DETERMINING PHYSICAL - CHEMICAL PROPERTIES OF ZAMBIAN SOILS USED AS PLASTER PASTE - LUAPULA

BY

BRIAN C. MULENGA

A dissertation Submitted to the University of Zambia in partial fulfillment of the requirements of the degree of Master of Engineering in Construction Management

UNIVERSITY OF ZAMBIA

LUSAKA

February 2019

DECLARATION

I, Brian Chileshe Mulenga do here by declare that the work presented in this dissertation, is from my own effort unless otherwise indicated in form of references or acknowledgements. This work according to my knowledge has not been presented for a degree by anyone at this university or at any other university.

Signed: …………………………………………………………………

Date: ……………………………………………………………………

APPROVAL

This dissertation of Brian Chileshe Mulenga is approved by the University of Zambia in partial fulfillment of the award of the degree of Master of Engineering in Construction Management.

Dr Edwin Nyirenda
…………………………… Signature: …………………… Date: ....
Examiner 1

Dr Backsion Tembo
…………………………… Signature: …………………… Date: ....
Examiner 2

Dr Joel Kabika
…………………………… Signature: …………………… Date: ....
Examiner 3

Prof Levy Siaminwe
…………………………… Signature: …………………… Date: ....
Chair person, Board of Examiners

Dr Erastus M. Mwanaumo
…………………………… Signature: …………………… Date: ....
Supervisor

ABSTRACT

Soil plaster pastes have been used around the world by local rural populations for centuries to give a finishing touch to their houses, and depending on the soil used, some chemical contamination cannot be ruled out. Some soils may contain heavy metals and other parameters depending on where it is located and the type of environment.

The purpose of this study is to determine the physical and chemical properties in the abundant Zambian coloured soils found in Luapula Province, Mwansabombwe area in Kawambwa District that are used for plastering houses mainly by rural communities. Similar types of soil are found in many other areas around the country. The presence of heavy metals and other parameters could affect the soil colour if binders are added in order to improve these plaster pastes.

Analysis of the soil samples was as follows: The pH meter with combined electrode and saturated potassium chloride (KCl) was used to analyze for pH; while for all heavy metals i.e. copper, iron, manganese and chromium, a laboratory protocol of sample digestion analysis for ore and soil was used. Organic content was analyzed by the Walkley Black method involving the reduction of potassium dichromate by the organic carbon compound. Barium sulfate precipitation was used for sulfates and chlorides in titration.

Traces of heavy metals found averaged as follows: Copper in all the six samples was 20% , Iron in all the six samples was 0.5395 %% , Chromium in all the six samples was 0.002% , Manganese in all the six samples was 16.17 % respectively. While Organic matter in all the six samples was 18.47 ppm, Chlorides in all the six samples was 11.76 ppm, Sulfates in all the six samples was 10.26 ppm, pH in all the six samples was 5.62

Traces of heavy metals: manganese, iron copper and chromium including parameters: pH, organic matter, sulfates and the chlorides were found in the soil samples. Signifying that, an addition of a binder may trigger a reaction that may alter the original natural colour of the soil. If soil colour is lost then, the desired results of improving the soil paste for use in the construction industry as a plastering material is defeated.

Key words: Soil colour, Soil plaster paste, heavy metals, pH measurement.

DEDICATION

Dedicated to people who love to increase knowledge to society and especially my own wife Nelly, and children Lombe, Pule, Chiyeya, Mawili, Jeftel, Kasonde, in that order; and of course to my late mother Helen Lombe because it was from her sacrifices even when she never tested formal employment but she managed to sponsor my education at lower level or foundation stage which was the most important time of my life. Special recognition to my late uncle Edmond Kasonde who always helped whenever, my mother did not find enough money.

ACKNOLEDGEMENT

In such rare moments it is very gratifying to acknowledge people who are really dedicated to their work without fear or favor, Dr E. M. Mwanaumo as my supervisor gave me direction, encouragement, reminders and all forms of shaping of my approach to this study.

Dr J. Nyirenda the Head of Department – Chemistry as my co-supervisor for increasing my understanding of chemical analysis of elements and parameters involved in this study.

My acknowledgements to all who had the opportunity to make comments and critic this study

TABLE OF CONTENTS

CHAPTER TWO - LITERATURE REVIEW...9

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

pH	The acidity or alkalinity
OM	Organic Matter
SO4	Sulfates
Cl	Chlorides
Fe	Iron
Cu	Copper
Mn	Manganese
Cr	Chromium
PSD	Particle Size Distribution
%	Percent
S1	Soil type 1
S3	Soil type 3
S4	Soil type 4
S5	Soil type5
S6	Soil type6
ppm	Parts per million
Cob	A mixture of clay, sand, straw
ATSDR	Agency for Toxic Substances and Disease Registry
CBU	Copper Belt University
VOC	Volatile Organic Compounds

PRM	Passive Removal Material
GRZ	Government of the Republic of Zambia
DSM	Department of Surveys and Mapping
HATAB	Hospitality and Tourism Association of Botswana
CSO	Central Statistics Office
UNCHS	United Nations Centre for Human Settlements
XRPD	X-ray Powder Diffraction
PLM	Polarized Light Microscopy
XRFS	X-ray Fluorescence Spectrometry
SEM-EDS	Scanning Electron Microscopy Equipped, Energy Dispersive Spectrometer
GSD	Grain-Size Distribution
MIP	Mercury Intrusion Porosimetry
GLP	Good Laboratory Practice
AAS	Atomic Absorption Spectrophotometer

CHAPTER ONE – INTRODUCTION

1.1 Introduction

Traditional African architecture focuses on the gains of using local materials and possible integration of technology into housing on the African continent. Three well-defined materials that are prominent in the building traditions of Africans are; stone, straw and earth (Ejiga et al., 2012). An estimated 30% of the world population lives in earth built structures (Dethier, 1981). According to Oshike (2015) citing Walker and McGregor (1996), earth is the most basic, building material used.

Zambia's history of local housing architecture and construction has revolved from the use of timber poles and grass-walls with thatched roofs to poles and mud-walls and thatched roofs; and from timber poles smeared with mud and thatched roofs to adobe bricks and stabilized brick walls. In order to make these houses attractive, earth is mixed with water forming mud that is applied to the walls by hand as a plaster paste and this leaves the surfaces very rough and porous. The method solves the inhibiting costs of formal paint for rural communities. It has also given rural people the opportunity to innovation. However, the quality of this plaster paste must meet the correct properties of a paint-like final finished film that is smooth, continuous, and attractive to the eye. There is need therefore, to actively promote the development of local building materials through research by improving the quality of the soil plaster paste. This study, seeks to start the process of improving the quality of the earth plaster paste paint by assessing the physical chemical properties of the soils obtained from Salanga village in Kawambwa, Luapula Province of Zambia.

Before the use of Portland cement, most earth, brick and stone structures were protected by earth plasters. Earth plastering is still used in other parts of the world; and the advantages of these plasters include breathability, softness to the touch, beauty and workability. They are versatile, easy to repair and made from inexpensive materials (Kennedy, 2003).

1.2 Zambia's Traditional Housing Revolution

Houses that, the Kaonde tribe have utilized from the very earliest houses to homes closer to what many Kaondes live in today, in sequential order as shown in the following (Figures 1.1 – 1.4); while Figures 1.2 and 1.3 particularly depict African vernacular architecture.

Figure 1.1. The first house made out of a termite mound, photo by Tilbury (2011)

Figure 1.2 African Vernacular Architecture – Source: Pinterest.com (2018)

Figure 1.3 House decorated with earthen plaster paste Photo by Zebron (2011)

Figure 1.4 National Housing Authority low cost house Source: NHA (2004)

1.3 Definitions

Soil - is defined as a loose material formed by climatic factors such as the sun, wind, rain, frost, and may be referred to as earth in building construction. Earth plaster paste in this context is mud that is a wet plastic soil mixture with or without additives. It is a mixture of soil in its natural form and water (Estefan et al., 2013). Soil colour can be a useful indicator of some of the general properties of a soil, as well as some of the chemical processes that are occurring beneath the surface (Moody and Thi, 2008). Soil colour is usually due to 3 main pigments:

• Black- from organic matter

• Red- from iron and aluminum oxide

• White- from silicates and salts.

1.3.1. Paint

Paint - is a term used to describe a number of substances that consist of a pigment suspended in a liquid or paste vehicle such as oil or water. Paint is normally made for the purpose of protecting surfaces such as metal, wood or stone but it is used as a decoration as well. Essentially paint is a mixture of a binder, which sticks the paint to the surface, a pigment to give the paint colour, make it opaque and occasionally to prevent corrosion and solvents to make the paint spreadable.

Plaster paint has been used for many years around the world especially in Africa's rural communities on local houses. In Zambia the existence of very attractive soil colours in certain areas make houses appear as if formal paint has been applied (Prudenti, 2013).

Since there have been no formal paints that can stick well to the walls made out of mud plaster, and the inhibiting cost of formal paint, people in rural areas resort to locally available soils to beautify their homes. Those fortunate enough find soils that have naturally very good colours. So, there is need therefore, to actively promote the development of local building materials through research by improving the quality of local materials presently in use so as to extend the projected lifespan of the housing structures and maintain their natural colours that come with these materials.

According to Dobson (2015) however, the lack of knowledge and research on the uses of earth or soil as a construction material as compared with other more traditional construction materials like concrete, steel, masonry and timber means a lack of understanding of the material and its structural properties. The other problem, according to Dobson (2015), is lack of regulations about the use of earth materials for construction. Thus, the prospect of working with an unregulated construction technique discourages many engineers and architects.

In Figure 1.5, the photos show Zambian traditional houses being decorated with a finishing touch of coloured natural soils in Kawambwa, Luapula province. The housing structures are built depending on the locally available materials. Some areas have good quality clay that is used to make burnt bricks. Other areas have bamboo, an important building material. The main materials of brick, bamboo, thatch, and poles are used in various combinations and techniques. The colour of brick and plaster depends on the colour of the local clay (Sojkowsk, 2015).

Figure 1.5 Traditional home decoration in Kawambwa - Pictures by Sojkowski (2002)

An African or Zambian construction style should focus on vernacular materials, with modern materials used as reinforcement when needed for larger structures or for greater stability. Research is needed to understand different soil conditions and content in order to come up with load calculations for pole and mud-brick structures as suggested by Mwango (2005) and

Hadjri, (2007) in a research called" Attitudes towards earth building for Zambian housing provision" that, insufficient use of low-cost traditional construction techniques in the Zambian residential construction industry has resulted in expensive housing stock for the majority of the poor. There is therefore an urgent need to assess alternative building materials and techniques that are both affordable and sustainable. Earth is actually one material that should be considered as a viable building material. Vernacular architecture suggests a contemporary approach to building that uses local materials and crafts, as well as the indigenous architecture of tribal peoples, such as dwellings over tropical waters, and mud houses (Richards, 2012).

1.4 The Statement of the Research Problem

The construction industry in Zambia is lacking development of new construction materials through research (Mwango, 2005). Therefore, there is need to do more in the field of research to develop new materials from local raw materials in order to reduce on the cost of importing materials (Agarwal, 2007) and move away from the dependence syndrome where, research on construction materials is mainly done outside Zambia. A call was made in the Zambia Daily Mail of Tuesday 29th December 2015, for research proposals under the Industry category by the Ministry of Higher Education, through National Science and Technology Council, for the development and or improvement of the quality of construction and building materials for Zambian conditions. This call for proposals suggests the need to conduct a study and establish whether the Zambian soils can produce improved plaster paste paint used by rural communities.

1.5 The Aim

To determine the physical - chemical properties of plaster paste paint made from Zambian soils that is used by rural communities with the view of improving the paste.

1.6 Research Objectives

1. To establish the types of colours from soil samples that, were collected from
Kawambwa District, Luapula Province
2. To determine the presence of chemicals and heavy metals in terms of Physical- chemical

properties in the soil.
3. To establish the extent to which current conventional additives can apply to the developed soil plaster without altering natural properties.

1.7 Research Questions

1. What were the types of colours found in this particular research areas in Kawambwa, Luapula Province?
2. What could be the physical – chemical properties present in the soil samples?
3. What current conventional additives could be applied to the soil plaster paste that would not, alter the natural soil colour?

1.8 Rationale of the study

The study will help to increase the knowledge base about Zambia's soils that exhibit natural colours and are widely used mainly by households and schools in rural parts of the country as a construction material.

1.9 Scope of the Study

The research concentrated on one type of paint that is used in the construction industry, this is, water paint. The study was carried out on samples from Salanga village, Kawambwa, Luapula Province of Zambia due to the various soil colours that exist within the 1kilometer radius of the study area.

1.10 Organisation of the Dissertation

In Chapter one, the subject of the whole study is introduced including the statement of the research problem and the aim of the study. The research objectives and research questions, the rationale and scope of the study are given. While Chapter two discusses the work done by several other research related to this topic from various authors and countries.

Chapter three discusses the methods that were used to select the sample area, the sampling method, research design, sample analysis methods, sample size, limitations, objectivity and some ethical considerations.

