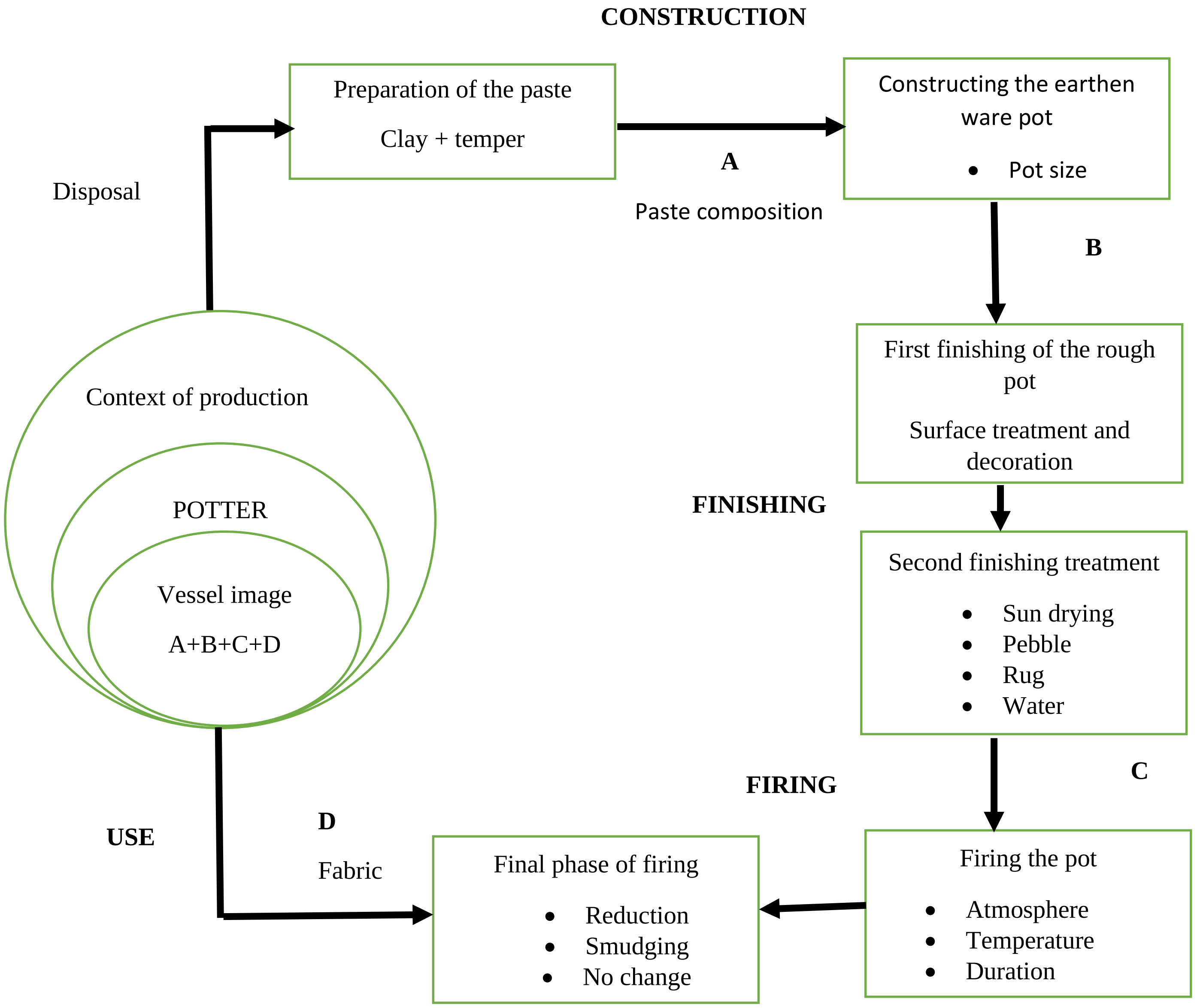


Figure 4. 1 The cycle of production of pottery

4.1 Research Methods and Materials

4.1.1 Data collection approach (Research design)

A cross-sectional research of mixed methods comprising qualitative and quantitative techniques (Adjei-Mensah & Kusimi, 2019) were employed.

The qualitative technique deals with the collection of data by using words to describe and understand the distinctions between pottery works in the two study areas. This approach also appraised the singularity perspective of participants (Leedy & Omrod, 2005). The descriptive technique made it possible for one to appreciate cultural practices based on non-participation and participant observation, informal and formal interviews in gathering of socio-economic data.

The narrative technique was used to illustrate how things were done differently grounded by traditions and culture. It also helped brought out relevant information such as the historical background of the people within the study areas. Again, the narrative portrayed how the relationships between potteries work, settlement, culture and art influenced each other. The study covered the population within the Mpreaso district in the Eastern Region and Vume in the Volta Region as discussed in the previous chapters.

4.1.2 Sampling method and sample size

The main target population for the study was resident potters in the study area within the ages of 18 years and above and who has been in practice for a period of 2yrs or more. These targert population is believed to be adults with the needed experience in potting. The study focused primarily on traditional potters within the communities. There is no database on the number of potters in both communities. The non-probability sampling technique of snowballing was used to reach out to the respondents. A total of 163 respondents were identified with; 109 questionnaires administered among potters in Mpraeso and 54 in Vume.

4.1.3 Data collection methods and survey instruments

Data was compiled using primary and secondary sources to gather information. In gathering primary data, subjective interactions were made with the respondents. This was done using methods such as interviews, observations, questionnaire administration, informal discussions, photography, and videoing. This involved describing and understanding the distinctiveness in the participants' viewpoint (Leedy & Omrod, 2005). Antubam,(1963) and Asante-Kyei *et al.*, (2016) explained that such methodology focuses on exploring and describing how pottery in the study areas can integrate into everyday life as a socio-cultural heritage. Secondary data was from sources such as on-line resources, scientific journals, magazines, newspapers, periodicals, thesis, charts, and books.

Survey instruments included interview guides, questionnaires, and on-site observation. Prior to data collection questionnaires were pretested involving forty-five (45) respondents (22 in Mpreaso and 23 in Vume) to help fine tune it. Consent of participants mainly potters was sought before the questionnaires were administered. Open ended questionnaires though interspersed with a few dichotomous survey questions were used (Table 4.1 and for detail questionnaire see Appendix B). The combination of learning hands on and through research and discussion gives a broader scope for understanding this area of study. Questionnaires were administered to potters and structured interviews conducted with related institutions (Assembly, EPA, Sanitation office etc.). Interviews were also conducted with very elderly women who were no longer making pots on the history of pottery making in Mpraeso, pottery types, and the socio-economic and cultural importance of pottery in Mpraeso. During the unstructured interviews, the potters shared information on the history of pottery in the community and on cultural beliefs pertaining to pot making, which were particularly vivid. This enabled cataloge production processes (or chaine operatoire) of pottery over the years in the communities.

Table 4. 1 Overview of questionnaires for potters

Data group	Description
Demographics	Gender and educational background
Structured Questions	
Potters and pottery processes	Years of practice, source of raw materials, processes involved in the production of pots
Social impact	Existing arrangements and effects on production systems
Sociocultural impact	
Unstructured Questions	
Historic events	History of pot making
Cultural believes	Taboos, cultures associated with pottery production, festivals, funerals
Structured Questions	
Gender	Sex dominating the craft, roles played in the production cycle
Acquisition of skill	Who taught the potter the craft
Economic impact	Marketing of products, demand of products, effects of influx of foreign materials
Others	Modern trends, indigenous knowledge applied in pot making etc.

Questions revolved around processes, social impacts, socio-cultural and economic impact of pottery activities.

With reference to the unstructured interviews approach, potters gave information on the history of pottery in the community, cultural beliefs pertaining to pot making, which were vivid.

No respondents had difficulty in answering the questions because the questions were open, simple, and straight to point. Where additional information was needed for clarity, respondents were asked to shed more light on those issues. In some cases, the presence of an interpreter made respondents to express themselves freely in their local dialects rather than asking them to write which helped in bringing out valuable information. Other technique applied was through observation. In this case, both methods of participant observation and non-participant observation were used which was very helpful.

4.1.4 Data analysis

The interview and observations data gathered from the field was transcribed and the results presented in narratives. The questionnaire data was organized and managed using the Statistical Package for the Social Sciences (SPSS) software. A database was developed by assembling, editing, and coding the questionnaire data. The first stage of the analysis involved descriptive analysis where frequencies and percentages were derived to describe the social and demographic characteristics such as the sex, age, and educational level of respondents. The second stage of analysis used the data generated to employ a bivariate analytical method where cross tabulations were done to establish whether there were statistically significant associations between variables. The use of chi-square test enabled the study to assess and compute for various statistical significance and association between the variables. The computer software, Microsoft Excel was used to enhance additional data analysis using descriptive statistical tools. Pie charts, bar graphs, histograms, figures, cross tabulations, plates, and tables were subsequently developed to enhance visual presentation of result.

4.2 Results and discussions

There were seven information categories from the questionnaires that were analyzed using SPSS. Results on the information pertaining to demographic characteristics of respondents, potters and pottery processes, social impacts of pottery, socio-cultural and economic impacts were discussed.

4.3 Demographics of respondents

The field data indicated that all respondents were females and matriarchs of pottery in both study sites. Educational level of respondents ranged from basic to tertiary with a few without any formal education (Fig.4.2). A large percentage of them had basic education (87%) at Mpreaso and (41%) at Vume with secondary school graduates of Mpreaso being the least number. The women combine the pottery work with petty trading and farming. Earnings from these pottery activities of the women are used in furthering their children education and skills training in specialized fields.

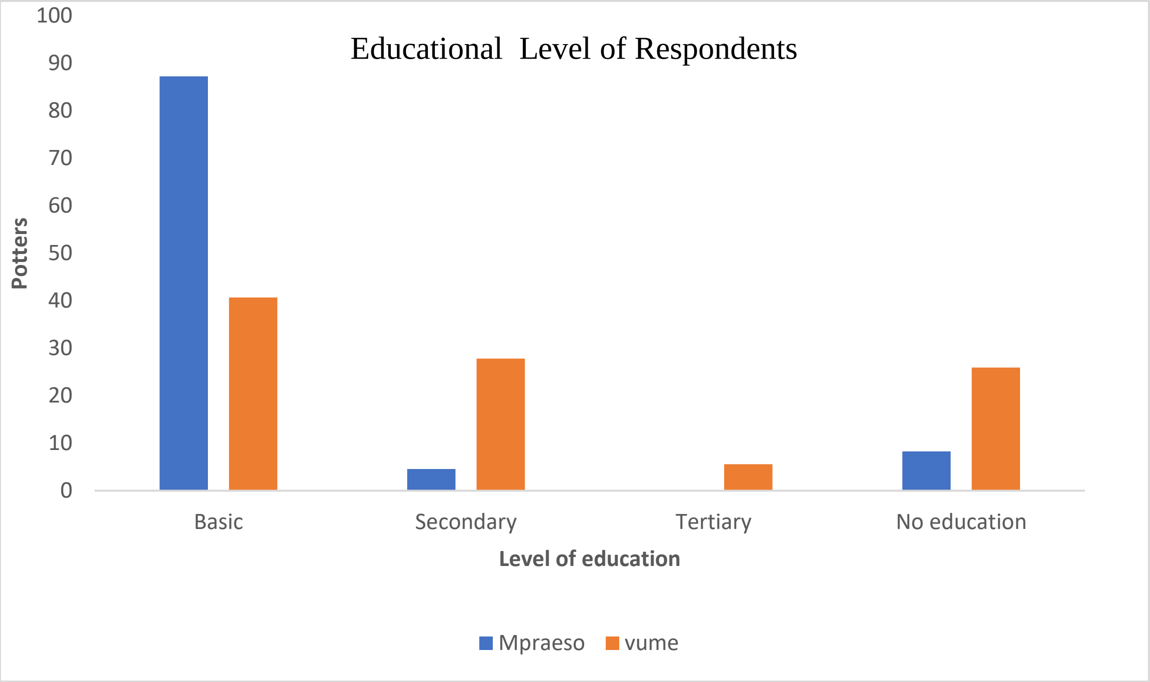


Figure 4. 2: Level of education of potters in Mpreaso and Vume.

4.4 Pottery processing

All respondents mentioned similar procedure used for processing and manufacturing of the earthenware pot in the respective study towns Mpraeso and Vume. The pottery methods are discussed below.

4.4.1 Pottery processing materials at Mpreaso-

In Mpraeso pottery is produced from impure clays and clay additive locally called amodine (temper). Materials are transported to the working site (manufacturing sites) and stored. These raw materials used in the pottery are impure clay materials of silica, sand, quartz, flint, silicates, and aluminosilicates (e. g., clays and feldspar). In Mpraeso various rudimentary tools used include *sabrobaa* (wooden paddle), *sikyie* (piece of wood) *kwaboba* (stone) and *ponoye* (metal) during the pottery. Each is defined as follows:

- *Sabroba:* This is a wooden paddle (Plate 4.1 (a)) used to beat the back of the pot to give it a base or footing.
- *Sikyie:* This tool (Plate 4.1 (b)) is used in polishing the pot both inside and outside.
- *Sonie:* Is a metal strainer (Plate 4. 1 (c)) is used in sieving grog (Amodine).
- *Ponoye:* Is used in scrapping the inside of the pot so as it will be levelled. This tool is normally obtained from bags containing second-hand clothing’s (plate 4.1 (d)).

(a) Sabrobaa (b) Sikyie

(c) Sonie (d) Ponoye

Plate 4. 1 Pottery processing tools in Mpraeso.

- *Ntomago:* Is a rug (Plate 4.2 (e)) used with water to moisturise the pot which gives it smoothness.
- *Sapo:* Is a net (Plate 4.2 (f)) which the women also use in smoothing the pot.
- *Dadwe:* Is a decorative tool (Plate 4.2 (g)) in striations in the grinding pots.
- *Kwaboba*: It is a well braided pebble (Plate 4.2 (h)) with a smooth surface used in fine tuning the polishing.

(e) Ntomago (f) Sapo

(g) Dadwe (h) Kwaboba

(i) Ahwenie

Plate 4. 2 Decorative tools during pottery processing in Mpraeso.

- *Ahwenie:* These are beads (Plate 4.2 (i)) which the potters use with black clay for final smoothing of the pot after it has been sun dried and fine-tuned with the braided pebbles.

4.4.2 Processing and manufacturing of Mpraeso pots

All the respondents in Mpraeso use the same method of forming which starts with the preparation of the raw material. The potters clean the clay materials of all debris to begin the process. The clay is then soaked in water for a day or two to enable the potter work more easily with the material. Wet clay slurry is then made Plate 4.3 (a).

(a) Clay and Amodine slurry (b) Amodine

(c)Mixing clay with hands

Plate 4. 3 Forming methods in Mpraeso.

This is followed by component mixing where the wet clay slurry is then mixed with sieved dry temper which the community calls ‘Amodine’ (Plate 4.3 (b)). The amodine, is a local sand like substance which makes the clay material more plastic and smoother in texture through binding thereby improving the handling, packing and compaction. This mixing is done with bear hands as gloves (protective gear) obstruct their work. Sometimes sharp objects are found while working on the raw clays, potters claimed (Plate 4.3 (c)).

This turns out to be an occupational hazard. Purging, pinching, wedging, and kneading of the clay are procedures that follow. These stages of the craft enable potters to work comfortably with the clay material. Many skills and techniques are required for these various stages and the clay is kneaded until a desired texture based on the knowledge and skills of the potter is achieved. The third step in forming is shaping of the wares by molding of the clay mixture using an improvised potter’s wheel into the grinding pots as the case in Mpreaso.

The improvised potter’s wheel consists of a raised platform made up of objects such as rocks or wood of a comfortable height for the potter while she is standing. At the very top of the piled rocks is a piece of board that acts as the working surface (Plate 4. 4 (a)). A ball of clay is place on the board, a hole is created in the middle of the clay ball and is molded to the desired shape manually. The clay stays on the piece of board while the potter walks around it using both hands and the fingers to skillfully smoothen the edges of the clay to mould the pot (Plate 4.4 (a)).

Throwing and cutting is proceeded expertly to ensure that the pastes are consolidated properly and molded to produce a cohesive body of the desired shape and size of the product. This follows with a piece of rug (tomago) which is dipped in water and rubbed around the pot gently to further smoothen it (Plate 4.4 (b)).

(a) Improvised potter's wheel (b) Tomago for smoothening

(c)first sun drying of pots.

Plate 4. 4 Forming, Smoothening, and drying of pots.

The pots after smoothened are left to dry in the sun for a maximum of 24hrs depending on the sunny condition of the weather (Plate 4. 4 (c)).

4.4.3 Surface treatment of processing pots of Mpraeso

All respondents smoothen their pots using wood (Sabrobaa) which had flat side for tapping/beating the formed clay to give it a base (Plate 4. 5 (a)). Another wood (sikyie Plate 4. 5 (b)) is used in polishing both the inside and outside of the pot after which a metal (Ponoye Plate 4. 5 (c)) is used to scrap the inside of the pot so that it will be levelled.

(a) Sabroba for tapping pot base (b) Sikyie for polishing.

(c) Ponoye for scraping inside of pots.

Plate 4. 5:Surface treatment of pot in Mpraeso.

A smooth beach pebble stone (kwaboba) is used to polish the pot for it to attain its smooth surface texture. The Dadwe is then used on the pot to design it while the beads and the net further smoothen the pot and prepares it for sun drying. After forming, the wares are dried in the sun (Plate 4.6 (a)) for 2 or more days. Drying must be carefully controlled to strike a balance between minimizing drying time and avoiding differential shrinkage, warping, and distortion.

This is mostly experienced during the dry season. And during the raining season potters are unable to dry their wares due to unavailability of the sun. After sun drying, the pots are further dried by charcoal burning (Plate 4.6 (b)) before firing.

(a) Sun drying of pots (b) Charcoal burning of pots

Plate 4. 6 Drying of pots in Mpraeso.

4.4.4 Firing procedures of Mpraeso pots

All respondents employ the open firing method in which the pots are proficiently packed on firewood (Plate 4.7 (a)**)** and openly fired in the backyards of the potters' residence to make them stronger (Plate 4.7 (b)). After that, they are placed in sawdust (Plate 4.7 (c) and 4.7 (d)) to acquire the black colour. This process is only characteristics of Mpreaso production as Vume production process often do not employ this technique though they are aware of this.

(a) Pots packed for firing

(b) Open firing of pots.

(c) Pots in sawdust

(d) Black pots from sawdust

Plate 4. 7 Firing of pots in Mpraeso.

4.4.5 Use and Disposal of Mpraeso pots

The final stage of the pottery process is to take the objects into the markets for sale or to leave them at "the factory" for merchants to come and purchase. When these pots are finally in homes and restaurants, they are used for grinding vegetables **(**Plate 4.8**)** or as eating bowls**.**

Plate 4. 8 Pots use for grinding sauce and serving of food.

Some restaurants and eateries in Ghana also use this popular kitchen utensil preserving it as an iconic souvenir of an aspect of Ghanaian culture. After the pot's usage for a period, it expires and then disposed off into the environment which induces the beginning of a new cycle, or they are crashed and soaked and recycled if the expired/worn out/broken pots are in the home of a potter.

4.4.6 Other potteries of Mpraeso

Apart from the grinding pots, there are several products that are produced by the Mpreaso potters. Though most Mpraeso potters have a flair for making the grinding pots (Ayiwa), a few other types of pottery wares are produced alongside the grinding pots. Big pots in which water is stored for drinking known as *Ahena* (Plate 4.9 (a)) are made by these potters. Another type of pot commonly used and produced is for boiling herbs and in medicinal preparation known as *kukuo* (Plate 4.9 (b)**).** The kwanseng (Plate 4.10 (a)**)** is used in cooking and food preparation while the Asanteyiwaa (Plate 4.10 (b)**)** for serving of meals.

(a) Ahena for drinking water (b) Kukuo for medicinal purpose

Plate 4. 9 Potteries in Mpraeso.

The *Dwasen* is used in bathing especially chiefs when they die. A few of the potters are skilled in molding flowerpots (Plate 4.10 (c)**)** and effigies (Plate 4.10 (d)). The porters who are skilled in molding other craft apart from the *Ayiwa* are of the view that the youth in recent times are not interested in the craft hence some aspects of the skills are going into extinction. An example was given as the molding of the effigy which is locally called *Sanpon*.

(a) K*wanseng for cooking*

(b) Asanteyiwaa for serving meals.

(c) Flowerpot

(d) Sanpon

Plate 4. 10 Other potteries in Mpraeso.

The sanpon is an effigy used ceremonially by the people in Mpreaso and its environs. It is believed to be molded in the image of a chief and so when that chief die, the effigy is placed in a big grinding pot with the picture of the chief accompanying the effigy. This is paraded throughout the community during the funeral rites of the deceased chief. Currently the only one who can mold the sanpon is over 90 years old Abena Fante. According to her, she learnt the skill from her late mother in-law. Her fears are that when she also dies no one will be able to mold the sanpon again.

4.4.7 Pottery processing materials at Vume

Pottery is produced also from impure clays and clay additive known as grog (temper) in Vume. Both the impure clay and grog are dug from a valley within the town whiles another type of reddish clay used as slip/decorant is from an island in the Volta Lake. The materials are transported to the manufacturing sites, stored, and processed.

(a) Abaabe (b) Tsubliti (c) Ayie

(d) Abobogoe (e) Kpedonakpe/zeninikpe

Plate 4. 11 Pottery processing tools in Vume

The mineral composition of the impure clay is silica, sand, quartz, flint, silicates, and aluminosilicates (e. g., clays and feldspar). The working tools in Vume are basically of the same material as Mpreaso but of different shapes/forms and names because of the differences in the languages. In Vume the tools used are the *Abaabe* (wooden paddle) (Plate 4.11 (a)), *Tsubliti* (shaping tool) (Plate 4.11 (b)) and *Ayie*/*Akorɔe* (a metal scraper) (Plate 4.11 (c)).

- *Ayie*: This metal scraper is used for scraping the rough inner surfaces of pots.
- *Emedzeti:* Is a wooden fork tool decorative tool used for ruling lines and decorating the inside, rim, and neck of pots.
- *Sranu:* Is a metal strainer (sieve) used for sieving grog.
- *Abobogoe:* Is a snailshell used after scraping the inner surfaces to level the inside walls of the pots (Plate 4.11(d)).

(a) Cushion (b) Rug

Plate 4. 12 Decorative tools during pottery processing in Vume

- *Kpedonakpe/zeninikpe*: It is a smooth stone/pebble used to smoothen the surfaces of the pots (Plate 4.11(e)).
- *Cushion*: For cleaning hands and wetting pots during formation process (Plate 4.12 (a)).
- *Cloth*: Dipped in a bucket of water for smoothen the edges of pots. This has replaced *edzo* a forest leaf which was formerly used (Plate 4.12 (b)).

4.4.8 Processing and manufacturing of Vume pots

All traditional potters interviewed in Vume stated they use the coiling and pinching practices as their forming method. The very strong coarse-grained raw clay material is first sun dried. The clays first dried and foreign objects removed from it. The dried clay is soaked in water for a day to make it moist and easy to work with. This is done in a workstation which is usually outdoors of the potter's residence (either in the middle of the compound or at the backyard of the home) where a thatched roof structure (Plate 4.13) provides shade for potters while working. Porches of homes serve as storage facility for storing drying pots as well as finished pots.

Plate 4. 13*: Workstation under a hut in a compound*

The soaked clay is mixed with grog material a couple of times to acquire a suitable texture for the potter. Grogs are raw clays dug from the first layers of earth from the extraction pits. The women light fire on these materials and burn them for 3 days after which it is gathered and transported separately to their workstations. The potters pound the burnt coarse material into a fine sand like texture which is sieved using the metal strainer (*Sranu).* When the grog is added to the unfired soaked clay it gives the material a certain strength and texture suitable for molding.

The mixed clay is kneaded, and a clay ball obtained. The size of the clay ball determines the size of the intended pot to be molded. A coil thread is formed from the clay ball which is placed on the ground and a loop is formed. The circumference of the loop is widened with the fingers from one end to the other. A considerable circumference is obtained as the potter bend and whirl or run her fingers around the inside and outside bottom of the pot for the molding to stick to the ground. One hand is used in holding the clay while the other pinches simultaneously while trotting backwards in a circle. Subsequently the entire body run around the clay on the ground to mold the pot (Plate 4.14 (a)). This is done until the pot reaches the height the potter wants and then beats/tap the pot with the *Ababe* (Plate 4. 14 (b)) till the molding is well shaped and compact with a smooth surface.

(a) Forming of pot (b) Smoothening with *ababe*

Plate 4. 14 Forming and smoothening of Pots.

4.4.9. Surface treatment of Vume pots

All respondents use *Tsubliti* to further shape and smoothen the pot while *edgo* which is either a leaf or a piece of cloth soaked with water does the polishing of the pot. At this stage, the mouth of the pot is properly and smoothly shaped by holding the piece of cloth with the fingertips and gently drawing it around the lip of the pot. Lines and other decorations around the edges of the pot is done on the outside of the pot. Previously potters used leaves at this stage of the pot making but due to the increased lip size of pots makes the leaves to be too small to be applied.

The partially completed pots are sun dried for some time with length of time depending on the weather to obtain a leather hard stage after which the half-made pots are picked from the ground. The potter places the half pot on her lap and the *Abobogoe* is used to scrap bulk of the excess clay from the base and the rims of the pot. The *ayie* is then used to smoothen it after which coils of thick clays are added to fix the base. The cushion is dipped in water to dampen the inside of the pot and further smoothen with the pebble rock. The pots are thoroughly sun dried again under shade and in the sun. Pots are then glittered using the pebble and sun dried again. They are then glossed with red clay slip and the potter ensures the pot gains a shiny surface using a net over the pot.

4.4.10 Firing process in Vume

Firing of pots in Vume uses the kiln method (Plate 4.15). The pots are packed in a kiln and the firing of the pots are performed. This takes a period of three days. Preheating is first done to dry the pots. If pre-heating is skipped there is a greater chance for pots to break during bisque firing.

Plate 4. 15: Kiln method of firing pot

4.4.11 Use and disposal of Vume pots

The final stage of the pottery process just like Mpraeso is to take the pots into the markets for sale or to leave them at “the factory” for merchants to come and buy. The use and disposal processes are similar as discussed under Mpreaso. Pots are used in food preparation and eating, and expired products are recycled or discarded into the environment as wastes.

4.4.12 Other potteries of Vume

Respondents indicated that apart from the grinding pot the people in Vume mold a variety of pottery wares spanning from pots for cooking, storing of water, palmwine and flower vases for aesthetic purposes. Vume potters have the flair for making beautiful flowerpots which they decorate using azar paint and iron oxide. Respondents specified that.

(a) Fafa (b) Akplexevi pot (c) Ede

Plate 4. 16 Other potteries in Vume

Fafa pot is for storing water (Plate 4.16 (a)) while akplexevi pot (Plate 4.16(b)) and Ede (Plate 4.16 (c)) are for cooking and fetching water respectively. The latter can be used to store water as well.

4.5 Social arrangements for clay mining in Mpraeso and Vume

In Mpraeso two land pits are used for clay material extraction. One is an ancestral pit that belongs to the Chiefs and people. The arrangements for digging from that pit include offering a token in a form of money and a bottle of schnapps to the chiefs. The other pits are owned by individuals and potters are charged a fee depending on the quantity of clay hauled.

Some individual landowners charge Ghc100 for a portion of 100 by 100m and potters are permitted to dig for five days. Others pay Ghc500 for a certain quantity of clay that can mold medium size about 800 pots. More potters organize themselves into groups of three members or four to contribute between Ghc1500 -2800 for a full KIA truck load of clay materials which they share equally among themselves to use for a period of one year. The potters in Mpreaso are natives of their neighbouring towns and satellite villages namely Oframase, Amanfro, Jejeti, Atibie, Nkwakwa and Ampekrom. They therefore own these lands that the clays are hauled from.

In Vume, the lands on which the raw material is hauled from is either from a wetland in the town or a few kilometers away from Vume towards the Accra road. These lands, as in Mpraeso are owned by individuals, chiefs and the people. Just as the case in Mpraeso, clays are sold by individuals who own it and token in addition to schnapps are given to chiefs who own the land on which clays are mined.

4.6 Socio-cultural Significance of the pottery industry in the study area

4.6.1 History of pottery in study area

The respondents in Mpraeso narrated that through oral tradition, it is believed that a farmer by name Animapor saw a crab digging sand near a wetland on her way to the farm. She observed the crab for some time and thought of taking the clay material, which the crab dug out home and molded it like the way the crab was doing. With time, she decided to mold it into cooking pots. People then got interested and made her to lead them into discovering the clay material. They all took samples, brought it home and molded it into pots as well. The chief at that time expressed interest in what the women were molding and demanded to be sent to the site where the raw material was found. He poured libation and sacrificed a goat invoking the gods to make wealth out of the raw materials, which is the clay until today.

The story in Vume though different very interesting. Oral tradition has it that the people of Vume are migrants from Denkyira in Ashanti Region and pottery happens to be their source of livelihood. According to these migrants their ancestors learned the art of pottery from a wasp. Their female ancestors observed the creative modelling of the insect's habitat that was a replica of a pot. This was tried at home with the use of the clay and a miniature pot was produced.

Female generations were thought and soon pottery became the art of these people. The continual wars of Denkyiras with the Ashantis made them to migrate through the leadership of chief Arkunoh in 1701. They first settled in Torgormerh where they enjoyed peace for a short while. There were series of wars which made them to migrate from Torgormerh and finally settled in Vume while keeping their pottery technique and the traditional stool with them.

While enjoying the peace in Vume they move around the neighbouring villages with canoes on the lake Volta telling everybody they meet how they are enjoying peace in their local dialect ‘Afedie ma hume’. This literally means ‘now I am at rest’ or have peace of mind. The indigenes could not speak the Akan dialect and adulterated it saying Vume which means the people in the canoe which has eventually come to stay. ‘Hume’ is the right name of the town which means to rest and upon finding the clay to work with they felt at home and settled. The stool was then sent to Kpoviagzi where wars were not too intense. This made the stool to remain in Kpoviagzi but the people moved and settled in nearby towns such as Xrokpe and Gbeleme. Despite settling in these towns, they recognize Vume as their traditional area capital with their chief been Togbe Yao Akornor (II).

4.9 Similarities in pottery production at the two communities.

With reference to similarities in the craft dynamics, as it was noted women were solely involved in the production of pottery and travelled between 2-5km to dig the clay. The production processes are similar as both communities add grog to their clay, allow pots to dry, decorate pots with similar tools before firing with personal protective dress code unlike the advanced countries where similar production is carried out under strict conditions and surveillance. Above all, potters had no good proper bookkeeping record. Both study towns had mean age of potters within the older age group of 50-54 years with not less than four dependents. The trend was that most women were now taking up the work slightly later in life. Education made younger women had no time to actively participate in the vocation. Also, younger women are of the notion that pottery was for the uneducated or illiterates.

Indeed, it is an undeniable fact that pottery making is a dirty manual work which requires lots of physical strength and not academic qualifications. This was evident in the field data as most potters had just basic education with high frequency of illiterates.

Most of the sales were on credit and could not account earnings either monthly or annually. The attitude towards pottery was very much similar in both study areas. The youth showed no interest thus only the elderly was engaged in it. Likewise, the two communities had close taboos though currently have been influenced by western education, religion, and civilization.

4.6.2 Taboos and rituals in pottery production

Respondents and interviewees explained that winning of clay is associated with taboos and rituals that natives who are potters do observe to avoid the wrath of the earth deity on them and their pottery works. In both communities, before the commencement of the clay digging, a special libation is poured to the earth divinity to beseech her consent and request for success in the usage of the clay material by the women.

The women involve chant their request trusting the earth deity to bless their efforts, obtain greater achievements in the usage of the clay and make their intentions achievable. Also, the potters do not enter the extraction pits with foot wears as respondents in both communities believe that the earth goddess who is the overseer of the clay material is tainted by that act. They stated that there are days for the extraction of clay materials.

In Mpraeso clay mining is on Wednesdays and Fridays while in Vume it is all the days except Fridays and Sundays. In Mpraeso clay winning activities are done on Wednesday’s and the heap of clay left by the side of the pit to be gathered, collected, and transported on Fridays. It is believed that the rest of the days are resting period for the earth goddess. Anyone who defiles this taboo suffers the wrath of the earth goddess such as pit collapsing on such persons during clay harvesting in Mpraeso. In Vume the local god Axava N and others on the forbidden days inspect the land and those who defile this tradition sees weird creatures such as abnormally short people at the pits and eventually contract long ailments without cure. The entire community also experiences famine as there will be no rains.

All respondents in both communities clarified that the craft is believed to be an art for women only making it gender subtle. Men are forbidden to be anywhere near the pits. This is to prevent the men from sighting the nakedness of women who go into the pits almost naked to extract the clay. In Vume, any man who does not observe this is believed to become impotent. Oral tradition also tells the people that men are also not allowed to mold, and the reason given is that any man who gets indulge in this craft becomes impotent.

Respondents and interviewees in both communities elucidated that women in their menstrual cycles do not engage in clay winning process. They are impure to the dislike of the earth deity hence should not go to the extraction site. In Vume such a woman will experience discontentment such as infertility from the earth deity. It is a taboo for uninitiated girls and girls who have not gone through puberty rites to win clay since the earth deity considers such girls as “unclean”. Again, a taboo in Vume is told of potters not pounding grog at night, not using *abaabe* in tapping and smoothing pots at night, not molding pots in anger, and not placing prices on pots before finishing. Failure to adhere to this taboo will make you obese; the pots lose their beauty when molding is completed and breaking of pots during firing, respectively.

Mpraeso respondents all attested that, it is a grievous offence and a taboo to whirl around the improvised potter's wheel and fall as a potter of the land. Such a potter must pacify the gods of the land by killing a goat. However, in recent times these taboos are mildly observed, and this is fostered by general spate of modern civilization, Western education, religious belief, and economic hardships.

4.6.3 Cultures associated with pottery production.

According to respondents and interviewees, pots play very important role in their culture. The people of Mpraeso described how pots are of essence especially during death and even after death. According to them the pots in Mpraeso are turned upside down and arranged linearly along the streets in town when a chief dies and women are warned to stay out of business until the burial of the chief.

It is believed that anyone who disrespects this directive encounters bad deeds which include the destruction of pots (cracking) during firing of pots produced after the burial. Also, during the death of a potter, her colleagues flood the home of the deceased with lots of pots as a symbol of her career. They are also seen molding the pots during the final funeral rites amidst wailing and singing. This is a positive aspect of local pottery wares which are molded according to cultural purposes giving the industry an aspect of inherited cultural identity. These local cultural values and attributes makes local pottery distinct from the imported pots.

4.6.4 Gender perspectives in the pottery industry

It was observed that in both study areas, the traditional pottery was done by women only and all the respondents attested to it. According to respondents, oral tradition restrains men from actively engaging in the craft. All the 109 respondents from Mpraeso and 54 from Vume investigated were all females. In both areas' females dominated the craft. Indigenes of the two sites under study practiced pottery as an art and a profession. It was observed that all the processes involved in pottery production were controlled by women, ranging from clay mining and processing, forming and firing and this agrees with observations made by (LaDuke, 1991). Respondents added that though the men abide by the taboo of not molding, they rather give helping hand to female family members by doing menial jobs such as breaking of firewood, helping in the removal of pots from the fire, fetching of water among others. Respondents expressed knowledge on the gender biasness of the craft. According to them, men are of a stronger species and when given the opportunity will outpace them and they will be marginalized. So, these were indigenous measures that their forefathers took in ensuring sustainability in the pottery industry for women.

In recent years western education has made mothers not to be interested in making their girl child learn pottery instead they are breaking the cycle by doing it themselves and encouraging their children to be formally educated. It was observed that women in these study areas combine household chores and pottery perfectly without any conflict as indicated in Berns (2007).

4.6.5 Acquisition of skill

About 59.6% and 29.6 % of the potters in Mpraeso and Vume learnt the art directly from their mothers. Others had tuition from other relatives such as sisters, 40.7% in Vume and 4.6% in Mpraeso. Some also gained the skills from their grandmothers which accounted for 11% in Mpraeso and 7.4% in Vume. A few more were taught the skill by their friends thus 8.3% in Mpraeso and 14.8% in Vume (Fig.4.3). These findings confirmed the industry was female dominated. It was also observed that in both areas, homes of potters were situated near homes of other potters who double as neighbors and kinsfolks.

Women are known to be housewives and so they are mostly at home and the constant molding makes the girlchild acquire the skills easily accounting for the high percentage of mothers and sisters impacting the knowledge.

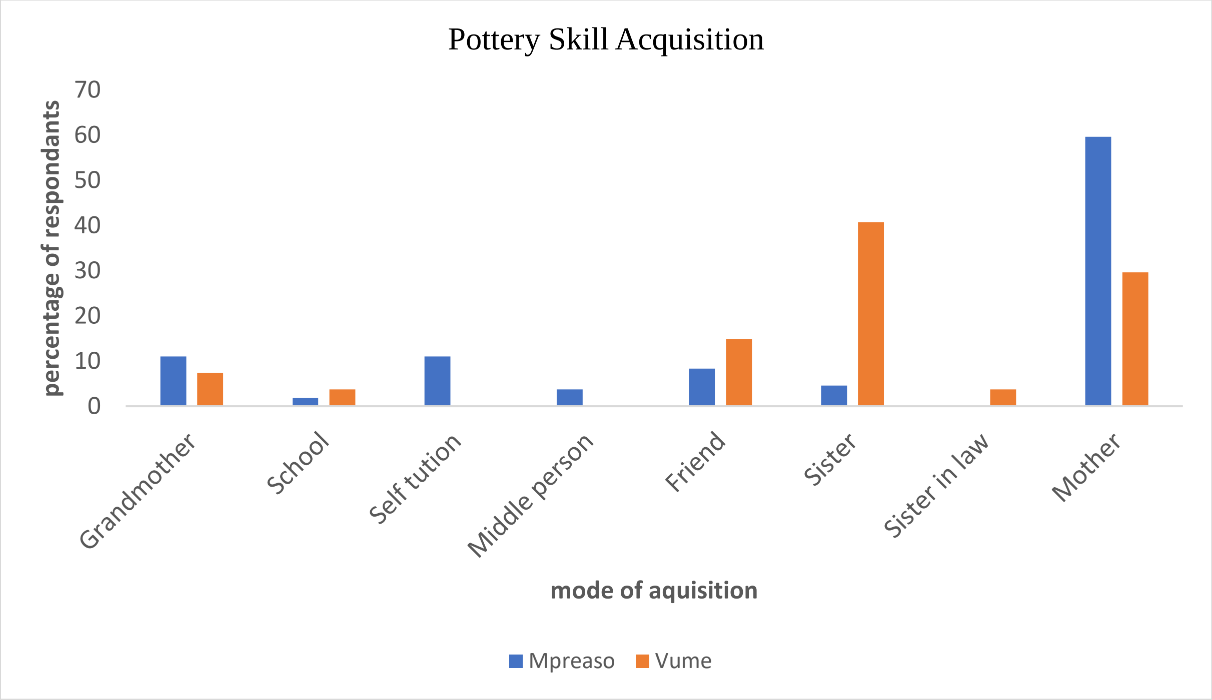


Figure 4.3: Mode of pottery skill acquisition

4.7 Economic significance of traditional pottery

Although fragile, pottery is inexpensive to purchase and shipping to the markets can be done personally, through a middleman, or by bus service. In Mpraeso (79.8%) and in Vume (88.9%) respondents believed the demand for pots was seasonal (Figure 4.4), mostly during festive occasions such as Christmas, New year, Easter, funeral celebrations and other

Ghanaian traditional festivals. According to potters' people buy them not only for their personal use but as gifts for friends and loved ones. All the same, respondents attributed the low sales of pots to economic hardships among Ghanaians. Additionally, the Mpraeso potters, claimed the diversion of the road and the geographical location of Mpraeso also affects sales of pots as would be buyers prefer to go to neighboring villages (Jejeti, Amanfro, etc) along the roadside than to climb the mountains to Mpraeso for the same pots.

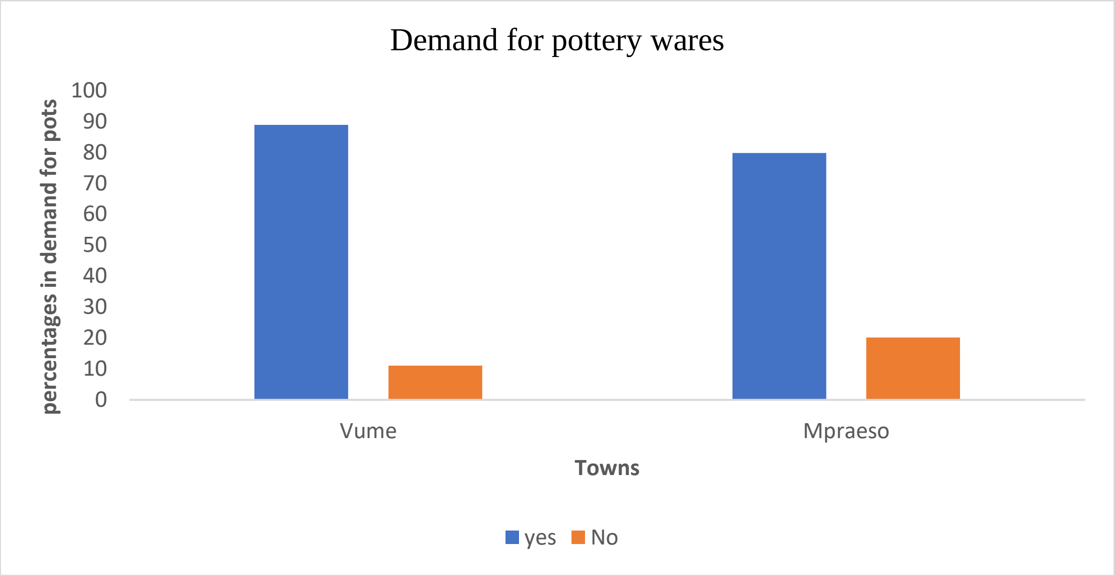


Figure 4.4: Demand for pottery (Source: Field data, 2018).

According to the people, the peak season of marketing pots is in the dry and rainy season. In the case of marketing, pots are placed along the roadside on ordinary days. Respondents claimed as roads through both study areas are very busy, travelers easily got attracted by the beautiful pots.

Sometimes they got orders from customers from Accra and the neighboring countries from Togo, Benin etc and far away Europe. Despite these, the respondents were of the view that the local traditional pottery must be protected from going into extinction because of the threat of influx of plastics, metals and other imported ceramic wares and utensils into the country. Respondents in Mpraeso expressed fears of the influx of new pots from the Brong-Ahafo Region which are not man-made but made by machines and are of low quality and therefore of lower prices thus threating their market (Figure 4.5).

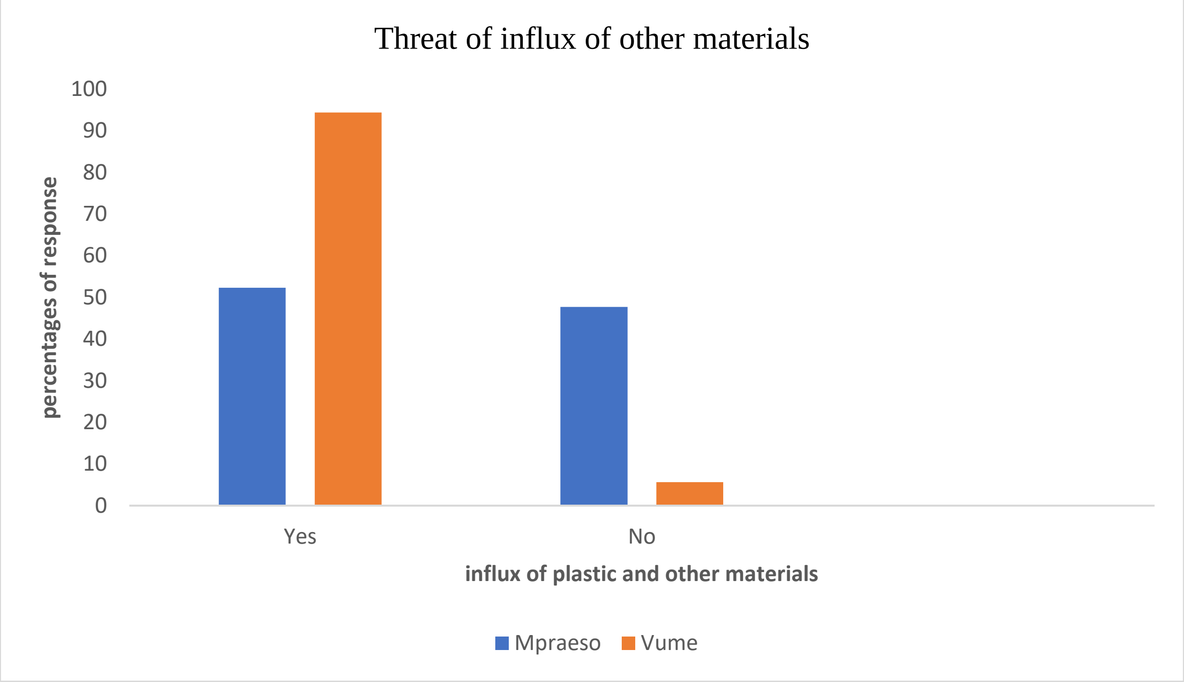


Figure 4.5: Threat of influx of plastics and other materials

On the other hand, interaction with the District head of the National Board for Small Scale Industry (NBSSI) in Mpraeso, proved futile as they had no data on the activities of the potters, production and sale levels.

4.8 Chi-squared test of independence.

From the chi-square test of independence analysis, it was deduced that demographics (gender, marital status, age, number of dependents and identity) had a 5% level of significance on pottery (X^2=10.412 P=0.001). The test indicated that the relationship between one's educational level and pottery showed significant relationship at 5% level of significance (X^2=38.877, P = 0.0004).

Again, a chi-squared test of independence was used to test whether the demand of pottery products is dependent on the influx of plastics and foreign products. The test concludes that, the influx of foreign and plastic products does not have a relationship with the demand for pots since $(\chi^2 = 1.4320, p-value = 0.2314)$ at 5% level of significance for Mpraeso (Appendix B2) and in Vume (X^2 = 2.089, *P-Value* = 0.148) at 5% level of significance for Vume.

4.10 Differences in pottery production at the two communities.

As regards pottery productions, the history tells pottery in Mpraeso was initiated by a crab while in Vume it was a wasp. Production cycles have little differences whereas potters in Mpraeso move round an improvised potters' wheel Vume potters bend on the ground and move anticlockwise when molding. Mpraeso uses open firing at the firing stage whereas Vume practices the kilns. On the other hand, Mpraeso decorate their pots with black clay slips before the pots are fired and Vume uses red clay slip rich in iron oxide.

4.11 Conclusion

In conclusion, the pottery processes and manufacturing in both communities were seen to be similar. Procedures for pottery production are closer to one another except in the finished product; Vume has one type of grinding pot whereas Mpraeso has 2. With reference to firing Vume uses kiln whereas Mpraeso comes by bon fire. Cultural practices and taboos are little close among the two communities. Lastly homes of potters were situated near homes of other potters who double as neighbors and kinsfolks. This augmented sharing of ideas and skills in the industry. Additionally, Mpraeso potters had the flair for the grinding pot compared to Vume potters who were interested more in molding flowerpots for aesthetic purposes.

CHAPTER FIVE

LEACHABILITY OF HEAVY METALS AT USE STAGE OF THE EARTHENWARE POT.

5.0 Introduction

Pottery products from Mpraeso and Vume, two well established production hubs in Ghana, have been used in variety of ways in households for decades. The products include clay grinding pots, water storage pots, mugs, and cooking pots, for domestic users; and flower vases, flowerpots and trays among others are used for other purposes. The grinding clay pot known locally as *Asanka* or *Ayiwa* in Akan and *Vegba* or *Kole* in Ewe, has gained much popularity for its preferred choice for manual grinding of pepper/sauce and to serve special traditional dishes within households and at local restaurants.

In recent times, research attention has been given to the potential health hazards associated with the constant use of clay pottery products in the food preparation value-chain (World Health Organisation, 2001). Some patrons of the pottery wares believe there is possible leaching or migration of heavy metals from the wares into food which can lead to human exposure. This fear stems from the recognition that clayey materials naturally contain heavy metals namely Cd, Pb, As, Na, Mg, Fe, Zn, Co, Ni, Mn, Cr and Cu (Boisa *et al.*, 2017; Nkansah *et al.*, 2016).

Though some of these metals such as Cu, Fe, Zn, As, Ni and Mn play important roles in biological units, they can produce toxic effects when found in high concentrations just as in deficient amounts (Boisa *et al.*, 2017; Dabonne *et al.*, 2010; Singh *et al.*, 2011). Toxicity of heavy metals in food is one alarming global menace and pottery has for some time now been identified as a source of heavy metal poisoning (Boisa *et al.*, 2017; Bongalaisin et al., 2011; Jaishankar *et al*., 2014). Accordingly, many thinks that the risks of unglazed clay pots and pans outweigh the potential benefits of the good minerals (Fe, Ca etc.) that might leach into food.

Consequently, several nations have carried out comprehensive studies on the leachability of heavy metals in glazed ceramics (Aderemi *et al.*, 2017; Ahmed *et al*., 2018; Omolaoye *et al.*, 2010; Valadez-Vega *et al.*, 2011) and unglazed traditional clay pots (Dabonne *et al.*, 2010; Nsengimana *et al*., 2012; Uriah *et al.*, 2014). Findings from these works have enabled authorities in these countries to monitor these food wares for possible release of toxic metals.

Policy makers in these countries have fixed the maximum allowable concentrations of leachable toxic metals for these products (Flavo *et al.*, 2008). Internationally, the European Union directive 84/500/EC amended by directive 2005/31/EC was set to fix the specific migration limit of Pb and Cd leached from ceramics (Boisa *et al.*, 2017). The USA has established a more stringent regulation on the amount of toxic metal that may leach from earthenware eg. Pb is 0.1 to 0.23ug/ml (U.S Food and Drug Administration, 2000).

Yet in most African countries, the Food and Drugs Administration (FDA) compliance programs do not make available records of toxic elements in food wares to consumers (Flavo *et al.*, 2008). In Ghana, the grinding pot prepared from local clay are very popular in homes, eateries and restaurants who advertise its use in preparation and serving of meals. Great concerns have been raised over the possibility of toxic metals leaching into food therefore the need to evaluate raw clays and finished clay-based products (Samlafo *et al.*, 2016).

Studies on heavy metals leaching from unglaze traditional grinding pots into foods consumed have not yet been reported in Ghana. Few studies available dwelt on constituents and properties of earthenware clay deposits and potentially harmful heavy metals (Samlafo *et al.*, 2016). In the present work, the toxicity potential of metals leaching from pots of two different regions have been assessed using time, temperature, and pH over a period of 12 hours for the first time.

The data is compared with that of the FAO/WHO and Council of Europe committee of experts on materials encountering food, the Committee of Experts on Nutrition, Food Safety and Consumer Health. The study additionally gives information on heavy metals leached from grinding pots from Vume and Mpraeso through laboratory simulation of grinding at different time intervals, different temperature intervals and varied pH.

5.1 Methodology

5.1.1 Sample collection

Clays were obtained from the same extraction pits and given to potters to mould a total of 18 pots, 12 from Mpraeso and 6 from Vume. The samples were labelled and transported to the laboratory for the leaching test.

5.1.2 Sample treatment

Grinding pots were washed in a warm liquid soap solution, rinsed with de-ionized water, and placed in an oven at 60^0C overnight. The wares were then stored in polythene or plastic bags for use.

5.1.2.1 Reagents and instruments used.

Instruments used include pH meter electrode to measure pH, and polypropylene airtight storage containers to collect samples. Reagents used were 4% acetic acid solutions used as leaching reagents, HNO_3 from Fluka (Munich, Germany) and HCl obtained from Fisher Co were utilized. Reagents used in all the tests were of analytical grade. Ultrapure water from a Millipore Milli-Q system (18 MΩ cm resistivity) was always used.

5.2 Leaching in tap water

Two types of pots are produced in Mpraeso (black and red) whiles it is only one in Vume which is the red type. Thus, 6 pots were used for each media during the experiment (water, acetic acid, and sauce). In all 18 pots were used for the experiment. 400ml of ordinary tap water was ground with a traditional grind pestle which served as baseline data. The experiment was carried out at 3 grinding duration; 5 minutes, 10 minutes, and 15 minutes of continues grinding and three replicates (n) of grinding experiments was done for each grinding duration and their mean values recorded.

The set up was at room temperature and sample stored up to 12hrs after preparation to find out whether leaching increases with storage. 10ml of sample was filtered immediately after grinding (0hrs) and then at intervals of 1hr, 3hrs, and 12hrs for heavy metal analysis. Pots were sealed with aluminum foil to prevent evaporation and to avoid reaction of certain heavy metals especially Cd in the presence of light. To find out the effect of wear and tear in the leaching of heavy metals replicating the traditional daily usage of the pots, pots were washed with sponge and soap after each grinding experiment. They are then immersed in a bath of de-ionised water and rinsed after which they were oven dried at 60^0C overnight before being used for the next cycle of grinding.

5.3 Leaching in simulated food method (acetic acid)

Leaching of heavy metals in clay pots by simulated food method (4% acetic acid) was carried out according to ASTM C-738-94 standard test method and FDA method for determination of heavy metals extracted from ceramic food ware (U.S Food and Drug Administration, 2000). For specific metals such as cobalt, manganese and nickel the European Commission Directive 84/500/EEC suggests 4% acetic acid solutions to be appropriate simulated solution for acidic food for leaching test since this is almost equivalent to household vinegar. The number of fresh pots; 2 black pots from Mpraeso, 2 red pots from Mpraeso and 2 pots from Vume were used in this experiment at similar grinding times; 5minutes, 10minutes and 15minutes. Similarly, the sampling procedures and protocols used under water was also applied in the acetic acid case.

5.4 Leaching in traditional food preparation.

Fresh pepper sauce traditionally called *shito* was prepared according to traditional methods using pepper, tomatoes and onions purchased in bulk from one shop in a local market. The grinding was also done in 6 new different pots of the two sites applying the same time intervals. In obtaining baseline values, vegetables were pounded in the porcelain mortar. The pepper sauce was prepared by grinding 400ml puree of the vegetables at the durations 5, 10 and 15mins. Three replicate samples (n) was taken for analyses following same protocols and storage times as that of water and 4% acetic acid.

5.5 Effects of Temperature on Leaching of Heavy metals from pots.

Ceramic pots are used to serve cooked food, so it was imperative to investigate whether hot food facilitates heavy metal leaching at hot temperatures. Thus, the experiment was duplicated using the samples of water, acetic acid, and sauce at different temperatures. The experiments were conducted at varying temperatures; room temperature (28°C), warm temperature (60°C) and boiling point (100°C) to reflect the various temperature conditions at which food is served traditionally. For room temperature the respective sample water, 4% acetic acid or sauce was placed in the pots and samples taking for analysis after 30 mins. For warm and boiling point temperatures, samples were boiled in conical flasks to the required temperature measured with a thermometer and emptied into the pots and samples taking for analysis after the 30mins storage time. To prevent contamination, the vegetables were ground in a mortar in the laboratory and 400ml of it sampled and boiled at the various temperatures i.e 60°C and 100°C and poured into the pots and 10ml of samples taken after 30 mins for analysis. Leaching will probably occur when food is in the pot while eating hence 30mins was used as a reasonable time for eating a meal when served. All samples were analyzed using Atomic Absorption Spectrometry (AAS) method in the Ecological Laboratory of the Department of Geography and Resource Development, University of Ghana.

5.6 Laboratory analysis and procedure

The same digestion and analytical procedures of Atomic Absorption Spectrophotometer (AAS) was employed as was done in section 3.1.5.2 of this thesis to measure the presence of the following Cd, Pb, As, Na, Mg, Fe, Zn, Co, Ni, Mn, Cr and Cu metals in leachate samples of water, acetic acid, and sauce.

5.6.1 Quality Assurance and Quality Control

5.6.1.1 Cleaning of laboratory glass wares

Pyrex glass volumetric wares were used for the experiment. The glass wares and grinding pots were washed in a warm liquid soap solution and rinsed with de-ionized water. Only the glass wares were dip in 10% HNO_3 at room temperature for three days after which the glass wares were rinsed three times with de-ionised water. The glass wares were again immersed in 50% HNO_3 bath at 90°C for 24hours, after which they were further rinsed using de-ionised water severally and placed in an oven at 60°C overnight. The wares and pots were then stored in bags for use.

5.6.1.2 Blanks for laboratory analysis

Quality assurance and quality control criteria were satisfied by running reagents, blanks, standard solutions, a reference material, and replicate analyses. Recoveries ranged between 85-102%.

5.7 Results and discussion

5.8 Overview of leaching in three solvent media

The baseline data of all the 3 solvent media showed results of metals not been detected in them. Generally, the leaching studies carried out in the 3-solvent media (water, acetic acid, and sauce) showed some variation with specific elements and not others (Table 5.1-5.9) for the toxic elements Cd, Cr, As and Zn were not detected in all the media suggesting they could not be in neither the media nor soil sample. Cu and Co were also detected in some cases and in others they were absent (Table 5.1-5.9) which was hard to explain. However, the heavy metals Fe, Mn and Ni were found in all the studies.

Pb was found in all the solvents studied except for the sauce. Fe was largely always in higher concentrations tables 5.1-5.9. In all cases the grinding in the selected pots for the study was carried out periodically at 5,10 and 15 minutes. Samples were immediately taken and then allowed to stay within 1, 3 and 12 hours before examining for metal leachates. This was done to mimic the most probable waiting periods practiced by the indigenes within the 2 communities. Thus the levels of distribution and variation being reported rest on these factors taking into account. The pH for the 3 solvents water, acetic acid and sauce varied accordingly with the acetic acid registering the lowest (Tables 5.1-5.9).

5.8.1 Leaching in water

The pH in water leachate after grinding ranged between 5.1 and 6.3 in all the pots, (Tables 5.1-5.3) Co, As, Zn, Cd and Cr were not found in any of the pots which perhaps were not present in the raw clay material from which the pot was made. This agreed with the results in Chapter 3. In some cases, the elements were not present, and others present. What it meant was that those which came by these ways presupposed that those which were very soluble were lost during the preparation of the pot. The slightly insoluble ones were the ones which stayed. Hence the discrepancies being observed in all the solvent studied. Large quantities of Fe were observed to have leached out from pots comparing the grinding and storage times Table 5.1-5.3.

More Fe was recovered in the 5 minutes grinding and on storing. In all the Vume pot showed the lowest concentration of Fe comparatively. Likewise, Pb showed a different pattern. Grinding after 10 minutes gave more of the element compared to the other timings of 5 and 15 minutes in relation to storage time, Tables 5.1-5.2.

Table 5. 1 Concentration of elements for 5 min grinding of water.

Pot	pH	Time	Element (mg/kg)				
		(hrs.)	Cu	Fe	Pb	Mn	Ni
Mpraeso black	6.3	0	9.2 ± 0.1	133.0 ± 1.0	48.4 ± 0.2	5.3 ± 0.1	15.2 ± 0.3
		1	10.2 ± 0.1	414.4 ± 0.5	14.4 ± 0.1	10.1 ± 0.1	10.2 ± 0.1
		3	10.4 ± 0.2	502.0 ± 1.0	28.6 ± 0.7	1.8 ± 0.1	9.2 ± 0.1
		12	10.1 ± 0.4	266.4 ± 0.7	19.2 ± 0.8	20.3 ± 0.9	12.9 ± 0.2
Mpraeso red	6.1	0	9.5 ± 0.3	43.8 ±1.6	29.2 ± 0.5	1.5 ± 0.2	14.1 ± 2.1
		1	7.2 ± 0.1	32.9 ± 1.2	21.9 ± 0.2	10.9 ± 0.9	9.7 ± 1.5
		3	6.1 ± 0.1	86.7 ± 2.8	36.9 ± 2.6	13.5 ± 0.8	13.0 ± 0.9
		12	7.3 ± 0.6	61.2 ± 12.0	56.3 ± 1.8	10.7 ± 0.2	5.4 ± 0.7
Vume	6.0	0	9.5 ± 0.1	58.2 ± 2.5	15.7± 0.1	1.3 ± 0.2	6.8 ± 0.1
		1	6.1 ± 0.2	97.5 ± 0.9	58.4 ± 0.4	7.5 ± 1.2	6.6 ± 0.7
		3	4.7 ± 0.2	53.2 ± 2.0	52.0 ± 2.0	8.4 ± 0.7	15.2 ± 2.5
		12	5.8 ± 1.1	50.0 ± 9.3	59.6 ± 10.6	7.5 ± 2.0	12.7 ± 7.9
Limits							
FAO						200	10
WHO						12.2	12
EU							

Table 5. 2 Concentration of elements for 10 min grinding of water.

Pot	pH	Time	Element (mg/kg)				
		(hrs.)	Cu	Fe	Pb	Mn	Ni
Mpraeso black	6.3	0	1.4 ± 0.4	50.3 ± 9.7	60.9 ± 8.6	8.1 ± 2.2	14.4 ± 3.6
		1	BD	127.5 ± 21.0	49.5 ± 10.3	11.8 ± 2.4	13.8 ± 2.8
		3	BD	174.2 ± 28.8	44.9 ± 7.9	14.2 ± 3.8	11.4 ± 1.8
		12	BD	147.1 ± 29.0	53.1 ± 7.6	12.4 ± 2.2	14.5 ± 1.5
Mpraeso red	5.1	0	BD	36.9 ± 12.1	74.4 ± 9.5	8.7 ± 1.2	10.3 ± 4.9
		1	BD	25.6 ± 10.2	43.7 ± 7.9	8.6 ± 4.3	14.3 ± 1.6
		3	BD	14.4 ± 1.5	52.9 ± 14.1	10.2 ± 4.2	19.0 ± 2.9
		12	BD	2.7 ± 0.9	62.9 ± 21.5	10.7 ± 1.3	22.4 ± 7.8
Vume	6.1	0	BD	42.2 ± 8.1	64.6 ± 5.9	8.8 ± 1.2	14.5 ± 1.5
		1	BD	8.4 ± 1.2	48.5 ± 10.9	10.8 ± 2.0	18.4 ± 0.8
		3	BD	40.4 ± 3.5	BD	11.1 ±1.6	31.9 ± 3.0
		12	BD	41.8 ± 13.1	58.5 ± 1.5	13.7 ± 1.1	40.4 ± 1.7

BD – below detection

Table 5. 3 Concentration of elements for 15 min grinding of water.

Pot	pH	Time	Element (mg/kg)				
		(hrs.)	Cu	Fe	Pb	Mn	Ni
Mpraeso black	6.0	0	0.9 ± 0.1	29.2 ± 1.5	17.8 ± 0.9	9.8 ± 0.9	38.7 ± 1.7
		1	BD	396.2 ± 0.9	14.7 ± 2.1	9.9 ± 1.0	17.7 ± 1.1
		3	BD	445.3 ± 0.7	12.9 ± 1.0	13.3 ± 0.8	13.4 ± 0.7
		12	BD	338.6 ± 0.9	15.6 ± 0.3	11.2 ± 1.5	15.1 ± 0.5
Mpraeso red	6.1	0	BD	154.3 ± 1.1	37.0 ± 2.6	12.4 ± 12.1	37.1 ± 0.2
		1	BD	129.4 ± 21.0	21.8 ± 1.0	9.3 ± 0.2	22.2 ± 0.6
		3	BD	111.8 ± 0.8	25.9 ± 0.7	7.1 ± 0.2	26.8 ± 0.8
		12	BD	98.5 ± 1.5	29.8 ± 0.3	8.1 ± 2.2	34.7 ± 1.2
Vume	5.7	0	BD	29.5 ± 0.7	BD	10.5 ± 0.6	75.3 ± 1.1
		1	BD	0.7 ± 0.2	31.7 ± 0.8	13.3 ± 0.6	47.8 ± 0.2
		3	BD	30.1 ± 0.9	25.6 ± 1.0	14.8 ± 1.0	58.6 ±0.9
		12	BD	38.6 ± 0.9	54.8 ± 0.7	22.7 ± 0.2	123.9 ± 0.6

BD – below detection

Comparing the Mpraeso black and red pot, Pb concentrations in these pots did not vary much at the different storage times. Interestingly the Vume pot showed consistent Pb concentration of at least 55mg/kg for 12-hour storage at all grinding times of 5, 10 and 15 minutes, respectively. No Pb was detected at the 3rd hour storage for 10 minutes grinding could be an instrumental error. On the other hand, Mn and Ni were also found in smaller quantities at all grindings and the studied storage hours. The levels and distributions were not comparable to that of Pb and Fe. Overall, their presence was found to be from the geology as they were also present with the raw clay.

5.8.2 Leaching in Acetic Acid

Unlike the water, the acetic acid had a low pH ranging from 2.9-3.5 (Tables 5.4-5.6). The levels of leachates of Fe, Pb, Mn and Ni were very high within the grinding working range of (5-10) minutes. The concentrations of Fe peaked at the maximum, the 12th hour in all cases (Tables 5.4 – 5.6), whether Mpraeso or Vume pots. A similar trend was also observed for Ni (Tables 5.5-5.6). Copper was only found in all the hours within the first 5 minutes of grinding time. The rest of the samples particularly the Mpraeso pots had no Cu in the leachates. Like the water leachates, no Cd, Cr, Co, As and Zn were found in all the sample leachates collected for Mpraeso or Vume pots except in the Table 5.4 where Cu was seen in the Vume red pot.

Overall, leaching of metals in acetic acid occurred in all the grinding times of 5-10 minutes coupled to the storage times, and except for Fe the concentration of metal leachates was higher than the water phase.

Table 5. 4: Concentration of elements for 5 min grinding of Acetic Acid.

Pot	pH	Time	Element (mg/kg)				
		(hrs.)	Cu	Fe	Pb	Mn	Ni
Mpraeso black	3.4	0	BD	57.2 ± 1.5	66.4 ± 2.2	11.7 ± 1.2	36.0 ± 1.7
		1	0.6 ± 0.2	63.1 ± 0.7	78.2 ± 1.6	12.1 ± 1.4	34.8 ± 1.1
		3	BD	BD	BD	BD	BD
		12	5.8 ± 0.9	122.1 ± 1.7	60.9 ± 0.9	46.1 ± 1.5	47.5 ± 1.2
Mpraeso red	3.5	0	BD	64.2 ± 1.5	45.1 ± 1.6	11.9 ± 1.2	40.6 ± 0.9
		1	0.5 ± 0.2	17.7 ± 1.1	90.1 ± 1.5	12.8 ± 0.9	33.2 ± 1.2
		3	BD	3.5 ± 0.7	55.0 ± 2.3	10.8 ± 0.9	31.7 ± 0.9
		12	BD	77.9 ± 1.1	40.6 ± 0.9	17.4 ± 1.0	38.8 ± 1.5
Vume	3.0	0	2.0 ± 0.3	65.9 ± 0.9	88.1 ± 1.5	12.1 ± 1.4	49.3 ± 0.8
		1	4.5 ± 1.1	39.6 ± 0.9	54.5 ± 2.2	12.6 ± 1.0	41.8 ± 1.3
		3	4.5 ± 1.1	20.8 ± 1.1	44.1 ± 1.5	5.9 ± 1.1	35.5 ± 2.9
		12	6.4 ± 0.9	174.4 ± 10.7	66.1 ± 1.3	10.8 ± 0.8	34.9 ± 0.5

BD – below detection

Table 5. 5 Concentration of elements for 10 min grinding of Acetic Acid.

Pot	pH	Time (hrs.)	Element (mg/kg)				
			Cu	Fe	Pb	Mn	Ni
Mpraeso black	3.2	0	0.1 ± 0.04	26.5 ± 0.7	32.6 ± 0.8	10.7 ± 0.8	55.3 ± 0.8
		1	BD	77.4 ± 0.8	72.5 ± 0.8	16.6 ± 1.0	49.5 ± 0.7
		3	BD	47.4 ± 0.8	69.4 ± 0.7	16.5 ± 0.7	54.3 ± 0.9
		12	2.8 ± 0.6	104.5 ± 0.8	51.6 ± 0.8	40.4 ± 0.8	105.4 ± 0.7
Mpraeso red	3.0	0	BD	23.6± 0.8	41.1 ± 1.3	9.9 ± 1.0	53.6± 1.1
		1	BD	32.1 ± 1.3	52.1 ± 1.7	11.7 ± 1.1	54.3 ± 0.8
		3	BD	64.4 ± 0.8	45.5 ± 0.7	16.4 ± 0.7	50.7 ± 0.7
		12	BD	70.5 ± 1.0	27.0 ± 0.3	113.1 ± 0.8	55.0 ± 1.3
Vume	3.2	0	BD	71.2 ± 1.3	58.4 ± 0.6	9.6 ± 0.6	54.5 ± 0.7
		1	BD	72.4 ± 0.6	38.1 ± 0.3	8.7 ± 0.8	49.3 ± 0.8
		3	BD	7.6 ± 0.6	38.4 ± 0.7	7.1 ± 0.2	60.2 ± 1.2
		12	BD	149.6 ± 0.6	14.2 ± 1.0	9.5 ± 0.8	65.3 ± 2.1

Table 5. 6 Concentration of elements for 15 min grinding of Acetic Acid.

Pot	pH	Time (hrs.)	Element (mg/kg)			
			Fe	Pb	Mn	Ni
Mpraeso black	2.9	0	16.5 ± 1.0	50.2 ± 0.8	11.5 ± 1.2	59.6 ± 1.9
		1	48.4 ± 0.9	61.7 ± 1.2	12.1 ± 1.4	56.2 ± 1.8
		3	27.9 ± 0.3	58.9 ± 0.6	12.9 ± 1.0	58.4 ± 0.7
		12	59.3 ± 0.6	45.8 ± 0.7	37.7 ± 1.5	95.7 ± 0.9
Mpraeso red	3.0	0	5.4 ± 0.7	52.1 ± 1.7	10.4 ± 0.8	58.5 ± 1.1
		1	12.1 ± 1.4	57.3 ± 1.5	12.1 ± 1.4	56.1 ± 1.8
		3	7.7 ± 0.2	54.0 ± 2.2	14.0 ± 1.6	57.3 ± 0.4
		12	68.4 ± 0.7	43.3 ± 1.5	97.2 ± 0.9	61.0 ±1.2
Vume	2.9	0	28.8 ± 0.8	46.4 ± 1.3	10.3 ± 0.2	61.4 ± 19.1
		1	31.2 ± 1.2	29.0 ± 0.5	10.1 ± 0.1	55.1 ± 16.5
		3	13.9 ± 2.8	27.5 ± 0.7	6.3 ± 0.2	72.2 ± 8.9
		12	162.3 ±18.3	11.7 ± 1.8	9.7 ± 0.3	78.4 ± 9.5

5.8.3 Leaching in Sauce

Apart from Pb the usual metals detected in the water and acetic acid were also found in the sauce (Fe, Mn, Ni, and Co) likewise Cd, Cr, Cu, As and Zn were absent in the leachate. However, larger concentrations of Fe, Co and Ni were found in all the different grinding times as well as the storage times, (Tables 5.7- 5.9.) the maximum was found at 15 minutes grinding time, at all the storage hours for both Mpraeso and Vume pots. Overall Ni was the only element which was arbitrary leached (Table 5.7-5.9.) Mn was in lower concentration throughout the study time.

Table 5. 7 Concentration of elements for 5min grinding of sauce.

Pot	pH	Time (hrs)	Element (mg/kg)				
			Cu	Fe	Mn	Ni	Co
Mpraeso black	4.7	0	4.6 ± 0.9	106.3 ± 5.6	BD	28.6 ± 0.7	93.6 ± 0.9
		1	2.0 ± 0.5	462.5 ± 3.1	9.6 ± 0.8	BD	94.5 ± 0.9
		3	BD	50.5 ± 0.8	18.4 ± 0.7	4.2 ± 0.8	99.4 ± 0.7
		12	BD	42.6 ± 0.6	5.2 ± 0.6	BD	89.3 ± 1.2
Mpraeso red	4.5	0	2.3 ± 0.5	205.3 ± 1.6	14.4 ± 0.7	20.6 ± 0.8	90.4 ± 0.7
		1	BD	43.4 ± 0.6	3.3 ± 0.5	BD	97.4 ± 0.6
		3	BD	20.5 ± 0.7	4.3 ± 0.4	BD	97.4 ± 0.6
		12	BD	33.4 ± 0.6	8.9 ± 1.1	62.4 ± 0.6	96.4 ± 0.6
Vume	4.6	0	2.2 ± 0.4	263.4 ± 0.6	17.4 ± 0.6	55.3 ± 0.6	96.4 ± 0.6
		1	BD	40.5 ± 0.6	8.3 ± 0.5	47.5 ± 0.7	96.5 ± 0.8
		3	BD	49.4 ± 0.6	10.4 ± 0.7	BD	107.4 ± 0.6
		12	BD	56.4 ± 0.6	8.8 ± 0.4	4.1 ± 0.2	109.4 ± 0.7

Table 5. 8 Concentration of elements for 10min grinding of sauce.

Pot	pH	Time (hrs)	Element (mg/kg)			
			Fe	Mn	Ni	Co
Mpraeso black	4.7	0	61.4 ± 0.6	8.8 ± 0.3	26.3 ± 0.7	102.6 ± 0.7
		1	68.4 ± 0.7	11.4 ± 0.6	56.4 ± 0.7	107.3 ± 0.7
		3	BD	BD	BD	BD
		12	76.5 ± 0.6	12.4 ± 0.6	BD	115.5 ± 0.7
Mpraeso red	4.5	0	58.6 ± 0.6	10.5 ± 0.7	8.5 ± 0.6	106.4 ± 0.6
		1	140.7 ± 1.2	10.5 ± 0.7	71.6 ± 0.7	111.4 ± 0.6
		3	191.9 ± 1.2	6.6 ± 0.3	BD	105.4 ± 0.7
		12	387.4 ± 0.6	6.8 ± 0.4	BD	104.4 ± 0.6
Vume	4.6	0	57.4 ± 0.6	11.6 ± 1.1	30.3 ± 1.2	99.4 ± 0.6
		1	238.4 ± 0.6	6.4 ± 0.5	9.4 ± 0.5	94.4 ± 0.6
		3	191.4 ± 0.6	5.4 ± 0.6	6.9 ± 1.0	92.6 ± 0.7
		12	325.4 ± 0.7	7.5 ± 0.6	40.7 ± 0.7	100.5 ± 0.6

Table 5. 9 Concentration of elements for 15min grinding of sauce.