Chapter 4 discusses the results obtained from all the laboratory analysis, interpretation of the results and the value added to the study. Tables, pie charts and graphical presentations are given.

Chapter five presents the discussion of the results, the soil colour charts, interpretation of colour charts, the first, second ,third and fourth objectives, the Binders, Additives, costs of formal paint and costs of soil plaster pastes.

Chapter six presents conclusion and recommendations. In this chapter the colours that were identified are given in a table too.

1.11 Conclusion

Chapter one has therefore, given the background to the study and has given a hint on what is contained in the whole dissertation. The chapter has highlighted that the dissertation has ended with the recommendations, references and appendixes.

CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction

In this chapter, the uses of natural materials for purposes of building construction especially by rural communities around the world will be explored. Soil or earth as it is referred to in construction will be the main subject; although the chapter will look at related materials such as synthetic materials too. Some research work that has been done on this subject will be discussed including some advantages and disadvantages of using earthen plaster pastes. A conceptual frame work will be introduced to guide this study.

2.2 Natural Building Materials

Natural building means, sustainable building in which natural building utilizes little processed, nontoxic materials and systems used appropriately for the climate, site and intended use. It incorporates mainly natural materials rather than high energy processed commercial materials with a focus on getting these natural materials from as local a source as possible mostly, from the building site itself (Weismann, 2008).

Choosing natural building materials helps reduce on the use of man-made materials. Additionally, it also minimizes the use of products that require a great deal of energy during manufacture and transport. The focus is on simple construction methods that do not damage the environment, consume fossil fuel and are sustainable. Some natural building materials include the following (Wanek, 2012):

Adobe - Adobe continues to be one of the oldest building materials that, has remained in use to the present day. Adobe is made up of dirt mixed with water, and sometimes other fibres as well, to add additional strength. It is then sun-dried into the desired shape - which is most often like bricks - that are then stacked with a mud mortar in order to form a wall.

Straw Bale - Straw bale building has become almost main stream in the South western parts of the United States. Straw is a renewable resource with excellent insulation properties that has the added benefit of being fire-resistant. Straw bale is also used as infill for timber frame and in a load bearing capacity to carry the weight of the roof.

Cob - Cob is a sustainable material that can be traced back to ancient times and is a multi-faceted green building material. Cob structures are made with clay or sand, local earth and with added fibres like straw. It is all then made into a stiff mud that is formed into cobs. The materials are then mixed together and applied over a concrete or stone foundation.

Wood - Wood continues to be one of the most commonly used building materials. However, for natural building purposes, the wood should be renewable and sustainably harvested. Wood is also used for frames, trim and flooring.

Cord wood - Cord wood is similar to what is considered firewood. Using cord wood is resource-efficient because this type of wood may not have any other value.

Bamboo - is fast-growing and strong for its weight. The sustainable material is used in many building applications. This includes a concrete replacement for rebars and as pins for straw bale building.

Masonry - is also an ancient building material and includes brick and stone. Brick and stone are used for foundations, floors, walls, walkways and landscaping.

Earth bags - are also referred to as sandbags. Long used by the military, they provide a strong protective barrier, especially against flooding. The success of using earth bags in this capacity has made them useful in a variety of building applications. This includes the building of massive, substantial walls that resist severe weather - as well as bombs and bullets.

Earth - is used to construct different types of homes. A rammed earth technique, used since ancient times, is made up mostly of clay and sand material, then tamped or compressed into place - usually creating a flat vertical surface. The poured earth construction technique uses Portland cement as a binder and is then mixed and formed like concrete and the poured earth technique uses specific ordinary soil.

2.3 Reclaimed Materials

Help reduce building waste. Modern day construction causes massive amounts of waste during the building process. Building waste reclaimed includes salvaged wood, doors, windows, piping, insulation and chunks of concrete. By using the reclaimed waste in the building process, it serves as a means of reducing the environmental impact on society (Wanek, 2012).

The building industry is a vital element of any economy but has a significant impact on the environment. By virtue of its size, construction is one of the largest users of energy, materials resources, and there is growing consensus among organisations committed to environmental performance targets that appropriate strategies and actions are needed to make building activities more sustainable (Abidin, 2010). With respect to such significant influence of the building industry, the sustainable building method has a high potential to make a valuable contribution to sustainable development.

2.4 Reasons to build with natural material

There are many reasons that can be advanced to justify the use of natural materials in building but for this study, only a few have been referred to as follows:

1. *Local and Environmentally Friendly*

Natural building promotes locally occurring, natural materials that don't require the use of large amounts of petroleum or minerals. If abandoned, natural buildings will degrade into the surrounding land (Amanda, 2013).

2. *Inexpensive*

Since cob and adobe are made of clay, straw, sand and water, little materials will be bought hence, a home can be built on a very low budget (Amanda, 2013).

2.5 For good health

Homes built with earthen materials are porous and actually help keep the air to breathe fresh and clean (Amanda, 2013).

2.6 Minimize waste through sustainability

A lot of sustainable building materials use recycled materials so that, the more we re-use products, the less we acquire new products and deplete world resources and at the same time waste less energy manufacturing new materials (Little, 2014).

3. *Locally available materials*

Local materials are extremely sustainable because they eliminate the cost and energy consumption that goes into transporting goods from all over the places (Little, 2014).

2.7 Understanding earth

One of the challenges of working with earth is that no two sites are the same. Therefore, recipes one learns on one site may not work on another, because the earth found there are composed differently. Earth building in this case should depend on a mix of sand and clay, which may be present in a single place (McIntosh, 2014).

4. *Straw bale*

Straw bales are bricks of straw created by compressing and tying loose straw after the grain seeds have been removed. Straw is an annual renewable material, available wherever grain crops are grown (Ruppert, 2013).

5. *Bamboo*

Bamboo actually has been locally-sourced in some regions of the world for millennia as a building material. What makes bamboo such a promising building material for modern buildings is its combination of tensile strength, light weight, and fast-growing renewable nature. Used for framing buildings and shelters, bamboo can replace expensive and heavy imported materials and provide an alternative to concrete and rebar construction, especially in difficult-to reach areas, post-disaster rebuilding, and low-income areas with access to natural locally-sourced bamboo (Peckenham, 2016).

Bamboo is a highly sustainable, cost-effective and beautiful construction material for homes. It can be used throughout the entire structure, inside and outside especially if preventative measures are taken to avoid rotting and termites (Kati, 2012).

6. *Cob*

Is a mixture of sandy-sub soil, clay and straw. It is the most sustainable form of building materials. Materials for the cob walls are usually excavated from the foundation trench and on-site. This means that, there is no manufacture or transportation of the required materials. It is an ancient technique of building monolithic walls using moist earth mixed with straw (Edwards and Eve, 2017).

7. *Wood*

From Wagner Meters, Loffer (2017) reports that, wood is both a common and a historical choice as a building material. It is strong in compression and tension, easily worked and beautiful. While in conventional construction wood is often used wastefully. Wood has a natural resistance to electrical conduction when dried to standard moisture content. Wood absorbs sound, rather than reflecting or amplifying it and it has many more useful characteristics.

2.8 Sustainability Concept

The concept of Sustainable development as defined by Singh (2016) has emerged from an agreement on how to tackle the "burning issues" of the 21st Century such as: poverty, increasing inequality, environmental and human health degradation. Sustainability is a broad and complex concept, which has grown to be one of the major issues in the building industry. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The idea of sustainability involves raising the quality of life, so that people live in a healthy environment, with improved social, economic and environmental conditions.

A sustainable project is designed, built, renovated, operated or reused ecologically and resourcefully (Ortiz et al., 2010). An ideal project should be inexpensive to build, last forever with little maintenance, but return completely to the earth when abandoned. Two key concepts emerge: the concept of "needs", in particular the needs of the world's poor, to which priority should be given; and the limitations imposed by the state of technology, social and the environment's ability to meet present and future needs (WCED, 1987). World Commission on Environment and Development

2.9 Framework for Sustainance

In order to achieve a sustainable future in the building industry, Asif et al (2007) suggest adoption of multi-disciplinary approach covering a number of features such as: improved use of materials, material waste minimization, pollution and emissions control etc. According to Asif, there are many ways in which the current nature of building activity can be controlled and improved to make it less environmentally damaging without reducing the useful output of building activities. A review of literature has identified three general objectives which should shape the framework for implementing sustainable building design and construction (Figure 2.1), while keeping in mind the principles of sustainability which are social, environmental and economic. These objectives are: (1) Resource conservation (2) Cost efficiency and (3) Design for Human adaptation.

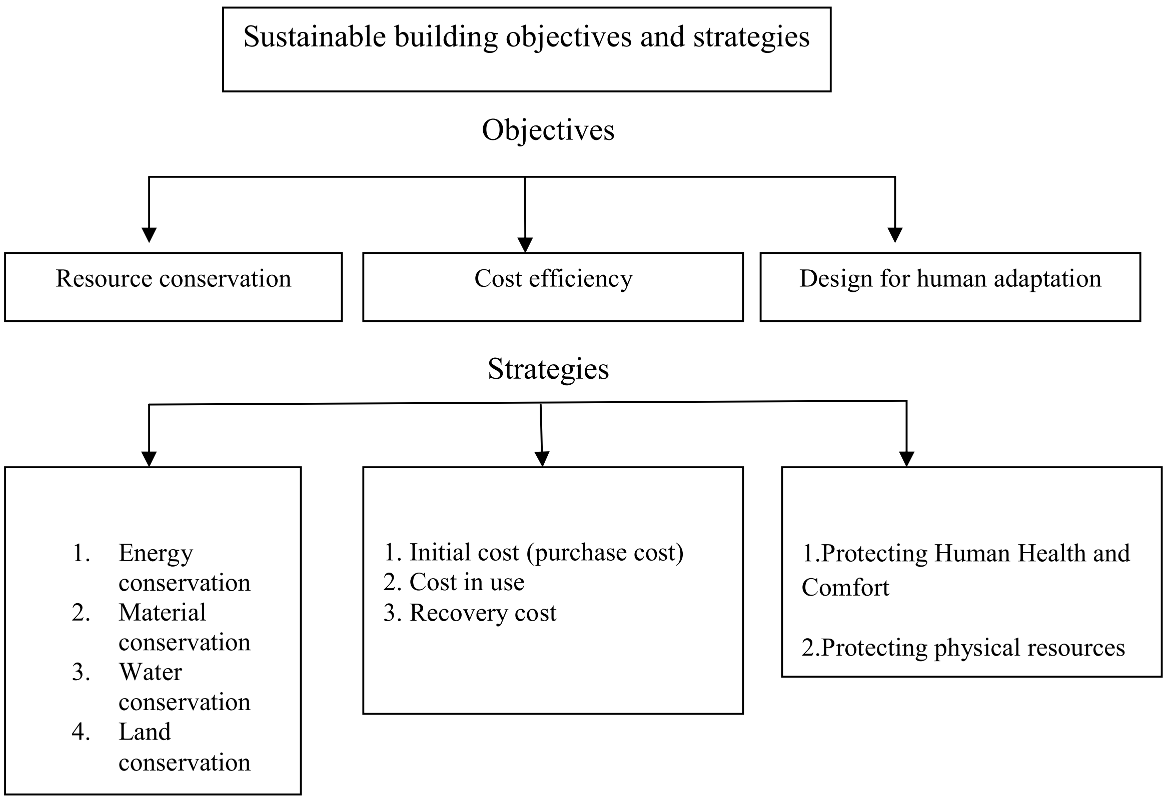


Figure 2.1 Sustainability Frame work in Building Construction (Asif et al 2012).

2.10 Durable materials

Mora (2007) defined durability as an indicator of the extent to which a material maintains its original requirements over time. The sustainability of a building can be enhanced by increasing the durability of its materials and a material, component or system may be considered durable when its useful service life is fairly comparable to the time required for related impacts on the environment to be absorbed by the ecosystem. Materials with a longer life relative to other materials designed for the same purpose need to be replaced less often. This reduces the natural resources required for manufacturing and the amount of money spent on installation and the associated labour. The greater the material durability, the lower the time and resources required to maintain it (De Silva et al., 2004). Durable materials that require less frequent replacement will require fewer raw materials and will produce less landfill waste over the building's lifetime

2.11 Green Materials

Green building materials are materials that are composed of renewable, rather than nonrenewable resources. Green materials are environmentally responsible because impacts are considered over the life of the product (Spiegel and Meadows, 1999).

According to Russell (2010), Researchers from different backgrounds such as engineering, materials science, architecture, and chemistry are beginning to investigate the different properties of earth or soil with the aim of promoting construction techniques and developing new or improved materials from it.

Cai et al (2011) report that, since the reform and opening up of China, there is rapid development of the economy, society and living standards, and there is more demand for better quality housing and environment, hence, there is more research, development and use of green building materials in terms of construction and decoration.