Pot	pH	Time (hrs)	Element (mg/kg) Fe	Mn	Ni	Co
Mpraeso black	4.7	0	165.3 ± 23.1	10.7 ± 0.8	82.4 ± 2.8	116.7 ± 0.8
		1	169.2 ± 19.1	10.2 ± 4.2	88.7 ± 0.6	118.7 ± 10.7
		3	173.3 ± 10.7	11.5 ± 1.8	74.0 ± 0.7	121.0 ± 1.6
		12	178.9 ± 28.6	12.1 ± 2.1	BD	120.3 ± 0.6
Mpraeso red	4.5	0	185.4 ± 0.9	9.1 ± 0.3	4.3 ± 1.1	121.0 ± 0.8
		1	193.3 ± 0.9	10.2 ± 4.2	3.4 ± 0.6	123.5 ± 1.6
		3	197.0 ± 0.6	11.0 ± 1.6	BD	127.8 ± 21.0
		12	201.8 ± 28.8	12.3 ± 0.2	BD	125.1 ± 0.6
Vume	4.6	0	152.8 ± 2.1	10.3 ± 0.1	3.6 ± 0.4	124.3 ± 1.1
		1	163.8 ± 29.0	7.7 ± 1.2	3.1 ± 0.7	121.0 ± 0.5
		3	155.7 ± 21.0	6.4 ± 0.7	2.9 ± 0.3	116.8 ± 19.4
		12	217.4 ± 0.7	8.3 ± 1.2	11.7 ± 1.2	112.5 ± 2.1

5.8.4 Leaching in water at different temperature

The pH of water at different temperature is shown in Table 5.10. The pH was at the maximum temperature of 100°C. Figures 5.1-5.3 show leaching of heavy metals at varying temperatures of warm water in the pots.

Table 5. 10: pH of boiled water at different temperatures

	---------------------Temperature°C---------------------		
Pot Type	**28**	**60**	**100**
Mpreaso black	5.0	3.4	5.6
Mpreaso red	5.9	3.3	4.4
Vume	5.1	3.4	4.9
Mean	5.3	3.4	4.9

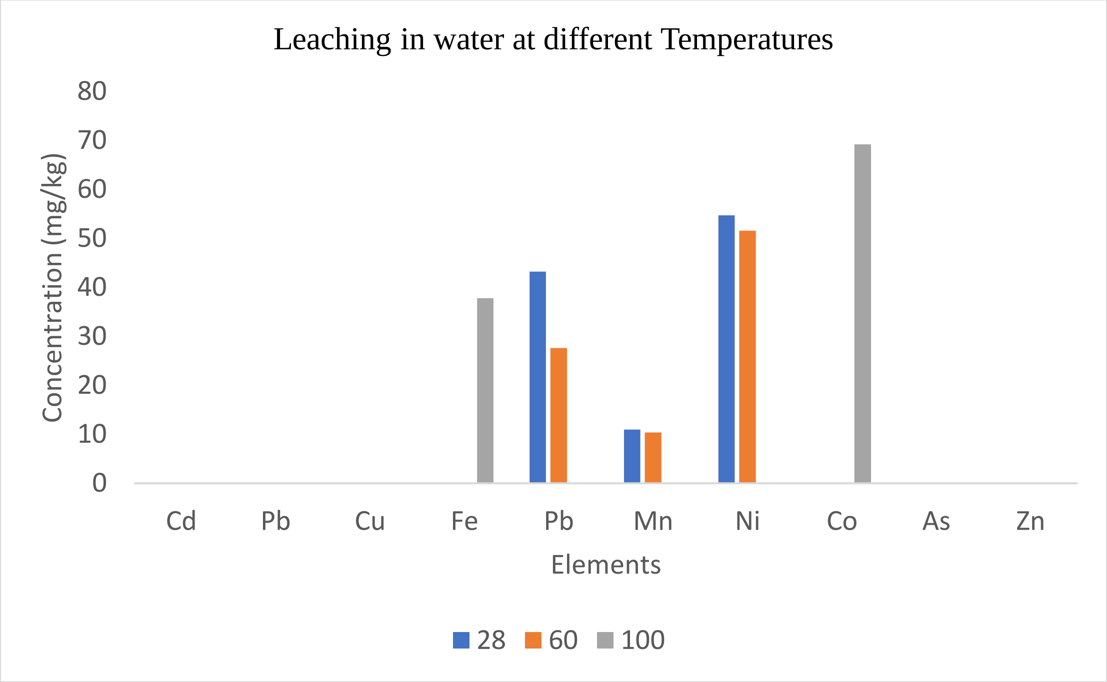


Figure 5. 1 Mpreaso black pots leaching at varying temperatures of water.

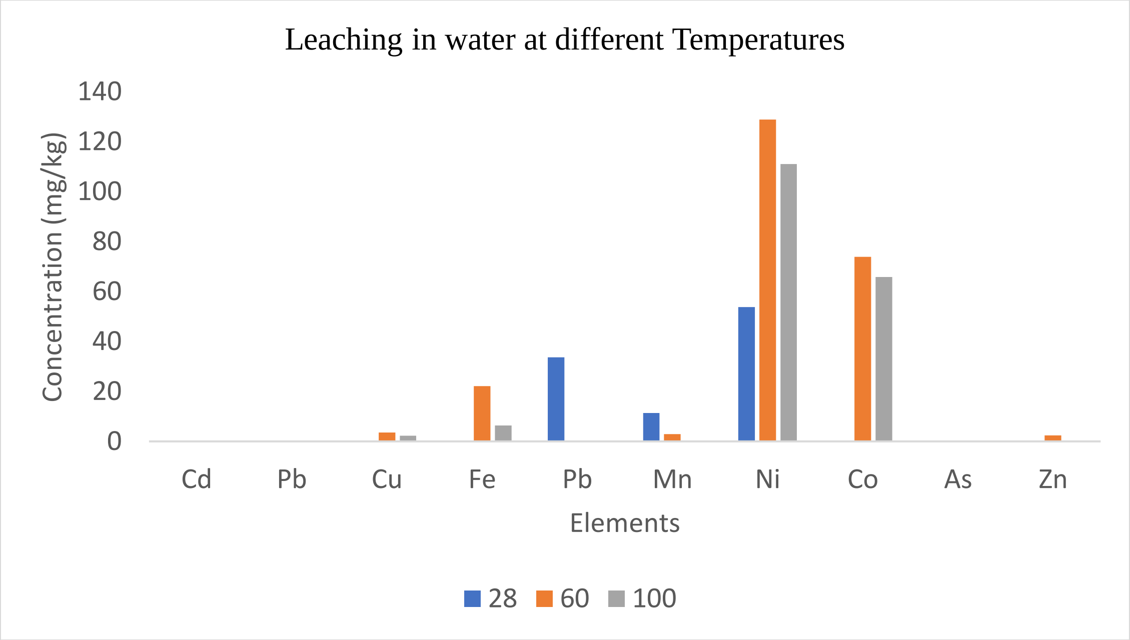


Figure 5. 2: Mpraeso red pots leaching at varying temperatures of water.

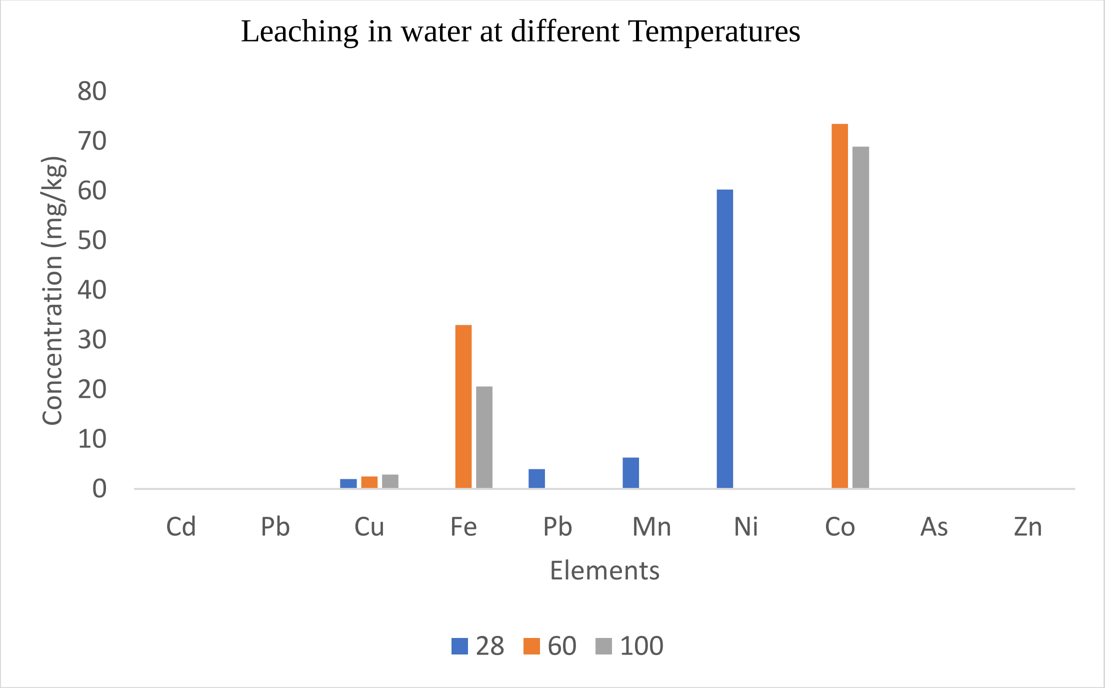


Figure 5. 3: Vume pots leaching at varying temperatures of water.

Elements leached included Fe, Pb, Mn, Ni, Co, Cu and Zn however there was variability in elements leached with respect to pot types and different temperatures. Copper (Cu) was very low and only detected in Mpraeso red pots at 28 and 60°C and for Vume at all temperatures (Figs.5.2 & 5.3). Zinc was detected only in Mpraeso red at 60°C (Fig.5.2). Manganese concentration levels were below WHO/FAO/EC criteria with the highest at 11mg/kg at 28°C declining to 10mg/kg at 60°C (Fig.5.1). Iron concentration decreased with temperature (Figs. 5.2 &5.3) except Mpraeso black pots which recorded the highest value of 38mg/kg (Fig.5.1) whereas lead concentration was below detection at 100°C in all cases of study. Besides, Co leached at higher temperatures (Figs.5.2 & 5.3) except that of Mpraeso black where Co was detected only at 100°C. Ni leached at room temperature in all the pots and the levels were higher than WHO/FAO limits but within that of EC for ceramics. Generally, all elements that leached decrease in concentration with time.

5.8.5 Leaching in Acetic Acid at different temperatures

The pH of acetic acid in all the pots were almost the same except Mpraeso (red) which was 2.7 at 60°C, as seen in Table 5.11. Similar to the water Cd and As were not detected at all temperatures in all the pots, Figs.5.4-5.6. Copper, Zn and Mn were found at insignificant levels in Mpraeso.

Table 5. 11: pH of acetic acid at varying temperatures

	Temperature °C		
Pot Type	**28**	**60**	**100**
Mpreaso black	3.3	3.2	3.2
Mpreaso red	3.1	2.7	3
Vume	3	3.2	3.1
Mean	3.1	3	3.1

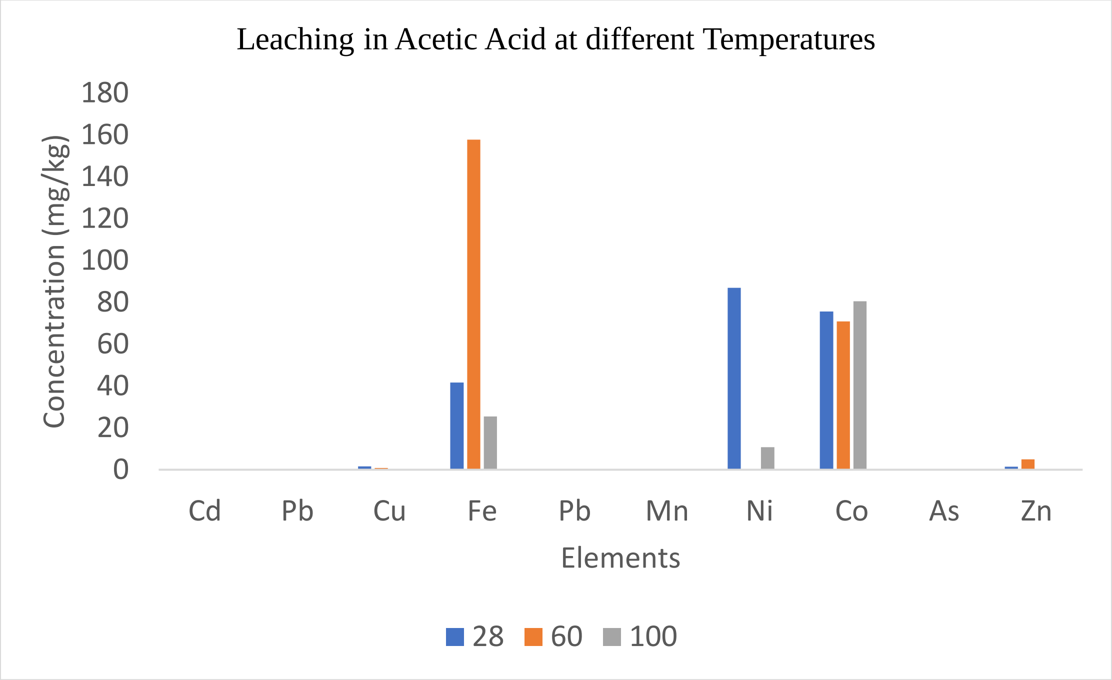


Figure 5. 4: leaching of heavy metals from Mpraeso black pots at different temperatures.

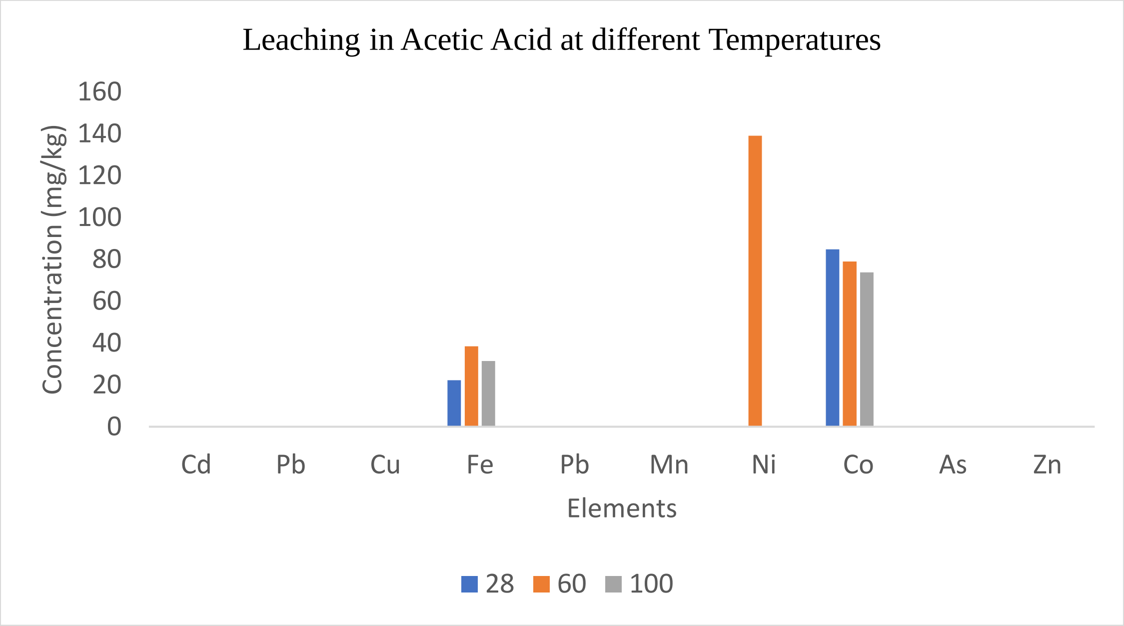


Figure 5. 5: leaching of heavy metals from Mpraeso red pots at different temperatures.

black pots and Vume (Fig.5.4 & 5.6) whereas it was in trace concentration in Mpraeso red pots (Fig.5.5). Lead was only found in Vume pots at about 27mg/kg.

Iron was recorded in all the three pot types and exhibited a fluctuated pattern. Iron concentration levels increased from 28–60°C and declines at 100°C (Figs.5.4-5.6). Significant amount of Ni was detected at 28°C for both Mpraeso (black) and Vume pots (Figs.5.4 & 5.6) and at 60°C for Mpraeso (red) pots (Fig.5.5) but none was traceable at 100°C. Higher levels of Co was detected in all the three temperature stages and its concentration were steady ranging between 71–81mg/kg (Fig.5.3) and 74–85mg/kg (Fig.5.4.). Similarly, Co level of leaching was high in Vume pots, at 28 and 60°C (Fig.5.5).

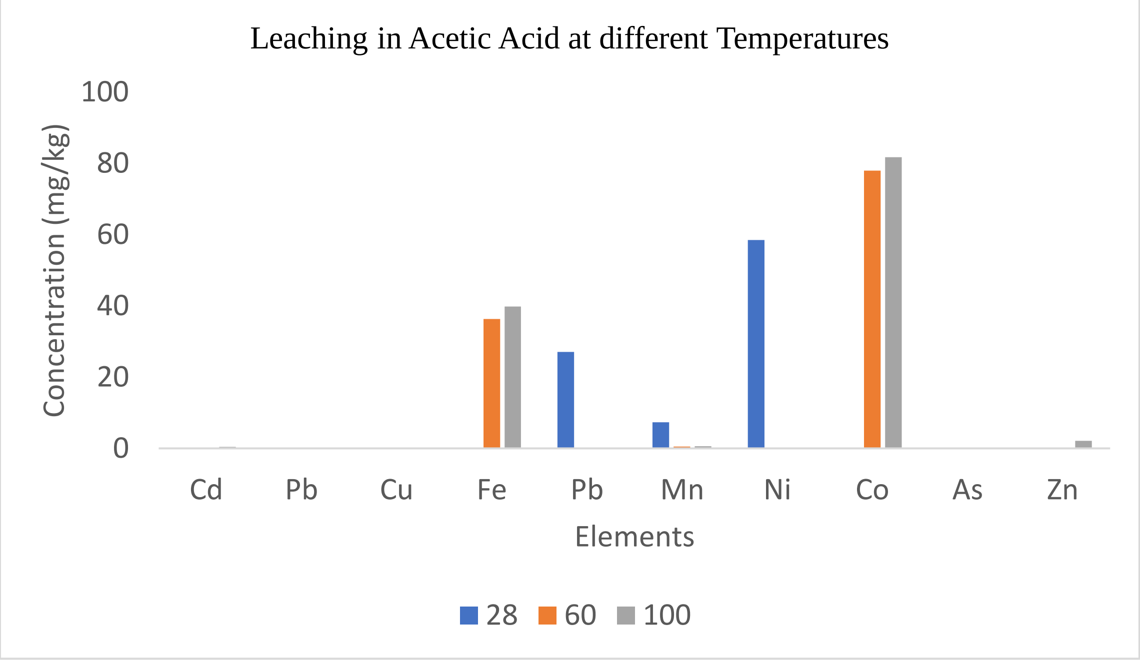


Figure 5. 6: Leaching of heavy metals from Vume pots at different temperatures.

5.8.6 Leaching into sauce at different temperature

The pH of sauce at room temperature and warmed sauce varied from 4.1 at room temperature to 4.8 at 100°C in Mpraeso and Vume pots respectively (Table 5.12). Leaching of heavy metals in warmed sauces are illustrated in Figs.5.7-5.9. Only four elements Fe, Mn, Ni and Co leached in the warmed sauces at the various temperatures. Like the water and acetic acid, manganese levels were within the range of acceptable standards of FAO/WHO and EC (Figs.5.7-5.9). Nickel was found in all pots at almost all temperatures except 60°C in Mpraeso red pot (Fig.5.8). For Mpraeso (black) pots (Fig.5.7), Ni concentration level increased from 51mgkg at 28°C to 73mg/kg when the sauce was warmed (60°C) but decreased from 73mg/kg to 24mg/kg at 100°C. For Mpraeso (red) pots and Vume pots, concentration of Ni dropped when sauce was warmed (60°C) reaching below detection for Mpraeso red pots but shot-up to 82mg/kg and 93mg/kg for Vume and Mpraeso (red) pots respectively at 100°C (Figs.5.8 & 5.9).

Table 5. 12: pH of sauce at varying temperatures

Pot Type	**Temperature °C**		
	28	**60**	**100**
Mpreaso black	4.1	4.5	4.7
Mpreaso red	4.1	4.5	4.8
Vume	4.2	4.7	4.8
Mean	4.1	4.6	4.8

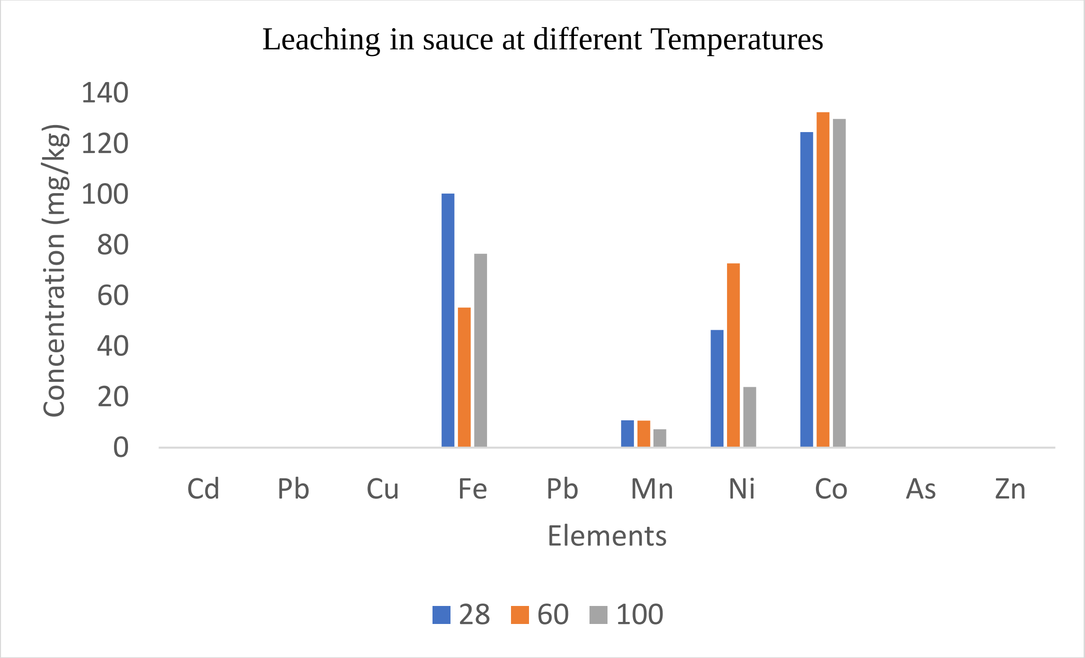


Figure 5. 7: leaching of heavy metals from Mpreaso black pots at varying temperatures.

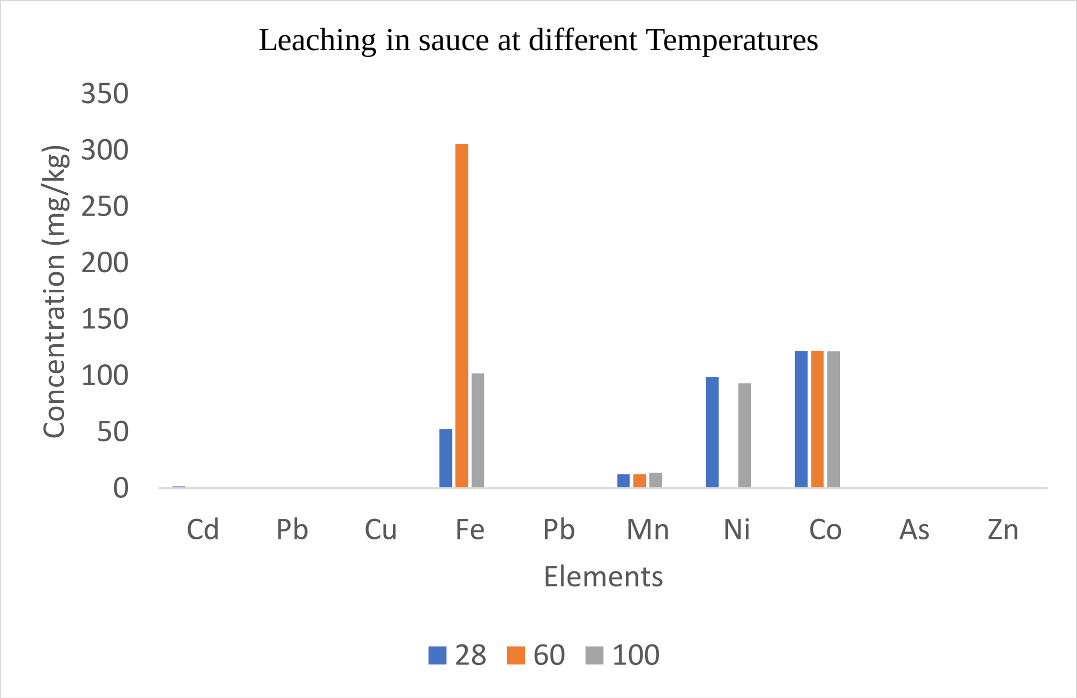


Figure 5. 8: leaching of heavy metals from Mpreaso red pots at varying temperatures.

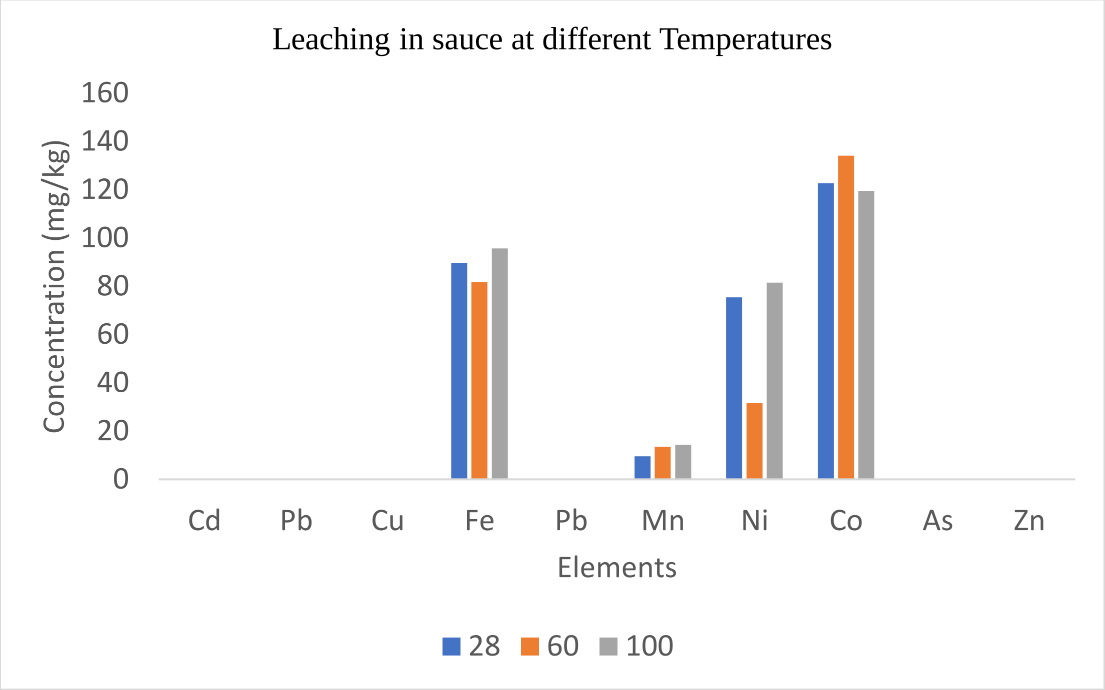


Figure 5. 9: leaching of heavy metals from Vume pots at varying temperatures.

Iron concentration decreased from 28 to 60°C but increases at 100°C for Mpraeso black and Vume pots (Figs.5.7 & 5.9) respectively. The lowest Fe values were recorded in Mpraeso (black) pots with a mean of 77mg/kg whiles the highest values were detected in Mpraeso (red) pots with a mean of 153mg/kg. Cobalt heavily leached in all pots with mean values of 129mg/kg (Mpraeso black pots), 122mg/kg (Mpraeso red pots) and 125mg/kg (Vume pots) Figs.5.7-5.9, respectively. These numbers were all above the recommended thresholds of FAO/WHO and EC. The relationship between temperature and the trends in the leaching of the metals was irregular.

5.9 Variations in Concentration of elements with friction

5.9.1 Leaching in water at varying grinding time

Figures 5.10-5.12 show results of leaching of trace metals by grinding water at varying times to determine friction/wear and tear for daily usage of the pots. Elements that leached in water for both the black and red pots of Mpraeso are copper, iron, lead, manganese, and nickel (Figs.5.10 & 5.11). For Fig.5.10 Cu and Fe concentrations decreased with increasing grinding time from 5 to 15 mins whiles Pb concentration increased from 49mg/kg (5 mins) to 60mg/kg (10 mins) and decreased to 18mg/kg for 15 mins of grinding time. The concentration of manganese and nickel rose from 5 to 15 mins grinding period. Though marginal, manganese concentration increased steadily from 5 to 9mg/kg whereas nickel concentration dropped marginally for 10mins grinding but increased sharply to 38mg/kg for 15 mins grinding time (Fig.5.10).

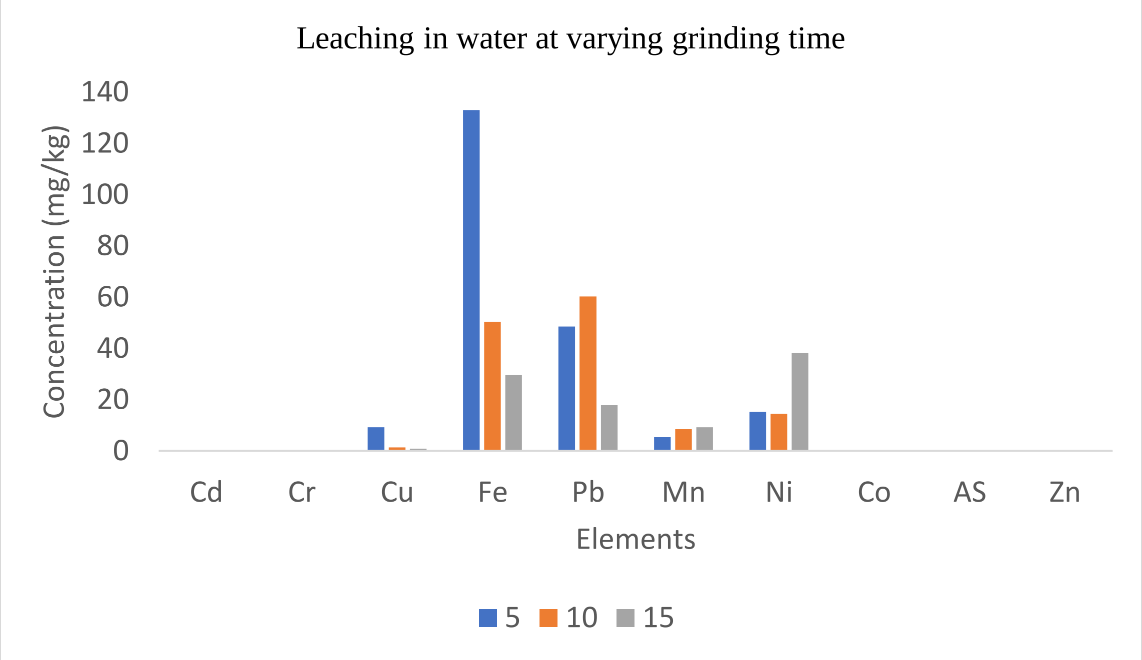


Figure 5. 10: leaching of heavy metals from Mpraeso black pots at varying grinding time.

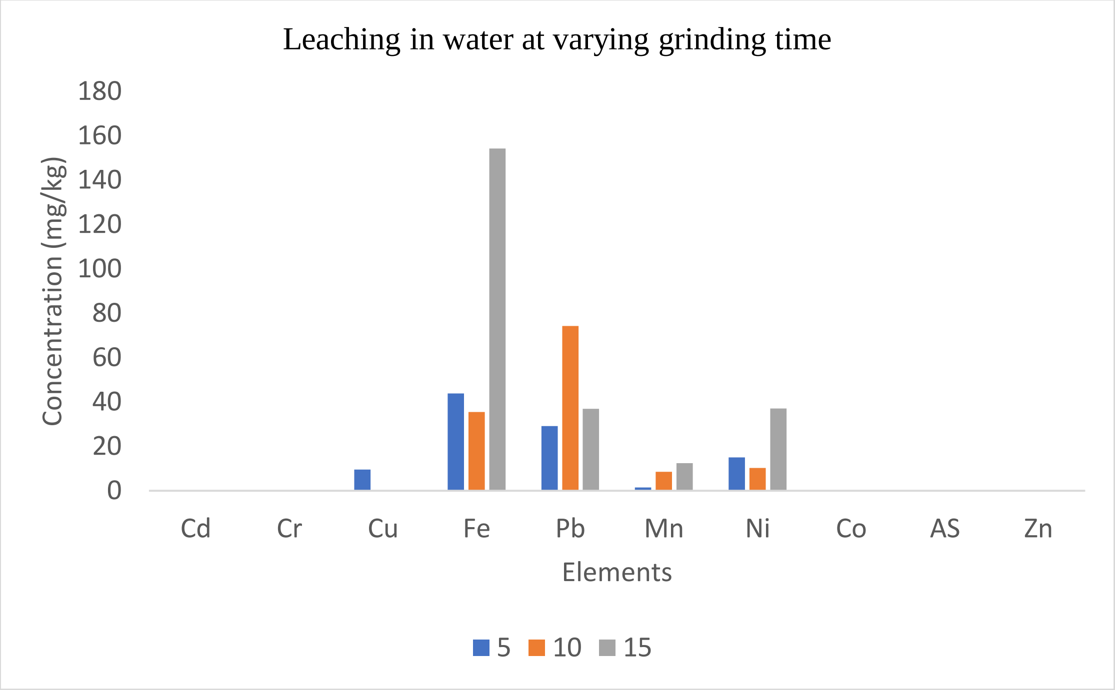


Figure 5. 11: leaching of heavy metals from Mpraeso red pots at varying grinding time.

For Fig.5.11, Cu concentration decreased from 10mg/kg for 5min to zero whiles Fe and Ni decreased and increased sharply particularly Fe from 44mg/kg at 5min to 154mg/kg at 15mins grinding. However, Pb concentration increased from 29 to 74mg/kg (5-10mins) and decreased to 37mg/kg for 15mins. Manganese concentration level increased by 7mg/kg and 4mg/kg from 5 to 10 mins and 10 – 15mins grinding durations, respectively.

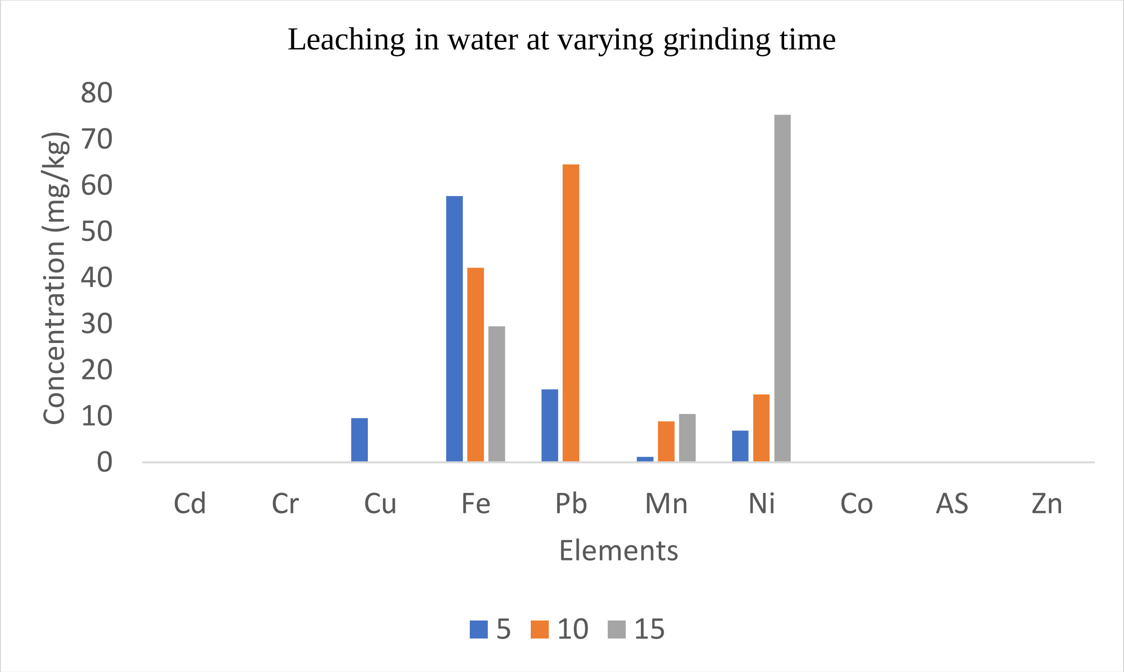


Figure 5. 12: leaching of heavy metals from Vume pots at varying grinding time.

Like the Mpraeso (black) pots, concentration levels of Cu and Fe in Vume pots decreased with Fe level also decreasing from 58mg/kg to 30mg/kg from 5 to 15mins duration (Fig.5.12). Lead levels shot up sharply from 16 to 65mg/kg and was zero at 15mins but manganese and nickel levels increased steadily in all three durations. Nickel increased from 7 to75mg/kg whiles manganese rose from 1 to 11mg/kg. Generally, the concentration levels of Cu and Fe tend to decrease with increasing length of grinding, Pb fluctuates; it increases and decreases whereas that of manganese and nickel increase with increasing length of grinding or wear and tear. Ni is the only heavy metal with concentrations above FAO/WHO threshold which were still within the limits of European Commission limits in ceramics.