2.12 Green Buildings

Kamana and Escultura (2011) defined "sustainable building" or "green building" as an outcome of a design which focuses on increasing the efficiency of resource use - energy, water, and materials - while reducing building impacts on human health and the environment during the building's lifecycle, through better location, design, construction, operation, maintenance, and removal. Pan et al (2011) added that a green building is an outcome of a design philosophy which focuses on increasing the efficiency of resource use. Deuble and de Dear (2012) stated that green buildings, often defined as those featuring natural ventilation capabilities, i.e. low-energy or free-running buildings, are now at the forefront of building research and climate change mitigation scenarios. Figure 2.2 illustrates the meaning of Green Building.

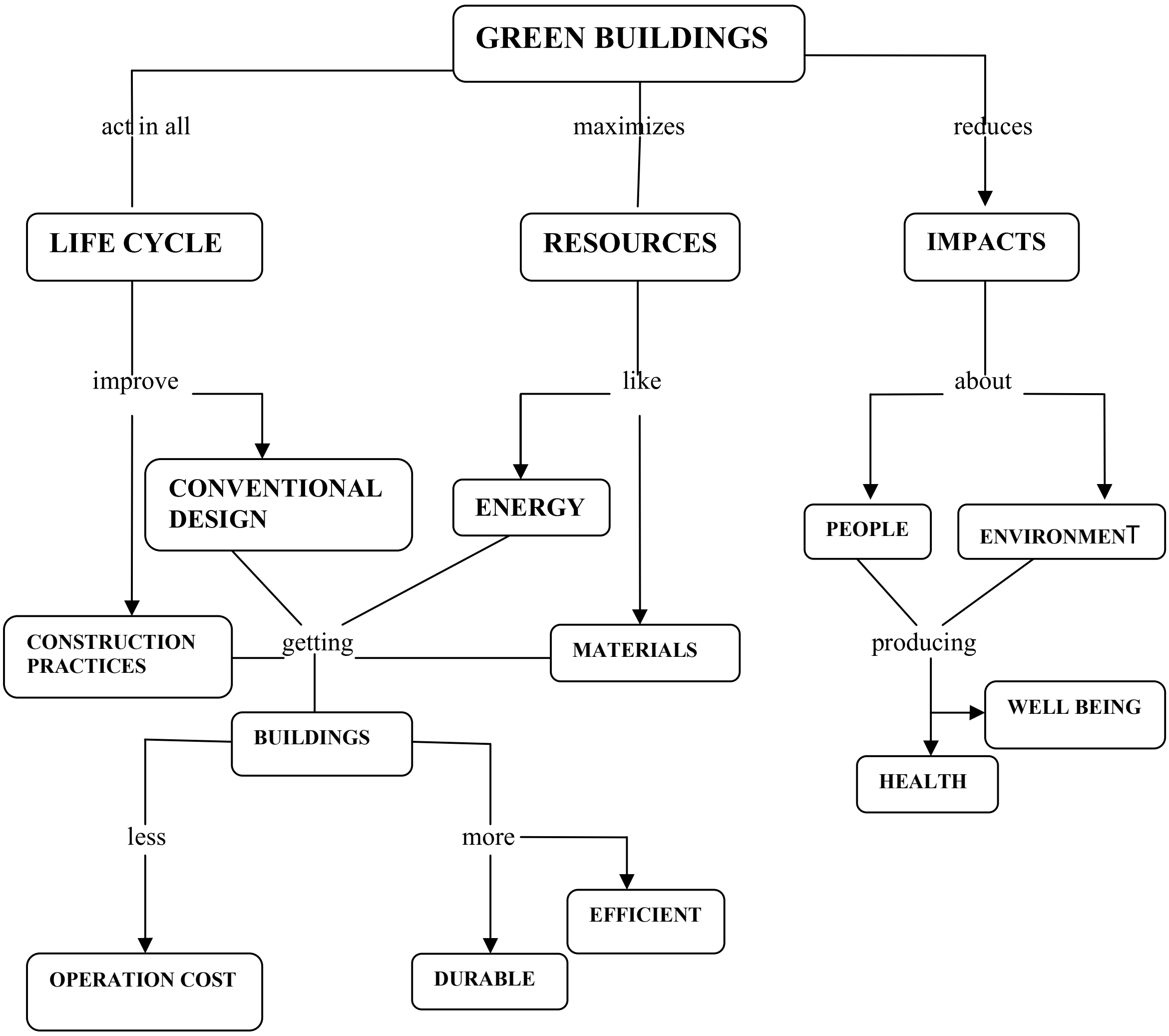


Figure: 2.2. The meaning of Green Building (Owens 2012)

According to World Green Building Council (2016 - 2018), a ‘green’ building is a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on climate and natural environment. Green buildings preserve precious natural resources and improve quality of life. Some features which can make a building ‘green’ include: efficient use of energy, water and other resources, use of renewable energy, such as solar energy, pollution and waste reduction measures, and the enabling of re-use and recycling. Good indoor environmental air quality, use of materials that, are non-toxic, ethical and sustainable. However, not all building should be the same because different countries and regions have a variety of characteristics such as distinctive climatic conditions, unique cultures and traditions, diverse building types and ages, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building.

2.13 Synthetic Materials

Mishra (2017) the author of ‘Constructor’ a Civil Engineering News Letter defines building material as any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to construct buildings. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic. Building materials can be generally categorized into two sources, natural and synthetic. Natural building materials are those that are unprocessed or minimally processed by industry, such as timber or glass. Synthetic materials are made in industrial settings after much human manipulations, such as plastics and petroleum based paints.

According to Lembeck (2007), synthetic pigments, in general, are manufactured by rather toxic and energy-consuming processes. In addition, a lot of these pigments contain large amounts of heavy metals such as lead. All the synthetic components are derived from crude oil called petrochemicals that are known to contain many toxins. Toxins are known to contribute to or cause cancer, ozone depletion, lead poisoning and respiratory problems. Others are depression of the central nervous system, headache, nausea and dizziness, irritation to the skin, eyes, and respiratory tract, asthma, anaemia, and bronchitis.

2.14 Earth as a building material

Daniela (2015) put it that, lack of knowledge and research on the uses of earth or soil as a construction material as compared with other more traditional construction materials such as concrete, steel, masonry and timber, and lack of regulations about the use of earth materials for construction means a lack of understanding of the material and its structural properties

2.15 Pigments

Soils are one of our most important natural resources. They also are important for the beauty their many colors add to our landscapes. Most of us overlook this natural beauty because we see it every day. Often these colors blend with vegetation, sky, water, etc. Soil colors serve as pigments in bricks and pottery. Soil colour is usually due to 3 main pigments: black from organic matter, red from iron and aluminium oxides, white from silicates and salt.

Merriam Webster Dictionary, defines pigment as a substance that imparts white or a colour to other materials; especially : a powdered substance that is mixed with a liquid in which it is relatively insoluble and used especially to impart colour to coating materials such as paints. Figure 2.3 shows Pigments made from ore deposits around the world (Natural pigments, 2015) while Table 2.1 below gives the description or names of these pigments.

Pigment 1 - is Vermilion, a dense red mineral, is made by subliming a mixture of mercury and sulfur, and is usually described as an intense reddish orange or sometimes as a dark reddish purple. Vermilion varies in masstone colour from strong red to vivid reddish orange in Munsell range from 5R to 7.5R. Vermilion is red mercuric sulfide made from ore deposits in the Huan province of China and prepared according to a Chinese ancient process known as the "dry process." It exhibits a beautiful masstone colour of strong red with a tendency toward reddish orange.

Pigment 2 - is usually found in mineral deposits of calcite along with orpiment and sometimes with other sulfide minerals, such as cinnabar. Excellent specimens of realgar were discovered in cavities of dolomite in Binnentale, Switzerland, and in calcite voids in Mercur, Utah, U.S.

Realgar is obtained from deposits in the Hunan province of China where it is found in large druses (cavities in a mineral filled with protruding crystals) of beautifully formed crystals. It exhibits an intense orange red colour with a scintillating quality of the coarse ground pigment.

Pigment 3 - Natural Red Oxide is from ocher deposits in the French quarries of Gargas and Rustrel nestled in a 12 mile long enclave in the heart of the Luberon Massif, the ocher country. Red iron oxide is the principle colouring agent in red ochers, such as Indian red, Terra Pozzuoli, Venetian red, etc. These pigments are basically composed of the mineral hematite with varying proportions of accessory mineral, such as clay, chalk and quartz. They differ from yellow ocher and brown ocher in that they do not contain water combined in their chemical structure. In other words, the iron to which they owe their colour is iron oxide not iron oxide hydroxide.

Pigment 4 - Azurite is a natural carbonate of copper usually described as a bright blue or sometimes as a greenish blue. Azurite varies in colour from deep blue to pale blue with a greenish undertone depending on such factors as the purity of the mineral and the grade (particle size) of the pigment.. It is a natural carbonate of copper from ore deposits in Dzhezkgazgan, Kazakhstan.

Pigment 5 – is an artificial basic copper carbonate pigment mentioned in 17th century literature. The manufacture of basic copper carbonate was carried out by silver refiners in the 17th century. The process was difficult, slow and somewhat unpredictable, and the resulting hue could vary from an azure blue to a green with a distinctly bluish cast.

Pigment 6 - Naples yellow is produced by fusing lead and antimony together, yielding a pale to deep yellow pigment that is ground and screened through a fine mesh. Lead antimonate yellow contains lead and is rated toxic, especially by prolonged exposure through ingestion or inhalation. Utmost care should be used in handling the dry powder pigment to avoid breathing the dust. It is only moderately toxic in contact with the skin.

Figure 2.3 Examples of Pigments from Ore deposits – (Source: Natural pigments 2015)

Table 2.1 Pigment Legend: **(**Source: Natural pigments 2015)

S/N	PIGMENT DESCRIPTION
1	Rublev colours Vermillion
2	Realgar pigment
3	Natural red oxide – Indian red pigment
4	Azurite is natural carbonate of copper from ore deposits in Dzhezkgazgan
5	Green Bice pigment
6	Rublev colours Naples Yellow Light

2.16 Advantages of using earthen based paints

Clayworks (2014) reports that, while each type of finish has its own advantages and disadvantages, clay plastered walls stand out with many unique properties not found in any other finish. Natural earthen plasters fall into three main categories, clay, lime, and gypsum. There are many reasons why natural plasters are the best choice for building finishes. Some of the advantages of using clay earthen plaster are as below (Crews, 2016).

- Clay plaster can be applied by hand or with a trowel.
- There is no need to apply a primer on the walls (Ziggy, 2008)
- Clay plasters are the most versatile of the three because its wide range of applications
- It is affordable (Agarwal, 2007)
- It is easy to obtain
- Clay sub-soils can be found almost everywhere in the world,
- They are often free to excavate
- They can be used in indoor and outdoor
- Can be used to make sculptures and relief carvings,
- They are easy to maintain.
- Clay based plasters can be made with clay rich subsoil or purchased
- It does not require any heating or processing
- Can be mixed with other binders, fibres, and pigments to enhance its inherent durability and aesthetic qualities (Delinière, 2014)
- Earth is very good in fire resistance (Walker et al., 2005)
- It is visually pleasing.

Other Benefits include:

- To begin with, earthen plasters can actually improve health because clay plasters maintain a consistent relative humidity of around 50-60%, which is beneficial for people with asthma or other respiratory problems. Clay contains no nasty chemicals, and is able to absorb toxins and thus improve indoor air quality. Of course, you'll try not to use toxic cleaners or buy toxic household products, but in this day and age, it's difficult to avoid toxins completely, and so clay plasters can help (Clayworks, 2014).

- They are entirely non-toxic (Lamble et al., 2011)
- They contain no Volatile Organic Compounds (VOC's),
- Clay and lime even resist mold and bacteria growth in the home
- An overlooked benefit of clay is that when it comes into contact with water it emits a negative charge. These negative ions which are released into the air help humans to absorb

oxygen which increases energy. This also helps to counteract the positive charges and ions that are emitted by home electronics and certain plastics which have a damaging effect on our bodies (Moreira, 2017).

- Because all of these varieties of plaster are porous, which allows the plasters to "breath" by absorbing moisture and humidity they help to control the interior climate and air quality of a building. This helps to regulate temperature and to prevent the growth of mold. Especially in the case of clay, this respiration can absorb and dissipate odours and even filter toxins in the air (Lamble et al., 2011).

- On top of the health benefits natural plasters are inherently environmentally friendly and have a low embodied energy in their production. Natural plasters are also affordable, durable and easy to repair. Anyone can learn to mix and apply them. Lastly, all earthen plasters are fire retardant which helps to improve the safety of the home (Liblik, 2015).

2.17 Disadvantages of using earthen based paints

Compared with some building materials earth can have some disadvantages as follows:

- It has relatively low compressive strength (Henry, 2015)
- Its tensile strength is low (Russell, 2010),
- The abrasion resistance is also low
- It may lose a lot of its rigidity in the presence of water.
- Neither local nor European Standards exist for this type of mortars, only the Germany Standard DIN 18947 on the subject was released recently called as DIN. (2013); Lima and (Faria, 2014). It is better to use water-based paints on walls because of better vapor diffusion and breathability which is defined by Collins English Dictionary as the ability to let air to pass through so that perspiration can evaporate. There is no need to apply a primer on the walls (Ziggy, 2008). The lack of knowledge, regulations and research, on the uses of earth or soil as a construction material as compared with other more traditional construction materials like concrete, steel, masonry and timber means a lack of understanding of the material and its structural properties (Dobson, 2015).