5.9.2 Leaching in acetic acid at varying grinding time

Figures 5.13 to 5.15 shows results of leaching of heavy metals in acetic acid owing to wear and tear simulating the day-to-day usage of the pots. Only four metals namely Fe, Pb, Mn and Ni were detected in Mpraeso pots (Figs. 5.13 & 5.14) and for Vume pots the metals were five thus Cu, Fe, Pb, Mn and Ni (Fig.5.15). Iron concentration level declined from 57 to 17mg/kg (5 to 15mins), Pb concentration dropped from 67 to 33mg/kg for 5 and 10mins grinding and increased to 50mg/kg for 15mins grinding schedule for Mpraeso black pots (Fig.5.13). Concentration levels of manganese and nickel had been increasing with the respective increasing lengths of grinding in the Mpraeso black pots, manganese from 10 to 12mg/kg and nickel 36 to 60 mg/kg.

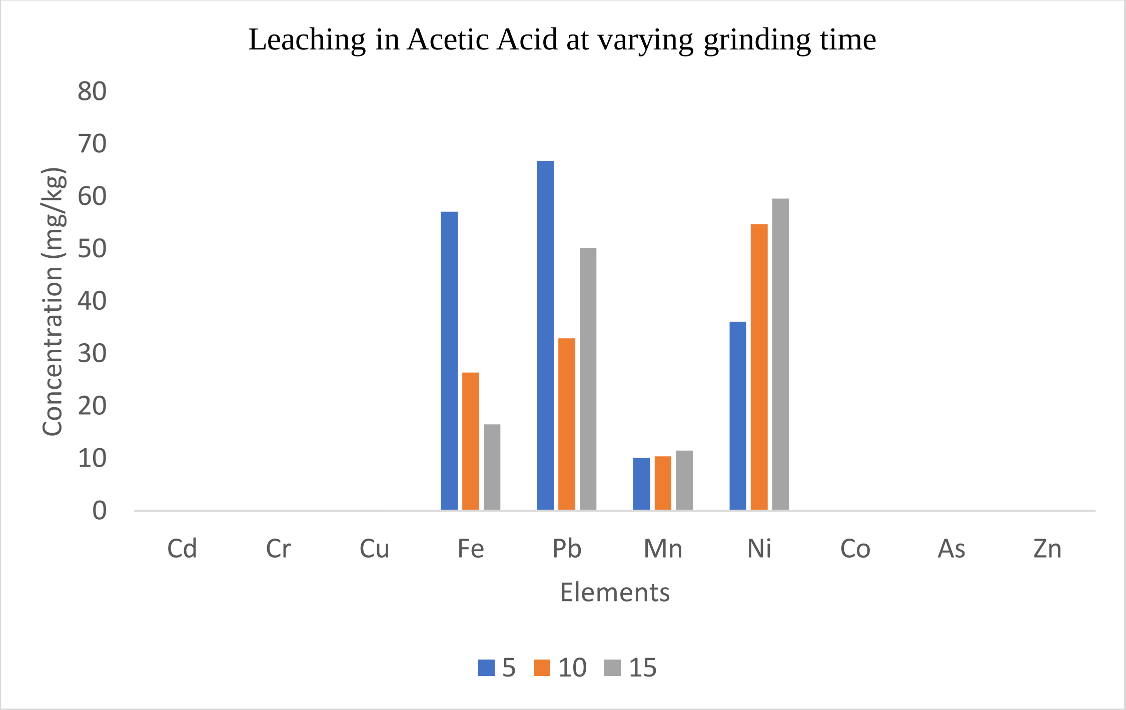


Figure 5. 13: leaching of heavy metals from Mpraeso black pots at varying grinding time.

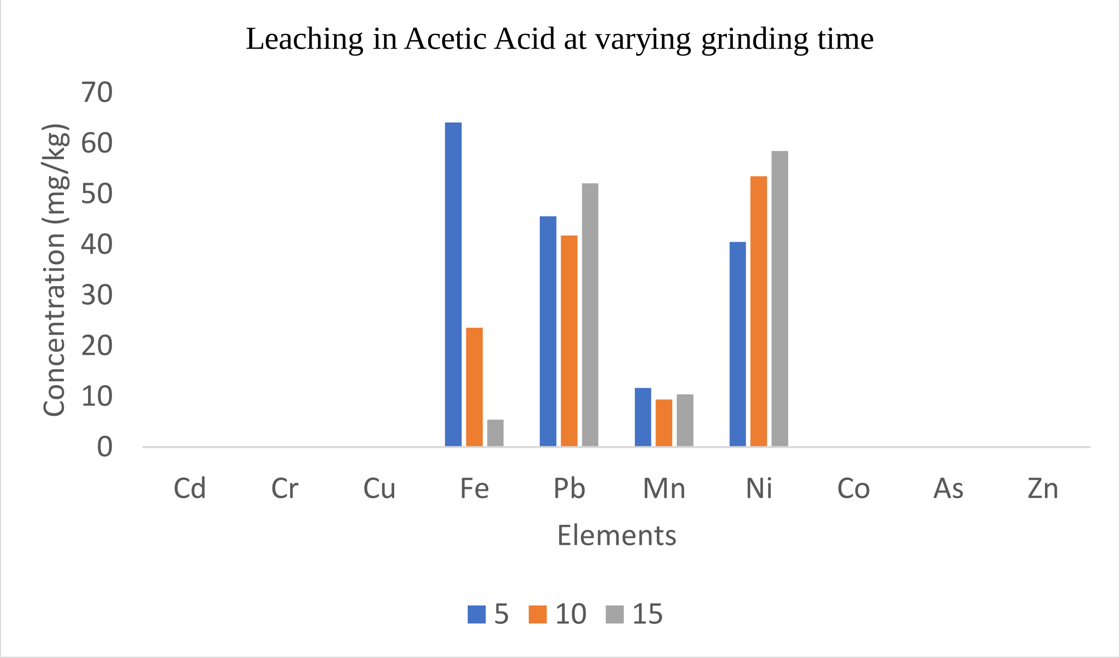


Figure 5. 14: leaching of heavy metals from Mpraeso red pots at varying grinding time.

Like Mpraeso black pots results, Fe concentration decreased with increasing reuse from 5 to 15min (64 to 5mg/kg), Pb concentration also dropped and rose again from 46 to 42mg/kg and to 52 mg/kg with manganese showing a similar trend from 12 to 9mg/kg and to 10mg/kg in Mpraeso red pots (Fig.5.14). Nickel on the other hand increased from 41 to 59 mg/kg from 5 to 15mins grinding duration in Mpraeso (red) pots.

For Vume pots (Fig.5.15), Cu was detected at 3mg/kg only after 5min of grinding. Iron (Fe) concentration level increased marginally (5mg/kg) between 5 and 10mins of grinding and dropped (41mg/kg) to 29mg/kg for 15mins grinding time scale. Concentration levels of Pb and Mn declined within the 5 and 10mins time span with lead declining from 89 to 46mg/kg and Mn slightly from 13 to 10mg/kg (Fig.5.15).

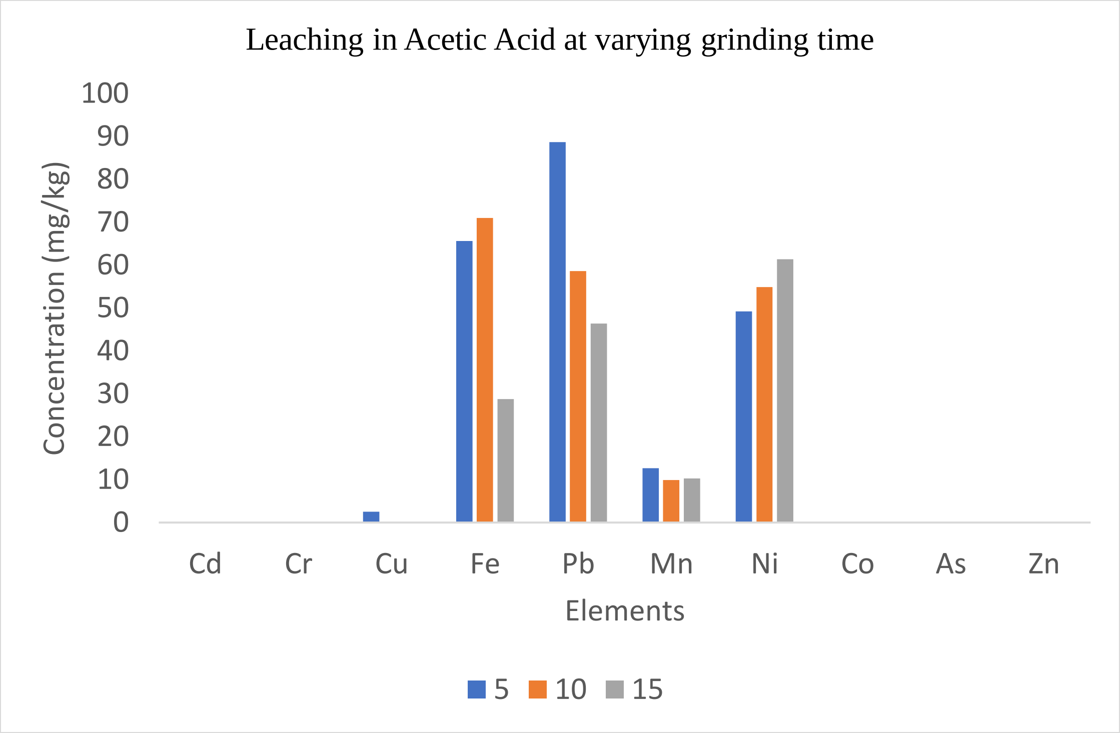


Figure 5. 15: leaching of heavy metals from Vume pots at varying grinding time.

Nickel concentration increased by 12mg/kg within the 5 and 10mins grinding periods. Overall, Fe concentration decreased, Pb and Mn fluctuated but with a declining pattern whiles Ni increased within the same period. Except Ni whose concentration levels exceeded FAO/WHO limits, all other metals were within the acceptable levels of the international organizations.

5.9.3 Leaching in sauce at varying grinding time

Figures 5.16 to 5.118 shows results of leaching of heavy metals into food prepared by grinding sauce at different time scales in the pots. Six elements namely Cu, Fe, Mn, Ni, Co, and Zn are found in the sauce. The concentration levels of almost all elements decreased with grinding time except Co which increased marginally with time (94 to

121mg/kg) (Figs.5.16 to 5.18). Concentration levels of Cu, Mn and Zn decreased below detection levels with increasing time span. Fe recorded a very high value of 910 at 5mins grinding, decreased to 61mg/kg for 10mins grinding and increased to 185mg/kg for 15mins grinding duration (Fig.5.16).

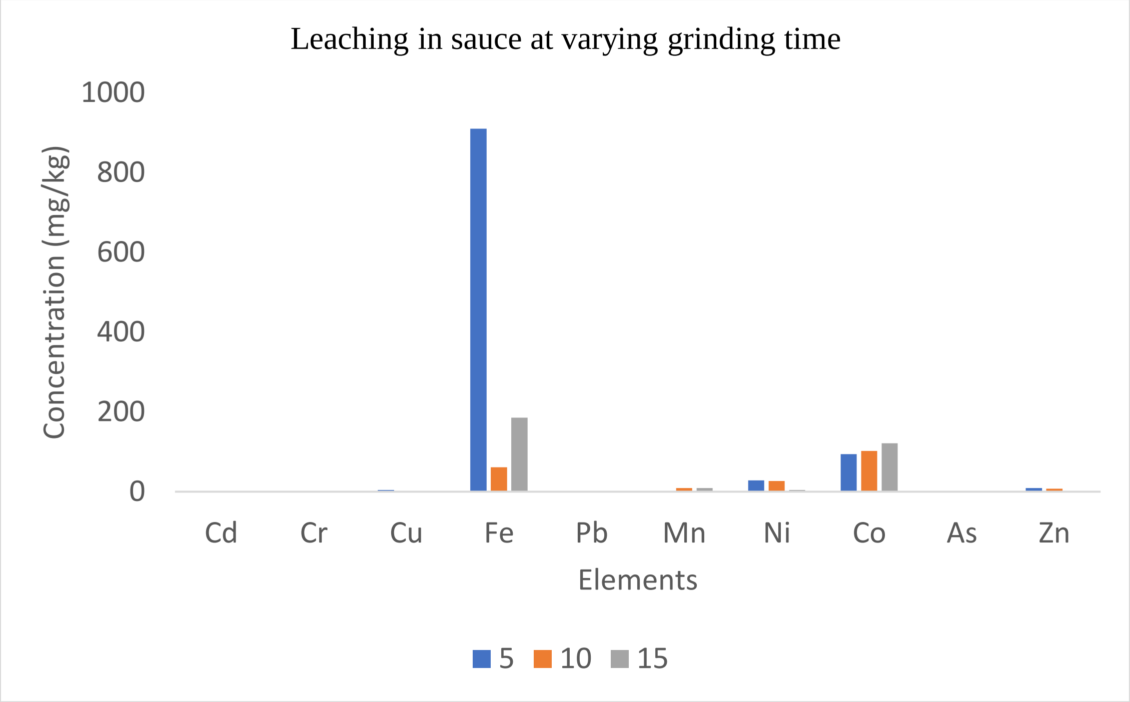


Figure 5. 16: leaching of heavy metals in Mpraeso black pots at varying grinding time.

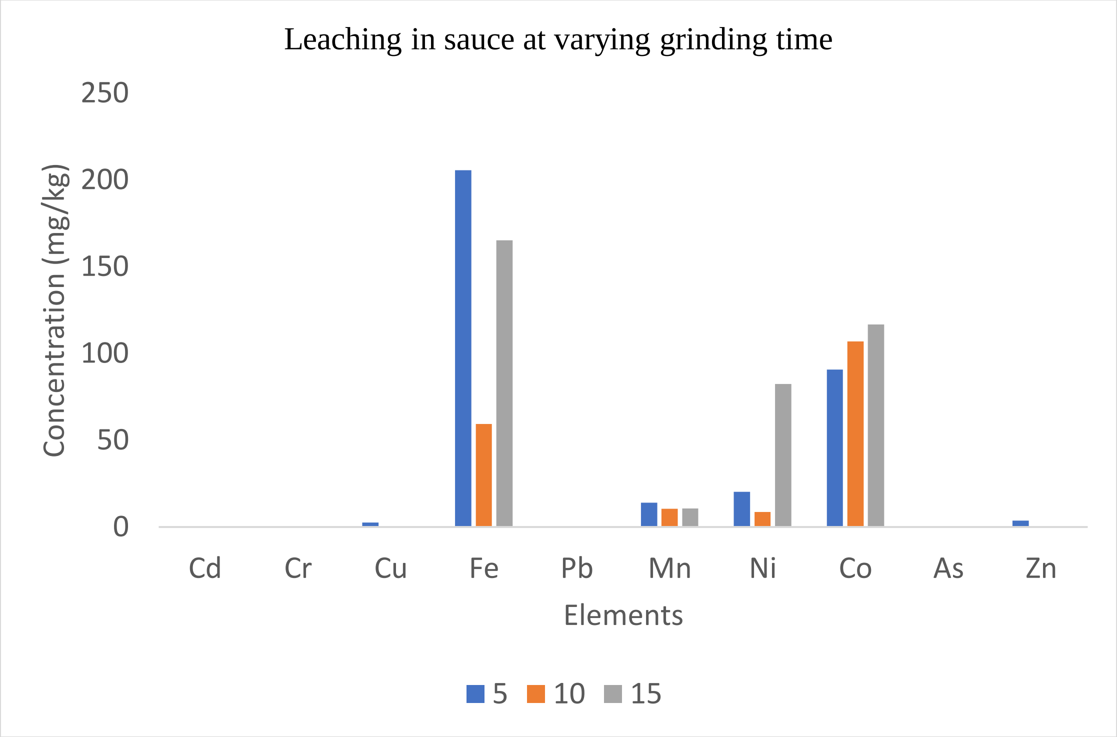


Figure 5. 17: leaching of heavy metals from Mpraeso red pots at varying grinding time.

Similarly, concentration levels of Cu, Mn and Zn had been very low and declined with time span of grinding reaching non-detectable limits for Cu and Zn about 11mg/kg for Mn (Fig.5.17). However, Co levels increased from 91 to 117mg/kg from 5 to 15mins grinding schedule. Iron and Ni concentration levels however declined from 206 to 59mg/kg and 20 to 9mg/kg and increased again to 165 and 82mg/kg respectively within the time frame of grinding.

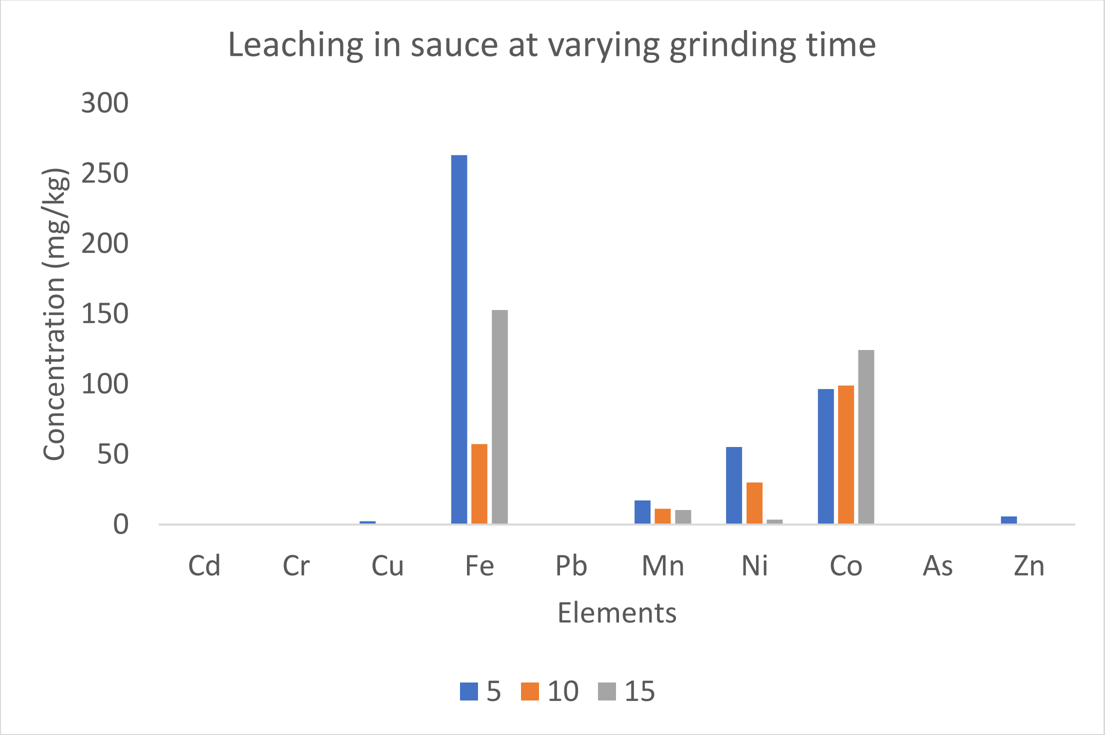


Figure 5. 18: leaching of heavy metals from Vume pots at varying grinding time.

Likewise leaching of Cu, Mn, Ni and Zn decreased with increasing grinding time (Fig.5.18). Just like in other pots, Fe concentration decreased from 263mg/kg (5mins) to 57mg/kg (10mins) and increased to 153mg/kg (15mins). Co on the other hand leached a bit more with increased time of grinding from 97 to 124mg/kg. There has been consistency in the leaching of the metals in the 3 different types of pots, Fe fluctuating, Co rising whiles the rest generally decreased in concentration with respect to duration of grinding. Concentration levels of Ni and Co are beyond FAO and European Commission limits on ceramics.

There is variability in the pH of the sampling materials of the study for both normal/uncooked and cooked samples. Water recorded the highest pH, followed by sauce with acetic acid recording the least pH values for both uncooked and cooked samples though the mean of water was lower than that of sauce. The pH of water ranged between 5.1 and 6.3 with a mean of 6, followed by sauce with a range of 4.5 – 4.9 and a mean of 4.8 and acetic acid had the minimum pH with a range of 2.9 <pH<3.5 and a mean of 3.1 for uncooked samples. Cooked water still recorded higher pH levels especially at 100°C with a range of 3.3 <pH< 5.6 (mean = 4.2), cooked sauce within values of 4.5 and 4.8 (mean = 4.7), and acetic acid having the minimum pH of range 2.7 <pH< 3.2 (mean = 3.1). Comparatively, the pH of cooked samples was lower than the respective uncooked samples.

In this project increase in temperature of food samples in pots increased the pH levels of the samples. There is therefore a linear relationship between food temperature in pots and pH. Heavy metals that leached in all the uncooked ground materials (water, acetic acid and sauce) were Cu, Fe, Pb, Mn, Ni, Cd, Co and Zn. Further with the exception of Cd all heavy metals that leached when uncooked materials (water, acetic acid and sauce) were ground are also detected in cooked samples (i.e. Cu, Fe, Pb, Mn, Ni, Co, and Zn).

All the elements except Ni and Co were detected to be below WHO level. For instance, about 41.7% of samples' Ni concentration was above threshold in 5min grinding and in 10min grinding it is 83.3% and 100% in 15min grinding (Tables 5.1 – 5.3) for uncooked substances ground. A linear relationship between grinding time and migration of Ni from pot into food was observed. For uncooked samples Ni concentration level was found to increase with increasing length of grinding in water whiles that of cooked samples is of a variable pattern.

As observed in the clay samples, Ni concentration levels in ground sauce is influenced by pH since lower pH of acetic acid is associated with higher levels of Ni leaching in the pots as compared to results of water and sauce which had higher pH levels. These results conform to works of Kabata-Pendias & Pendias, (2001) among others. As discussed earlier, Ni levels in the clays and pots are derived from geological processes and rock weathering.

Concentration levels of Co in ground sauce and cooked samples are above standard limits of FAO (1.5 mg/kg). For the grinding of sauce Co concentration generally increased with storage after grinding (Tables 5.6 – 5.8) whereas that of cooked samples are of variable trends (Figs.5.1.-5.9). Cobalt is a natural earth element present in trace amounts in soil but its concentration in the soil is not the only factor determining toxicity, but the soil chemistry greatly influences cobalt toxicity.

The more acidic the soil, the greater the potential for cobalt toxicity. Co leaching is therefore prevalent/pervasive in slightly acidic conditions. Co usually occurs in association with other metals such as copper, nickel, manganese, and arsenic in the soil. Other natural sources of cobalt in the environment are dust, seawater, volcanic eruptions, and forest fires. Natural conditions that can release Co into the environment are rock weathering, seawater, and bush fires for Vume and for Mpraeso it can only be bush fires and rock weathering.

Soils with high cobalt concentrations usually also have high arsenic and, nickel concentrations (Ministry of Environment, 2001). Cobalt is also released to the environment from burning coal and oil, from car, truck, and airplane exhausts, and from industrial processes that use the metal or its compounds. These anthropogenic activities that emit Co into the environment are less prevalent in the study areas and cannot account for its levels in the sauce.

5.11 Conclusion

Studies of leachability of elements from pots depending on class of solvent revealed heavy metal leachates. The results further showed that grinding sauce and eating hot food in the ceramic pots from Mpraeso and Vume could expose people to only the toxic elements Fe, Ni and Co. Other heavy metals like Cd, As, Zn, Pb, Cu, Mn and Cr did pose less health risks during leaching.

CHAPTER SIX

POTENTIAL HEALTH RISK AND HAZARDS IN THE LIFE CYCLE OF EARTHENWARE

6.0 Introduction

In the life cycle of the earthenware production, there may be potential health risks at each stage of the production cycle that needs critical attention. Some heavy metals like Cd, Cr, Cu, Fe, Pb, Mn, Ni, Co, As and Zn commonly occur in the environment and humans are exposed to them. There is a possibility then that these metals may be absorbed into the body during the life cycle of the earthenware production and at levels lethal to humans. The Ghanaian clay pottery industry is rather a smaller-scale enterprise but widespread owing to the distribution of the clay deposits in all parts of the country, exposing a great number of people to this hazard. The possible exposure pathways of these metals are through inhalation, ingestion, and dermal contact.

At the extraction and manufacturing stages of production, airborne dust composed of a complex mixture of minerals and metals may be inhaled by humans. The health impacts of heavy metal exposure through dust are a global concern (Aldabe *et al*., 2011; de Miranda *et al*., 2012). In assessing the human health risks, a process is used to estimate the health effects that might result from the exposure of the metals. The process is based on recommendations by several American publications in which models are used in the calculations of contaminated soils inhaled by humans. These models are discussed and applied subsequently to aid calculating of metals inhaled by humans during pottery production (De Miranda *et al*., 2012).

Dermal exposure pathways of metals to humans can also occur during the manufacturing stage (Tchounwou *et al*., 2012). All the potters that were interacted with during field work did not use hand gloves as a protective gear. Thus, the intensity, frequency, and duration of exposure of clay through their bare hands in the production process is used to assess the metal contaminant exposure to humans. The United States Environmental Protection Agency (USEPA) has guidelines and models in calculating the dermal contact effect of metals on humans (US EPA, 2011). These models have been employed in this study.

End users of the clay product in this scenario the pot; can also be exposed through ingestion pathways as some of these metals may leach into foods cooked or consumed in them (Jabeen *et al*., 2016; Jarup, 2003). This follows the fact that food processing, storage and consumption in locally made grinding pots in Ghana is common. But a number of studies in recent times have shown that some of the cook wares used in cooking, storing and eating of food may also be contributing toxic pollutants to our bodies (Ogidi *et al*., 2017).

It is argued that some cook wares especially the traditional ones, do not have protective layers of inert material to thwart contamination of foods hence the possibility of metals leaching into foods prepared or eaten in them (Jabeen *et al*., 2016). Most traditional Ghanaian homes use clay grinding pots to mash fresh pepper, tomatoes and onions together into a spicy paste known locally as *shito*. Others also prefer to eat *fufu* and soup a popular Ghanaian dish in the grinding pot.

Numerous studies revealed that trace metal levels can be increased in food depending on the nature of cook wares, cooking process, storage, processing and consumption (Said, 2015). In view of this, heavy metal pollution in food chains has attracted much attention especially in recent years (Harmanescu *et al*., 2011; Yahyavi *et al*., 2012). This chapter seeks to use results of heavy metals' leachability in food in Chapter Five to assess the health risks of the production processes of the pottery industry.

The United States Environmental Protection Agency (USEPA) has proposed a reasonable and widely recognized index for the evaluation of heavy metals intake by consumption of contaminated food. The agency has further proposed the target hazard quotients (THQ) for estimation of the potential health risks to human health associated with the ingestion of these heavy metals of interest if they should leach into ground shito that is consumed by humans. The study appraised both cancer and non-cancer risk of heavy metals through the consumption of shito in taking safety measures.

6.1 Materials and Methods

The reagents and instruments used, quality assurance and quality control were same as discussed in Chapter Five. Test on the simulated food preparation methods in pots done previously (Chapter Five) and mean concentrations values of metals in crude clays at the extraction and processing stages of production (Chapter 3) was applied.

6.1.1 Sample collection

Sample collection procedure for clays sampled is discussed in Chapter 3 while sample collection procedure for pots is described in Chapter 5

6.1.2 Sample treatment

Grinding pots were washed and rinsed with deionized water while destructive physico-chemical sample treatment was conducted on the crude clay samples as described previously (Chapter 3).

6.2 Laboratory analysis

6.2.1 Digestion and Analysis of clay samples.

Clay samples from the extraction stage and processing stages of production, mimicking inhalation and dermal risk of potters was digested using 10g of clay sample and treated with aqua regia for each analysis. Similarly, 10ml of the ground *shito* mimicking the ingestion risk of potters was taken as sample at the use stage to complete the pots life cycle. All the clay and food samples were treated with aqua regia, and the procedure followed by AAS as described in Chapter 5 previously. The results of these metals (Cd, Pb, As, Fe, Zn, Co, Ni, Mn, Cr and Cu) obtained from chapter five were used in the calculations of the health risk assessment.

6.3 Calculation of Health Risk Assessment during the extraction stage of the earthenware pot

This was calculated as described by the USEPA inhalation model for soil particulates and gases as

$$\mathrm{EDIM}_{inh} = \frac{\mathrm{Cs} \times \mathrm{IR}air \times \mathrm{EF} \times \mathrm{ED}}{BW \times AT \times PEF} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.1)$$

Where EDIM$_{inh}$ is the estimated daily intake of metal by inhalation from the soils in mg/kg/day, C$_s$ is concentration of heavy metals in the soil in mg/kg, IR$_{air}$ is the inhalation rate in m^3/day, PEF is the particulate emission factor in m^3/kg, EF is the exposure frequency in days/year, ED is the exposure duration in years, BW is the body weight of the exposed individual in Kg, AT is the time period over which the dose is averaged in days.

6.4 Calculation of Health Risk Assessment during the processing stage of the earthenware pot

The dermal contact of clay with the potters was calculated using the model

$$\mathrm{EDIM}_{dems} = \frac{\mathrm{Cs} \times \mathrm{SA} \times \mathrm{FE} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{BW \times AT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6.2)$$

In which EDIM_{derms} is the exposure dose via dermal contact in mg/kg/day. Cs is the concentration of heavy metal in soil in mg/kg, SA is the exposed skin area in cm^2, FE is the fraction of the dermal exposure ratio to soil, AF is the soil adherence factor in mg/cm^2, ABS is the fraction of the applied dose absorbed across the skin, CF is the conversion factor in kg/mg. EF, ED, BW and AT are as defined in the equation 6.1 discussed previously.

6.5 Calculation of Health Risk Assessment during the user stage of production

The Estimated Daily Intake of Metals (EDIM) assesses the initial risk exposure of heavy metals for users of grinding pots and consumers of substances in the grinding pots. The average heavy metal content of each sample was calculated and multiplied by the respective ingesting rate. The health risks associated with the consumption/intake of heavy metal via oral exposure were then calculated based on the formula:

$$\mathrm{EDIM}_{ing} = \frac{\mathrm{C(metal\ concentration)} \times \mathrm{D(food\ intake)}}{B(average\ weight)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.3)$$

Where C (metal concentration) represents heavy metal concentration in residue sample (mg/kg) D (food intake) represents daily intake of food and B (average weight) is the average body weight. The rate of daily intake was calculated to averagely estimate the daily metal loading into the body system of a specified body weight of a consumer. In the World Health Organization., guideline (1998), daily required vegetable intake in a diet must be between 300 to 350g per person. This research used an average daily consumption of the vegetables used in preparing shito to be 350g (0.35kg) for an average body weight of 60kg for adults and 15kg for children as found in World Health Organisation, (1993) guidelines.

Table 6. 1: Exposure parameters used for the health risk assessment through different exposure pathways

Parameter	**Unit**	**Child**	**Adult**	**References**
Body weight (BW)	kg	15	60	
Exposure frequency (EF)	days/year	350	350	
Exposure duration (ED)	years	6	30	
Ingestion rate (IR)	mg/day	200	100	
Inhalation rate (IR_{air})	m^3/day	10	20	
Skin surface area (SA)	cm^2	2100	5800	
Soil adherence factor (AF)	mg/cm^2	0.2	0.07	
Dermal absorption factor (ABF)	none	0.1	0.1	
Dermal exposure ratio (FE)	none	0.61	0.61	
Particulate emission factor (PEF)	m^3/kg	1.3×10^9	1.3×10^9	
Conversion factor (CF)	kg/mg	10^{-6}	10^{-6}	
Average time (AT)				
For carcinogens	days	365 × 65	365 × 65	
For noncarcinogens		365 ×ED	365 × ED	

Source: Kamunda et al., 2016; USEPA, 2012

6.6 Non-Cancer Risk

Several procedures have been proposed for the estimation of the potential risks to human health caused by toxic metals. The target hazard quotients (THQ) is one among the many, proposed by the US Environmental Protection Agency (USEPA).

6.6.1 Target hazard quotients (THQ)

This standard is applied in the assessment of heavy metals intake by consumption of contaminated food (Joint FAO/WHO, 1985; Lanre-Iyanda & Adekunle, 2012). The non-carcinogenic risks for heavy metals in the samples was appraised by computing the target hazard quotient (THQ) based on the formula below (Farokhneshat *et al*., 2016).

$$\text{THQ}=\frac{\text{EDIM}}{RfD} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.4)$$

Where EDIM has been discussed already and RfD is the oral reference dose of the metals. The RfD values used in this research are shown in Table 6.2. In estimating the target quotient risk values for human health risk, an assumption was made according to the United States Environmental Protection Agency (US EPA, 1989) that; ingested dose of pollutant is equal to the absorbed dose.

Table 6. 2 Reference dose and oral carcinogenic potency slope factor

Heavy metals	**Oral RfD**	**Dermal RfD**	**Inhalation RfD**	**Oral CSF**	**Dermal CSF**	**Inhalation CSF**
Fe	7.0×10^{-01}					
Mn	1.4×10^{-02}					
Co	2.0×10^{-02}	5.7×10^{-06}	5.7×10^{-06}	-	-	9.8×10^{0}
Pb	3.6×10^{-03}	-	-	8.5×10^{-03}	-	4.2×10^{-02}
As	3.0×10^{-04}	3.0×10^{-04}	3.0×10^{-04}	1.5×10^{0}	1.5×10^{0}	1.5×10^{0}
Zn	3.0×10^{-01}	7.5×10^{-02}	-	-	-	-
Cd	5.0×10^{-04}	5.0×10^{-04}	5.7×10^{-05}	-	-	6.3×10^{0}
Ni	2.0×10^{-02}	5.6×10^{-03}	-	1.7×10^{0}	-	0
Cu	3.7×10^{-02}	2.4×10^{-02}	-	-	-	-
Cr	3.0×10^{-03}	-	3.0×10^{-05}	5.0×10^{-01}	-	4.1×10^{1}

Source: USEPA 2012, Kamunda et al (2016)

6.6.2 Hazard Index (HI)

The assessment of the total potential health risk by different metals is obtained by summing up all the hazard quotients (THQ) of the various metals involve gives a known hazard index.

$$HI = \sum_{k=1}^{n} THQ_k = \sum_{k=1}^{n} \frac{EDIM}{RfD_k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.5)$$

In which THQ_K, EDIMk and RfDk are the heavy metal k values. When HI values are less than 1, the expose population are not likely to experience adverse health effects but if it is greater than 1 then there is a need for concern of potential non carcinogenic effect.

6.7 Cancer Risk Assessment

6.7.1 Target Cancer Risks (TR)

In indicating carcinogenic risk of the shito source Target Cancer Risk (TR) model was used. The method which is used to estimate TR is provided in USEPA Region III Risk-

Based Concentration Table 6.1 (US EPA, 2012). It is dimensionless and calculated using the equation 6.6:

$$TR=\frac{EDIM\times CSF\times EFr\times EDtot}{ATn}\ldots\ldots\ldots\ldots\ldots\ldots..(6.6)$$

Where EDIM, EFr and EDtot have already been explained. CSF is the cancer slope factor in (mg/kg/day). While ATn is the averaging time for carcinogens (365 days/year × 65 years). A life time of 65 years was used for carcinogenic effect in Ghana according to Nkansah *et al.*, (2016).

Humans probable lifetime exposure of contracting cancer due to carcinogenic metals is calculated as

$$CR= EDIM \times CSF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.7)$$

Where CR is the carcinogenic risk; EDIM and CSF have previously been explained. The associated risk of carcinogens can be expressed as excess probability of attaining cancer over a life time of 65years (US EPA, 2005). The cancer slope factor (CSF) used for this research was assessed in the integrated information risk system (IRIS) that was provided by USEPA data base and the Agency for Toxic Substance and Disease Registry (ATSDR). In this research Co Pb and Cr were the metals that their cancer risk values for inhalation pathway got calculated for. This is because the remaining metals have sparse data on their dermal pathway CSF values due to the unestablished fact on their carcinogenicity effect on humans.

6.8 Statistical analysis

Pearson correlation and ANOVA tests were done in SPSS to determine relationships and variance of metals of the health risk assessment models. The Pearson coefficient of correlation among metals was analyzed with results of the health risk assessments of the various production stages. Statistical significance was considered for a probability of $p< 0.01$ and $p<0.05$. In obtaining relationship between the metals one-way ANOVA test was also applied to study the variance in results of the health risk assessments of the various production stages. A $p<0.05$ or lower was measured as significant.

6.9 Results and Discussion

6.10 Health Risk Assessment in stages of the earthenware pot's life cycle.

Risk assessment was done through ingestion, inhalation, and dermal contacts of three stages of the pots cycle. Results obtained from the human health risk models suggested by USEPA, which includes carcinogenic and non-carcinogenic risks, are subsequently presented. Presently there is no agreed limit for acceptable maximum carcinogenic and non-carcinogenic risk levels in Ghana (Nkansah *et al.*, 2016). Hence the value verges recommended by USEPA was employed to assess the potential health risk involved in the Life cycle of the earthenware pot. Average concentrations of metals in mg/kg of clays from the extraction and processing stages of production in Mpraeso and Vume are presented in Table 6.3. These results revealed that As and Cd were below detection levels in Mpraeso, but in Vume, only As was below detection level and are therefore not indicated in the table presented.

6.10.1 Extraction Stage

As shown in Table 6.3, Other heavy metals varied significantly and decreased in the following order Fe > Ni > Cr > Mn >Zn > Cu >Co >Pb for Mpraeso and Fe > Ni > Mn > Pb > Cr > Zn > Cd > Cu > Co for Vume. The average concentration ranges were as follows: Fe (583-2885mg/kg); Ni (34.8-101.3 mg/kg); Cr (16.8-64.9 mg/kg); Mn (8-85.4 mg/kg); Zn (12.4-72 mg/kg); Cu (0-71.3 mg/kg); Co (0-23.9 mg/kg) and Pb (0-10.3 mg/kg) respectively for Mpraeso and Fe (1634 – 19350 mg/kg); Mn (24.8-184.3 mg/kg); Zn (0 – 142.6 mg/kg); Ni (66.7 – 93.3 mg/kg); Pb (0 – 86.3 mg/kg); Cr (9.4 -55.9 mg/kg); Cu (0-30.9 mg/kg); Co (0-16.3 mg/kg) and Cd (6.5 – 11.2 mg/kg) respectively for Vume. Fe (8307.11 mg/kg) and Ni (78.52 mg/kg) were both in high concentrations in the study areas with the highest concentrations recorded in Vume (Table 6.3). Heavy metals of Cu and Co were in low concentration in Vume (5.7 mg/kg and 4.7 mg/kg respectively) than in Mpraeso (15.85

Table 6.3: Mean concentration of heavy metals in clays at the extraction and processing stages in study sites

Town	Descri	Co	Zn	Mn	Ni	Pb mg/kg	Fe	Cr	Cu	Cd
					Extraction Stage					
Mpraeso	Min	<0.00	12.40	8.01	34.81	<0.00	583.32	16.82	<0.00	-
	Max	23.90	72.02	85.43	101.32	10.32	2885.02	64.91	71.31	-
	Mean	5.81	26.01	32.42	65.75	0.95	1636.82	36.45	15.85	-
Vume	Min	<0.00	<0.00	24.81	66.72	<0.00	1634.01	9.43	<0.00	6.52
	Max	16.31	142.63	184.32	93.31	86.33	19350.22	55.92	30.92	11.21
	Mean	4.72	16.89	59.86	78.52	46.20	8307.11	25.58	5.74	8.33
					Processing Stage					
Mpraeso	Min	<0.00	1.41	5.12	32.53	<0.00	271.03	18.21	<0.00	-
	Max	17.32	45.00	141.51	115.31	32.03	1793.02	56.83	48.93	-
	Mean	6.01	21.88	47.75	64.20	10.06	1135.55	29.83	12.09	-
Vume	Min	<0.001	<0.001	26.13	61.41	<0.00	1617.04	12.62	<0.001	4.83
	Max	32.8	137.4	154.01	124.23	100.31	28700.30	54.84	45.22	10.84
	Mean	15.13	29.84	67.58	79.31	57.94	8787.33	26.12	17.68	7.91

mg/kg and 5.81 mg/kg respectively) as seen in Table 6.3. Pb (46.2 mg/kg) was high in Vume but low (0.95 mg/kg) in Mpraeso whereas Zn (26.01 mg/kg) and Cr (36.45 mg/kg) were high in Mpraeso and low (16.8 mg/kg and 25.57 mg/kg respectively) in Vume.

The results also showed low concentration values when compared to both EU soil guidelines and WHO/FAO recommended values in soil (Table 6.4). Ni (65.75 mg/kg) in Mpraeso was within the recommended soil values of EU guidelines but above WHO/FAO recommended values in soils. Ni value in Mpraeso (65.75 mg/kg) was low compared to EU guidelines whereas that of Vume (78.52 mg/kg) was higher compared to both EU guidelines and WHO/FAO values in soils. Co showed low values for WHO/FAO whereas Cd and Fe were high compared to WHO/FAO values. Mn was within range of recommended values.

Table 6. 4: Recommended threshold limits of international organizations

Metal	**EU guidelines soil (mg/kg)**	**WHO/FAO soil (mg/kg)**	**WHO/FAO food(mg/day)**	**USA standard (mg/l)**	**Reference**
Cu	140	100	2-3	1.3	WHO/FAO 1998; 2005
Ni	75	50	1		WHO/FAO 1998; 2005
Fe	-	-	10-28	0.3	WHO/FAO 1998; 2005
Co	-	50			WHO/FAO 1998; 2005
Mn	-	-	11		WHO/FAO 1998; 2005
Cr	150	100	0.2		FAO/WHO 2001
Zn	300	300	11		Khan et al 2008
Pb	300	100			WHO/FAO 1998; 2005
As	-	20			WHO/FAO 1998; 2005
Cd	3	3			WHO/FAO 1998; 2005

Source: Kumunda et al., 2016

6.10.2 Processing stage

At the processing stage the mean concentration of the metals were found in decreasing order as follows Fe > Ni > Mn > Cr > Zn > Cu > Pb > Co [in Mpraeso] and Fe > Ni > Mn > Pb > Zn > Cr > Cu > Co > Cd [in Vume] (Table 6.3). Again, Fe and Ni continued to be high in both sites with Vume recording highest values for both metals. Mn concentrations in the analyzed clays from the communities under study ranged from 5.1 to 141.5 mg/kg in Mpraeso and 26.1 to 154 mg/kg in Vume, while Pb concentrations ranged from <0.001 to 32 mg/kg in Mpraeso and <0.001 to 100.3 mg/kg in Vume. Meanwhile Cd was below detection level in Mpraeso but ranged from 4.8 to 10.8 mg/kg in Vume. The highest levels for Mn, Pb and Cd were all recorded in Vume. Cr ranged from 18.2 to 56.8 mg/kg in Mpraeso and 12.6 to 54.8 mg/kg in Vume. Co also ranged from <0.001 to17.3 mg/kg in Mpraeso and <0.001 to 32.8 mg/kg in Vume. Mpraeso recorded the highest level of Cr while Vume recorded highest level of Co (Table 6.3).

From the results the levels of Cu, Co, Zn, Pb and Cr in both Mpraeso and Vume were found to be lower than the mean exposure levels recommended by both EU guideline and WHO/FAO standards in soil. Fe in Mpraeso and Vume were found to be above the recommended levels of EU guidelines and WHO/FAO standards in soil. However, Ni in Vume was above the level but in Mpraeso was within the EU guidelines though above WHO/FAO standards. Cd in Vume exceeded the values recommended (Table 6.4).

6.11 Cancer risk Assessment

The concentrations of the extraction and processing stages of production were used to calculate the estimated daily intake of metals in two of the pathways thus dermal and inhalation for non-carcinogenic and carcinogenic risk assessment in adults and children, respectively. The mean concentration values of clays from the extraction and processing stages (Table 6.3) of production was used to calculate for EDIM. EDIM*inh* is representative of the extraction stage of the pot's life cycle while EDIM*derm* is for the processing stage of the cycle. The results of the EDIM [Using equation (6.1)], of metals for Mpraeso and Vume for the exposed adult and children population during the extraction and processing stages in the pots life cycle is presented in Tables 6.5 and 6.6.

Table 6. 5: Estimated daily intake (EDIM) values for adult and children in clays at the extraction and processing stage for carcinogenic risk calculation.

Town	Receptor	Pathway	Co	Zn	Mn	Ni	Pb	Fe	Cr	Cu	Cd
Mpraeso	**Adult**	**Inhalation**	6.61E-10	2.70E-09	3.33E-09	6.21E-09	1.57E-10	1.57E-07	3.51E-09	1.85E-09	-
		Dermal	1.01E-06	3.46E-06	8.08E-06	9.95E-06	1.73E-06	1.73E-04	4.66E-06	2.20E-06	-
	Child	**Inhalation**	3.08E-10	1.26E-09	1.55 E-09	2.90 E-09	7.31E-09	7.34E-08	1.64E-09	8.63E-10	-
		Dermal	9.76E-07	3.34E-06	7.80E-06	9.61E-06	1.67E-06	1.67E-04	4.50E-06	2.13E-06	-
Vume	**Adult**	**Inhalation**	5.31E-10	2.66E-09	6.53E-09	7.23E-09	4.53E-09	8.50E-07	2.58E-09	7.46E-10	7.79E-10
		Dermal	2.46E-06	5.90E-06	1.11E-05	1.22E-05	9.04E-06	1.57E-03	4.22E-06	2.97E-06	2.46E-06
	Child	**Inhalation**	2.48E-10	1.24E-09	3.05E-09	3.37E-09	2.12E-09	3.97E-07	1.21E-09	3.48E-10	3.63E-10
		Dermal	2.37E-06	5.70E-06	1.07E-05	1.18E-05	8.73E-06	1.51E-03	4.07E-06	2.87E-06	1.15E-06

Table 6. 6: Estimated daily intake (EDIM) values for adult and children in clays at the extraction and processing stage for non-carcinogenic risk calculation.

Town	Receptor	Pathway	Co	Zn	Mn	Ni	Pb	Fe	Cr	Cu	Cd
Mpraeso	**Adult**	**Inhalation**	1.54E-09	6.29E-09	7.76E-09	1.45E-08	3.65E-10	3.67E-07	8.18E-09	4.31E-09	-
		Dermal	2.36E-06	8.08E-06	1.89E-05	2.32E-05	4.03E-06	0.000404	1.09E-05	5.14E-06	-
	Child	**Inhalation**	3.6E-09	1.47E-08	1.81E-08	3.38E-08	8.52E-10	8.56E-07	1.91E-08	1.01E-08	-
		Dermal	1.14E-05	3.9E-05	9.1E-05	0.000112	1.95E-05	0.00195	5.25E-05	2.48E-05	-
Vume	**Adult**	**Inhalation**	1.24E-09	6.21E-09	1.52E-08	1.69E-08	1.06E-08	1.98E-06	6.03E-09	1.74E-09	1.82E-09
		Dermal	5.13E-06	1.01E-05	2.29E-05	2.69E-05	1.97E-05	0.003	8.86E-06	6.00E-06	2.68E-06
	Child	**Inhalation**	2.89E-09	1.45E-08	3.56E-08	3.93E-08	2.47E-08	4.63E-06	1.41E-08	4.06E-09	4.24E-09
		Dermal	2.77E-05	6.65E-05	0.00012	0.00014	0.00010	0.018	4.75E-05	3.35E-05	1.34E-05

6.11.1 Inhalation and dermal results for carcinogenic

The results of EDIM*inh* for child and adult carcinogen for Mpraeso recorded values in decreasing mean concentration as follows Fe > Ni > Cr > Mn > Zn > Cu > Co > Pb, while that of Vume was Fe > Ni > Mn > Pb > Zn > Cr > Cd > Cu > Co (Table 6.5). In both study areas Fe and Ni recorded higher values compared to other metals while Cu and Co had lower values. Fe and Ni in adult and child population in the inhalation pathway in Mpraeso were of lower values than in Vume. Also, low values were recorded for Cu and Co in Vume child and adult population for inhalation pathway compared with Mpraeso. Concentration of Pb in Vume in the adult and child population were higher than in Mpraeso with the adult population in Vume recording greater values compared to Mpraeso (Table 6.5).

However, Cr concentration was high in the child and adult carcinogenic population in Mpraeso than in Vume with the adult population in Mpraeso recording the highest value of 3.51E-09 compared to the child population in Mpraeso of 1.64E-09, adult population in Vume 2.58E-09 and Vume child population 1.21E-09 (Table 6.5). Zn in the exposed population had mean concentration of child (1.26E-09) and Adult (2.69532E-09) in Mpraeso and in Vume, child was 1.24173E-09 while adult was 2.66085E-09 as seen in Table 6.5. The Mean EDIM*inh* concentration of Mn ranged between 3.37197E-10 to 3.59958E-09 for child population and 7.22565E-10 to 7.71338E-09 for adult population all in Mpraeso whereas Vume ranged 1.04531E-09 to 7.76818E-09 for child population and 2.23995E-09 to 1.66461E-09 for adult population.

The EDIM*derm* for carcinogenic risk calculated in the exposed population for Fe ranged between 1.67E-04 for child and 1.73E-04 for adult in Mpraeso while in Vume Fe ranged from 1.51E-03 for child and 1.57E-03 for the adult population. Ni in Vume adult*derm*

(1.22E-05) was higher than Vume child*derm* (1.18E-05), Mpraeso adult*derm* (9.95E-06) and Mpraeso child*derm* (9.61E Mpraeso -06). Cobalt also in Vume adult*derm* (2.46E-06) was higher than Vume child*derm* (2.37E-06), adult*derm* (1.01E-06) and Mpraeso child*derm* (9.76E-07). Mn was higher in Vume adult*derm* (1.11E-05) than in Vume child*derm* (1.07E-05), Mpraeso child*derm* (7.80E-06) and Mpraeso adult*derm* (8.08E-06) [Table 6.5]

Cr in Mpraeso adult*derm* (4.66E-06) had values higher than Mpraeso child*derm* (4.50E-06), Vume adultderm (4.22E-06) and Vume child*derm* (4.07E-06). According to Javed et al (2016) when the ratio of a metal's EDIM to its RfD is equal to or less than the RfD then the risk will be minimum. However, if it is >1–5 times the RfD then risk will be low, if >5–10 times the RfD then risk will be moderate, however, if >10 times the RfD then the risk will be high as stated in the New York State Department of Health (2007).

The EDIM*inh* values of Co and Cr were compared with their respective RfD values and were all within the stated dose for 365days of inhalation exposure. However, Pb, Ni, Cu, Zn, Mn and Fe have no RfD values for inhalation and so their EDIM*inh* values were compared with their oral RfD values. The results indicated that the EDIM*inh* values obtained were below these metals oral RfD values implying they are equally safe in a period of 365 days of exposure.

6.11.2 Dermal and inhalation results for non-carcinogenic

EDIM*inh* in metals for non-carcinogenic recorded Fe in adult (3.67E-07) and child (8.56E-07) for Mpraeso whereas highest values were recorded in Vume to be adult 1.98E-06 and child 4.63E-06 respectively. Ni in Vume child*inh* (3.93E-08) was higher than Mpraeso child*inh* (3.38E-08) and both were greater than Vume adult*inh* (1.69E-08) and Mpraeso adult*inh* (1.45E-08). Co had values lower in Vume adult*inh* (1.24E-09) and Mpraeso adult*inh* (1.54E-09) than Vume child*inh* (2.89E-09) and Mpraeso child*inh* (3.6E-09). Cr in Mpraeso child*inh* (1.91E-08) was higher than Vume child*inh* (1.41E-08) as well as Mpraeso adult*inh* (8.18E-09) and Vume adult*inh* (6.03E-09) (Table 6.6).

In the non-carcinogenic assessment Cd in child*derm* (1.34E-05) and adult*derm* (2.68E-06) in Vume were recorded however Cd in Mpraeso was below detection level. Co value in Vume child*derm* (2.77E-05) was greater than Mpraeso child*derm* (1.14E-05), Vume adult*derm* (5.13E-06) and Mpraeso adult*derm* (2.36E-06). Fe values in Vume childderm (0.018) is of higher value than Vume adult*derm* (0.003), Mpraeso child*derm* (0.00195) and adult*derm* (0.000404) (Table 6.6).

Ni in Vume childderm (0.00014) is greater than Mpraeso child*derm* (0.000112), Vume adultderm (2.69E-05) and Mpraeso adult*derm* (2.32E-05). Mn in Vume child*derm* (0.00012) was of higher value than Mpraeso child*derm* (9.1E-05), Vume adult*derm* (2.29E-05) and Mpraeso adult*derm* (1.89E-05). Cr also showed lower value in Vume adult*derm* (8.86E-06) but was high in Mpraeso child*derm* (5.25E-05), Vume child*derm* (4.75E-05) and Mpraeso adult*derm* (1.09E-05). Zn was high in Vume child*derm* (6.65E-05) than in Mpraeso child*derm* (1.14E-05), Vume adult*derm* (1.01E-05) and Mpraeso adult*derm* (8.08E-06) (Table 6.6).

The EDIM value of Co for child*derm* (1.14E-05) in non-carcinogenic assessment was above the RfD value of 5.70E-06 stated for dermal exposure for 365 days. Though there were no established dermal RfD values for Pb, Cr, Fe and Mn their EDIM values were compared with their available oral RfD values. The results indicated that all the values were within the given values. Nonetheless Cd, Ni, Cu and Zn had dermal EDIM values that were below their dermal RfD values implying the metals are safe in a period of 365 days of exposure.

6.11.3 Pearson coefficient of correlation for carcinogenic and non-carcinogenic risk Assessment

The Pearson correlation for the heavy metals of health risk models was computed to interpret the data. The coefficient of correlation is represented in Tables 6.7-6.10. For correlation significance, the criteria values of probabilities ($p<0.05$ and $p<0.01$) were used. From the Table 6.7 the correlation among the heavy metals were significant at $p<0.05$ and $p<0.01$.

From Table 6.7 positive strong coefficient of correlation was recorded between Mn/Zn ($r=0.764$, $p<0.01$) and Cu/Zn ($r=0.790$, $p<0.01$) and moderate Cr/Co ($r=0.670$, $p<0.05$), at extraction stage in Mpraeso.

Table 6.7: Pearson coefficient of Correlation among metals at Mpraeso during the extraction stage

	Co	*Zn*	*Mn*	*Ni*	*Pb*	*Fe*	*Cr*	*Cu*
Co	1							
Zn	0.463	1						
Mn	0.351	0.764**	1					
Ni	0.423	0.449	0.462	1				
Pb	-0.223	-0.185	-0.241	-0.480	1			
Fe	-0.222	0.177	0.546	-0.230	0.400	1		
Cr	0.670*	0.480	0.479	0.361	0.002	0.134	1	
Cu	0.399	0.790**	0.569	0.336	0.047	0.279	0.442	1

* Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed)

On the other hand, the coefficient of correlation of heavy metals at Vume during extraction recorded strong positive correlation between Mn/Zn ($r=0.897$, $p<0.01$) and moderate correlation between Ni/Zn ($r=0.648$), Fe/Zn ($r=0.664$), and Fe/Mn ($r=0.529$). Also, moderate negative coefficient of correlation was recorded between Pb/Cd (r= -0.622), Cd/Zn (r=-0.509) and Cu/Ni (r=-0.513) respectively (Table 6.8).

Table 6.8: Pearson Coefficient of Correlation at Vume during the extraction stage

	Zn	Mn	Ni	Cu	Fe	Cd	Pb	Co
Zn	1							
Mn	0.897^{**}	1						
Ni	0.648	0.458	1					
Cu	-0.218	-0.160	-0.513	1				
Fe	0.664	0.529	0.423	0.196	1			
Cd	-0.509	-0.497	-0.361	0.264	-0.378	1		
Pb	0.282	0.295	0.479	-0.442	0.462	-0.622	1	
Co	-0.243	-0.233	-0.008	0.228	0.206	-0.275	0.370	1

** Correlation is significant at the 0.01 level (2 tailed)

At the processing stage, a strong positive coefficient of correlation was recorded between Cu/Mn (r=0.869) and Mn/Zn (r=0.737) at 0.01 level of significance while moderate positive correlation was recorded between Cu/Zn (r=0.629, $p<0.05$), Fe/Zn (r-0.538), Cr/Mn (r=0.593), Cu/Fe (r=0.532), and Cu/Cr (r=0.565) at Mpraeso respectively (Table 6.9).

However, the processing stage at Vume recorded strong positive coefficient of correlation between Mn/Zn (r=0.907), Ni/Zn (r=0.849), Ni/Mn (r=0.799), and Pb/Cu (r=0.830) at $p<0.01$ whereas Fe/Zn (r=0.788) at $p<0.05$ while a moderate positive was also recorded between Fe/Mn (r=0.615) and Pb/Mn (r=0.507). Similarly, a strong negative correlation was recorded between Cd/Ni (r=-0,845, $p<0.01$) while moderate negative correlation was recorded between Cd/Zn (r=-0.599), Cd/Mn (r=-0.623), and Cr/Pb (r=-0.578) respectively (Table 6.10).

Table 6.9: Pearson's Coefficient of Correlation at Mpraeso during the processing stage

	Co	Zn	Mn	Ni	Pb	Fe	Cr	Cu
Co	1							
Zn	0.312	1						
Mn	0.055	0.737**	1					
Ni	0.435	0.126	0.179	1				
Pb	-0.372	-0.192	0.096	-0.317	1			
Fe	-0.091	0.538	0.436	0.068	0.350	1		
Cr	-0.029	0.498	0.593	0.190	-0.161	0.235	1	
Cu	-0.179	0.629*	0.869**	0.175	0.309	0.532	0.565	1

**Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)

Table 6.10: Pearson's Coefficient of Correlation at Vume during the processing stage

	Zn	Mn	Ni	Cu	Fe	Cd	Pb	Co	Cr
Zn	1								
Mn	0.907**	1							
Ni	0.849**	0.799**	1						
Cu	0.064	0.348	-0.144	1					
Fe	0.788*	0.615	0.474	0.124	1				
Cd	-0.599	-0.623	0.845**	0.249	-0.226	1			
Pb	0.279	0.507	0.171	0.839**	0.381	-0.056	1		
Co	-0.370	-0.195	-0.040	0.339	-0.492	0.130	0.295	1	
Cr	-0.239	-0.327	-0.213	-0.371	-0.254	0.385	-0.578	0.075	1

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)

6.11.4 Target Cancer Risk results for Mpraeso and Vume

The carcinogenic risk values for adults and children were calculated for metals of Co, Pb, and Cr in the extraction stage only using equations 5.6 and 5.7. The results for the target risk (TR) and cancer risk (CR) in both adults and child population are both presented in Table 6.11.

The USEPA and ATSDR considers the permissible predicted cancer risk for carcinogens (CR and TR) to be within the range of 1 in 1,000,000 (10^{-6}) to 1 in 10,000 (10^{-4}) (Farokhneshat *et al.*, 2016; US EPA, 2000, 2011). If a metals risk factor falls below 10^{-6} then it can be disregarded from further consideration as a metal of concern.

Table 6.11: Results for carcinogens of children and adults in Mpreaso and Vume

Town	Receptor	Pathway	TR			CR		
			Co	Pb	Cr	Co	Pb	Cr
Mpraeso	Adult	Inhalation	1.04E-04	7.29E-09	2.70E-04	1.04E-04	7.29E-09	2.70E-04
	Child		2.48E-10	2.52E-13	2.70E-05	3.02E-09	3.07E-12	6.71E-08
Vume	Adult	Inhalation	8.42E-06	3.53E-07	1.91E-04	4.18E-09	1.75E-10	9.47E-08
	Child		7.86E-07	3.29E-08	1.78E-05	1.95E-09	8.18E-11	4.42E-08

Note: Mn, Fe, Ni, As, Zn, Cu and Cd were below detection limits (BD)

The results of the TR factor for Cr in Mpraeso adult inhalation (2.70E-04), child inhalation (2.70E-05) and Vume adult inhalation (1.91E-04) and child inhalation (1.78E-05) were within the predicted permissible lifetime risk for carcinogen (Table 6.11). The cancer risk (CR) in Mpraeso adult inhalation for Co (1.04E-04) and Cr (2.70E-04) were also found to be within the predicted permissible lifetime risk for carcinogen. This is suggestive that Cr in Mpraeso and Vume for target risk and for cancer risk, Co and Cr are chemicals of concern during extraction stage of the pot’s life cycle. These metals could result to cancer due to carcinogenic daily lifetime exposure to Co and Cr through the inhalation pathway in the extraction stage (Table 6.11).

6.12 Non-Cancer risk

The non-cancer risk for both children and adults were calculated using equation 6.4 and 6.5 based on the RfD values of the metals of interest and EDIM values in table. Values of target hazard quotient (THQ) and hazard index (HI) that are less than 1 have no risk to the population but when values exceed 1 the population need to be concerned with potential non carcinogenic effects. Results of the THQ and HI of metals Co, Zn, Ni, Cu, Fe and Cr were all less than unity (1) an indication that there may not be health concerns of these metals.

Table 6.12: Results of non-carcinogens of adults and children in Mpreaso and Vume

			THQ						
Town	**Rece.**	**Patwy.**	**Co**	**Zn**	**Ni**	**Cu**	**Fe**	**Cr**	**HI**
Mpraeso	**Adult**	**Inhal..**	2.15E-16	7.31E-12	2.47E-12	1.39E-11	4.93E-09	2.56E-14	4.95E-09
	Child	**Dermal**	3.58E-13	9.90E-09	3.89E-09	1.71E-08	5.50E-06		5.53E-06
Vume	**Adult**	**Inhal.**	0.00E+00	5.01E-16	1.71E-11	5.77E-12	3.25E-11	1.15E-08	1.16E-08
	Child	**Dermal**	1.73E-12	4.78E-08	1.88E-08	8.25E-08	2.66E-05		2.67E-05

Note : Pb, As, Mn and Cd were below detection limits (BD)

6.13 Ingestion of metals at user stage

Metal's concentrations of interest included As, Cd, Cu, Pb, Zn, Cr, Fe, Mn, Ni and Co in the ground shito sauce for oral health risk assessment. Except Fe, Ni, Mn, and Co the remaining were found to be below detection limits and are not presented in Table 6.13. The mean concentration of metals Fe, Mn, Co Ni in ground shito sauce from Mpreso and Vume pots are represented in Table 6.13.

Table 6. 13 Mean concentrations of metals in ground shito sauce from pots.

Metal	**Mblack (mg/kg)**	**Mred (mg/kg)**	**Vred (mg/kg)**	**Recommended oral daily intake levels (mg/kg)**	**References**
Fe	238.41	174.93	461.67	(10-14) and 100	WHO 1994 and FAO
Mn	8.60	8.37	8.93	1-8.00	WHO 1994
Ni	47.37	25.10	53.07	(0.02- 4.0) and 2.3	FAO/WHO and EU guidelines
Co	116.03	116.17	117.03	1-5ug	Food and Nutrition Board, 2004

Note: Cr, Pb, As, Zn, Cu and Cd were below detection limits (BD)

Three pots which were Mpraeso black (Mblack), Mpraeso red (Mred) and Vume red (Vred) had different mean concentrations of metals in them. The concentrations of these metals by various agencies as recommendations for permissible limits were compared with the values obtained from this study. These metals were assessed as they leached from the clay pots during grinding of the vegetables into the shito sauce. Mean concentrations of the metals that leached and is consumed by humans (oral pathway) were compared with the recommended levels as in Table 6.13. The results showed that Fe in all 3 pots were of very high concentrations.

Iron is an essential mineral used in transporting oxygen and carbon dioxide in humans and for use in anemia conditions (Grupta, 2014). Yet high doses of Fe intake especially for children can cause poisoning deaths (Mekonnen, 2019). Doses as low as 60 mg/kg can also be fatal. Iron poisoning can cause many serious problems including stomach and intestinal distress, liver failure, dangerously low blood pressure, and death (WebMD, 2016). High intake of Fe is also assumed to be associated with increase in heart diseases (Hunnicutt *et al.*, 2014). Mn concentrations in all 3 pots were marginally above the recommended daily intakes. Excessive Mn tends to accumulate in the liver, pancreas, bone, kidney and brain, with the latter being the major target of Mn intoxication (Chen *et al.*, 2018).

Ni was found to be above the FAO/WHO and EU recommended values for daily intakes. Though Ni is vital in the growth and reproduction of human, in high quantities it could be deleterious to humans (ATSDR, 2005; Das, 2008), however, in the right quantities Ni acts as a cofactor for enzyme Urease (Ciurli et al., 1999; Merrouch et al., 2018). Co concentrations were very high and above the permissible limit. These high levels can be related with numerous health problems. Once cobalt enters your body, it is distributed into all tissues, but mainly into the liver, kidney, and bones (ASTDR, 2004; Leyssens et al., 2017).

6.13.1 Estimated Daily intake (EDIM*ing*)

The estimated daily intakes were calculated using the mean concentration in table 6.13 and equation (6.3) as already mentioned and values obtained presented in Table 6.14.

Table 6.14: Calculated EDIMing (mg/kg/day) of heavy metals?

Metal	**Mblack**	**Mred**	**Vred**
Fe	1.39 ± 0.94	1.02 ±0.6	2.69 ± 2.78
Mn	0.05 ± 0.01	0.05 ± 0.02	0.05 ± 0.01
Ni	0.28 ± 0.18	0.15± 0.22	0.31± 0.11
Co	0.68 ± 0.02	0.68 ± 0.04	0.68± 0.06

Note: Cr, Pb, As, Zn, Cu and Cd were below detection limits (BD)

The estimated daily intake for oral pathway (EDIM*ing*) values were compared with their respective reference doses and conclusion were made. The EDIM*ing* for Fe in this study of all the pot types recording values greater than (1.39 ± 0.94, 1.02 ± 0.6 and 2.69 ± 2.78) RfD of Fe with a low risk as presented in Table 6.14. Mn, Ni and Co all had EDIM values which were equal to or less than their RfD so their risk to the expose population is at the minimum state. Prolonged period of clay grinding pots for cooking and serving of food may be a source of excessive Fe introduction into human systemic circulation. Fe is good for the growth and development of the human body however Fe accumulation in critical organs such as liver, heart and pancreas may be a source of organ dysfunction owing to the generation of oxidative stress (Steinbicker & Muckenthaler, 2013). Systemic iron levels must therefore be tightly balanced.

6.14 Ingested health Risk assessment

Cancer risk and non-cancer risk models for oral pathway was estimated using the EDIM*ing* values which was used in estimating Target Cancer Risk (TR), Target Hazard Quotient

(THQ) and Hazard Index in humans exposed to these chemicals in polluted media as previously discussed using the equations.

6.15 Cancer risk

Cancer risks possibility through intake of some heavy metals like As, Cd and Pb that may be carcinogenic was found to be below detection levels. Other metals like Fe, Mn, Co and Ni that were present did not have any established cancer slope factor (CSF) values because these metals are purported not to cause any carcinogenic effects (Javed *et al.*, 2016; US EPA, 2012). Due to this, the incremental lifetime cancer risk (ILCR) calculations were exempted for these metals except Ni. The CR of Ni was found to be 0.476, 0.255 and 0.527 for Mblack, Mred and Vred respectively. These values are higher than the tolerable level (1E-06 to 1E-04). Ni therefore appears to be a major contaminant with the potential to cause cancer through ingestion (oral pathway) as its exposure route.

6.15.1 Target cancer risk (TR)

Target Cancer risk (TR) value of only the intake of Ni was calculated to show its carcinogenic risk. TR of nickel (Ni) was calculated and found to be 958.5, 513.5 and 1061.2 for Mblack, Mred and Vred respectively. These are higher than the acceptable regulatory cancer risk values as previously stated. The acute toxicity of nickel has immediate symptoms which include headache, vertigo, nausea, vomiting, insomnia and irritability which usually last a few hours (Duda-Chodak *et al.*, 2008). The delayed symptoms that appear include tightness of the chest, nonproductive cough, dyspnea, cyanosis, tachycardia, palpitations, sweating, visual disturbances, vertigo among others (Das *et al.*, 2008). Ni helps in the absorption of Fe from the intestines, but chronic exposure of Ni is connected with increased risk of lung cancer, cardiovascular disease, neurological deficits, developmental deficits in childhood, and high blood pressure (ATSDR, 2005)

6.16 Non-cancer risk

6.16.1. Target hazard quotient (THQ)

In calculating the THQ for the oral pathway equation 6.4 was employed and the result presented in Table 6.15. The index was calculated based on the RfD of the metals specifically Fe, Mn, Ni and Co for all pots. The Hazard Index (HI) of the metals which is the summation of the THQ is also presented in Table 6.15. The THQ values should not be greater than 1. But if it does, it implies the expose population may be at risk of the metal's toxicity and vice versa. The results in Table 6.15 shows that the values obtained ranged between 0.0004 to 0.0384mg/kg for Mblack pot, 0.0004 to 0.0146mg/kg for Mred and 0.0004 to 0.0384mg/kg for Vred. These ranges are all less than 1 which indicate that there may not be adverse health concerns for these metals.

Table 6.15: The target hazard quotient

Metal	**THQ (mg/kg)**			
	Mblack	**Mred**	**Vred**	**HI**
Fe	0.0198	0.0146	0.0384	0.0729
Mn	0.0004	0.0004	0.0004	0.0011
Ni	0.0014	0.0008	0.0016	0.0037
Co	0.0034	0.0034	0.0034	0.0102
Max	0.0384	0.0146	0.0384	
Min	0.0004	0.0004	0.0004	

Note: Cr, Pb, As, Zn, Cu and Cd were below detection limits (BD)

The results of the HI value should also not exceed 1, else it is an indication of a potential non carcinogenic risks to exposed population and vice versa. The HI ranged from 0.0011 to 0.0729. From the results of the HI, the exposed population may not be at risk.

6.17 Statistical analysis using ANOVA.

In finding relationship between the metals and the pot types, the one-way ANOVA test of significance was applied to study this variance. A $p<0.05$ or lower was measured as significant.

6.17.1 Iron (Fe)

The interaction between pots only, between metals only and between metals and pots only indicated significantly high mean concentration value for Fe in all scenarios. Vume red pots (Vred) recorded the highest Fe concentration of 461.67mg/kg followed by Mpraeso black pot M-black (238.4 mg/kg) and then Mpraeso red pot (174.93 mg/kg). Comparison between metals also revealed that Fe had huge mean concentration in all scenarios. Fe levels among the pots were significantly different from each other with high Fe concentration in Vred and low concentration in Mred as in table 6.16 in Appendix C. The variation between metals and pot types were highly significant in all pots at 0.05 level using oneway Tukey HSD ANOVA test and when the mean concentration values were compared with the recommended limits, they were significantly above them (Table 6.16 Appendix C).

6.17.2 Mangenese

The trend in the mean concentration of Mn metal contents from ground shito sauce was Vred > Mblack >Mred with values of 8.9mg/kg, 8.6mg/kg and 8.3 mg/kg respectively as presented in Table 6.17 in Appendix C. The concentration values were low with non-significant differences however the variations for manganese content in shito from Mred and Vred as indicated in the ANOVA test had a significant mean difference at a 0.05 level. Mn also indicated overall lower mean concentration records as compared to Fe, Co and Ni as (Table 6.17 Appendix C).

6.17.3 Nickel

The mean values for nickel is presented in Table 6.18. The results show high values of nickel in Vred pot (53.07 mg/kg) followed by Mblack pot (47.37 mg/kg) and Mred pot (25.10 mg/kg). The variations for nickel content had significant mean difference among all the pots except Mblack and Vred at a 0.05 level as presented in the ANOVA test. Though Ni's mean concentration was higher than Mn it is lower than Fe and Co in all the sauce from the 3 pots (Table 6.18 Appendix C).

6.17.4 Cobalt

The Co results showed high mean concentrations in shito as Vred (117.03 mg/kg) > Mred (116.17 mg/kg) > Mblack (116.03 mg/kg) as presented in Table 6.19 in Appendix C). The mean values showed a non-significant difference between them. However, the Tukey test showed the mean difference in concentrations of Co between the pot type to be highly significant at 0.05 level in all the pots.

6.18 Conclusion

With the observed values of metals in the grinding pot Fe and Cd concentrations in Vume were high at the extraction stage of the pot's life cycle. Fe had high concentrations in Mpraeso and Cd was below detection level. In the processing, Ni and Cd concentrations exceeded the recommended levels in Vume only in the ingestion pathway. The risk assessments were within safe limits except Ni. Ingestion results of the study confirm that unglazed pots do not have significant health risk associated with food consumption and storage. Again, human contact during processing and inhalation during extraction over a long period will affect their health.

CHAPTER SEVEN

HEALTH AND ENVIRONMENTAL SUSTAINABILITY OF THE TRADITIONAL POTTERY INDUSTRY.

7.0 Introduction

Every product has a life and all activities in a product's life results in some environmental impacts due to consumption of resources and emission of substances into the environment. There is a growing concern on the environment with respect to resource depletion and environmental pollution and various governments across the globe are putting mitigation measures in place to safeguard the ecosystem. Here in Ghana, there has been only marginal success and the environmental sustainability is a great question.

The Traditional pottery manufacturing set up has been with us since time immemorial resulting in massive land degradation and emissions of toxic air pollutants especially in areas where this cottage industry is concentrated. The materials for the pottery are produced from the existing natural resources through artisan mining since traditional times. This has affected the environment due to continuous exploration and depletion of natural resources.

Many man-made ponds have been created coupled with heaps of clay wastes and several uncultivable tracts of lands uncultivable. Moreover, various toxic gases particularly carbon dioxide, oxides of nitrogen, oxides of Sulphur, etc. and suspended particulate matter are constantly emitted to the atmosphere during the processing and firing of the pots. These toxicant gases contaminate air, water, soil, flora and fauna and ultimately impact human health.

This has been the situation all over the country where this industry is operated, thus the two study areas chosen, Mpraeso and Vume are case in point. Yet, there is a dearth of studies on the environmental and health sustainability of the pottery industry in Ghana. Therefore, this work considered for the first-time studies into the sustainability of pottery industry with reference to the environment and health of the indigenes involved and the community, as there are eventual consequences on the ecosystem.

7.1 Methods and Materials

7.2 Qualitative data collection approach (Research design)

The study employed the descriptive-analytic method as already discussed in Chapter Four to define the environment, some occupational hazards and health impacts of the industry. The descriptive technique defines the state of the environment. Health and environmental data were obtained from appropriate institutions and relevant respondents contacted. Through the descriptive method the potters and respondents professed the state of their environment and health**.** Relevant information and relationship between environment and health and their influences on each other was identified. The study covered a population within the Mpraeso district in the Eastern region and Vume in the Volta region as previously discussed.

7.2.1. Sampling method and sample size

The sampling method and sample size used are the same as Chapter Four. Environmental and health institutions within the municipality were questioned besides the 163 potters who were also asked about the environment.

7.2.2 Data collection and survey instrument

In-depth interview guide (in addition to the 163 questionnaires), and unstructured interviews, were administered to the Assembly, the Environment and Sanitation Officer, the EPA Officer of Kwahu South District Assembly, the Atibie Health Directorate and some affected schools in the municipality. The overview of the in-depth interview guide is presented in Table 7.1, 7.2 and 7.3, respectively. Additionally, potters also gave their opinion on the environment, how they manage waste from their pottery activities as seen in Table 7.1 (Details of the in-depth interview guide administered, Appendix D2).

Table 7. 1 Overview of in depth interview guide for potters

Data group	**Description**
Environmental impacts	Environmental impacts of raw material extraction, potters' level of education on environment, unclaimed pits emissions and firing
Waste management	Waste management and disposal
Occupational hazards and health care	Hours of work and rest, occupational hazards, health care, use of PPE's, postural discomfort and chronic diseases.