Researchers from different backgrounds such as engineering, materials science, architecture, and chemistry are beginning to investigate the different properties of earth or soil with the aim of promoting construction techniques and developing new or improved materials from it. Generally, earth plasters mainly consist between Clay 15 - 35%, Silt 0 - 10%, Sand 55 - 75% and Organic Matter 0 - 3%, (Lacinski and Bergeron, 2010). It might not be very easy to state what the proportions of an earth plaster should be, this is because the proportion of clay, silt and sand influence the properties, amongst other factors such as the grain size distribution of the sand fraction itself, the water content, the type of clay, the method of preparation and the additives. As a test for appropriateness of earth plasters, the earth plasters must stick very well on earth bricks, concrete and stone surfaces, while the surface should be rough enough (Ruppert, 2013).

2.18 Additives to earth plaster paste

Earth plaster may be affected by shrinkage cracks, to prevent cracking the following measures should be considered (Minke, 2011).

- A bit of animal or human hair, coconut or sisal fibres, cut straw or hay should be added as additives but not too much to reduce the ability of the plaster to adhere to the substrate.

- For interior plastering, sawdust, cellulose fibres, chaff of cereal grains or similar particles can also be used as additives.

- In order to develop enough binding force, the adhesive forces of the clay minerals should be sufficiently activated by adequate water and movement.

When the plaster sticks to a sliding metal trowel held vertically, yet is easily flicked away, the correct consistency has been achieved. If the surface of the walls demands a plaster thicker than 15mm, it should be applied in two layers, with the ground layer containing more clay and coarse aggregates than the second layer. If the ground layer gets shrinkage cracks, it is not problematic, but could help by providing a better bond to the final layer of plaster (Mahlke, 2013).

2.19 Earth plaster paste tests

In order to test the characteristics of an earth plaster, a simple adhesion test can be carried out. The plaster to be tested is applied 2cm thick to the flat surface of an upright burnt brick. The plaster has to stick to the brick until it is completely dry, which might take two to four days (Mahlke, 2013). If it falls off in one piece by itself, it contains too much clay and should be thinned with coarse sand. If it falls off in portions after the sample is hammered on the floor then it has insufficient binding force and should be enriched with clay. If the plaster sticks to the brick but shows shrinkage cracks, it is too clayey and should be slightly thinned with coarse sand (Ruppert, 2013). However, it could be used without thinning as the first layer of a two-layer plaster. If the surface shows no cracks and the plaster does not come off when hammered, the sample might be adequate. If shrinkage cracks occur, the mixture needs to be thinned with coarse sand or mixed with fibres (Minke, 2011).

2.20 Weather effects on earth plasters

Ruppert (2013) wrote that, exposed exterior plasters have to be seasonably weather resistant or must be given perfect weatherproof coating. It is important in cold climates that the plasters together with their coating have a low vapour diffusion resistance, so that water condensed in the wall can be easily transported to the exterior. The exterior plaster must be more elastic than its ground in order to meet thermic and hygric influences without cracking. In general, for cold climates, an external earth plaster is not recommended unless sufficient roof overhang, plinth protection and good surface coating can be assured. Suryakanta (2014) writes that, the prevailing weather at the time of plastering or during the setting, drying and hardening period may affect the setting and hardening times of all plasters as they are lengthened by a reduction in the atmospheric temperature. Where plastering has got to be carried out in cold weather, the time intervals should be lengthened
to allow for setting and hardening times.

2.21 Guidelines for plastering earth walls

Earth can be used as plaster for internal walls and ceilings as well as for external walls that are protected from adverse weather. A mixture of clay or loam and coarse aggregates with an additive improves the stability and abrasion resistance of the plaster (Schreckenbach, 2004). The coloured fine clay plasters are made of specially selected clay and earth with distinctive colourings and mixed with aggregates. Pigments can also be used to colour the clay mixture. These are applied manually rather than a machine and the surface colouring is such that no further painting or treatment is required.

- The surface to be plastered has to be dry, so no more shrinkage occurs.
- All loose material should be scraped off the surface.The surface should be sufficiently rough and, if necessary, moistened and grooved or the mortar joint chamfered, as described in section 2.
- Before plastering, the substrate should be sufficiently moistened so that the surface softens and swells and the plaster permeates the soft layer.
- The plaster should be thrown with heavy impact so that it permeates the outer layers of the ground and also achieves a higher binding force due to the impact.
- If the plaster has to be more than 10-15mm thick, it should be applied in two or even three layers in order to avoid shrinkage cracks.
- To reduce shrinkage cracks while drying, the mortar should have sufficient amount of coarse sand, as well as fibres or hair.
- To improve the surface hardness, cow dung, lime, casein or other additives should be added to the top layer.
- In order to provide surface hardness and resistance against wet abrasion, the surface should be finished with a coat of paint.

While using plasters, the change of physical properties caused by additives and coatings should be kept in mind especially with respect to vapour diffusion resistance.

2.22 Earthen plastering mortars

Faria et al (2016) wrote in the Journal of Materials in Civil Engineering, that Earthen plastering mortars have been found to be highly eco-efficient although at the moment only a German Standard is existing on technical properties. As loam plaster retains its plastic state for a long time and is not corrosive to the hands like lime or cement plasters, it becomes ideal to moulding with the hands (Minke, 2013).

Earth-based plasters can also contribute to indoor air quality because clay acts as a passive removal material (PRM), lowering indoor ozone concentrations, and therefore the probability of occurrence of indoor ozone reaction with other building materials. This leads to lower concentrations of oxidized reactions products, which could be toxic and irritating to mucosal membranes and other tissues (Darling et al., 2012).

2.23 How to make clay plaster

Natural earth plaster is made of three main elements, sand, clay and fibre (Ziggy, 2008).
Sand provides structural strength and makes up the bulk of any earthen plaster mix. Fine, sifted sand is used to provide a smooth finish without small stones or pebbles to interfere in the application (Henry, 2014). Clay is a binding agent which helps to make the earthen plaster sticky and adhesive. Clay is typically soaked and mixed to break up larger chunks before being mixed with the other ingredients. Your earthen plaster's colour may be determined largely by the colour of your clay and local clays come in a wide variety of colours (Fitzpatrick, 2012).

Fibers such as short, chopped straw, fluff, or fresh cow manure and Cattail fluff are common and important additions to earthen plasters (Mires and Peat, 2013). Fibres help make the plaster strong and resistant to cracking. Manure is the fibre of choice of many traditional peoples. Additional additives such as wheat paste help increase durability and stickiness. These ingredients can be mixed by foot or with a hoe in a wheelbarrow (Aubert et al., 2015). For an earth plaster recipe, the ratio of these basic ingredients may differ depending on the quality or type of materials that are chosen for example the recipe below (Ziggy, 2008).

- parts sand sifted through a 3.125mm screen
- 1 part soaked clay
- 3/4 part cow manure
- Cattail fluff 8 cups wheat paste

Clay plasters are now used all over the world in cities and in steel and modern buildings. However they have typically been used a lot in straw bale constructions and buildings with a lot of timber, due to their moisture-absorbing properties, and in other buildings where sustainable building products are key. Since clay is one of the most naturally abundant minerals, clay blocks and clay building methods are being rediscovered all around the world as a sustainable material with relatively low carbon intake (Goldberg 2017).

In Figures 2.4 and Figure 2.5 earthen plaster is applied by hand and with a trowel depending on the evenness of the wall's surface. The final mix should be soft, sticky, and wet, and it should hold readily to the pre-soaked wall. Small amounts of water may be added if plaster seems difficult to spread on the surface. Using hands at this stage may reduce cracking. Aim for 3/8″ to 1/2″, or whatever depth is necessary to smooth the wall or achieve the desired effect. Consider filling holes deeper than an inch and a half with cob rather than plaster. One technique that works well is to wet some plaster more than usual and apply a 1/8″ layer first. Then apply a second layer, also by hand, to the desired depth. It is recommended to work with such mixes as follows (Dancing Rabbit Eco-village, 2016):

- Pre-soak the work area 30 to 90 minutes before application
- Re-wet a small working area
- Smear on the plaster with a hand or with a trowel
- Make smooth the plaster with a trowel
- Finally, polish the plaster

After the plaster has dried for a few hours, use a plastic disc to remove the remaining small ridges and to further smooth the surface. The plaster should be stiff but not dry to do this step correctly. This may be performed several times as the plaster dries, and stop when it looks finished.

Figure 2.4 Application of earthen plaster – (Photo Source: Ziggy 2008)

Figure 2.5 Soil Plaster Paste – (VSNBD, 2017)

2.24. Paints

Crown Paints Kenya PLC defines paint as a coloured or clear, liquid or solid substance which when applied to a surface and exposed to heat, certain chemicals or air converts to a dry, coherent and adherent film offering protection, etc., to the underlying substrate. On the other hand Tortnum (2015) indicates that, contemporary paints and coatings consist of countless compounds uniquely formulated to fulfill the varied requirements of hundreds of thousands of applications. Paint ranges from the broad group of environmentally-sound latex paints that many consumers use to decorate and protect their homes and the translucent coatings that line the interior of food containers, to the chemically-complex, multi-component finishes that automobile manufacturers apply on the assembly line Edwards (2013) writes that, in most paints the four basic ingredients include: Solvents, Binders, Pigment and Additives.

2.25. Solvent

is a volatile liquid used to obtain desired viscosity and flow of the paint. It keeps the solid components of paint in suspension and also influences the adhesion properties of the surface. It is an optional component of paint since paints may not have solvent. Solvents evaporate after the application of paint leaving a solid dry film on the surface. The most common solvents are water and mineral spirits. Water is used in acrylic paints for both interior and exterior use while mineral spirits are used in oil based paints (Edwards, 2013).

2.26. Binder

May be called a vehicle or resin, it is one of the most important and necessary components of paint. The most common of these oils and resins are given in Table 2.1. They bind the pigment particles together to form a cohesive layer after the evaporation of the solvent. Binders influence other properties such as gloss, toughness, flexibility and durability. Linseed oil and poppy seed oil are two of the most common oils used as binders in paint. In solvent based paints the binder is usually an alkyd resin while in water based paints the binder is usually an acrylic emulsion but some vinyl emulsions are also used. Solid binders that are dissolved in a solvent but dry at the evaporation of the solvent are known as lacquers (Jamal, 2017). Binders may be natural, synthetic or oils, and the table below gives the most common oils and resins that are used as binders.

Table 2.2 Common Oils and Resins

Drying Oils	Natural Resins	Synthetic Resin
Linseed Oil	Kauri	Epoxy
Poppy Seed Oil	Damar	Alkyd
Soybean Oil	Ester	Acrylic
Tung Oil	Lac	Polyurethane
Olive Oil	Rubber	Silicone

Binders are substances that are used to bind inorganic and organic particles and fibres to form strong, hard or flexible components. This is generally due to chemical reactions which take place when the binder is heated, mixed with water or other materials, or just exposed to air. The binder is the actual film forming component of paint. The binder consists of acrylics, polyurethanes, polyesters, resins, epoxy or oils. As the wet paint is put on the wall, the binders control how the paint dries or cures. As the water component of the paint evaporates, the binder forms a solid film on the top layer of the paint. Latex paint is a water-based paint that means any spills can be cleaned up using water. Depending on the binder, some paints "cure" meaning all the parts of paint fuse together so that water will no longer affect the paint. Enamel type of paint usually cures unlike the latex paints that simply dry.

2.27. Four main groups of binders

1. Mineral binders – These can be divided into three categories: Hydraulic binders require water to harden and develop strength. The most common hydraulic binder is cement. Hydraulic and semi-hydraulic lime, are obtained from burning limestone, which contains a large or moderate amount of clay. Limestone and clay being the main raw materials for cement production. Pozzolanas also when mixed with non-hydraulic lime, form a hydraulic cement. Hydraulic binders are usually available in the form of a fine powder and the finer they are ground the larger is the specific surface area per unit weight. And the larger the surface

area, the more effective and complete is the chemical reaction with the water that it comes into contact with. Due to their affinity to water, hydraulic binders must be stored in absolutely dry conditions, to avoid premature setting and hardening. Even humid air can cause hydration. Non - hydraulic binders, which can only harden in the presence of air. The most common non-hydraulic binder is clay, which is present in most soils, causing them to harden on drying and soften when wet. Its main uses are in earth constructions and in the manufacture of burnt clay products. Another common non-hydraulic binder is high calcium or magnesium lime. Hardening depends on its combination with carbon dioxide from the air (carbonation), by which it again becomes calcium carbonate (limestone). But limes are rarely used as the only cementitious binder, and more usually react with clay or a Pozzolana to form hydraulic cement. Gypsum is a non-hydraulic binder which occurs naturally as a soft crystalline rock or sand. The chemical name is calcium sulfate all-hydrate ($CaSO_4.2H_2O$).

a- *Thermoplastic binders* – which harden on cooling and become soft when heated again. Thermoplastic materials require heat in order to be processed, and harden on cooling. Their properties remain unchanged on reheating and cooling, so that they can be reclaimed and reprocessed numerous times. But the only thermoplastic mineral binder used for building is Sulphur.