Table 7. 2 Overview of in-depth interview guide for health directorate

Data group	Description
General health	Common diseases in out patients department, occupation of patients,
Dust related diseases	Common reports on dust related diseases, possible causes
Heat related diseases	Major complains of heat related diseases, prevalent types, complains resulting from excessive heat
Ergonomic related diseases	diseases caused by repeated actions of any kind for a period, patient with specific musculoskeletal disorders of any kind,

The Health Directorate in Atibie in Mpraeso and Sogakope in Vume were contacted and an overview of the in-depth interview guide for health is presented in table 7.2. The Environmental protection Agency (EPA), the Environment and Sanitation office and the

District Assembly were also contacted with a separate interview guide of which an overview is in table 7.3.

Table 7. 3 Overview of in-depth interview guide for environmental related institution

Data group	Description
Environmental related institution	Impact of craft on environment, role of institution on craft sustainability, regulations on craft activity, role of institution on the craft, concerns of citizenry about craft to the institution
Economic related institution	Institution's knowledge on the scale of production, income returns of craft, revenue collection from potters

7.3 Data analysis

The data obtained was analysed by SPSS.

7.4 Results and Discussion

7.5 Environmental impacts of raw material extraction in Mpraeso.

All potters who participated indicated clay for pottery is obtained from neighbouring towns and satellite villages including Oframase, Amanfro, Jejeti, Atibie, Nkwakwa and Ampekrom during dry season (December – January) by open pit mining method with rudimentary tools, as shown in Plate 7.1. Extraction of raw materials in the rainy season is avoided due to waterlogged conditions of the sites and possible collapse of pits on potters and clay harvesters. At the extraction sites harvesting was done using open pit mining method with the use of rudimentary tools such as the axe as seen in Plate 7.1 (a).

(a) Mining clay with simple tools (b) Un-reclaimed pit

Plate 7. 1 Mining of clay and its environmental impacts

Respondents further revealed that clay harvesting destroys the general aesthetic view of the environment, Plate 7.1 (b). In general, respondents had limited knowledge on the numerous effects that the activities have on the environment.

Overall, about 42% of respondents were of the view that almost 20-40 uncovered pits found on an acre of land, become death trap for humans and animals who are not familiar with the terrain. Many of their colleagues have died because of collapse of pits. Some respondents also cited some clay harvesting pits were close to water bodies and affect the turbidity of the water.

7.6 Environmental impacts of raw material extraction in Vume

All respondents in Vume, explained that the extraction of clay is done in a wetland of the Volta Lake by potters and clay harvesters' Plate 7.2 (a). Others walk about 5km from Vume settlements along the Accra Road to win clay around the Afafale tree and individual lands for clay harvesting. Like Mpraeso, all respondents confirmed no reclaiming of harvested site after their activities (Plate 7.2 (b)**)** posing environmental and public health threat; this compromises the aesthetic view of the community.

(a) Extraction site in a wetland in Vume (b) Un-reclaimed pit in Vume

Plate 7. 2 Clay extraction in Vume.

Moreover, potters and clay harvesters had little knowledge on these impacts on the environment apart from the destruction of the aesthetic environment. The bottom-line of all these is education about the society's environment. This was evident in their expression of disagreement of their activity impacting the aquatic ecosystem.

7.7 Firing and Emissions in Mpraeso

Potters expressed concern of the firing stage of the production cycle, particularly about the heat and emission of gases produced (Plates 7.3 (a) and 7.3 (b) respectively).

heat during firing in Mpraeso (b) Emissions in Mpraeso

Plate 7. 3 Firing stage of production cycle.

In Mpraeso, pregnant women were seen enduring higher temperatures than is expected of them (Plate 7.4 (a)) and female children actively participated in pottery to support their mothers earn a livelihood (Plate 7.4 (b)).

(a) higher temperatures borne by women (b) Child participating to support Mother

Plate 7. 4 High temperatures and smoke emission during firing of pots.

Besides respondents (51.4%) complained of other health issues such as general fatigue during the firing

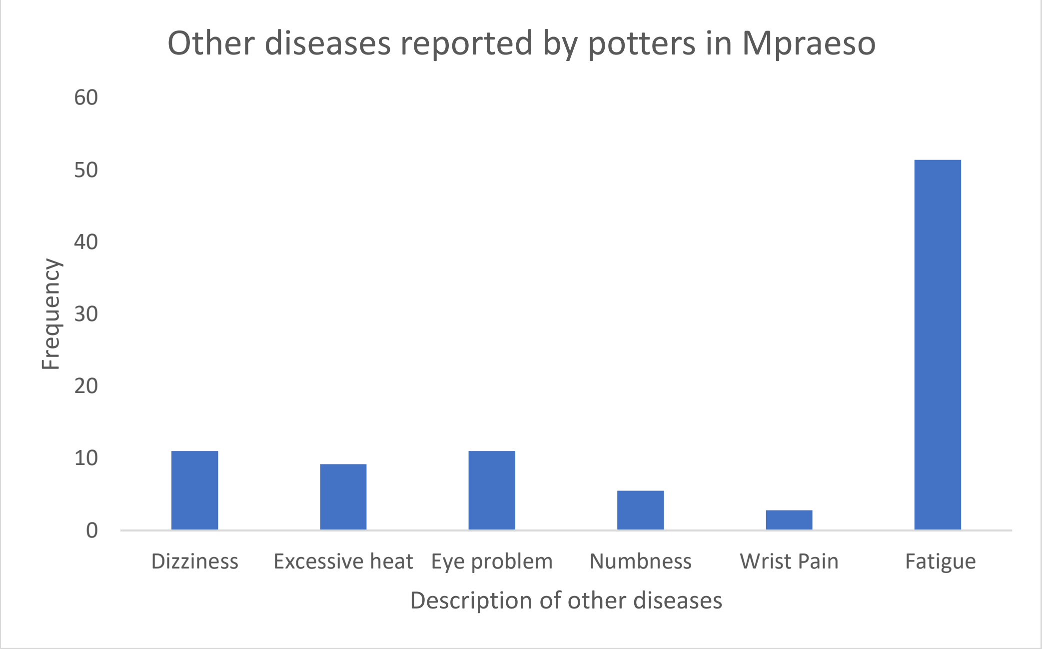


Figure 7. 1 Bar chart showing other diseases potters complained of during firing

while 11% made mention of regular eye problems and dizziness as illustrated in Figure 7.1. General weakness, headaches and numbness of the hands and feet amidst numerous other heat exhaustion symptoms were also listed by the respondents.

7.8 Firing and Emissions in Vume

All the respondents in Vume described the firing stage of pottery as a desperate task. They added, the use of kilns in firing (plate 7.5 (a)) reduces inhalation of emissions from the surroundings. However, emission inhalation is highest during pre-heating of the pots prior to bisque firing. The kilns being high in their design (plate 7.5 (b)), allow the firing emissions to rise through the kilns into the skies, dispersing into the environment; thus saving potters from inhalation of the concentrated emissions.

(a) Vume kiln in use

(b) Vume kiln

Plate 7. 5 Kilns used during firing in Vume.

Like Mpraeso potters also suffered other diseases like general fatigue (57.4%), wrist pain (22.2%) and excessive heat (16.7%) related diseases Figure 7.2.

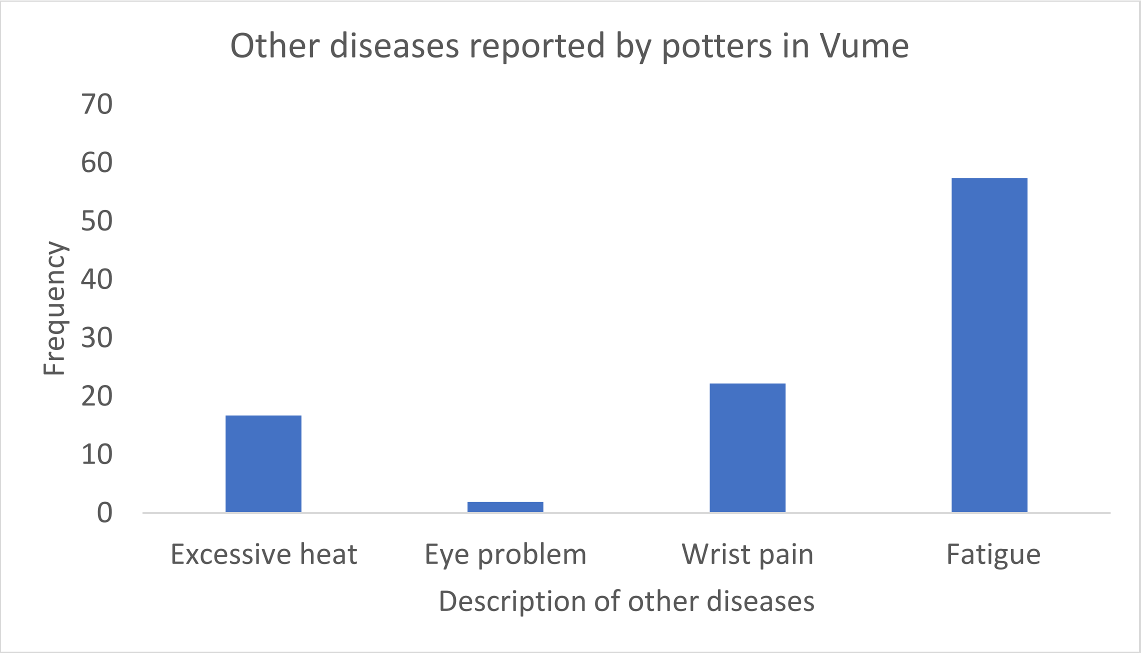


Figure 7. 2 Bar chart showing other diseases complained by potters during firing.

7.9 Waste Management in Mpraeso and Vume

Waste disposal in the communities is of less importance according to potters both solid and liquid wastes generated are negligible. Waste obtained in the form of cracked pots during firing are recycled by pounding them as grog and adding them to the production cycle again. Slurries of the clay and other used water are so negligible during production such that they are hardly disposed of into the environment.

7.10 Occupational hazards in Mpraeso and Vume

7.10.1 Ergonomics

Ergonomic related diseases such as rheumatism, joint pains and arthritis are hazards that respondent in both Mpraeso and Vume experience. From Figure 7.3 there is a clear indication of 49.5% respondents in the industry had waist pains, 7.3% and 5.5% had back pain and neck pains respectively; likewise Vume the main problem was waist pain, Figure 7.4.

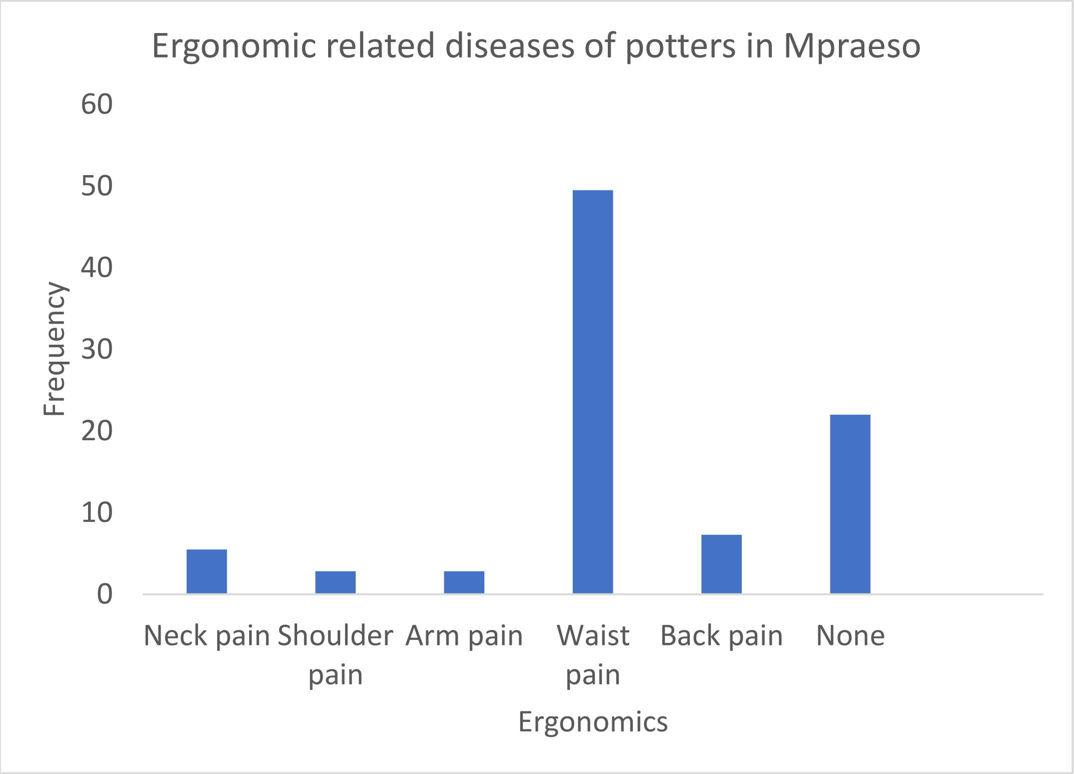


Figure 7. 3. Bar chart showing ergonomic related diseases of potters in Mpraeso.

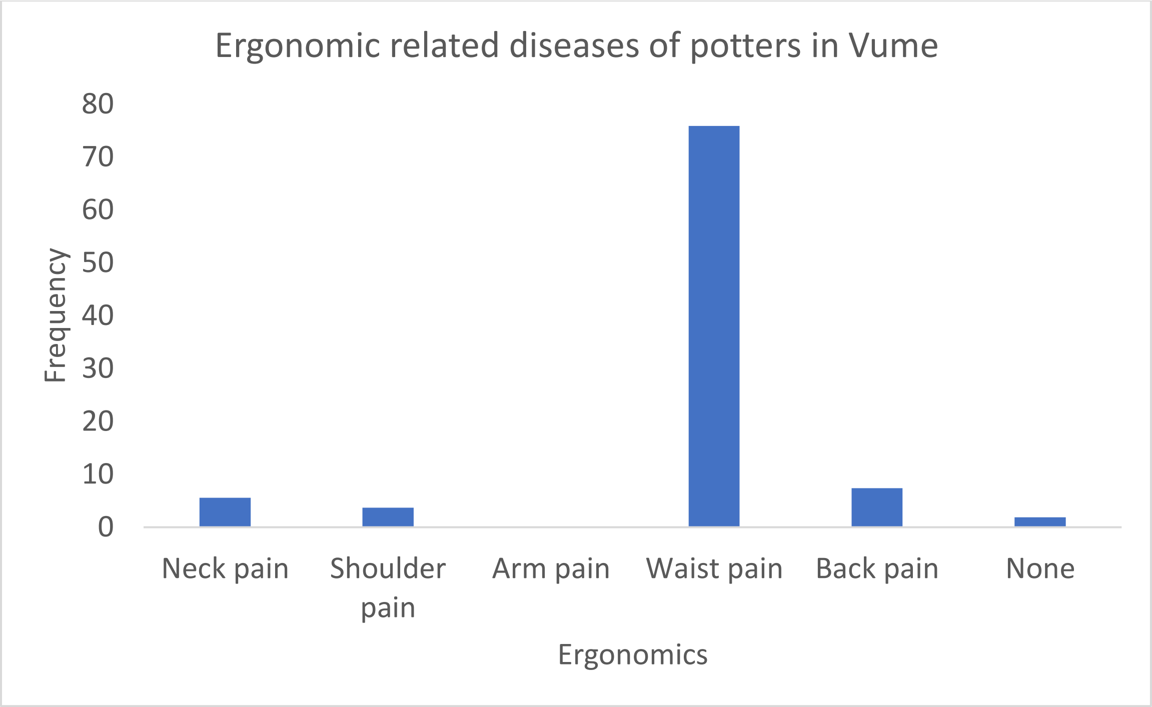


Figure 7. 4 Bar chart showing ergonomic related diseases of potters in Vume.

7.10.2 Postural discomfort in Mpraeso and Vume

The postural discomfort of respondents in both communities was due to lack of appropriate workstation as seen in Plate 7.6 (a) Mpraeso and 7.6 (b) Vume. This agreed with the National Institute for Occupational Safety and Health (NIOSH) in (2013).

(a) Postural discomfort in Mpraeso (b) Postural dicomfort in Vume.

Plate 7. 6 Postural discomfort of potters in Mpraeso and Vume

7.11 Health of Mpraeso and Vume potters in the pottery industry

Mpraeso potters (57.8%) attested to having numerous medicals complains resulting in their frequent visitation to the health facility Figure7.5.

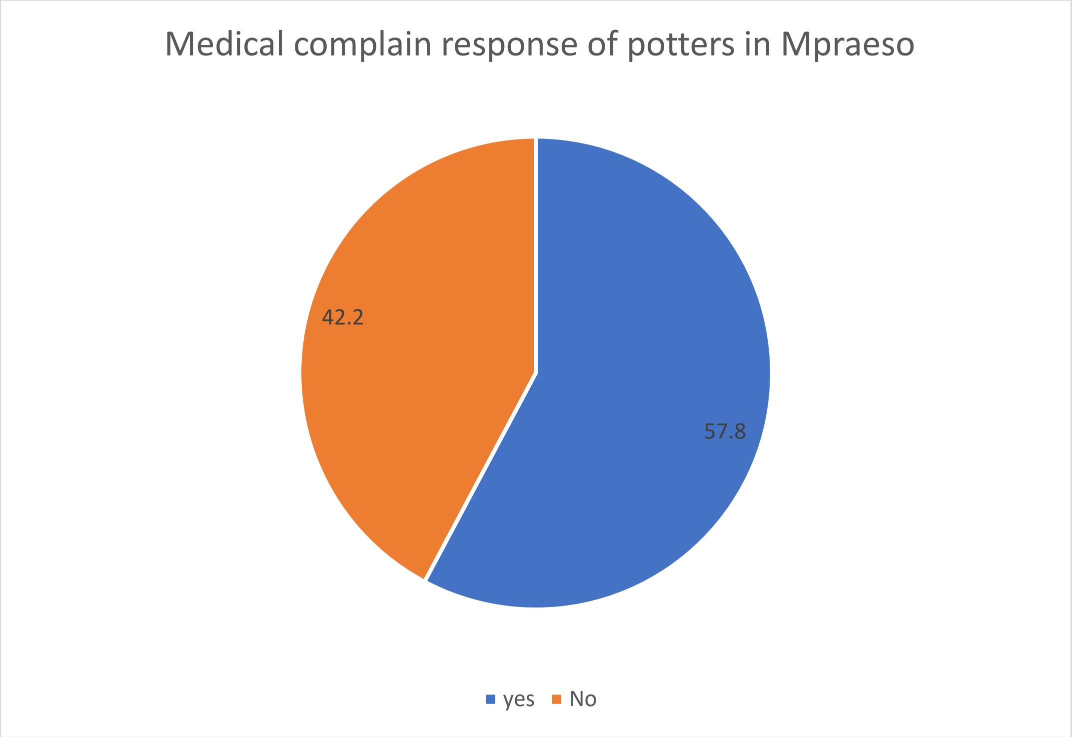


Figure 7. 5 Pie chart showing medical complain response in Mpraeso

Records from the Atibie General Hospital near Mpraeso demonstrated RTI, malaria, ergonomics and heat related diseases were among the ten most common diseases reported, Figure 7.6. The Health Superintendent attributed this to clay mining within Atibie and its environs encompassing Mpraeso. Infections of silicosis were due to inhalation of free silica. There is also the inhalation of gases during the open- firing of the pots in Mpraeso.

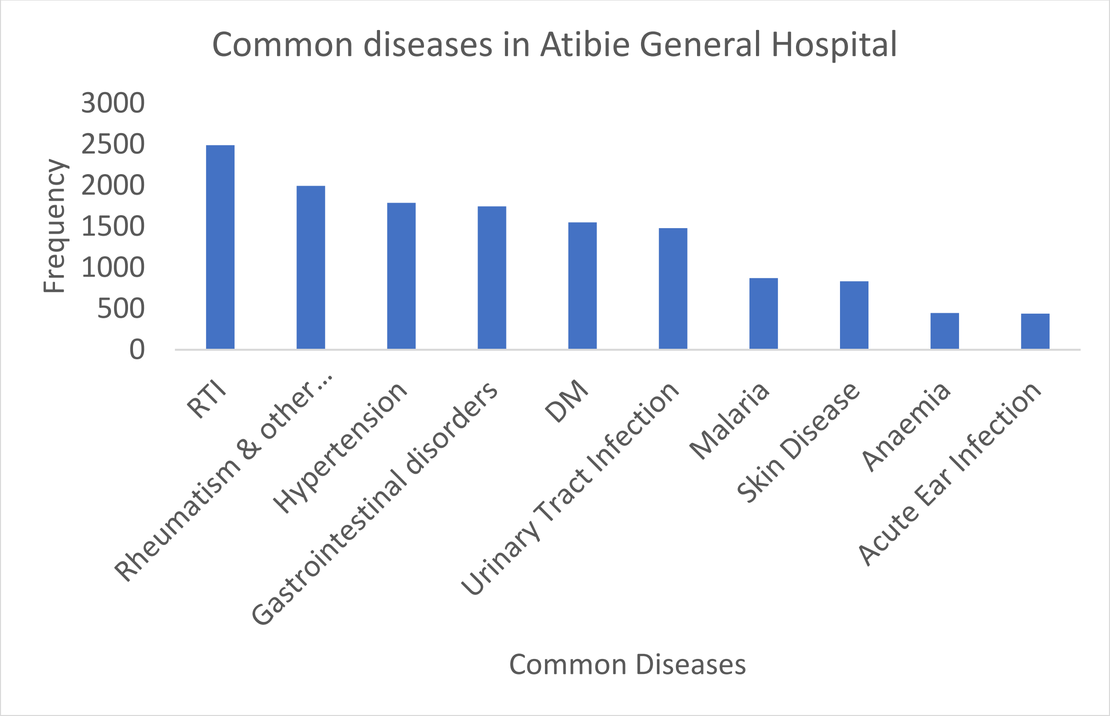


Figure 7. 6 Bar chart showing top ten common diseases in Atibie General Hospital

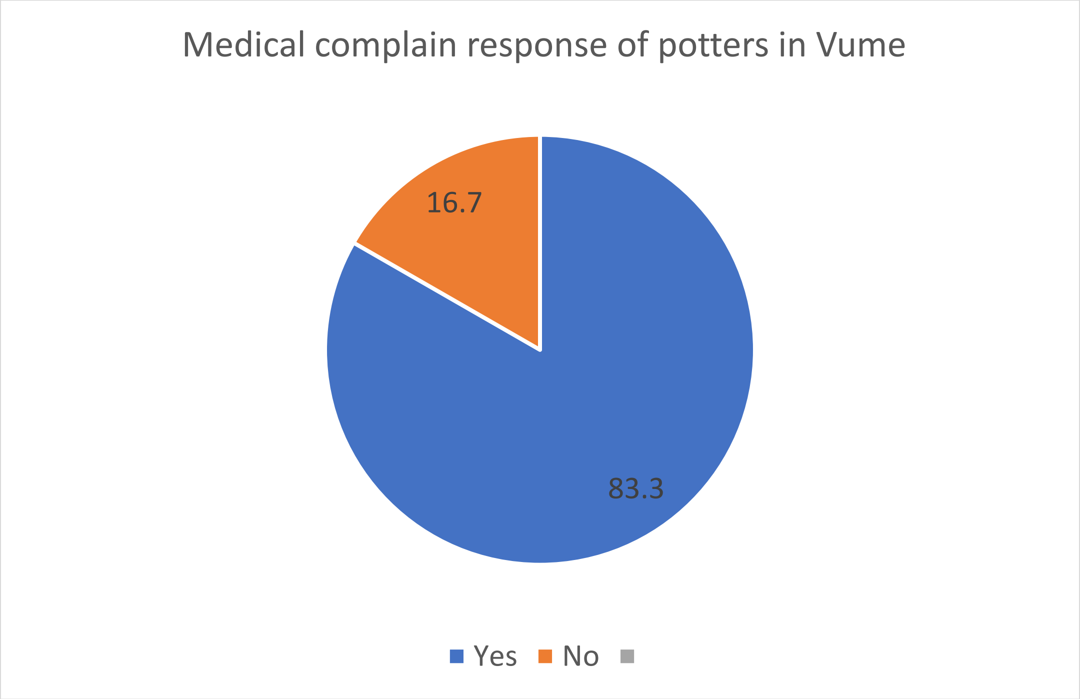


Figure 7. 7 Pie chart showing medical complain response in Vume

On the contrary only 83.3% had medical complains, Figure 7.7. this was gathered from personal/in-depth interviews with potters and health experts in Sogakope.

In Vume Respiratory Tract Infection (RTI) diseases were not the highest complained of unlike Mpraeso. This could be the result of the use of the kiln method during the firing of pot. Besides malaria was identified as a prevalent disease among potters. They treat at pharmacy or rely on traditional treatments for cure.

7.11.1 Hours of work and rest

In the case of work and rest in both communities, majority of potters rested once in between the working day Figure 7.8. (Mpraeso) and Figure 7.9 (Vume)

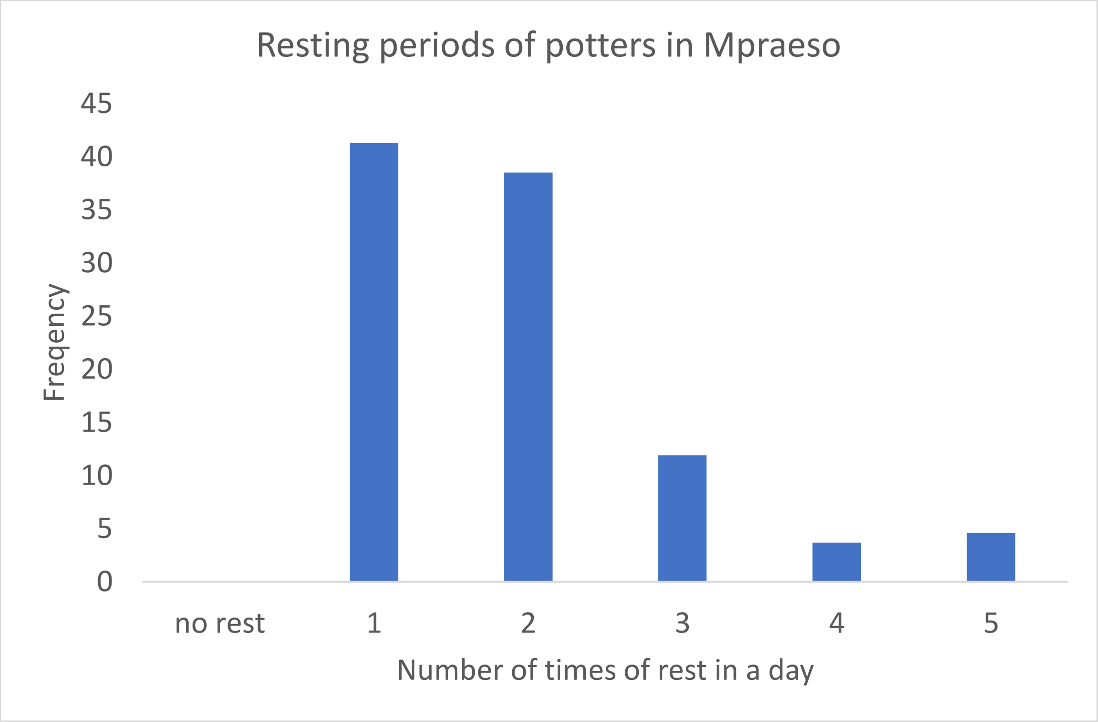


Figure 7. 8. Resting periods of Mpraeso potters in a day

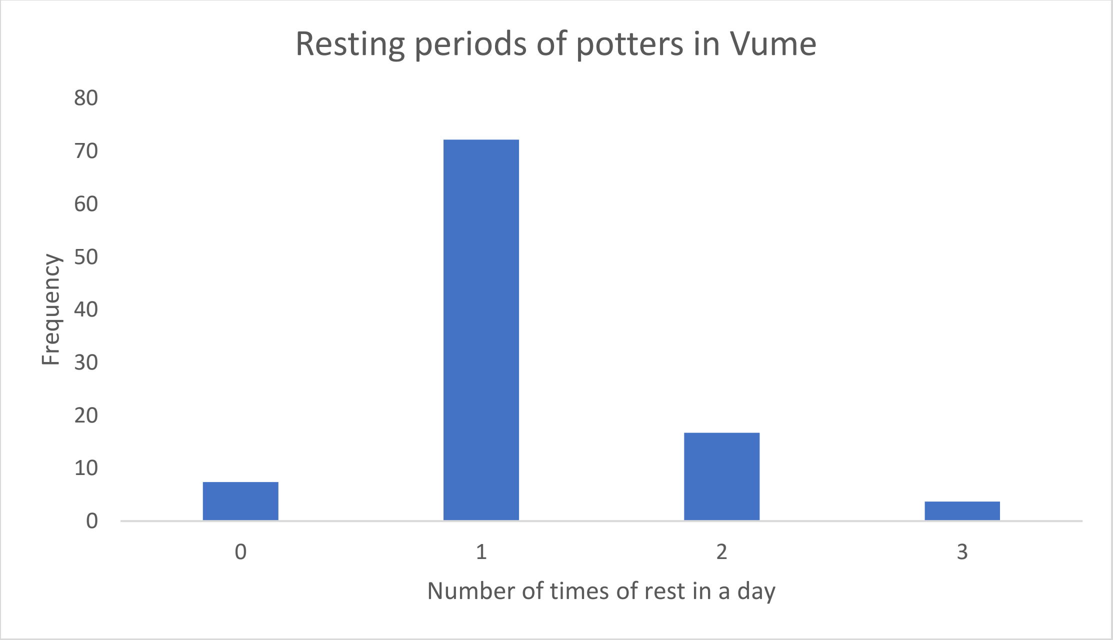


Figure 7. 9. Resting periods of Vume potters in a day

7.11.2 Use of personal protective equipment (PPE)

In all the study areas, potters confessed not using any protective gear during working. Such gears interfere with their work and would prefer not to wear them.

7.12 Energy consumption in the pottery industry in Mpraeso and Vume.

All respondents iterated previously they use to bring dried wood from branches and trunks of trees to serve as sources of energy for firing pots. However, in recent times fuel wood for firing of pots are transported after harvesting unsustainably from neighboring villages in Kia trucks for them to buy. All respondents in Mpraeso and Vume use wood fuels which is a traditional energy source in which bulk energy is supplied to the industry for all the firing of grinding pots as indicated in Plate 7.7 (a) Mpraeso and 7.7 (b) Vume respectively

(a) Mpraeso (b) Vume

Plate 7. 7 Fuel wood used for firing in Mpraeso and Vume

The fuel wood used in both communities is dependent on the number of pots as illustrated in Table 7.4

Table 7. 4 Number of pots and corresponding fuelwoods used in firing.

Number of pots	Length of wood		Number of woods used
	Short	Long	
102	110	60	170
130	150	66	216
143	107	131	238
43	40	35	75
26	26	19	45
17	15	15	30
9	8	7	15

Moreover, potters confirmed that no officials from any of the governmental institutions nor the Assembly had visited to educate them about the environmental problems resulting from their activities.

7.13 Statistical results

The period of work in a day and the number of rest the potter had within the day was at a 5% level of significance.at Mpraeso (p-value - 0.0066) and Vume (p-value - 0.000006) respectively. There was not much difference between those with medical complaints over long years of work and those with no medical complaints at Mpraeso and vice-versa at Vume. At 5% level of significance the years of practice could not affect the health status of Mpraeso potters (Appendix D) while it was significant at Vume $X^2 = 24.773$, $P = 0.00588$.

Ergonomics diseases of waist pain and back pain $(\chi^2 = 20.899, p-value = 0.0039)$ and years of practice $(\chi^2 = 280.512, p-value = 0.0305)$ have significant relationship Therefore, the more you work as a potter the more prone you are to ergonomic diseases.

Moreover, the number of years of work and the past medical records of a potter have a significant relationship with the chronic diseases.

7.14 Institutional roles and responsibilities

7.14.1 Environment and Sanitation office in Mpraeso and Vume

The Environment and Sanitation office in Mpraeso agreed that the activities of the traditional potters were of great concern to the Assembly as there are several impacts on the environment. The emission of gases and smoke as the major environmental nuisance apart from the destruction of the aesthetic environment. The office indicated efforts being made together with the Assembly to agree on how to put all potters under one umbrella to operate under one hub which will safeguard the environment a little.

Additionally, discussions are ongoing to regularize the industry to bring sanity into the environment to avoid such conflicts between heads of elementary schools and the pottery industry. The schools are constantly faced with smoke and gaseous emissions full of particles. Further to resolve many of the issues, the office felt that the government initiative of the one district one factory could help in amalgamating the industry under one umbrella to make governance and supervision easier.

The office finally emphasized they do not have the mandate to suppress gases rather the Environmental Protection Agency (EPA) is responsible. The office agreed that this inspection is not singled out to potters' but they are included owing to the absence of laws and policies specifically used in guiding the activities of the potters currently. Laws or policies with regards to insanitary activities could be applied to the industry by the office. Hence the Public Health Act 851 environmental sanitation-noxious trade was the most applied law of which the environment and sanitation department used to prosecute offenders. Besides the economic contribution of pottery in the society cannot be overlooked as activities surrounding the industry must be done in a sustainable manner. Though 2018 environmental action plan was used, issues of environment and sanitation must be intensified through the local media and durbars to educate the public.

The office also acknowledged that their outfit alone cannot regulate the activities of the potters and mentioned the support of the Assembly, the Environmental Protection Agency and the community development among others as their partners in the field.

Meanwhile EPA officials saw this activity as core directive of the Assembly. The EPA's mandate is to assess the environment which they had not involved themselves with the local pottery production. They were also not aware of any policy guiding the activities of these potters. The unregularized nature of pottery activities thwarts the enforcement of the small-scale mining law LI 703 216 and the Public Health Act 851. The situation was not different from officials of the institution's office in Vume

7.14.2 Environmental protection Agency in Mpraeso and Vume

In an interaction with the Environmental Protection Agency (EPA) office in Mpraeso, it agreed activities of potters were one that had impacts on the environment. The office mentioned destruction of land, water and vegetation cover as some impacts the activities had on the environment. Environmental education and meeting with community-based organizations were measures used to curb the environmental pollution.

Lack of database on the traditional pottery activities is a major barrier which limited the institutions' role in sustainability advocacy. Regularization of the industry by government will be a needed enabler to sustainability. Acknowledging the industrious scheme of pottery, the office pledged a more active attitude as regulators.

7.14.3 Environmental Policies and Regulations

The institutions responsible for environment and sanitation showed little to no interest in Environmental and Health impact of the potters. Environmental Protection Agency (EPA) and the Minerals Commission had not properly regulated Clay mining in Ghana hence no supervision and monitoring making clay harvesters to pollute the environment with impunity. The existence of numerous laws like the Environmental Sanitation Noxious trade, the Environmental Protection Agency Act of 1994, (Act 490), the Minerals and Mining act LI:703, 216 and the National land use policy, 1999) and policies could be used in protecting the environment, ensure better management of natural resources and reclaim all destroyed lands.

Despite all these laws, reclamation of lands had never been done and this had increased the vulnerability of agricultural lands as the top fertile soil richer in N, P, K and other micronutrient elements are excavated out (Sheoran *et al*., 2010). If law enforcement agencies could ensure that lands were reclaimed, food security could increase as farmlands could be replenished and fodder patches for grazing farm animals could be available.

The EPA of Ghana in 2008 also collaborated with the United States Agency for International Development (USAID), the United States Environmental Protection Agency (USEPA) and the United Nations Environment Programme (UNEP) to set up an air quality-monitoring network in Ghana with the pilot project in Accra. The objective of the project was to characterize the serious nature of air pollution problems and to make recommendations for the development of air quality management for Ghana. Ambient air quality assessment prepared by the Environmental Protection Agency (EPA-Ghana) stated that, reference should be made according to regulation 20 of the National Environmental Standards. Available policies are sufficient to streamline activities of potters if only the afore mentioned stakeholders would be more responsible.

7.15 Discussion

Mining sores fish and other organisms that interact in complex ways and play crucial roles in nutrient turnover and energy processing. In Vume, mining of clay is done in lake Volta in which aquatic ecosystems are interconnected by flow of water downstream as nutrients are received by fishes and other organisms. The lake served as spawning and rearing sites for fish and amphibians, breeding locations for many birds, and locations for food chain support for dozens of mammal species. Mining interrupted activities occurring within the lake’s ecosystem. Several impacts through processes such as erosion, sinkholes and biodiversity lost occurred on the environment. Fodder for animals to graze were challenged and agricultural lands were contested.

If society engaged in these activities were to be ecologically knowledgeable, more measure would have been put in place in minimising the destruction of the environment which they depended on. One such measure will be that the pits will be reclaimed after digging. Though aspects of the society's taboos regulate the garnering of the resources which are indigenous ways of sustaining the environment, there isn't any taboo that ensures the reclamation of these pits after clay harvesting is done.

During firing, heat exhaustion could also trigger other diseases like skin diseases, high blood pressure, etc. as researchers have linked certain heart, kidney and liver damage to long term heat exposure as reported in (NOISH, 2013). The report encouraged pregnant women to work within a heat temperature of 39-39.5^{0}C but during the field work pregnant women were seen enduring higher temperatures than is expected of them and female children were also seen enduring these temperatures and inhaling emission in Mpraeso. Apart from children seen actively participating in pottery activities and been exposed to all the numerous occupational hazards associated with the craft others whose interest were in education suffered from the inhalation of emission while in school and learning. This was the case in Masada School in Mpraeso and this fostered the interaction between all stakeholders in the district to solve the problem amicably.

The overuse of the wood resource can be threatening to the environment. In Mpraeso, energy-efficiency aspects of their open-firing method is an issue potters recognize and wished for better interventions and technologies to reduce their health and environmental issues. The potters and the citizenry are exposed to air pollution and heat in a form of smoke each time firing of pots are done. Apart from the strong correlation between the combustion emission of fuelwood and respiratory tract infections, environmental and climate changes are definitely affected too. The potentially significant implication of fuelwood combustion emission in the pottery industry is relatively a new issue in Ghana that is yet to gain greater attention for climate change.

The smoke emitted in a form of tiny particulates are toxic and so high with the possibility of these toxic elements exceeding recommended levels of World Health Organization (WHO) and other environmental agencies around the world (WHO, 2010). Climate change advocates seldom address fuelwood energy use in traditional pottery industry but with current awareness creation it may be a considered issue. Though fuelwood is a renewable energy, harvesting them in an unsustainable manner can lead to pressures on the community's forestry resources which will have implications on local and global environments.

7.16 Conclusion

In both communities no land reclamation effort is made on the pits by the community members or the authorities responsible for their activities. Public health diseases can be minimised through education and with regards to malaria, fumigation, medications and malaria control activities can be introduced to control this significantly. In Vume where the wetlands are mined vector control activities can enhance the health status of the community.

Through effective management systems, better government interventions and quality ecological education on global issues related to the environment such as; global warming, carbon emission and deforestation can be efficiently reduced and recovered. Policy makers must develop effective policies and programs to address this problem. The institutions especially EPA and minerals commission needs to attend to the industry and enforce all applicable laws of the environment to protect and ensure a sustainable use of our resources.

CHAPTER EIGHT

THE LIFE CYCLE ASSESSMENT (LCA)

8.0 Introduction

The manufacturing process of earthenware pots from raw materials to finish product generates various environmental hazards to the earth and mankind. In Ghana, the history of pottery dates to the Palaeozoic era (Anquandah, 1998). The grinding pot is a product of pottery which is an important utensil in most Ghanaian homes. Mpraeso and Vume are communities in Ghana noted to produce these earthenwares. Ghana's pottery sector is characterised by traditional firing technologies, high dependency on human labour and low modernisation rate.

Research conducted into the small-scale production of ceramics shows heavy pollution from the sector contributing significantly towards global warming, ozone depletion, acidification, and eutrophication while medium to large sectors contribute lesser amounts (Muthukannan et al 2018). The reason is that small-scale industries are dominated by limited technology, equipment, financial, technical, and managerial capacity as well as the raw material clay and fuelwood. The use of modern machinery is therefore noted to reduce environmental impacts.

The grinding pots are made of clays, additives, and water. Mining of the clays and other related raw materials like additives, water, and fuel wood is extremely labour intensive as well as environmentally degrading. Much capital is channelled towards human labour and coupled with rudimentary techniques (Ibanez Fores et al., 2016) with no measures to mitigate environmental pollution during the production of these pots.

Whereas some industries like the construction industry is increasingly worried about the environmental impacts over a buildings life cycle and always thinking of improving its environmental sustainability, this is not the case with traditional pottery in Ghana or sub-Saharan countries in general. The construction industry uses several raw materials like the pottery industry. Therefore, the choice of cleaner production becomes imperative and environmental assessment is the only solution for the choice of specific materials.

Life Cycle Assesssment is a recognised approach to evaluate the environmental impacts associated with a products life cycle from the extraction of raw materials through to the end-of-life treatment (de Souza et al 2015). Literature review reveals there exists several publications on environmental performance of roofs (Saiz et al., 2006; Kosareo et al., 2007), brick production (Ozkan et al., 2016; Bribian et al., 2011) and ceramic tiles (Edirisinghe, 2013).

However, studies as regards the LCA of traditional earthenware production are lacking except one publication by Quinterio et al., 2012. Additionally, several reports on LCA on glazed ceramic pots are documented. Taking cognizance of these and with reference to Ghana, there is paucity of information on LCA on pottery products. Therefore, the study seeks to compare life cycle impacts of traditional earthen pots in Ghana from two areas among the number of production centres across the country.

The analysis will help one to understand the effects on different impact and damage categories of the pottery life cycle stages in Mpraeso (Eastern region) and Vume (Volta Region). As these 2 notable towns have different approaches in terms of firing after making the pots. This study also quantified the environmental and health impacts of grinding pots by cradle to grave approach through the life cycle assessment of the traditional grinding pot production in Mpraeso and Vume.

8.1 Methodology

8.1.1 Data collection sources

The data required on the raw clay material (1kg) and other material consumed during pottery were collected from the two communities from December 2017 to December 2018. This was done in accordance with ISO 14040:2006 and ISO 14044:2006 standards. Simapro 7.1 databases with Ecoinvent data library and some publications (Nicoletti *et al.*, 2002; Tikul & Srichandr, 2010) were used to supplement missing data on the field. A summary is given in Table 8.1.

Table 8. 1: Sources of data collection for the LCA Phases of the traditional pottery

Life cycle Phases	**INPUT**		**OUTPUT**	
	Mpraeso	Vume	Mpraeso	Vume
Extraction				
Clay	1kg	1kg	1 grinding pot	1grinding pot
Transport	Eco invent	Eco invent	Eco invent	Eco invent
Processing				
Amodine / Grog	1kg	1kg		
Water	Tap water	Lake Volta		
	Eco invent	Eco invent	Eco invent	Eco invent
Drying	Eco invent	Eco invent	Eco invent	Eco invent
Firing				
Transportation of firewood to site	Eco invent	Eco invent	Eco invent	Eco invent
Firewood	45	45	NOx - 0.75	NOx – 0.06
Firewood	45	45	SOx - 5.9	SOx -1.79
Firewood	45	45	CO_2 - 2498	CO_2 – 1088.42
Firewood	45	45	Other gases - Eco invent	Other gases - Eco invent
Number of firing sites	10 sites sampled	3kiln in Vume		
Size of an open firing area	0.03m^2 for 1 pot			
Size of kiln		Length-5m Breadth-4.8m Height- 3.8m Chimney height- 4.29m		
Number of firing men/women sampled	>6 people per firing	>8 people per firing		
Transportation market and homes	Eco invent	Eco invent	Eco invent	Eco invent
Use			Grinding pot	Grinding pot
Health				
Disposal				
Household and Municipal	Eco invent	Eco invent	Eco invent	Eco invent

Source: Field data 2017-2018

8.2 The Life Cycle Assessment (LCA) Methodology

The Life Cycle Assessment (LCA) is a comprehensive methodological tool used in assessing the environmental impact of a product or an activity over its entire life cycle. This study was conducted in accordance with international ISO procedural framework for performing LCA in the ISO 14040-14044 series as indicated in Table 8.2. Data storage and analysis were performed using licensed Simapro 7.1. LCA software (Amersfoort, The Netherlands) to calculate the environmental impact categories. The method used for the impact assessment is the ReCipe Endpoint (H) V1.10/ European ReCipe H/A methods, developed by the Centre for Environmental Science, University of Leiden, Sweden. The results obtained from the ReCipe methods were compared with a second method Eco-indicator 1999 and the results achieved were the same. According to the ISO standards, LCA study has four main phases, namely, goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation of results.

Table 8. 2. ISO 14040 series

Standard	Description	Edition
ISO 14040:2006	Environmental Management. LCA. Principles and framework	2006
ISO 14044:2006	Environmental Management. LCA. Requirement and Guidelines	2006
ISO 14047:2012	Environmental Management. LCA. Illustrative Example on how to apply ISO 14044 to impact assessment situations.	2006

8.2.1 Goal and Scope of the study

The goal of the study necessitates details on the intended audience and applications understudy. The scope on the other hand described the system understudy. The goal was to understand where the environmental impact arose during the traditional pottery production, using the LCA method. In doing this, environmental information would be generated on the production of pottery in Ghana. The method identified all the potential environmental hotspots during the production chain. These environmental hotspots stages identified determined the impact categories for climate change, mineral resource depletion and human toxicity.

8.2.2 Aim, objective, scope and function of product

The research aims to identify potential impact reduction strategies for the design of future earthenware. The objective of the afore-mentioned benchmark studies was in two-folds, depending on the target stakeholders:

i) At sector level: The project intends to use the life cycle environmental consequences in revealing the industry's production processes with highlights on improvements towards the environmental performance of selected activities. Priorities for environmental action plans and strategies at sector level will subsequently be set.

ii) At individual potter level: It was fundamental for individual potters to have sector-wide environmental indicators (for instance, average wood consumption or amounts of CO_2 emitted) so that they could then assess their own position regarding each one and establish targets for improvement, correct any areas in which the production skills might be outdated and more.

The thesis was written for environmental science practitioners familiar with LCA, but hopefully it is also accessible to the non-experts. Hence the intended user of this document are stakeholders of the pottery industry thus the potters, Assembly, Minerals Commission, EPA, and the Public.

8.2.3 Scope of the Study

According to ISO 140140, (2006), the scope includes items such as the system boundary, the functional unit, allocation procedures and data quality requirements. The scope of the study is illustrated in Figure 8.1, which shows the flows of inputs (raw material, energy, fuel, water, etc.) and outputs (airborne emissions, emissions into water and soil, as well as solid waste) produced throughout the stages that go to make up the life cycle of the pot. An examination of tools used at each of the stages of production was exempted in the scope of this study. The system of the analysis is the traditional grinding pot, and the function of the system is to ensure proper and safe pots produced for preparation, storage and serving of food.

8.2.4 Functional unit

The functional unit is a quantitative measure of the output of products or services that the system delivers. In this comparative study, it is crucial that the systems are compared based on equivalent function. The functional unit to use is 1 pot of diameter 25cm with weight of pot 1kg. The amount of clay measured in weight that was used in molding each of the pots is 1kg.

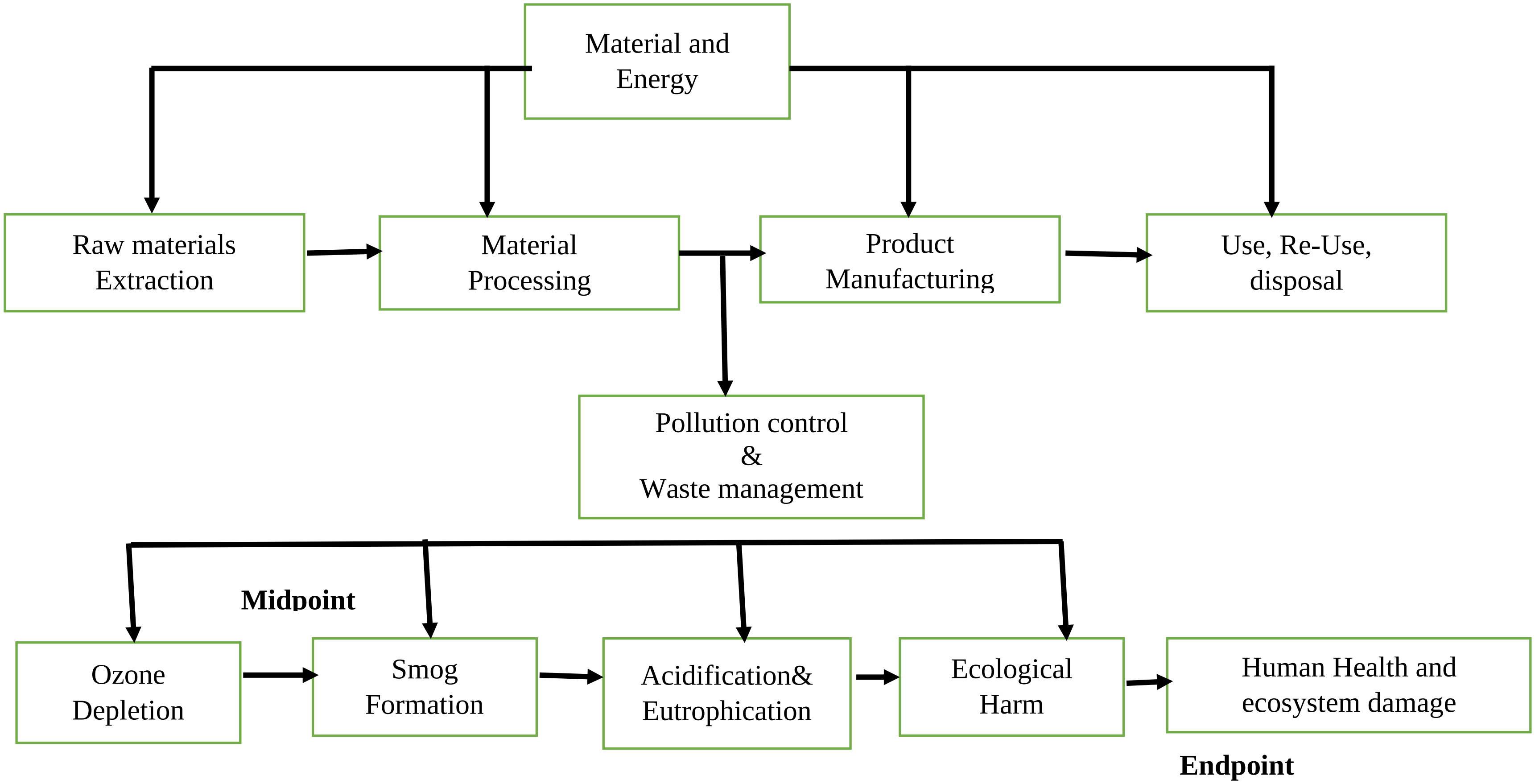


Figure 8. 1 Inputs and outputs of a pottery production cycle

8.2.5 System boundaries

The process chain of traditional pottery manufacturing is in the following stages: mining and transportation of raw materials, body preparation, component mixing, forming, and shaping, drying, decoration, firing and packing of finished products. The system boundary is represented in Figure 8.2. The limitations of the data collection and the assumptions made in this work are define as follows:

1. Water consumed as raw material was exempted: Water is used during the mixing of raw material, which is the clay. The traditional technology consumes negligible quantities of water during mixing.
2. Wastewater generated was not included: Lot of wastewaters is generated in the glaze preparation and application stages. The traditional technology in the study sites does not use glaze hence the use of less water. This makes the quantities of wastewater produced negligible. The environmental component of surface and ground water pollution during processing in the form of sludge thrown into the environment was therefore ignored.
3. Transportation: This included emissions and quantity of fuel used in transporting raw materials, products transported for marketing and transportation during disposal stage (pots at end of life) were disregarded.
4. Packaging of finished products was overlooked. Straw sacks and dry grass are used in packaging which has insignificant impact on the environment.
5. The production, use and disposal of the working tools were excluded as well.

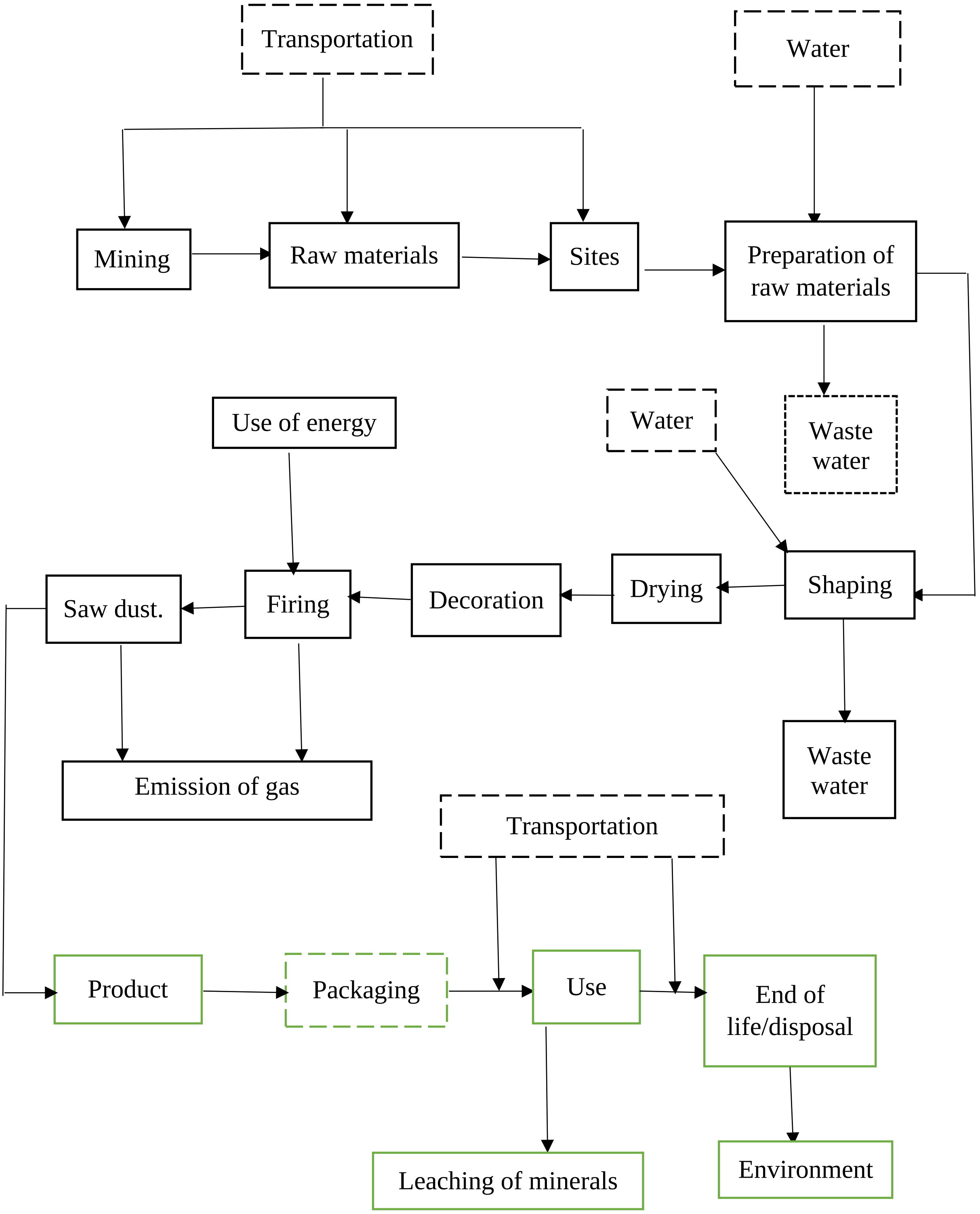


Figure 8. 2: System boundary flow chart for life cycle of traditional pottery. The broken lines are exempted stages in the data collection of the industry.

This work made the following assumptions due to difficulty in data collection and availability.

- The distance that the raw material was transported was assumed as 15km.
- The average life of the pot was assumed one (1) year. This assumption is based on consumer preferences and the technical characteristics of the pot.

To this end, specific LCI was developed and some of the data was collected directly from the two communities involved while others were obtained from Eco invent database as summarized in Table 8.1.

8.2.6 Limitations of the work

The greatest limitation to this study was the lack of tools to effectively measure different gases and particulate matter released during burning and firing at the study sites. Unfortunately, the EPA, the country’s institution responsible for emissions of gases and particulates had no instrument to evaluate emissions in the industry nor data to use. Therefore, for almost 15 months, all efforts to get an instrument to quantitatively and qualitatively establish the gases and particulate matter failed. So, this vital component of the work was suspended.

8.2.7 Data Quality Requirements

Data quality clarification were imperative in considering and relying on the results of the study which aided in the appropriate interpretations of the study. Based on this established precedence the following data collections were necessitated.

- Direct on-site measurements of data were obtained.

- Mass and energy balances were employed where no direct measurements existed.
- Calculations based on technical literature were used only if direct data could not be obtained.

8.2.7.1 Allocation

This is the process of grouping the environmental burdens thus the inputs and outputs for processes which beside the focal product also has a few other co-products of economic value in accordance with the ISO 14040-14044 series. The methods recommended by PAS 2050:2011 to circumvent allocation were not attainable to apply due to the absence of data (Quinteiro *et al.*, 2012). The PAS 2050:2011 methodology recommends economic allocation in place of applicable supplementary requirements. However, in this research the allocation criteria were not applicable because pots produced were not of the same size hence some require more energy than others thereby generating more emissions than others. Again, allocation based on market prices was also disregarded because the market price of the pot’s changes according to the market request. These variations required the formulation of new research anytime there is change in prices of pots. Data from Simapro 7.1 database were therefore used.

8.2.8 Life cycle inventory (LCI)

The second phase of the LCA methodology is the LCI which involved the compilation and quantification of the inputs and outputs for each process in the life cycle. This analysis consisted of two major steps specifically, data collection and the compilation of the data which is in Table 8.1.

This inventory data depicted all the specific inputs in the form of materials and energy resources and outputs in the form of emissions into the environment that was generated in each stage of production as already illustrated in Figure 8.1. Collection of these data was done for each of the life cycle stages studied. Drawing up an LCI is the costliest task in an LCA study due to the large amounts of resources that must be consumed (especially time) to obtain up-to-date and reliable information. To make this task easier, there were several public and private LCI databases that include inventories of specific materials and processes from different industrial sectors (Ecoinvent 2008; Idemat 2001; Franklin 1998; ELCD2011; IVAMLCA2005; etc.) that were used.

However, none of them include inventory data that cover all the stages of the life cycle of the traditional pottery industry in Africa, specifically Ghana. The one that came close was that of ceramics in India. This was used and supported with data from site visits and interviews with the potters. The impact assessment stage determined and analysed the potential human health, environmental impacts and resources consumption associated with the inventory data. Others considered which were mandatory steps considered by the (ISO 14042, 2000) were selection of impact categories, category definition, classification, and characterization were also carried out.

8.2.8.1 Selection of Impact Categories and Category Definition

The impact assessment methodology used was a “problem-oriented” assessment stated by the (ISO 140140, 2006). The inventory data was associated with specific environmental impact categories. To understand these impacts, data from both field and Simapro database were obtained. The impact assessment method ReCipe Endpoint (H) V1.10/ European ReCipe H/A methods, which is implemented in SimaPro 7.1 software developed by PRé Consultants was used to analyse the collected data. Reasonable assumption was made for data, which could not be obtained from the field.

8.2.8.2 Classification and characterization calculation

In the calculation of classification and characterization, inputs and outputs are first assigned to the various impact categories and their potential impacts quantified according to their characterization factors. Figure 8.3 indicates the conversion from emissions to impact potentials by means of classification and characterization.

The Eutrophication Potential which is the excessive content of nitrogen (N) and phosphorus (P) and other nutrients that make aquatic organisms, especially algae, blooms resulting in the decrease of dissolved oxygen in water. The Acidification Potential is the acidic substances such as SO_X, NH_3, NO_X, HCl and H_2S which could cause the acidification of environment where they are discharged. Human Toxicity Potential is the toxic substances that enters human body through respiratory tract and skin contact causing disorder in the human body function. Substances such as SO_2, NOx, CO_2, and CF_4 increases the potentials of Global Warming (GWP) in the environment as calculated in Figure 8.3.

8.2.9 Life Cycle Interpretation

The last stage in conducting an LCA according to ISO 140140, (2006) is the interpretation stage. The objectives of life cycle interpretation are to analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases. Significant issues that contribute most significantly during the LCA study is reported and interpreted in a transparent manner. For this thesis, the interpretation stage is presented as part of results and discussion.

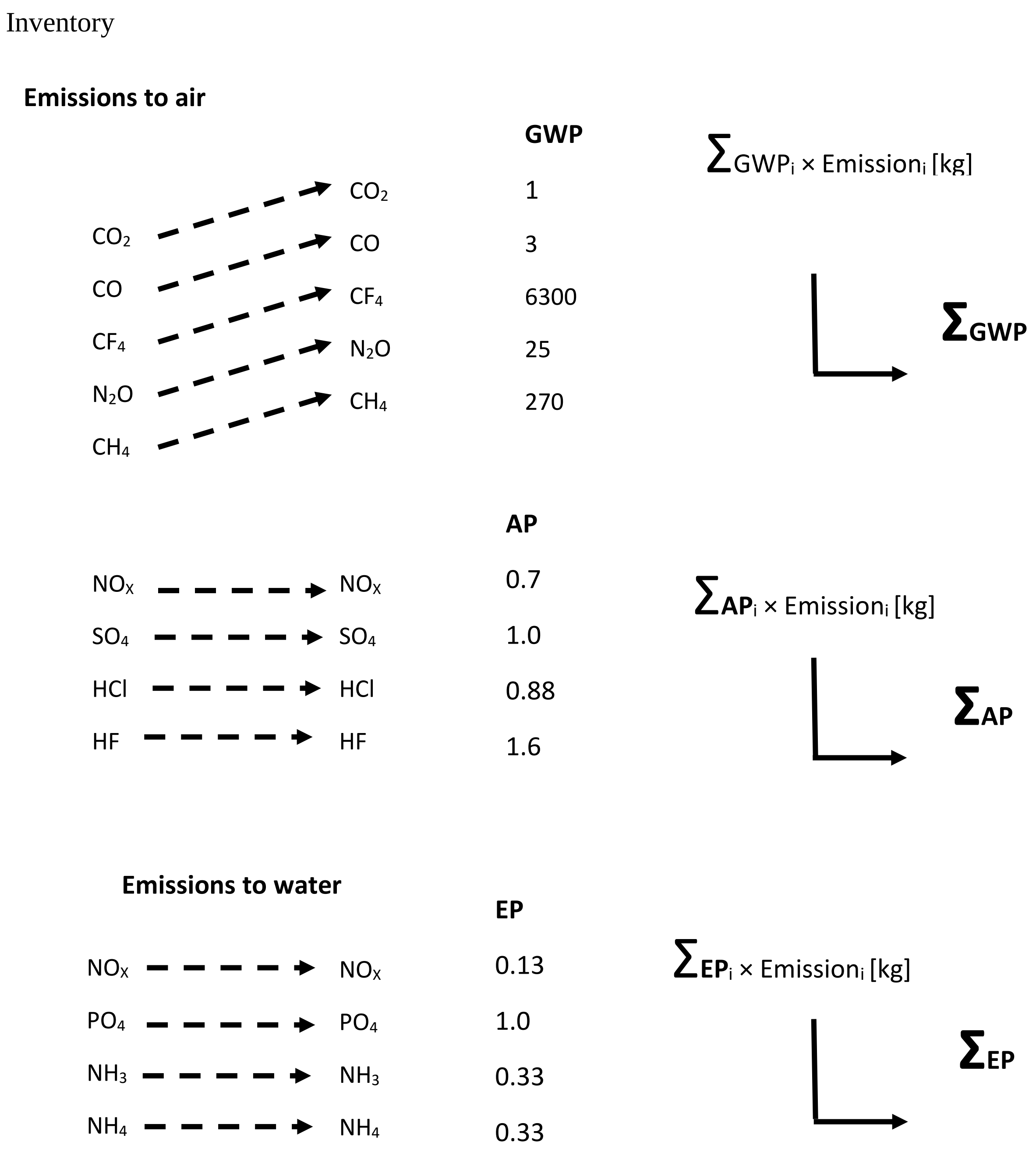


Figure 8. 3 Sample Classification and Characterization Calculation

8.3 Results and Discussion

8.4. Impact assessment

Many impact assessment methods on life cycle have been developed for use by LCA practitioners. Procedures used were what the ISO14042 standards designated for all LCA practitioners. The main impact assessment method chosen for this research is the ReCipe Endpoint (H) V1.10/ European ReCipe H/A methods; hierarchist version. The results obtained from ReCipe methods were however verified with another widely used impact assessment method, the Eco-indicator 1999 methods. The results were the same and are discussed below.

8.4.1 Characterization results obtained by using ReCipe Endpoint methods at Extraction Phase

The results of the characterisation of both sites in extracting 1kg of clay based on the ReCipe Endpoint methods is graphically illustrated in Figure 8.4 and Table 8.3 in Appendix E.

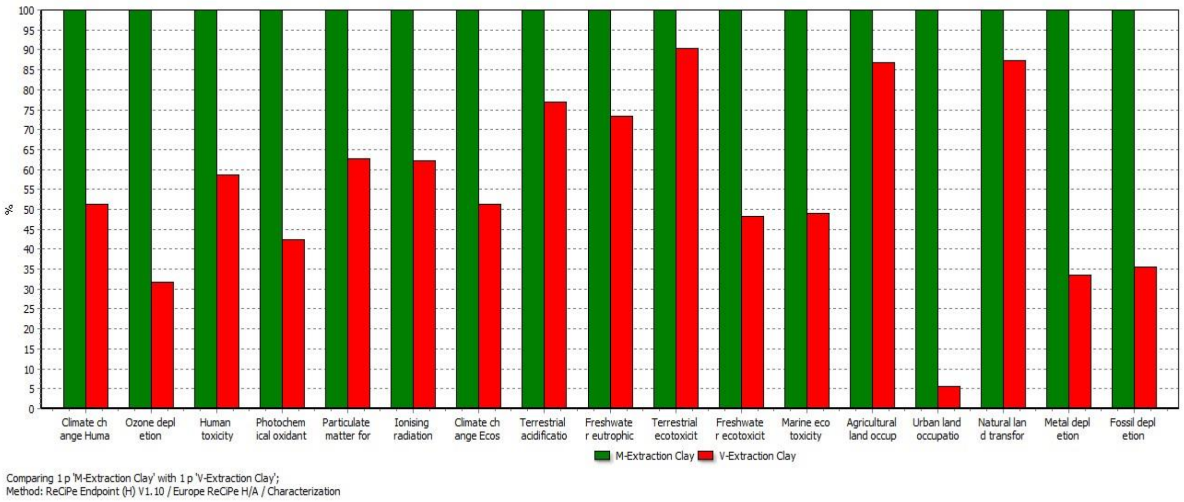
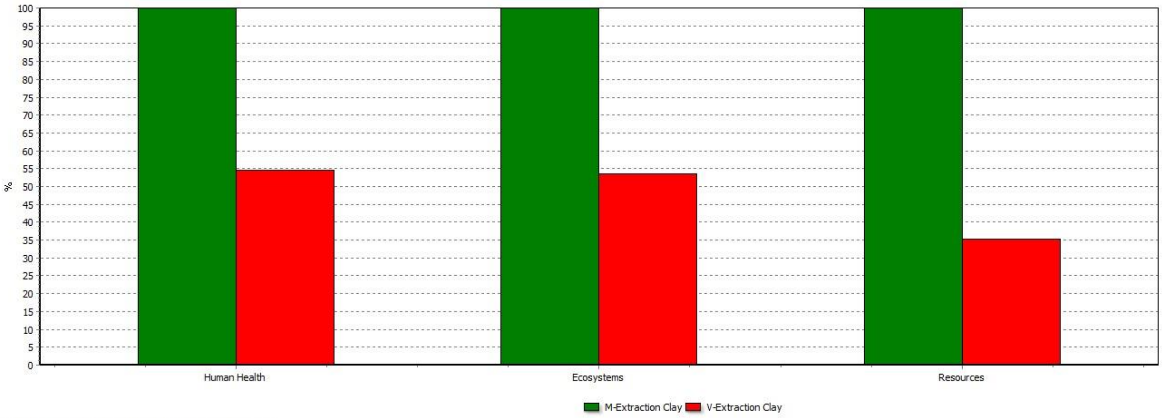


Figure 8. 4: Characterization results of ReCipe Endpoint methods at Extraction Phase

The contributions of impact categories to eco-indicator of both sites during acquisition of raw material for the pot production could be observed that Mpraeso raw material extraction scored the worse for all the impact categories. While in Vume the most significant categories were terrestrial eco-toxicity (90%), Natural land transformation (87%), Agricultural land occupancy (85%), terrestrial acidification (77%), freshwater eutrophication (72%), human toxicity (58%) and climate change (50%).

8.4.2 Damage Assessment results obtained using ReCipe Endpoint methods at Extraction phase.

The damage from the cause effect chain was modeled in three areas of damage or impact which are Human health, Ecosystem quality and Resources. The results are shown graphically in Figure 8.5.



Comparing 1 p 'M-Extraction Clay' with 1 p 'V-Extraction Clay';
Method: ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A / Damage assessment

Figure 8. 5: Damage Assessment using ReCipe Endpoint methods at Extraction phase

The potential environmental impacts estimated in areas of human health, ecosystems and resources were all highly significant in Mpraeso. In Vume human health (54%) scored the worse of impacts followed by impacts on Ecosystems (52%) and finally impacts on resources (35%).

8.4.3 Normalization results obtained using ReCipe Endpoint methods at Extraction phase.

The normalized impact indicator results which are non-dimensional in quantities allow the comparison between different areas of impacts to indicate those that were of normal amounts and those that were in relatively larger amounts. The normalized results of the impact categories were all combined and displayed in a single graph (Figure 8.6) because they no longer have different physical units.

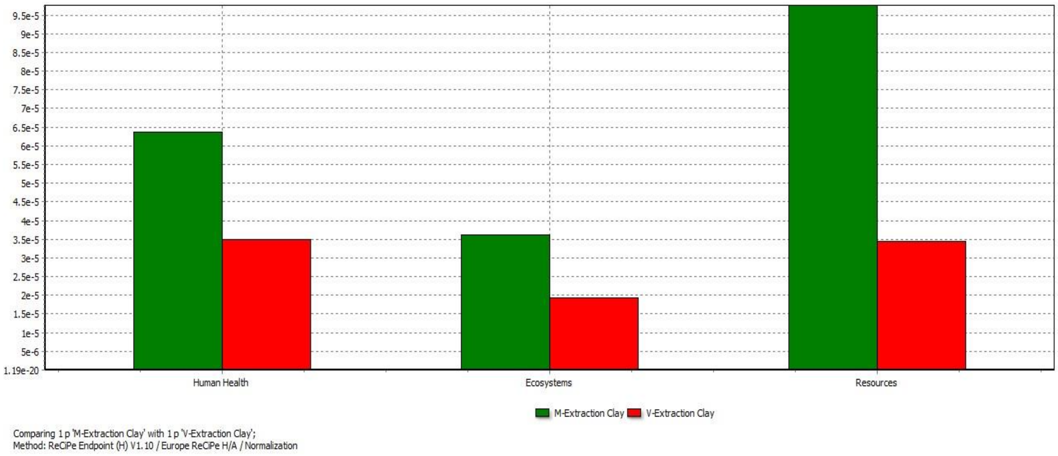
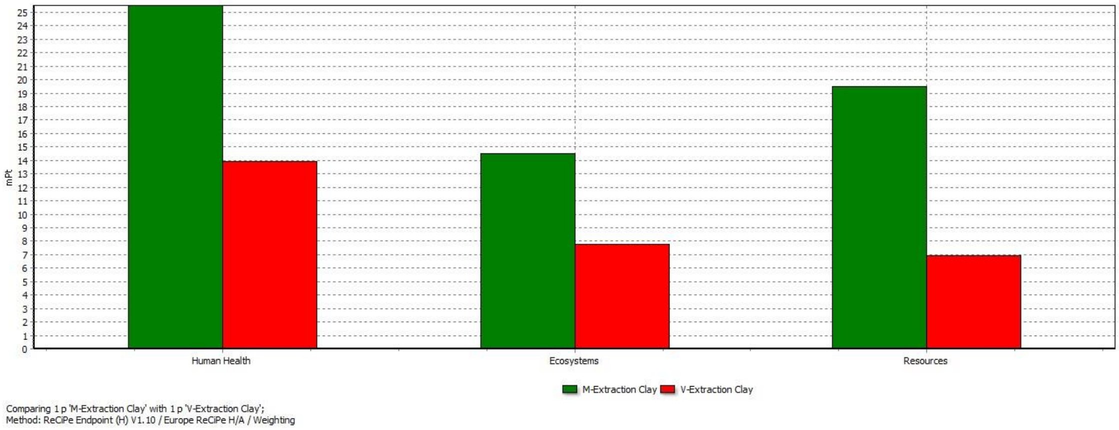


Figure 8. 6: Normalization at Extraction phase

In the extraction phase processes of the study, the relative contribution of the calculated damages to the total damage caused in the normalization phase using ReCipe Endpoint methods is indicated graphically in Fig.8.6. The result used a unifying parameter which was the environmental effect caused by one European person in one year. Therefore, large and small effects between impact categories are revealed by normalisation. From the graph, extraction in Mpraeso had a larger amount for impact category of resources which was followed by impact category of human health and Ecosystems. In the normalisation for Vume, human health and resources had the same impact which was of higher amount than that for the ecosystem.

8.4.4 Weighting results obtained using ReCipe Endpoint methods at Extraction phase

Weighting element in LCA is based on value-choices and not on scientific principles. This element was used in comparing the impact indicator results according to their significance which are expressed with weighting factors. In this study the Hierarchical recommended set approach was used to study the relative importance of the normalization effects. The graph obtained for weighting both sites during extraction is in Figure 8.7.



Comparing 1 p 'M-Extraction Clay' with 1 p 'V-Extraction Clay';
Method: ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A / Weighting

Figure 8. 7: Weighting at Extraction phase

The results showed that human health impact during the extraction phase at Mpraeso was twice that of the health impacts from that in Vume. This made human health damage category during extraction in Mpraeso the most severe followed by impacts on resources in Mpraeso during extraction, exceeding that of Vume extraction by three fold and then the ecosystems impact of Mpraeso during extraction is two times more than Vume.

8.4.5 Single Score of results obtained using ReCipe Endpoint methods at Extraction phase.

Finally, all the weighted scores were added using the Simapro software to give a total single impact score for each site during extraction of their raw material for production. Figure 8.8 was generated which indicated that Mpraeso extraction phase had higher scores in all the impact categories than Vume.