2. Bituminous binders are mechanical mixtures of different hydro - carbon (compounds of carbon and hydrogen) and a few other substances and are obtained as a residue in the distillation of crude oil, either in petroleum refineries or in nature (in pores of rocks in the form of lakes, close to petroleum deposits). Bitumen is generally dark black, oily, fluorescent thermoplastic substances, which are highly viscous to almost solid at normal temperatures. Compounds consisting of at least 40 % of heavy hydrocarbons are called bitumen. Asphalts are defined as mixtures containing bitumen and a substantial proportion of inert mineral matter (sand, gravel, etc.). In the USA, bitumen is called asphalt, thus causing some confusion.

a- *Tar* - is the thick black substance produced by the destructive distillation (or carbonization) of organic matter, such as wood or coal. While Pitch, is the residue of tar from coal.

b- Bitumen is not affected by either, light, air or water individually, but in combination they can make it brittle, porous and susceptible to oxidation, forming blisters and cracks. It becomes soft at temperatures between 30° and 100° C (no sharp melting point), and therefore must be protected from exposure to heat. It is insoluble in water and fairly resistant to most acids. Although bitumen is combustible, composite products, such as mastic asphalt, are not readily ignited. Bitumen and coal tar products may be poisonous hence contact with drinking water should be avoided. Bituminous products can be used as waterproofing materials (in soil stabilization, as paints, damp-proof membranes, roofing felt, joint filler, etc.), as paving materials (roads and floors) and as adhesives (for wood block flooring, insulating linings and felts). When bitumen is used, it must be either heated; or mixed with solvents example gasoline, kerosene or naphta, which is called "bitumen cutback"; or dispersed in water, which is called "bitumen emulsion".

3. Natural binders – A variety of natural binders are obtained from plants and animals, and can be used in their natural form or after processing. Examples of natural binders are plant juices such as juice of banana leaves; latex of certain trees; sisal juice; coconut, cotton and linseed oils, animal excrete example cow dung; horse urine and other animal products among them, bull's blood; animal glues from horn, bone, hooves and hide; casein or whey, made from milk. Natural birders have played an important role in traditional constructions since prehistoric times, but nowadays face low social acceptance. However, research today is giving such materials increasing importance, especially with a view to Cost effectiveness and environmental acceptability.

4. Synthetic binders - These types of binders are generally produced by industrial processes and, therefore, often expensive. Some synthetic binders are toxic. They can either be used as admixtures, as adhesives or as surface coatings or are either applied hot, or as an emulsion, or with a solvent. Synthetic admixtures which bond loose particles together are mainly resins

derived from plant materials or mineral oil. The variety of commercial products is very large and their use depends on the required performance such as strength development, waterproofing, elasticity etc.

Adhesives are used to stick larger particles, components, membranes, sheets, boards, tiles, etc. on another surface. Some adhesives are designed specifically for one job, whilst others can be used for a number of applications. Some adhesives are thermoplastic and retain their properties when reheated and cooled. Surface coatings can be used as a protective film, as a decoration or even to achieve a surface bonding.

2.28, Pigments

Are granular solids which give paints the most important properties of colour opacity, covering power and anti – corrosion properties. The pigments used in paint are normally in form of solid particles that are dispersed, but not soluble, in the binder and solvent. White paints use Titanium Dioxide as a pigment. In general, Pigments may be organic *i.e.,* contain carbon or inorganic. Majority of inorganic pigments are brighter and last longer than organic ones. Most pigments used today are either inorganic or synthetic and Synthetic organic pigments are derived from coal tars and other petrochemicals. Figure 2.3 shows that, there are various types of pigments around the world such as the natural and the Synthetic Pigments that include clay, lime, and talc (Kopeliovich, 2014).

Table 2.3 Types of Natural and Synthetic Pigments

Natural Pigments	**Synthetic Pigments**
Clays	Calcined Clays
Calcium Carbonate	Blanc Fixe
Mica	Precipitated Calcium Carbonate
Silica	Synthetic Pyrogenic Silicas
Talc	

2.29. Fillers

Fillers are a special type of pigment that is used to thicken the film, support its structure and increase the volume of the paint. They are usually cheap to acquire hence, they are used in order to reduce the cost of paint.

2.30. Additives

Are a special component of paint and are used in small quantities for additional characteristics to the paint and to improve the production and storing properties, reduce the drag of the paint, make the paint flow on a surface, add texture to the paint characteristics for special surfaces, give pleasant odour in case of interior painting and provide water proofing characteristics

2.31. Common Types of Additives

1. Drying and curing agents **-** used to improve and control the drying properties of Of the paint film
2. Stabilizers - used to improve long term storage properties of the liquid paint
3. Anti mold agents - are used to reduce mold growth on the paint film in very damp and humid environments
4. Wetting and dispersing additives - are used to keep the pigment particles wet and dispersed to the degree of fineness as required
5. Anti-settling Agents - these are used to reduce settling of pigment particles during storage
6. Anti-skinning agents - are used to prevent the formation of a tough skin film over the paint surface during storage

2.32. Quality Control of paints

Quality can be defined as fulfilling specification or customer requirement, without any defect. A product is said to be high in quality if it is functioning as expected and reliable. Quality control refers to activities to ensure that produced items are fulfilling the highest possible quality. Most of tools and techniques to control quality are statistical techniques. (Judi et al., 2011). The International Organization for Standardization ISO/TC 35/SC 9: 2009 for paints and Varnishes specifies methods for the determination of colour stability, process hiding power, re-dissolving, overspray absorption, wetting, surface texture and mottling.

In the United States of America, the National Institute of Standards and Technology on Compliance and in India, the Indian Standard Part 8, Third Revision control quality of paint in their countries respectively through various methods such as examining for quality in terms of the ingredients and the manufacturing process, and the finished product is also checked to make sure that it is of high quality. Among the parameters checked include: density, fineness of grind, dispersion, and viscosity. Paint is then applied to a surface and studied for bleed resistance, rate of drying, and texture. Colour is checked by an experienced observer and by spectral analysis to see if it matches a standard desired colour. Resistance of the colour to fading caused by the elements is determined by exposing a portion of a painted surface to an arc light and comparing the amount of fading to a painted surface that was not so exposed (Ivanov, 2011). Paint's hiding power is measured by painting it over a black surface and a white surface. The ratio of coverage on the black surface to coverage on the white surface is then determined, however, gloss is measured by determining the amount of reflected light given off a painted surface.

Tests for other functional qualities include one for mar resistance, and Mar is described as a physical damage that usually occurs within a few micrometers of the surface of the topcoats; these damages are usually the cause of the changes in appearance observed on the paint coatings. Mar is therefore one of the major concerns of the automotive coating industry. Some causes of mar include keys, fingernails, branches, blowing sand and car wash is believed to be the main cause (Dubuisson, 2018). A test of Mar resistance involves scratching or abrading a dried coat of paint as described in ASTM D5178-16 the Standard Test Method for Mar Resistance of Organic Coatings.

Adhesion is tested by making a crosshatch, calibrated to 2 millimeters, on a dried paint surface. A piece of tape is applied to the crosshatch, then, pulled off; good paint will remain on the surface. Scrubbability is tested by a machine that rubs a soapy brush over the paint's surface. A system also exists to rate settling. An excellent paint can sit for six months with no settling and rate a ten. Poor paint, however, will settle into an immiscible lump of pigment on the bottom of the can and rate a zero. Weathering is tested by exposing the paint to outdoor conditions. Artificial weathering exposes a painted surface to sun, water, extreme temperature, humidity, or sulfuric gases. Fire resistance is checked by burning the paint and determining its weight loss. If the amount lost is more than 10 percent, the paint is not fire-resistant.

2.33. Health Problems Associated with Lead-Based Paint

The 1988 Agency for Toxic Substances and Disease Registry (ATSDR) Reported to Congress estimates in the United States that, there were 5 million tonnes of lead in the United States in household paint. Seventy percent of the houses built before 1960 had lead-based paint on interior and exterior surfaces. The ATSDR further estimated that there were 6 million homes with leaded surfaces that had decayed or deteriorated and in which 2 million young children resided. Ingesting lead from chipped, peeling, or chalking paint placed these children at extremely high risk of lead poisoning.

According to Lembeck (2007), synthetic pigments in general are manufactured by rather toxic and energy-consuming processes. In addition, a lot of these pigments contain large amounts of heavy metals such as lead. All the synthetic components are derived from crude oil called petrochemicals that are known to contain many toxins. These toxins are known to contribute to or cause the following: cancer, ozone depletion, lead poisoning, respiratory problems, including depression of the central nervous system, headaches, nausea, dizziness, irritation to the skin, eyes, and respiratory tract, asthma, anaemia and bronchitis.

Ukaegbu (2013) reports that, in order to arrive at a successful formulation of high quality textured paint, it is always necessary to understand not only the performance criteria but also the function of the components especially the base polymer of a base binder. For instance, the PVA provides the major proportion of the adhesive strength in the textured paint production process.

2.34. Mud mortars and Conventional Mortars

The need for a plaster and the type of plaster that should be used depends particularly on the method of construction and quality of construction. The provision of adequate footings, basements, eaves, and overhangs to a roof can in certain circumstances eliminate the need for a plaster coating altogether. As plastering can amount to 15 to 20 per cent of the total cost of a house, its benefits need to be considered relative to alternative options. In general, except in the case of highly exposed walls in areas of heavy rain, a plaster should protect against wind, rain, knocks and abrasion, and should improve the thermal insulation and appearance of a wall. At the same time it has to be easy to apply without requiring expensive and elaborate tools, and must be affordable.

Temperature Conditions of the building must be maintained in the uniform range of 13° to 21°C both day and night for an adequate period prior to the erection of gypsum plaster base, while the plastering is being done, and until the plaster is dry. The heat should be well distributed in all areas, with deflection or protective screens used to prevent concentrated or irregular heat on plaster areas near the source. Ventilation must be provided to properly dry the plaster during and sub-sequent to its application. To develop proper performance characteristics, the drying rate of plastering materials must be strictly controlled during and after application. Plaster should not be allowed to dry too slowly or too fast. If possible, maintain building temperature-humidity combination in the "normal drying" area. Excess ventilation or air movement should be avoided to allow plaster to properly set (USG 2014).

All types of mud plasters, but especially those on external surfaces, need to offer erosion resistance, impermeability to moisture, and impact resistance, and be well bonded to the wall.
In, a study that was carried out in India by Lekshmi et al (2016), dry mud was described to be of a composition of soil particles of varying sizes. When water of a required quantity was added, it became mud mortar of proper consistency. The constituents of mud mortar were sand, 2 mm – 0.075 mm in size, silt 0.075 mm – 0.002 mm, clay < 0.002 mm and water 30 – 35% by weight. The soil sample was collected from Chovvra Aluva in Ernakulam district from a depth of 60 cm below the ground level. It was subjected to field tests including colour test, touch, etc. Some of the properties were as shown in Figure 2.4 and Figure 2.5:

Table 2.4 Soil Properties - Source: (CiVEJ, June 2016)

S/N	Property	Result	Remarks (standard values)
1	colour	Reddish- orange	Suitable for construction
2	pH	6.387, 5.9-6.5	moderately acidic
3	Organic content	0.075% < 0.5%	low organic content

Table: 2.5 Particle size distribution

4	Clay	10%	18-22%
5	Silt	38%	40-42%
6	Sand	52%	30-40% for mud mortar

For Nigeria, Oshike (2015) reports that, the shortage, low quality, high cost, etc of housing in Nigeria like other developing countries is critical. According to United Nations (2005) estimates, about 1.3 billion urban residents live in inadequate housing world wide. The World Bank (1998) estimates that Nigeria requires 720,000 housing units to be built annually for the next 20 years in order to be able to close the housing deficit of about 17 million units that would cost about N35 trillion. It is therefore necessary to employ all possible measures, including the improvement of traditional and indigenous building materials, construction methods and technologies to ameliorate the situation. In many parts of the world, including developed nations, building with earth is being revived due to rising energy costs that impact strongly on building materials such as cement and fired bricks.

Housing delivery is a highly contentious and politicised issue in Nigeria and is of great concern to administrators, scholars and the public. In the last few decades, the influx of people into urban areas, the natural population increase and inadequate responses by the government have contributed to the worsening housing situation in the country (Afolabi and Oamide, 2012).The scholarly articles such as the ones shown in Table 2.6 advocate that, Governments should encourage the use of local building materials by using them in government projects all over Africa. And these materials should be included in building codes of various countries in Africa (Oamide, 2012).