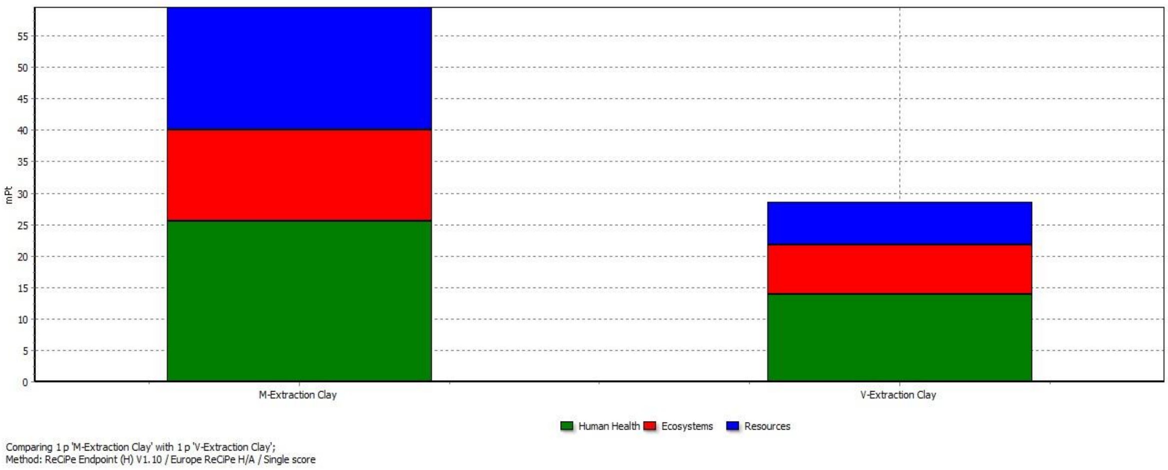
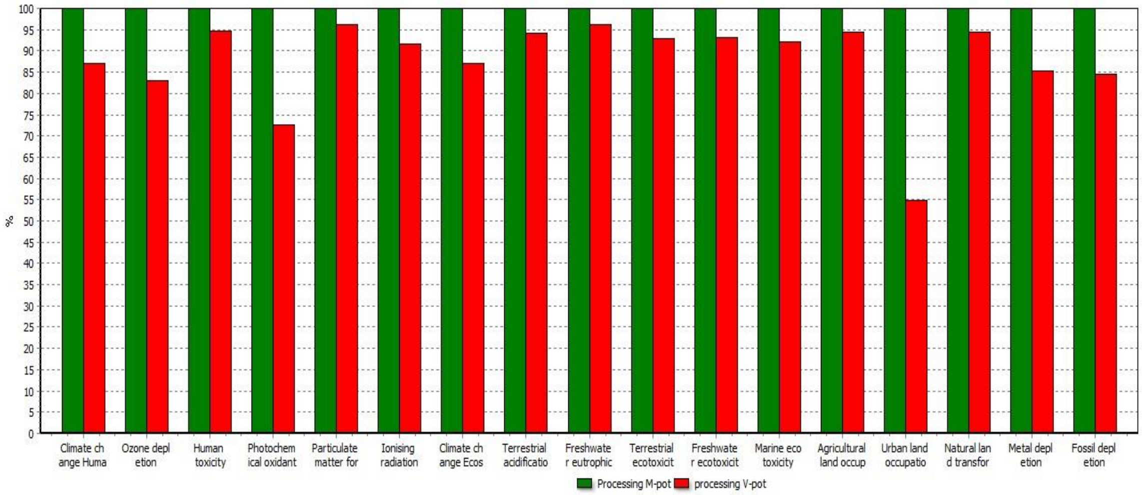


Figure 8. 8: Single Score results at Extraction phase

8.4.6 Characterization results obtained by using ReCipe Endpoint methods at processing Phase

The graphical representation of the characterization results in Mpraeso processing phase indicated striking results in all the impact categories as represented in Fig.8.9. In Vume processing the significant categories are human toxicity (95%), freshwater eutrophication (95%), particulate matter (95%), terrestrial eco-toxicity and acidification were 94% each, climate change (85%) and ozone depletion (83%) respectively as seen in (Figure 8.9).

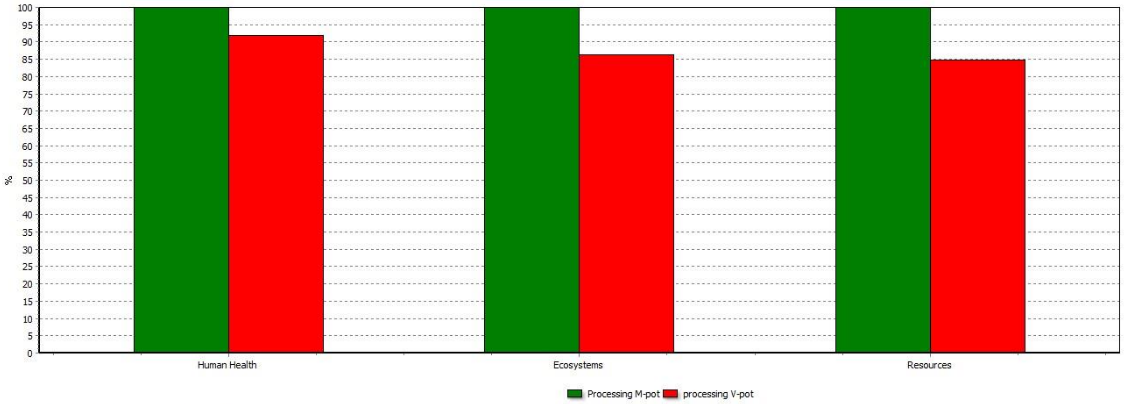


Comparing 1 p 'Processing M-pot' with 1 p 'processing V-pot';
Method: ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A / Characterization

Figure 8. 9: Characterization results at processing Phase

8.4.7 Damage Assessment results obtained by using ReCipe Endpoint methods at processing Phase

From the graph in Figure 8.10, Mpraeso showed significant impact category in all three areas of damage while Vume indicated high values in human health (93%), ecosystem (86%) and resources (85%) respectively.



Comparing 1 p 'Processing M-pot' with 1 p 'processing V-pot';
Method: ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A / Damage assessment

Figure 8. 10: Damage Assessment results at processing Phase

8.4.8 Normalization results obtained by using ReCipe Endpoint methods at processing Phase

The normalized results at the processing phase gave a detailed knowledge and overview of the phase and its contribution to environmental impact as shown in Figure 8.11.

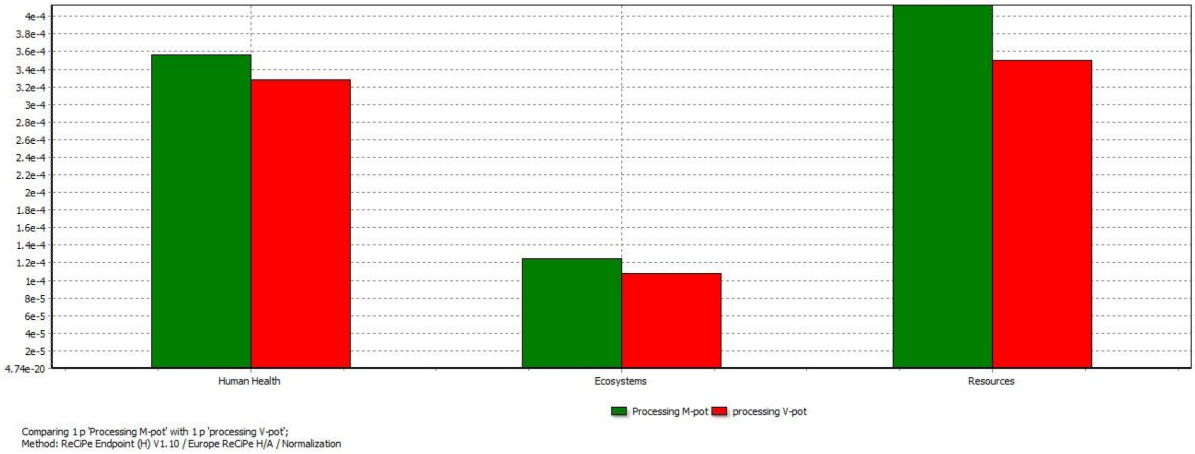
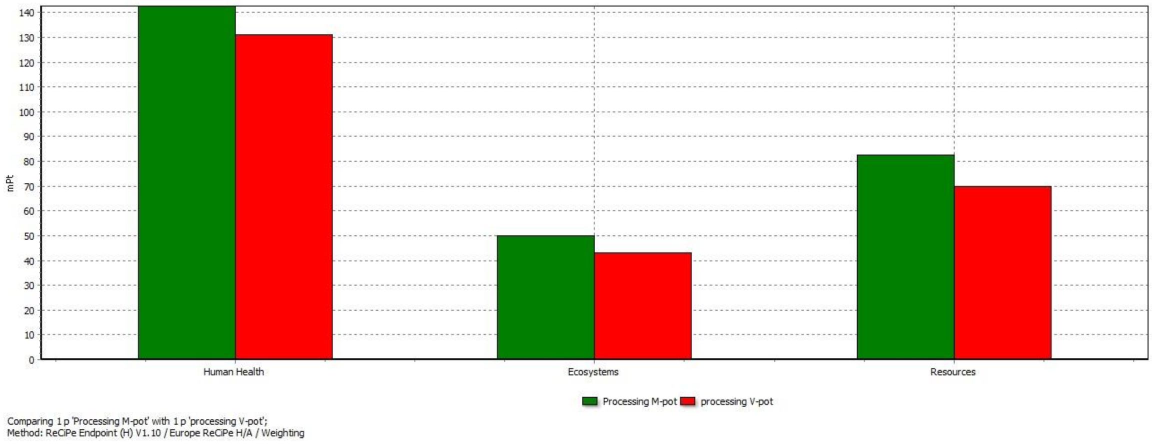


Figure 8. 11. Normalization results at processing Phase

In Mpraeso resources score was higher than human health and ecosystems during processing. The same order of score was observed in Vume thus resources had the highest scores followed by human health and then ecosystems.

8.4.9 Weighting results obtained using ReCipe Endpoint methods at processing Phase

The observation made during the studies (Figure 8.12) was that Mpraeso processing scored the highest value for the human health impact which was followed by resource impact category and the Ecosystem impact category, which was similar to Vume.

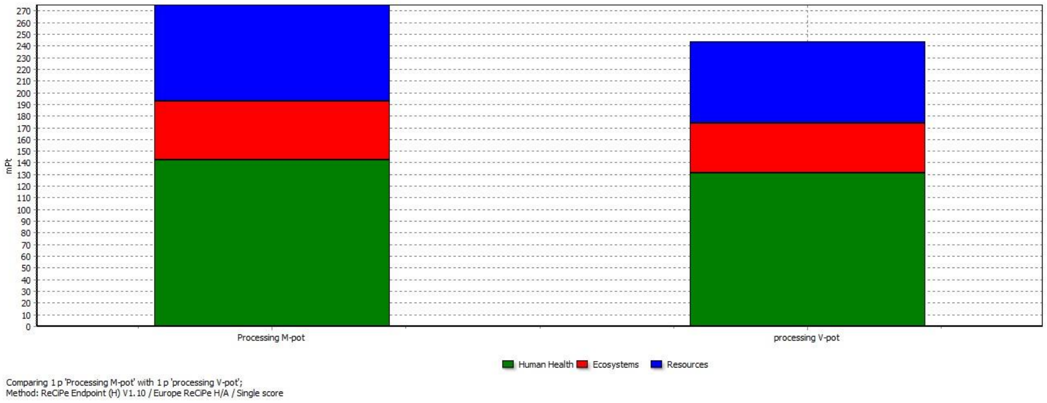


Comparing 1 p 'Processing M-pot' with 1 p 'processing V-pot';
Method: ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A / Weighting

Figure 8. 12: Weighting results at processing Phase

8.4.10 Single Score of results obtained using ReCipe Endpoint methods at processing Phase

The graph generated for single score is shown in Figure 8.13. The results show highest scores in human health followed by resources and ecosystems in both sites during processing.



Comparing 1 p 'Processing M-pot' with 1 p 'processing V-pot';
Method: ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A / Single score

Figure 8. 13: Single Score at processing Phase

8.4.11 Use Phase

There were no environmental impacts during the use phase of the grinding pot. A rational conclusion was drawn based on the Simapro 7.1 analysis.

8.4.12 Disposal Phase

The disposal phase of the pot has negligible impact on the environment because the pots were made of clays, and they are unglazed and so at their end of life they disintegrate back into the environment as soil.

8.5 Discussion

Comparing the two systems of production, Vume production system scored better than Mpraeso production system. Worse scores were obtained in all impact categories for characterization and damage assessment for both extraction and manufacturing phases in Mpraeso. The relationship between the phases is the same as both scored high burdens in all categories. However, in Vume the processing phase scored high values in all impact categories than in the extraction phase. This revealed that the processing phase in Vume had the highest environmental burden.

On the other hand, the contributions of the life cycle phase to the eco-indicators of the two systems of production showed that the system used in Mpraeso during production had more environmental burdens than that of Vume. The processing phase of Mpraeso were the most responsible for the gap between the two systems especially the open firing stage of processing which consumed more energy compared to the kiln method in Vume thereby impacting on the environment. The remaining results of the two phases between the two sites had similar trend where impacts on resources scored high values because impact categories related to resource consumption were energy used in the form of fuelwood which was applied during the firing stage of production. Human health followed because of inhalation of these emissions by potters and people within their community of operations and finally the ecosystems.

After analyzing the life cycle of pots from Mpraeso and pots from Vume it was concluded that the same functional units gave environmental impacts of Mpraeso pot to be twice the environmental impacts of Vume. This was deduced from the single scores of the graphs produced.

8.6 Considerations and Conclusion

A rational conclusion was drawn based on the analysis which excludes many substantial considerations due to lack of available data on field information. On field data could not be obtained for emissions from raw material acquisition. No baseline data for the pristine environment to enable scientific calculations and observations of the extent of environmental impacts of mining activities and abiotic depletion. There is not a conventional way to quantify the environmental impact of the land loss. Again, there is the non-existence of field data on emissions from transportation of raw materials to manufacturing sites.

Fuelwood used as energy in the industry is acquired by harvesting trees. Again, there was data deficiency on the environmental impact from the acquisition of fuelwood, logging equipment and transportation of logs. The environmental impacts of clean water consumption required in the manufacturing process was ignored and same for wastewater. Though negligible, data on the amalgamation of water use and wastewater disposed could have significant impact with time.

There are definitely environmental impacts associated with the use phase since grinding pots are normally washed with detergents and clean water anytime used; thus, the resulting waste water is disposed into the environment. Disposal emissions and environmental impacts from different disposal methods such as incineration, landfill, composting and open dumping all have associated emissions and environmental impacts. However negligible, all these will become significant with time.

To further resolve some of the problems of insufficient data, some field data obtained was used together with the database information provided in the software and literature to estimate life cycle. Therefore, the available data obtained through these means was transformed into comparable information and was used for the life cycle assessment. Nevertheless, it would be incredible to conduct an ideal full life cycle analysis on the grinding pot because the nature of the pot’s life cycle is extremely complex with various infinite outside parameters.

CHAPTER NINE

SUMMARY, LIMITATION AND RECOMMENDATIONS

9.0 Summary

In summary the following were drawn from this study:

(i) The clays in the study area are common clays of smectite, illite and kaolinites of both study sites and the addition of tempers improve the plasticity. Adding a temper of 1/5, the weight of the clay to be used was found to be ideal. This reduces carbonates in the clay hence reducing crack formations, a problem that the potters find difficult to address.

(ii) Clay mineralogical and chemical composition investigations showed that clayey soils from the communities are composed mainly of Si, Al, Fe, smectite (montmorillonite), kaolinite, illite and quartz as major minerals.

The clays were of high quality with metals like Co, Cu, Pb, Mn, Cr, Cd, As and Zn at safe levels. On the other hand, metals of Fe and Ni in Mpraeso and Fe, Ni and Cd in Vume were beyond WHO recommended levels.

(iii) Considering the life cycle analysis of the clay pot, the extraction processes in both communities were found to impose significant impacts on the ecosystem. Deforestation, land degradation, creation of pits and man-made ponds etc. littered on large tracts of land unreclaimable. The processing of the clay into pots per the life cycle yields minimal wastes in both communities. Wastewater generated is always thrown into the ground. Waste clay is recycled into the batch of processing. Production of pots in both study sites were similar but differed during firing; Mpraeso uses open firing of pots while Vume uses kilns. Fuelwood is the source of energy in both communities and potters were seen usually using tools found within their ecological terrains to work with. Both communities believe the craft is for the female gender and is a taboo for men to engage in.

(iv) In firing several gases are released into the environment in Mpraeso, the gases and the particulates enter the various homes and particularly schools close by have problems. This was not the case with Vume where gases and particulates were sent out into the atmosphere which fall back latter as wet/dry precipitation into the environment.

(v) The quantitative studies of heavy metals leachability at the use stage in the life cycle of the earthenware pot indicated that Cu, Fe, Mn, Ni, Co and Zn were present in ground *shito*. Apart from Cd all the elements were in uncooked *shito* that was ground at all the varying times of 5minutes, 10 minutes and 15 minutes and in the cooked sample at varying temperatures of $28^{℃}$ $60^{℃}$ and $100^{℃}$. Metals detected above WHO threshold limit were Fe Ni and Co. Increase in grinding time with low pH increased the leaching of Ni but was varied with temperature.

(vi) The potential risk in the life cycle of the pot showed high concentrations of Fe and Cd in Vume and Fe were observed only in Mpraeso at the extraction stage of the cycle. However, in the processing phase, Ni and Cd concentrations exceeded the recommended levels in Vume only in the ingestion pathway. Human contact at processing (dermal contact) and extraction (inhalation) stages over a long period will affect the human health.

(vii) The life cycle assessment performed on the grinding pots from the perspective of comparing two production systems involving local aspects of processes showed a production cycle than Mpraeso production cycle due to the kiln firing method used. The energy consumed in the industry is the major contributor towards resource depletion, environmental and health impacts in the industry.

9.1 Limitations of the study

In the collection and analysis of data for this thesis several setbacks were encountered which need to be enumerated to guide imminent studies of this kind. This includes lack of logistics and data. Vume is located within the South Tongu district and has Sogakope as its capital and so all information with regards to the activity must be confirmed with institutional heads in Sogakope.

All efforts made to meet the environmental and sanitation officer and the health superintendent in Sogakope failed hence some data on health and environment unavailable. A major challenge the research encountered is the inability to acquire aeroqual air sampler; a probe used in measuring air emissions. Thus, it was impossible for air emissions on the field to be measured quantitatively. All efforts made to obtain it from regulatory bodies (EPA, Atomic energy) with this probe proved futile. The project was not funded hence the equipment could not be procured owing to financial challenges. The research therefore relied on inbuilt ceramic data in the Simapro software which is like the industry to work with.

In this study, data pertaining to fuel wood collection and transportation were taken from the inbuilt databases of the Simapro software pertaining to Africa, since specific local or regional databases were lacking. Mungkung *et al.*, (2006) have also observed that in developing countries, baseline data, especially describing background systems, are not always available and thus LCA practitioners must supplement the missing data by using the databases provided in commercial LCA software.

A study of this kind required the use of a baseline data with respect to land degradation specific to pottery activity to be use in the comparative analysis. This could also not be carried out because of lack of data. Again, data on the number of traditional potters in both study areas was unknown due to the unorganised nature of the craft in the study areas.

9.3 Recommendations

The following recommendations are made to further the extent of knowledge of life cycle analysis of earthenware:

- A clear study into the chemical composition of gases and particulates emitted into the atmosphere and human health and ecological implications would be very interesting in both communities by other researchers.
- The intermediary interventions in pottery hubs to investigate the clay, the processing and the finished products to ascertain its safety before they are molded and sold to the public can be done by the government by setting up mini laboratories within these towns. The basic responsibility will be routine checks on the clay mineralogy and chemical constituents before, during and after production. Intense research by the nation’s research institutions can be conducted in the application of clay materials in other areas like biomedical, environmental remediation and more so as clay materials will be economically viable apart from earthenware and other ceramic production.
- During the firing stage of the production cycle, government may provide a common calibrated/scientifically firing facility or kiln for the potters for a fee. This will generate revenue, reduce emissions and heat into the environment thereby improving the health of potters and reducing environmental pollution. Government can put measures in place to launch specific strategies to support

local consumer culture, make regulations and take action to preserve local traditional ceramicists and support them to compete successfully with foreign (imported) ceramics and pottery. The foreign pottery wares seem to have beautiful and colorful finishing which is either because of the professionalism of the trained foreign potters or the use of machines.

- Public sensitization by the government needs to be made on molded pots so as users of the grinding pot will reduce the length of grinding time of vegetables in the pot to minimize the leaching of metals into food. Persons who eat in the pots must ensure that food are served at lower temperatures or when it is warm and not when boiling. It is also recommended that the European Union Directive 84/500/EC amended 2005/31/EC and the FDA should have migration limit for other metal leachate aside Pb and Cd in ceramics (eg Ni, Co and Fe). Policy makers in Ghana should have special regulations and policies concerning the amount of Ni, Co and Fe leached from traditional pots. This will lessen the dangers on consumer health.
- Public education on environmental impacts of clay harvesting must be intensified by the local authourities, EPA, Health and Sanitation officers, NGOs, and all other stakeholders. EPA needs to enforce the mining regulation laws of reclaiming the land after mining to reduce pits that could be death traps and mosquito breeding grounds. Further studies could use other tools to assess land use impact such as loss of biodiversity to compliment other efforts made by this LCA. Since energy used in the industry is the major contributor towards resource depletion, environmental and health impacts in the industry, efforts from concern groups, individuals, NGOs, and government can help implement

the use of better energy systems during the firing stage of the industry like the use of solar.

- Though there are several centres of pottery production in Ghana, the extent of damage to the ecosystem or the environment is unknown. Therefore, studies into the qualitative and quantitative assessment of damage and the resulting environmental impact assessment by research institutions in the country will be helpful.
- To derive the full potential of the economic gains of the clay mineral in Ghana it is recommended that pottery activities in Ghana needs to be regularized for national development. Government must put in place policies to enable potters acquire scientific knowledge on the materials they use in their production. Potters need to know the mineralogical composition, physio-chemical properties including plasticity of the clay to help understand the thermal properties of the processed material generated. This will minimize pot cracks during firing.

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APPENDICE

Appendix A

Table 3.15b Varimax rotated PC loading for Mpraeso Amodine (loadings >0.4 are shown in bold)

Element	**Component**			**Communalities**
	1	**2**	**3**	
Co	0.146	-0.201	**0.839**	0.765
Zn	**0.752**	**0.548**	0.287	0.949
Mn	**0.750**	0.176	0.304	0.685
Ni	**-0.799**	0.157	0.381	0.808
Pb	**-0.640**	0.307	-0.140	0.523
Fe	**-0.736**	**0.409**	0.316	0.809
Cr	**0.639**	**-0.461**	0.031	0.622
Cu	**0.566**	**0.713**	-0.245	0.888
Eigenvalue	3.467	1.379	1.204	
% of Variance explained	43.334	17.234	15.046	
% of cumulative	43.334	60.568	75.614	

Table 3.15c Varimax rotated PC loading for Mpraeso mixed clay (loadings >0.4 are shown in bold

Element	**Components**			**Communalities**
	1	**2**	**3**	
Co	-0.150	**0.810**	-.158	0.704
Zn	**0.774**	**0.437**	-.195	0.828
Mn	**0.924**	0.175	.091	0.892
Ni	0.349	**-0.595**	**-0.443**	0.673
Pb	0.106	**-0.531**	**0.739**	0.839
Fe	**0.526**	**0.574**	**-0.428**	0.790
Cr	**0.649**	**0.413**	.236	0.647
Cu	**0.934**	0.086	.206	0.923
Eigenvalue	3.180	2.021	1.095	
% of Variance explained	39.745	25.264	13.683	
% of communalities	39.745	65.009	78.692	

Table 3.16a Varimax rotated PC loading for Vume grog (loadings >0.4 are shown in bold)

Element	**Components**			**Communalities**
	1	**2**	**3**	
Zn	**0.904**	0.249	0.082	0.886
Mn	**0.840**	**0.472**	0.141	0.948
Ni	0.185	0.041	**0.874**	0.800
Cu	0.107	**0.834**	-0.168	0.736
Fe	**0.937**	-0.257	0.217	0.991
Cd	0.028	**-0.764**	**0.488**	0.822
Pb	**-0.617**	0.359	**0.437**	0.700
Co	**-0.481**	**0.488**	**0.591**	0.819
Eigen Value	3.060	1.998	1.644	
% of Variance explained	38.247	24.978	20.550	
% of communalities	38.247	63.225	83.774	

Table 3.16b Varimax rotated PC loading for Vume mix clay (loadings >0.4 are shown in bold)

Element	**Components**		**Communalities**
	1	**2**	
Zn	**0.897**	0.299	0.894
Mn	**0.811**	0.133	0.676
Ni	**0.767**	**-0.469**	0.808
Cu	-0.081	**0.944**	0.897
Fe	**0.916**	0.251	0.903
Cd	-0.280	**0.908**	0.903
Pb	**0.657**	0.030	0.433
Co	**0.682**	0.095	0.474
Eigen Value	3.874	2.115	
% of Variance explained	48.421	26.442	
% of communalities	48.421	74.863	

Appendix B

Questionnaires for potters and related respondents in Mpraeso and Vume.

ENVIRONMENTAL SCIENCE PROGRAMME – UNIVERSITY OF GHANA LEGON

This study looks at the socio-economic, health and environmental impacts of traditional pottery production in Vume and Mpreaso. The information given will be treated as confidential

A. Demographics

1. Gender male ( ) female ( ) Marital status Yes ( ) NO ( )
2. Age ( )
3. Level of education a. no formal education ( ) b. no formal education but can read and write ( ) c. basic (primary, middle , JHS) ( ) d. secondary (SHS, training college, vocational ( ) e. tertiary ( ) f. others……………………..
4. Do you hail from this district? a. Yes ( ) b. No ( )
5. If no what brought you here?

B. Potters and pottery processes in the community

6. Years of practice in pottery ....
7. Where do you get your raw materials?.................................
8. How do you mix the clay materials? (a) hands and feet (b) machine
9. What source of water do you use for the pottery activity?
10. What processes are involved with the manufacturing processes?
11. What method of firing do you apply? (a) open fire (b) kiln
12. How do you assess the quality of the raw materials Yes ( ) No ( )
13. If yes how and with what? ....
14. What type of fuel do you use for firing?
15. How much fuel is needed for the production of pots ....?
16. How do you beautify your wares?

C. Environmental issues in the community

17. Does the extraction of the raw material affect the land/air/water?
18. If yes in what form?
19. How do you dispose of your waste from pottery?
20. Does firing affect your surroundings?
21. What emission result from pot production?
22. What is the indigenous knowledge used in safeguarding the environment?

D. waste management during pottery production

23. how do you manage the wastes from 17 and 18

Existing arrangements and the nature of interaction among the key actors and how they affect the production systems

E. *Social issues*

24. Who owns the land on which you obtain these resources?
25. Do you pay any money for raw materials?
26. If yes how much for how long?

F. Socio-cultural issues

27. What is the history of pottery in this community?...
28. Any superstition attached to making of pots? ………………………………………
29. Is the craft gender bias? a. Yes b. No
30. If yes why?
31. How did you acquire the skill or technique of pottery?
32. What are the signature of this community's local pottery and pots?
33. Do various pots and their shape have meaning?
34. Does the pot play any role in the culture of this community?
35. If yes at which stage/period in life.
36. Does the craft make you feel any sense of belongness in your culture?
37. Has the craft been modified to suite new products and designs in the market?
38. If yes how?

G. *Economic Impact*

39. How do you market products
40. Is demand for pots seasonal? Yes ( ) No ( )
41. If yes when are peak season ………………………
42. Is the influx of plastics affecting production? Yes ( ) No ( )
43. If yes how do you intend to stay in business? …………………………….
44. Does the industry attract tourist into the community?..
45. Do you recieve financial support in your pottery business? Yes ( ) No ( )
46. If yes name the organisations………………………………………..
47. Is there any training programs organised for potters by government or any organisation? ……………
48. If yes in which form?...

H. occupational Hazards and Health impacts

49. How many hours do you work in a day?

50. How many times do you take a rest between working hours?

51. What are the occupational hazards in pottery

52. How do you take care of your health in pot business

53. Do you use personal equipment (PPE's)? Yes ( ) No ( )

54. If no why…………………………………………………………

55. Do you have existing or past medical complains that you feel is as a result of your pottery

occupation? Yes ( ) No ( )

56. If yes do you use orthodox medicine or traditional medicine? …………………………..

57. Have you visited the hospital with this problem? ……………………………………..

58. Would you agree to have a workstation design for you to increase production and work

comfort?

59. How do you protect yourself from the heat produced during the firing stage?

60. Check list for Respondents on basis of postural discomfort

Do you have:

Type of pain	Yes	No
Neck		
Shoulder		
Upper arm		
Lower arm		
Upper back		
Mid back		
Lower back		
Buttocks		
Thighs		
Legs		
Waist		

Description of other chronic disease as a result of pottery

B2: Chi-Square Tests of independence on influx of plastics and demand for pots.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.432	1	0.231
Continuity Correction	.917	1	0.338

Appendix C: Relationship between metals and pot type using ANOVA

Multiple Comparisons

Dependent Variable: Fe

Tukey HSD Table 6.1 significant mean differences in Fe

(I) Pot_type	(J) Pot_type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mblack	Mred	-192.9167*	3.86885	.000	-202.5092	-183.3242
	Vred	-206.1250*	3.86885	.000	-215.7175	-196.5325
Mred	Mblack	192.9167*	3.86885	.000	183.3242	202.5092
	Vred	-13.2083*	3.86885	.006	-22.8008	-3.6158
Vred	Mblack	206.1250*	3.86885	.000	196.5325	215.7175
	Mred	13.2083*	3.86885	.006	3.6158	22.8008

Based on observed means.

The error term is Mean Square(Error) = 89.808.

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Dependent Variable: Mn

Tukey HSD Table 6. 2 significant mean differences in Mn

(I) Pot_type	(J) Pot_type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mblack	Mred	-1.1917	.80029	.312	-3.1759	.7926
	Vred	1.0333	.80029	.412	-.9509	3.0176
Mred	Mblack	1.1917	.80029	.312	-.7926	3.1759
	Vred	2.2250*	.80029	.026	.2407	4.2093
Vred	Mblack	-1.0333	.80029	.412	-3.0176	.9509
	Mred	-2.2250*	.80029	.026	-4.2093	-.2407

Based on observed means. The error term is Mean Square(Error) = 3.843.

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Dependent Variable: Ni

Tukey HSD Table 6.3 significant mean differences in Ni

(I) Pot_type	(J) Pot_type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mblack	Mred	-6.3000*	.49760	.000	-7.5338	-5.0662
	Vred	-.7333	.49760	.319	-1.9671	.5004
Mred	Mblack	6.3000*	.49760	.000	5.0662	7.5338
	Vred	5.5667*	.49760	.000	4.3329	6.8004
Vred	Mblack	.7333	.49760	.319	-.5004	1.9671
	Mred	-5.5667*	.49760	.000	-6.8004	-4.3329

Based on observed means. The error term is Mean Square(Error) = 1.486.

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Dependent Variable: Co

Tukey HSD Table 6.3 significant mean difference in Co

(I) Pot_type	(J) Pot_type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mblack	Mred	-35.9417*	1.11782	.000	-38.7132	-33.1701
	Vred	-23.3500*	1.11782	.000	-26.1215	-20.5785
Mred	Mblack	35.9417*	1.11782	.000	33.1701	38.7132
	Vred	12.5917*	1.11782	.000	9.8201	15.3632
Vred	Mblack	23.3500*	1.11782	.000	20.5785	26.1215
	Mred	-12.5917*	1.11782	.000	-15.3632	-9.8201

Based on observed means. The error term is Mean Square (Error) = 7.497.

*. The mean difference is significant at the .05 level.

Appendix D: Chi-Square Tests of independence

Hours of work and Rest

	Value	df	P-value
Number of rest in a day	20.061[a]	12	.0066
Past or known medical records	0.849	3	0.838

Likelihood Ratio Tests

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	172.148[a]	0.000	0	
Years of practice	240.357	68.210	238	1.000
Past Medical complaints	196.588[b]	24.440	7	0.001

Chi-Square Tests of independence

	Value	df	P-value
Pearson Chi-Square	79.598[a]	56	0.021
Likelihood Ratio	59.838	56	0.338
Linear-by-Linear Association	1.781	1	0.182

Model Fitting Information

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	113.142			
Final	59.876	53.266	56	0.579

Appendix D2

ENVIRONMENTAL SCIENCE PROGRAMME – UNIVERSITY OF GHANA LEGON

This study looks at the socio-economic, health and environmental impacts of traditional pottery production in Vume and Mpreaso. The information given will be treated as confidential

Name of Institution……………………………………

Economic

1. Is pottery the only major local economic development activity in this locality? Yes ( ) No ( )
2. Does your institution know the scale of production of the industry in this community? Yes ( ) No( )
3. If yes what is the scale?
4. Does your institution know the income returns of the pottery production in the community? Yes ( ) No ( )
5. If yes how much?
6. What % goes to the Government
7. Does your institution collect revenue from the potters? Yes ( ) No ( )
8. If yes how much?
9. Do you think the pottery activity is having a positive economic impact on the citizenry? Yes ( ) No ( )
10. If yes in what ways?
11. What other economic activities can the citizenry engaged in apart from the pottery?

ENVIRONMENTAL SCIENCE PROGRAMME – UNIVERSITY OF GHANA LEGON

This study looks at the socio-economic, health and environmental impacts of traditional pottery production in Vume and Mpreaso. The information given will be treated as confidential

Name of Institution……………………………………

Environmental

1. Do the activities of these potters have impacts on the environment? Yes ( ) No ( )
2. What are some of the impacts?

3. If yes what measures are being put in place to curb this situation by your institution?
4. What role does your institution play in the sustainability of the pottery activity?
5. Which other institutions do you work with to regulate the activities of the industry?
6. Does the citizenry complain to your institution of any pollution by the activities of potters? Yes ( ) No( )
7. What is the form of pollution?
8. If yes what are the common complains that are made to your institution?
9. How does your institution resolve such complains?

10. Does your institution ensure the suppression of gaseous emissions from these potters?
    Yes ( ) No ( )

Regulatory

11. How involved is your institution with the local pottery production?

12. Are there any policies guiding the activities of the potters? Yes ( ) No ( )

13. If yes name the policies/laws/Act.
14. Does your institution enforce the public health Act 851 ‘Environmental Sanitation-noxious trade? Yes ( ) No( )

ENVIRONMENTAL SCIENCE PROGRAMME – UNIVERSITY OF GHANA LEGON

This study looks at the socio-economic, health and environmental impacts of traditional pottery production in Vume and Mpreaso. The information given will be treated as confidential

Name of Institution: The health Directorate.

General Health

1. What are some of the common diseases or complains brought by patient to the hospital?

2. Are these patients’ potters? Yes ( ) No ( )

3. If yes what age brackets do, they fall within

4. How many of these complains do you get in a month
5. What health advice do you give to such patients’?

6. Do they adhere to your institution’s advice? Yes ( ) No ( )
7. If No what reasons do they give for doing otherwise

8. Are there any deaths brought to your institution which is associated with the pottery industry? Yes ( ) No ( )

9. If yes how many in a year?

Dust related diseases

10. Do you get reports on dust related diseases? Yes ( ) No ( )
11. If yes which ones are common in this community?
12. What are the possible causes?

Heat related Disease

13. Do patients complain of heat related diseases? Yes ( ) No ( )
14. If yes which ones?
15. Are there other complains of patients that could be as a result of excessive heat on the body? Yes ( ) No ( )
16. What are they?

Ergonomic related diseases

17. Are there patient with diseases caused by repeated actions of any kind for a period of time? Yes ( ) No ( )
18. Does patient come to your institution with specific musculoskeletal disorders of any kind? Yes ( ) No ( )
19. If yes which ones?
20. Which occupation does most of these patient suffering from these diseases belong to?
21. Which sex and age brackets do these patients belong?

Appendix E

Table 8.3

SimaPro 8.0.3.14	Impact assessment	Date:	5/17/2019	Time:
Project	Extraction of raw materials			
Calculation:	Compare			
Results:	Impact assessment			
Product 1:	1 p M-Extraction Clay (of project Extraction of raw materials)			
Product 2:	1 p V-Extraction Clay (of project Extraction of raw materials)			
Method:	ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A			
Indicator:	Characterization			
Skip categories:	Never			
Exclude infrastructure processes:	No			
Exclude long-term emissions:	No			
Sorted on item:	Impact category			
Sort order:	Ascending			
Impact category	Unit	M-Extraction Clay	V-Extraction Clay	
Climate change Human Health	DALY	8.97857E-07	4.61022E-07	
Ozone depletion	DALY	8.50525E-11	2.69579E-11	
Human toxicity	DALY	6.22315E-08	3.65562E-08	
Photochemical oxidant formation	DALY	1.46479E-10	6.21857E-11	
Particulate matter formation	DALY	3.27228E-07	2.05101E-07	
Ionising radiation	DALY	1.03101E-09	6.41588E-10	
Climate change Ecosystems	species.yr	5.0842E-09	2.61E-09	
Terrestrial acidification	species.yr	1.53308E-11	1.17967E-11	
Freshwater eutrophication	species.yr	3.57389E-12	2.61918E-12	
Terrestrial ecotoxicity	species.yr	5.11757E-11	4.6185E-11	
Freshwater ecotoxicity	species.yr	2.81102E-12	1.35847E-12	
Marine ecotoxicity	species.yr	6.01181E-13	2.94509E-13	
Agricultural land occupation	species.yr	5.00636E-10	4.34462E-10	
Urban land occupation	species.yr	4.71854E-10	2.62322E-11	
Natural land transformation	species.yr	4.33148E-10	3.78069E-10	
Metal depletion	$	0.001813324	0.00060682	
Fossil depletion	$	0.02831537	0.010050938	