Table 2.6 Scholarly articles advocating for the use of indigenous Building Materials for Modern Housing

No.	Author(s)	Research/Paper title	Date
1	Ekong E. Daniel, Akpanim N. Ekpe and Samuel Okurebia,	Sustainable Development and usage of the Red-Brown Earth, in South-Eastern Nigeria	2014
2	Adogbo K.J. and Kolo B.A.	Stabilized Earth Housing Delivery through the Public-Private Partnership: Provision for the Low- Income in Nigerian Cities	2013
3	Kadiri, Kabir O.	Earth Construction Technology as facilitator of Mass Housing in Nigeria	2012

Onyegiri and Ogochukwu (2016) examined the major advantages, challenges and the way forward for traditional building materials in increasing low cost housing supply and affordability in Nigeria. The study found promotion of cultural heritage, availability and affordability of the materials, energy efficiency, reusability, biodegradability among others as the major advantages of traditional building materials. On the other hand, acceptability, durability, deforestation, low strength, frequent maintenance, among other issues were found to be the major challenges associated with houses built with traditional building materials.

Their recommendation for adoption and improvement of the traditional local building materials for building construction were made. They also suggested that, when the solutions being recommended are implemented the country's housing shortage and housing affordability issues would be minimised in view of the abundance of wealth and manpower resources vested on the country (Afolabi, 2012).

In Ghana - one of the drawbacks of mud mortar is the occurrence of shrinkage cracks on drying. Many studies have shown that, adding fibres into the soil increases the durability of soil matrix by reducing the cracks. Fibres increase the cohesion among the soil particles while the interaction of the fibres among themselves and the fibres flexibility makes them behave as a structural mesh that holds the soil together. Mud had proved to be an excellent material for construction in the form of mud bricks and earthen plasters, ever since man started his life on earth (Lekshmi et al., 2016).

Near Kumasi, the last remaining traditional buildings are testimony of the great Asante civilization, which reached its peak in the 18th century. The buildings are constructed of timber, bamboo and mud plaster and originally had thatched roofs. These buildings, with their rich colour, the skill and diversity of their decorations are examples of a traditional style of architecture that reveals powerful and wealthy Asante kingdom of the late 18th to late19th centuries. Asante traditional buildings show a complex technical, religious and spiritual heritage (UNESCO World Heritage Centre, 2017).The problems of housing, are more apparent in developing countries although it is a global issue (Oshike, 2015).

Ghana’s mud mortars have traditionally been improved by the addition of organic matter such as cow dung and ashes from agro processing waste. The Northern region

of Ghana is inhabited by a large group of people known as the Gurunsi. This is a large term for a group of people belonging to several different tribes, relating to both language and ethnic heritage mainly the Asante region of Ghana (Davoust, 2013).

The main village of the Kassena is called Tie’be’le’ located in the southern region of Burkina Faso bordering Ghana. The city has some of the best examples of the Gurunsi decorated architecture such as the ones shown in Figure 2.6 and Figure 2.7. majority of the people still leave in the traditional homes made of mud walls, usually a mixture of clay, straw and cow dung, either round or more rectilinear in form; though modern techniques have helped in the building process, utilizing mud bricks and stone foundations (Smith, 2013). Figure 2.6 shows women doing the final decorations to the walls in Tiebele Ghana.

Figure: 2.6 The Decorated walls in Tiebele – (Source; http://handeyemagazine.com)

The décor is made by married women of the tribe after the rainy season in order to protect them from water that could wash them away. This is a process that takes place through the use of the black color obtained by blacking out the stones on the fire and from the preparation of a clay slurry which is then covered with a thin layer of red laterite. The murals are weather-proof thanks to a natural dye of boiled beans, taken from the carob tree fruits. The extraordinary nature of this village, where art plays a leading role is testimony to an ancient civilization, skilled in architecture and the art of wall decoration which creates natural works of art and beauty.

Figures 2.7 and 2.8 show Gurunsi Architecture of the Gurunsi people in northern region of Ghana inhabited by a large group of people known as the Gurunsi. This is a larger term for a group of people belonging to several different tribes relating to both language and ethnic heritage mainly the Asante region of Ghana.

Figure: 2.7 Traditional Kassena house – (Source; http://photo.lacina.net)

All societies that have created a permanent built society have decorated their buildings in some way, making art out of what they have. The decorations are not always attached, some decorate with rugs or skins, but almost all have something to make the buildings more attractive. The mud huts that they create are unique to their culture and are elaborately decorated in ancient symbolic patterns, carrying on this very African tradition. The majority of the people still live in the traditional homes made of mud walls, usually a mixture of clay, straw and cow dung, either round or more rectilinear in form; though modern techniques have helped in the building process, utilizing mud bricks and stone foundations. The Gurunsi people have adapted this tradition for even their comparatively simple buildings
(Bischof, 2013).

Figure 2.8 Gurunsi Architecture – (Source; http://victoriabischof.weebly.com)

In Burkina Faso – the Tiebele village is home to the Kassena people, one of the oldest ethnic groups in the country. In this village, the clay walls of the low buildings that make up Tiebele Burkina Faso, have been decorated with frescoes and geometric patterns, turning each of the circular structures into a striking work of art. The isolated village is home to the royal court of the Kassena people, one of the oldest ethnic groups in Burkina Faso, who first settled the region in the 15th Century (Ryan, 2013). The Kassena tribe and its neighboring Frafra tribe reside mainly in the upper northern region of Ghana, on the border of the Republic of Burkina Faso (Davoust, 2013).

In the south of Burkina Faso, a landlocked country in West Africa, near the border with Ghana lies a small, circular village of about 1.2 hectares, called Tiébélé. This is home of the Kassena people, one of the oldest ethnic groups that had settled in the territory of Burkina Faso in the 15th century. Tiébélé is known for their amazing traditional Gurunsi architecture and elaborately decorated walls of their homes (Kaushik, 2012). Burkina Faso is a poor country, even by West African standards, and possibly the poorest in the world. But they are culturally rich, and decorating the walls of their buildings is an important part of their cultural legacy in this area of the country. Wall decorating is always a community project done by the women and it's a very ancient practice that dates from the sixteenth century AD. The Kassena people build their houses entirely of local materials: earth, wood and straw (Worthington, 2015). Sometimes soil mixed with straw and cow dung is moistened to a state of perfect plasticity, to shape almost vertical surfaces.

Today this technique is replaced by the use of mud brick moulding walls (Kaushik et al., 2007). After construction, the woman makes murals on the walls using coloured mud and white chalk. The motifs and symbols are either taken from everyday life, or from religion and belief. The finished wall is then carefully burnished with stones, each colour burnished separately so that, the colours do not blur. Finally, the entire surface is coated with a natural varnish made by boiling pods of néré, the African locust bean tree (Willaert, 2014). The designs also serve to protect the walls themselves.

The decorating is usually done just before the rainy season and protects the outside walls from the rain. Adding cow dung, compacting layers of mud, burnish the final layer, and varnishing with néré enable the designs to withstand wet weather hence, the structures in turn last longer (Bischof, 2013).

The small country of Burkina Faso near the border to Ghana may not have many resources or economic wealth, but with the plentiful raw materials available the Kassena people make some of the most culturally rich and architecturally beautiful villages, such as the ones in Tiébélé. Decoration of houses with frescoes, motivate the people of Kassena, its life and religion, it is women who are engaged in this art work (Cof, 2016). These techniques actually took over the well known mud-brick constructions of indigenous peoples in the area. Layer upon layer are added when needed, to maintain the necessary wall thickness to withstand rainstorms and extreme temperatures. Short walls are used as urban landscaping elements, provide a buttressing support, and offer supplementary places to sit or work (Curtiss, 2016).

In Tanzania, the Maasai are one of the best known tribes in Tanzania and by nature, they are nomadic livestock herders and move to greener pastures as need be. Due to the fact that the Maasai have to be ready to move at any given time, their houses are built to be temporary. It is however, interesting to note that men are not responsible to build the houses but it is the duty of the women. All natural materials used in the construction of these houses are collected from nearby areas (Kenya information Guide, 2015).

The first step is to build the frame which is done by fixing the gathered timber poles into the ground and small branches used to brace the main poles. Thereafter, the structure is plastered with a mixture of water, mud, cow dung and even human urine. Finishing touches are done with a mixture of cow dung and water (Nassrulla, 2016).

The roof is made and plastered with cow dung and then covered with grass collected from the bush. The cow dung makes the roof water proof. The houses are complete and the families use them to cook, sleep, eat, socialise and store reserves, fuel and small livestock in them. There are no windows making the houses very dark inside except for tiny holes in the wall. To build these houses may take a few days to a few weeks depending on the number of helpers and materials available (Nassrulla, 2016).

In Malawi, Chapinduka and Cloete (2007) reported that finance from the formal sector is accessible to fewer than 35 per cent of the urban population and less than 16 per cent of households in the major urban areas can afford an average house. No government subsidies are available for end users and development financing is limited and extremely dear. The contribution from non-conventional finance sources to housing finance is negligible. The analysis of the housing market has revealed that few people can access formal finance sources, due to low income levels and a high level of insecure jobs. This situation leaves the alternative of grants and subsidies and other modes as essential if housing delivery is to improve.

Figure 2.9 shows women in Malawi plastering with their hands which is called smearing and in some instances it is actually the technique of applying mud to the walls and floors, and it is done once a year. This plaster adds a layer of protection against the wind and rain. This housing construction type is used only for residential purposes. The building technique consists of timber poles as the core or base with a mud smear (plaster) applied on both sides. The plan is circular (only one floor) and the roof is formed by grass thatch supported on timber poles and cross members (Sassu and Ngoma, 2002).

Figure 2.9 Plastering the houses – (Malawi Vernacular Architecture 2011)

A mixture of mud and water is the basic components for the plaster. In many cases it was stated that the mud was gathered from a place off site. This was mainly done to have a specific or unique colour. The task of plastering is done once a year in order to protect the structure from sun and wind but mainly the rain. Water hitting a mud surface has a great impact on the structure. Walls, floors and veranda all receive a fresh coat of plaster (Sojkowski, 2011).

Earth plasters are composed of sand, clay and vegetal fibres. Sand provides particles most frequently of quartz with diameter ranging from 0.0625 mm to 2 mm. Clay consists of particles < 2mm and is a very complex mix of natural elements, including hydrous aluminium silicates with traces of metal oxides and organic matter. It serves as the binding element of earth plasters. Clay and sand are mixed with natural fibres, which help to hold the plaster together and provide some flexibility to the plaster once dried (Henry, 2014).

When indoor air humidity changes, the plaster changes its water content and the clay would tend to crack; the presence of fibres helps to reduce or avoid the formation of cracks. Natural or synthetic additives such as cellulose, linseed oil, bitumen emulsion, lime, etc. which may be added for particular purposes such as improving physical properties, shrinkage, absorption, increasing durability, preventing dusting, abrasion resistance, and changing the colour. The main concerns in the use of earth mortars as plasters are shrinkage, abrasion, erosion and absorption if applied on exterior walls (Minke, 2011). In earth mortars the only binding agent is clay, hence, the adhesion mechanism with the underlying wall is purely mechanical (Montana et al., 2014). The mechanical strength of an earth plaster is acceptable if after shrinkage there are no cracks through which water can penetrate into the wall (Hamard et al., 2013).

In Botswana, the silt content of most soils is low and this means they are mixtures in varying quantities of sand and clay. Whereas this is a disadvantage for agriculture, it is an advantage for building. According to DSM (2001) in Botswana, the clay makes the soils sticky while the sand gives them the strength.

Lyamuya (2013) in a paper presented on earth construction in Botswana said that, in the past two decades, there has been a decline in the use of traditional local building materials, techniques and styles. The possible causes that led to this decline include: socio-economic, cultural transformation, growth, invention of industrial or modern building materials and changing value systems that have been replacing traditional values. However, building with modern or industrial materials is hindered by several factors such as the high cost of producing these materials, and excessive transportation costs to deliver them from the production to the building sites. This makes the use of these industrial building materials in Botswana not sustainable. There is need to seek alternative non industrial materials which can be affordable to the majority of people especially those in rural areas.

The housing transformation is one of the major impacts of all forms of urbanisation. The term ‘housing transformation’ is used here to refer to informal, extra-legal and unplanned processes through which home-owners extend their houses, erect additional rooms or convert part of their homesteads into rental accommodation. It is similar to ‘rooming’ or multi-habitation – that is, “a situation in which people who do not define themselves as one households share a living space that is clearly not designed for multi-family purposes” (Schlyter, 2003:7).

Figure 2.10 Bakwena tribe house, Botswana- (Source: FeaturePics.com)

On the basis of design and construction materials, houses in Botswana can be divided into two major categories: traditional such as the house shown in Figure 2.10 a Bakwena tribe house, and modern houses. Modern houses are built with manufactured or processed materials such as sawn timber, concrete blocks / bricks, tiles and metal sheets based on western architecture. The traditional houses are those units built using vernacular architecture and locally available materials. Traditional Tswana houses are commonly found in the eastern hardveld among Tswana speakers (Grant et al., 1995).

A typical traditional Tswana house consists of a cone roof over a cylindrical wall. The roof structure is made of timber rafters covered by grass. The materials are obtained from the respective village and its surroundings. The walls are built of hand-moulded mud bricks of various sizes and shapes which are placed in vertical layers and immediately plastered with a rough coating of mud. One or two more coatings are added later to fill the cracks. The final coating is a thin layer of a mixture of cow-dung, soil and water. Cow dung is generally put in the mixture as it acts as binder. Finally, the wall is decorated using different types of soil or lime. The layer of colour is smeared on to the wall by hand and soils used for decorations vary from one village to other (HATAB, 2016).

Discussions about the rising cost of building schools and hospitals have been going on. Most building materials are imported from neighbouring countries. The few that are produced in the country are concentrated in a strip along the east of the country. Thus, the delivery of some of these building materials like bricks, cement, steel etc. involve 1000-1500 km by road to the various construction sites; as a result, projects turn to be very expensive. All these projects are erected in either clay face bricks or sand cement bricks made far from the construction sites. At the same time, not only does the country have a long tradition of building in earth, it has the ideal climate for building using earth. Countries with similar climate in West Africa such as Mali, Niger and Burkina Faso, have made great progress in promoting earth construction. In Botswana, earth buildings are limited to residential building in rural areas. UNCHS (1989) reported that, despite all the developments in earth construction technologies, there is no initiative or programme to support or encourage its use. However, Lyamuya (2013) in the paper attempted to document the strength of earth construction by looking at the various options and recommending some possible techniques that could be adopted in Botswana. It recommends the establishment of a building materials research centre as well as introducing the subject to construction colleges and brigades (CSO, 2004).

In Zimbabwe, historically earth and other local materials have been in dominant use in construction for both rural and urban housing in Zimbabwe, especially the Matabeleland Provinces in the Southern part of Zimbabwe. With advances in technology and improvement in living standards, people popularly tend towards a set of building materials, for durability and modernity. However, the adequacy and effectiveness of these materials, in terms of affordability and sustainability in rural housing remains below expectations (Kanyemba, 2004). The use of non-traditional materials is prevalent and the provision of affordable housing is still a major challenge in rural Zimbabwe.

It is believed that local materials are used with little or no scientific input, leading to their faster deterioration. As a result, communities want to construct durable structures and reduce on maintenance (Muchawonweyi, 2004). Notably these materials except clay bricks are imported', and their prices are beyond the reach of many. Their manufacturing processes consume a lot of energy and transportation costs are high. Further, environmental concerns lead to the reduction in use of materials like timber and fired brick as environmental protection in the district as deforestation has risen to alarming levels. But the use of these non-traditional materials such as steel, cement, plastic floor tiles, aluminium roofing sheets, etc easily proved inadequate.

According to Kuchena (2004), a study carried out in South Africa showed that traditional construction materials and methods were more cost effective than the conventional. Despite these factors, the popularity of non-traditional building materials continues to grow in Zimbabwe. This paper by Kuchena embodied the outcome of a research carried out in Matabeleland to identify trends in earthen construction with focus on the promotion of sustainable earthen construction. The objectives of the research were to promote earthen materials in rural housing and to investigate the aspects of further exploitation of the potentials of earthen construction in Tsholotsho District. Regionally, there are research efforts underway in Botswana, South Africa and Zimbabwe to establish a framework for developing performance-based codes. The use of performance-based codes would certainly preserve earthen building materials and methods in Southern Africa (Ngowi, 1997).

2.35. Use of Local Natural Materials

In Zambia, Zebron (2011) reported that, Zambia has an abundance of natural materials that are very useful for building. The vernacular architecture makes good use of what is readily available, so that people do not have to travel too far to get building materials. In some parts of the country, proper hardwood is not easy to find, or termite mounds are not readily available, so reeds and thatch is used instead to build dwellings. In other parts they use local soils to build bricks, and different coloured sand to paint and weatherproof their buildings. According to Strategies of the 1996 National Housing Policy (GRZ, 1996), the housing strategies of the policy are, housing Finance and development of Local Building Materials by actively promoting the development of local building materials through research by improving the quality of local materials presently in use in order to extend the lifespan of the buildings. However, very little has been done to realize this because an implementation strategy is yet to be formulated.

Hadjri (2007) however, reports that, there is a widespread perception among Zambian people that modern materials are better than vernacular ones. Traditional materials and techniques are thought to be temporary, "substandard," or "second class," while modern materials are seen as civilized or a symbol of affluence.

Houses delivered through formal programs have historically excluded the use of local building materials and current formal building codes and regulations do not authorize their use either. There have been no strategies or programs put in place to standardize and improve local building materials widely used by the informal sector as a way of fostering the production of affordable low income housing solutions for the poor. Consequently, housing and human settlement solutions being used today are beyond the effective demand of the poor in part due to the high cost of conventional building materials that have been in use since the British colonial days (Turner, 1976; Mitchell & Bevan, 1992; Payne, 2001).

The informal sector has been able to provide cost effective alternatives to peoples' planning and housing problems, and delivers up to five times more housing units at very little cost to the end user than conventional solutions (Martin, 1976; Turner, 1976 and Silavwe, 1998). Silavwe argues that by being outside the formal structures that are riddled with bureaucracy and administrative bottlenecks, the informal sector has shown the potential of some local building solutions including use of local building materials. He suggests that by incorporating both traditional and urban-African lifestyles and practices, the informal sector has been evolving a new way of urban living which is more related to Africa (ibid)

Underutilization of local building materials, techniques and services is one of the key problems affecting the housing sector in Zambia. This has been due to very little or no effort put into research, development and improvement of local building materials. The Copper Belt University (CBU) is one of several research institutions that have carried a lot of research into various building materials, including sun-dried or burnt clay blocks, and tested their performance against standards set by the Zambia Bureau of Standards. This paper proposes that these studies, such as the one done by (Siuluta, 2002) be done in collaboration with the National Housing Authority and the Zambia Bureau of Standards. Further, as the National Housing Policy recommended such studies need to be funded so that demonstration projects can be set up in order for local building materials to gain acceptance, especially within the private sector, political and professional circles whose vested interests currently hinder the adoption of such material (Mwango, 2006).

2.36. Comparative characterization of commercial clay-based plasters

Montana et al (2014) reported in their case study that, three pre-mixed powdered clay-based earthen plasters produced in Europe and specifically designed for wall undercoating were analyzed in the study. These materials were commercially available and used in green building practices all over the world. Their compositional and textural characteristics, as well as plastic behaviour were investigated through a multi-analytical approach: X-ray powder diffraction (XRPD), polarized light microscopy (PLM), X-ray fluorescence spectrometry (XRFS), scanning electron microscopy equipped with an energy dispersive spectrometer (SEM-EDS), mercury intrusion porosimetry (MIP), grain-size distribution (GSD) and semi-empirical tests (Atterberg Limits, Linear Shrinkage). In addition, a natural earth, a terra rossa red soil sampled in north-western Sicily, theoretically appropriate for the production of earthen plaster, was subjected to the same analysis and compared with the three commercially available pre-mixed products. The achieved results allowed to individuate the compositional and textural features that primarily influence the performances of the studied earthen plasters. The obtained data are expected to be useful in directing the selection of raw materials for local manufacture of specifically designed innovative products (Hamard et al., 2013).

2.37. Soil Colour

Soil colour is usually due to 3 main pigments:

- Black- from organic matter
- Red- from aluminium oxides and iron
- White- from salt and silicates.

Colour can be a useful indicator of some of the general properties of a soil, as well as some of the chemical processes that are occurring beneath the surface.

2.38. Munsell Revised Standard Soil Colour Charts

The Munsell Soil Colour Charts is an affordable way to evaluate the type of soil that is present within a given area. The book is set up to allow users to make soil color evaluations in the field quickly and easily. The soil classification system that has been developed around the Munsell colour system is an established and accepted process to assign a soil type. This classification system has been used in the United States for more than 55 years to aid in the management and stewardship of natural resources. Through the use of the Munsell Soil Colour Charts, practitioners from a wide range of professions can share reliable and consistent information about the color of soils at a particular site with colleagues anywhere around the world.

The Munsell Soil Colour Charts are used by a variety of industries and professions such as universities and high schools, forestry, forensics, environmental and soil science, building and contracting, landscaping, real estate, health departments, geology and archaeology. Relatively large crystals of goethite give the ubiquitous yellow pigment of aerobic soils. Smaller goethite crystals produce shades of brown. Hematite (Greek for blood-like) adds rich red tints. Large hematite crystals give a purplish-red color to geologic sediments that, in a soil, may be inherited from the geologic parent material. In general, goethite soil colors occur more frequently in temperate climates, and hematite colours are more prevalent in hot deserts and tropical climates.

Soil colour gives an indication of the various processes going-on in the soil as well as the type of minerals in the soil. For example the red colour in the soil is due to the abundance of iron oxide under oxidized conditions (well-drainage) in the soil; the dark colour is due to the accumulation of highly decayed organic matter; while the yellow colour is due to hydrated iron oxides and hydroxide; black nodules are due to manganese oxide. Soil colour is described by parameters called hue, value and chroma. Hue represents the dominant wavelength or colour of the light. While values refers to the lightness of the colour and chroma is for relative purity or strength of the colour. The colour of the soil in terms of the above parameters could quickly be determined by comparing with the note book for colours called Munsell colour charts. In these charts, the right hand top corner represents the Hue; the vertical axis – the value; the horizontal axis, and the chroma, (Munsell, 1973).

2.39. Soil pH

Soil pH is a crucial soil indicator, and is defined as the negative log of the hydrogen ion activity. Since pH is logarithmic, H-ion concentration in solution increases 10 times when its pH is lowered by one unit. It is the acidity or alkalinity of a substance such as soil and water. Most minerals nutrients are more soluble or available in acidic than in neutral soils. The pH range found in soils varies from 3 to 9 and the categories of pH may be said to be:

- Strong acid pH < 5.0
- Moderately to slightly acid 5.0 – 6.5
- Neutral 6.5 – 7.5
- Moderately alkaline 7.5 – 8.5 and
- Strongly alkaline greater than 8.5

Slightly alkaline soils range around 6.5. Extremely and strong acid soils pH 4.0 – 5.0 can have high concentrations of soluble aluminum, iron and manganese which may be toxic. The soil pH can also influence plant growth by its effect on activity of microorganism bacteria that decompose soil organic matter are hindered in strong acid soils. This prevents organic matter from breaking down resulting in an accumulation of organic matter and the tie up of nutrients particularly Nitrogen.

2.40. Organic Matter

Soils have many different properties, including texture, structure, water holding capacity and pH that is whether the soils are acid or alkaline. These properties combine to make soils useful for a wide range of purposes. Some organic matter represents the remains of roots, plant material and soil organisms in various stages of decomposition and synthesis, and is variable in composition (Estefan et al., 2013). The amount of sand, silt, clay and organic matter in particular soil plays a large part in the way soil behaves, how it can be managed and what it can be used for. The type of structure in the soil depends to a large extent on the texture and the amount of organic matter in it. The type of structure in soil depends to a large extent on the texture and the amount of organic matter in the soil, what it can be used for, and the amount of organic matter in the soil. Organic matter decreases particle density of the soil.

2.41. Sulfates

Sulfur is present in soils in organic and inorganic forms. The major source of sulfur is gypsum ($CaSO_4$) and pyrite (Fe_2S). The total Sulfur content in soils varies widely from soil to soil. Sandy soils in the humid regions have low sulfur as compared to soils in the arid regions which may contain 5% SO_4-S

2.42. Chlorides

Is a compound in which one of the elements is chlorine; sodium chloride – table salt is the most common example found in the body in a large quantity; it is an electrolyte, so it is involved in a water and acid-base balancing. This is so because electrolytes affect movement of substances throughout the body and are crucial for normal function and metabolism. To help determine electrolyte, fluid, kidney, and adrenal gland disorders, chloride levels usually are measured in blood and urine The Analytical Environmental Chemistry Research Group in Nigeria posted that, Chloride Ion is a chlorine anion that forms the negatively charged part of certain salts, including sodium and hydrogen chloride salts and is an essential electrolyte located in all body fluids responsible for maintaining acid / base balance, transmitting nerve impulses and regulating fluid in and out of cells.

.

Natural inputs of chlorine (Cl) to soils come mainly rain water, sea spray, dust and air pollution. In addition, human practices such as irrigation and fertilization contribute significantly to deposition and in soil solution, it occurs as the chloride anion (Cl^-). The anion does not form complexes readily, and shows little affinity or specificity in its adsorption to soil components. Hence, chlorine movement within the soil is largely determined by water flows and can affect colour of the soil, its smoothness and flow which are the parameters for paint quality (White and Broadley, 2001). Further investigations should therefore, be carried out to establish the outcome of mixing a binder with the soil containing chloride.

2.43. Iron

Iron is defined by Merriam Webster as a silver – white malleable ductile magnetic heavy metallic element that readily rusts in moist air, it occurs native in meteorites and combined in most igneous rocks, it is the most used of metals, and is vital to biological processes. From the chemical point of view, iron comes from the Anglo-Saxon name 'irene.'

Biologically Iron is an essential element for all forms of life and is non-toxic. The average human contains about 4 grams of iron. A lot of this is in haemoglobin in the blood. Haemoglobin carries oxygen from lungs to the cells where it is needed for tissue respiration. Humans need 10 – 18 Mill grams of iron each day. A lack of iron will cause anaemia to develop Foods such as lever, kidney, molasses, brewer's yeast, cocoa and liquorice contain a lot of iron (Emsley, 2011). Iron is the fourth most abundant element by mass in the earth's crust. The core of the earth is thought to be largely composed of iron with nickel and sulphur. Iron ore is mostly contained in haematite, but is found widely distributed in other minerals such as magnetite and taconite too (Emsley, 2011).

2.44. Copper

Copper is defined by Merriam Webster dictionary as a common reddish metallic element that is ductile and malleable and is one of the best conductors of heat and electricity. Copper was one of the earliest elements known to man. At one time, it could be found lying on the ground in its native state or un combined state. Copper's distinctive red colour made it easy to identify. Early humans used copper for many purposes, including jewellery, tools, and weapons. Copper is a transition metal, one of several elements found in rows 4 through 7 between groups 2 and 13 in the periodic table.

An important chemical property of copper is the way it reacts with oxygen. In moist air, it combines with water and carbon dioxide. The product of this reaction is called hydrated copper carbonate. The abundance of copper in the earth's crust is estimated to be about 70 parts per million. It ranks in the upper quarter among elements present in the earth's crust in small amounts of about 1 part per million.

2.45. Manganese

According to Collins English dictionary, Manganese is defined in chemistry as a hard, brittle, grayish-white, metallic element, an oxide of which MnO_2 (manganese oxide) is a valuable oxidising agent used mainly as an alloying agent in steel to give it toughness. It occurs in several allotropic forms, found worldwide especially in the ores pyrolusite rhodochrosite and in nodles on the ocean floor. It is hard to melt but easily oxidised. It is alloyed with steel to increase strength, hardness, wear resistance, and other properties and with other metals to form highly ferromagnetic materials. Manganese is reactive when pure and as a powder burns in oxygen, reacts with water, rusts like iron and dissolves in dilute acids Haynes ed (2015).

2.46. Chromium

Chromium belongs to elements in groups 3 through 12 that are known as the transition metals. These elements all have similar physical and chemical properties. Chromium was discovered in 1797 by French chemist Louis-Nicolas Vauquelin (1763-1829). The name comes from the Greek word chroma, meaning "color," because chromium compounds are many different colors. About three-quarters of chromium produced today is used in alloys, including stainless steel. Symbol 'Cr', its atomic number is 24, and the atomic mass is 51.996.

A. Chemical properties

Chromium is a fairly active metal. It does not react with water, but reacts with most acids. It combines with oxygen at room temperature to form chromium oxide (Cr_2O_3). Chromium oxide forms a thin layer on the surface of the metal, protecting it from further rusting.

B. Occurrence in nature

The abundance of chromium in the Earth's crust is about 100 to 300 parts per million. It ranks about number 20 among the chemical elements in terms of their abundance in the earth. Chromium does not occur as a free element. Today, nearly all chromium is produced from chromite, chrome iron ore ($FeCr_2O_4$) (Lenntech, 2017).

C. Health hazards associated with exposure to chromium

The health hazards associated with exposure to chromium are dependent on its oxidation state is a danger to human health, mainly for people who work in the steel and textile Skin rashes, Upset stomachs and ulcers, Respiratory problems, Weakened immune systems, Kidney and liver damage, Alteration of genetic material, Lung cancer or Death.

According to Wuana and Okieimen (2011), soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilisers, animal manure, sewage sludge, pesticides, waste water irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition. Heavy metals constitute an ill-defined group of inorganic chemical hazards, among the commonest found at contamination sites are chromium (Cr) and copper (Cu).

The Agency for Toxic Substances and Disease Registry ATSDR (2013) describes Chromium as a steel-grey metal that is highly resistant to oxidation, even at high temperatures. It is the sixth most abundant element in the earth's crust, where it is combined with iron and oxygen in the form of Chromite ore. It is used in three industries, mainly, Metallurgical, chemical and refractory i.e. the heat resistant applications. These industries are the most important industrial sources of chromium in the atmosphere (EPA, 1998; ATSDR, 2000). In the metallurgical industry, chromium is an important component of stainless steels and various metal alloys. Metal joint prostheses made of chromium alloys are widely used in clinical orthopedics. In the chemical industry, chromium is used mostly in: chrome plating, leather tanning, paint pigments (chromium compounds can be red, yellow, orange, and green), wood treatment. But in smaller amounts, it is used as a catalyst, copy machine toner, corrosion inhibitors, drilling mud, magnetic tapes, photographic chemicals, safety matches, and water treatment. Refractory uses of chromium include magnesite-chrome firebrick for metallurgical furnace linings and granular chromite for various other heat-resistant applications.

2.47. Particle Size Distribution (PSD)

Particle size distribution analysis (PSDA) is a measurement of the size distribution of individual soil or sediment particles, sand, silt and clay, which can be used to understand soil genesis, to classify soil or to define texture (Soil Survey Staff, 1993). The two classes of methods of determining the particle size distribution (PSD) of a given sample consist of classical and instrumental, both of which rely on physical segregation of particles followed by quantification by mass (Mudroch et al., 1997). Examples of classical methods are sieving and pipette methods. Instrumental methods tend to be faster and more reproducible (Welch et. al., 1979; Mudroch et al., 1997).

Examples of instrumental methods are optical determination of particles, electrical sensing zone or electro resistance particle counting (Coulter Counter), X-ray sedimentation (Sedigraph) and laser diffraction (Mudroch et al., 1997; Molinaroli et. al., 1999; Last and Smol, 2001; Goossens, 2008). X-ray The sedimentation technique is quick and reproducible, but is limited to the fine particles, generally <63 µm, and may be influenced by the different densities of particles (Buchan et. al., 1993; Last and Smol, 2004; Muller, 2009). Laser diffraction spectroscopy uses the same basic principle as the X-ray, but instead uses the intensity of the light scattered by the particle to determine its size (Mudroch et. al., 1997, McCave et. al., 2006; Taubner et al., 2009). All of these methods have distinct advantages and disadvantages and no one procedure gives exact results due to the nature and definition of soil particle size (Mudroch et al., 1997; Molinaroli et al. 2000; Last and Smol, 2004; Goossens, 2008).

With the pipette method, samples are usually pre-treated to avoid interferences, by flocculation and aggregates (Welch et. al., 1979; Mudroch et al., 1997). Standard pretreatment and dispersion procedure outlined in the Soil Survey Laboratory Methods Manual is to remove organic matter, carbonates, iron, silica, and to disperse soil aggregates (Soil Survey Staff, 2004). These pre-treatment methods were designed for the use in terrestrial soils and may not be suitable for some of the subaqueous soils (Shein, 2009). The results were given in Tables 4.9 – 4.14 presented in Chapter Four.

2.47.1 Air

Is a weakening factor and undesirable in building construction as it also entraps micro-organisms and water vapour, both of which can cause deterioration of the building components.

2.47.3 Water

Without which the soil cannot be used for building, but which can carry dissolve substances (salt) that may create problems. Most soils are suitable for use as building materials though in various cases, the addition or removal of certain constituents is required to improve their quality. Several tests need to be carried out in order to identify the characteristics of the soil and its appropriateness for building construction (Bahadori and Tofighi, 2015).

2.47.1 Soil

When referring to earth or soil in building construction, both terms mean the same material. Mud is a wet, plastic soil mixture, with or without additives, which is used to make mud bricks or adobe, or monolithic mud walls (SKAT, 1988). Soil is the loose material that results from the transformation of the underlying parent rock by the more or less simultaneous interaction of climatic factors (sun, wind, rain, frost) and chemical changes, brought about by biological agents (flora and fauna) and migration of chemical substances through rain, evaporation, surface and underground water.

Particle size distribution also known as gradation, refers to the proportions by dry mass of a soil distributed over specified particle-size ranges. Knowing the grain size distribution of a soil is important for a variety of reasons and for a range of uses in constructions. Particle size analysis is a prime laboratory test for classification of soils and it is equally important for civil engineering structure e.g. Roadwork, Dam, Water reservoir, Marine structures, Building Structure (Verma et.al. 2017).

Gillaspy (2017) defined soil as the organic and inorganic materials on the surface of the earth. Soil develops slowly over time and is composed of many different materials such as inorganic materials, weathered rocks and minerals of various size, as summarized in Table 2.7.

Table 2.7 Soil Classification

Material	Particle Size	Short Description
Gravel	60 mm	Coarse piece of rock like granite, lime, marble, of any shape; (round, flat, angular).Gravel forms the skeleton of the soil and limits its capillarity and shrinkage.
Sand	2 to 0.06 mm The smallest size that can be discerned by naked eye	Particles mainly comprising silica or quartz; beach sand contains carbon carbonate (shell fragments). Sand grains lack cohesion in the presence of water and limit swelling and shrinkage.
Silt	0.06 to 0.002 mm	Silt is physically and chemically the same as sand, but only much finer. Silt gives soil stability by increasing Its internal friction and holds together when wet and compressed.
Clay	Smaller that 0.002 mm	Clay results from chemical weathering of rocks, mainly silicates. The hydrated alumina silicate particles are thin plates of extremely great specific surface area, causing strong cohesion in the presence of water, also excessive swelling and shrinkage.
Colloids	Smaller than 0.002 mm	Fine particles resulting from decomposition of minerals and organic matter(clay is the chief mineral colloid), forming a gluey substance.
Organic matter	Several mm to several cm	Micro grains and fibres resulting from decomposition of plants and soil fauna.

2.48. What is paint?

According to Prudenti (2013), paint is a term used to describe a number of substances that consists of a pigment suspended in a liquid or paste vehicle such as oil or water. Paint is normally made for the purpose of protecting surfaces such as metal, wood or stone but it is used as a decoration as well.

Paint is composed of pigments, binders, resins or liquid; and various additives. The pigments give the paint color; the vehicle (water for latex paint) makes it easier to apply; binders help it dry; and additives serve as everything from fillers to anti-fungicidal agents. Hundreds of different pigments, both natural and synthetic exist. Paint is made up of different percentages of these components (Cole, 2011).

Ukaegbu (2013) writes that, in order to arrive at a successful formulation of a high quality textured paint, it is always necessary to understand not only the performance criteria but also the function of the components especially the base polymer of a base binder. For instance, the PVA provides the major proportion of the adhesive strength in the textured paint production process. Therefore, paints may either be categorized as water-based or latex, which are mostly used for home projects or the solvent-based, oil based or alkyd paints according to whether the solvent used is water or an organic compound (Smartdove, 2008). Water based paints have a binder that is dissolved in water, less toxic and contain fewer volatile organic compounds (vocs) than the solvent-based paints (Blueegg, 2011)

The manufacturer may put additives such as: Thickeners so that the paint covers the wall with a thicker layer of paint to hide what is underneath. Surfactant additives help prevent paint components from separating. Biocide preservatives help prevent mildew when paint is applied in wet areas like a bathroom. Defoamers as paint is applied, tiny bubbles of air are created and a defoamers burst these bubbles.

2.49. Cost of formal Paint

The three main ingredients of paint as described above may also have a fourth ingredient known as an "Additive". Some additives improve the flow of the paint when being applied, some improve the finished appearance, some control foaming, and some provide UV protection from the sun fading the paint and others fight bacterial growth when paint is applied in moist areas such as the bathroom. The more additives are added, the higher the quality of the paint and the higher the price per liter.

2.50. Cost of Soil plaster pastes

Human settlement solutions being used today are beyond the demand of the poor in part due to the high cost of conventional building materials that have been in use since the British colonial days (Turner, 1976; Mitchell & Bevan, 1992 and Payne, 2001). The informal sector has been able to provide cost effective alternatives to peoples' planning and housing problems, and delivers up to five times more housing units at very little cost to the end user than conventional solutions (Martin, 1976a; Turner, 1976 and Silavwe, 1998).

2.51. Conclusion

From the literature review, it has been established that, Soil pastes are the commonest building material used. From all the countries surveyed through literature use earth or soil for plastering in rural communities. Improvements to the soil pastes (mud) have been recorded by the addition of straw ball, animal fur, cowdung including human hair to the pastes to improve the strength, surface hardness and prevention of cracking due to shrinkage. In Burkina Faso, ne're' is used for this purpose. Other additives such as wheat paste help increase durability and stickiness (Aubert, 2015).

In other instances a mixture of clay or loam and coarse aggregates with an additive improves the stability and abrasion resistance of the plaster (Schreckenbach, 2004). A pigment may be added too in order to give colour to the plaster paste in which case the pigment could be synthetic or natural. However, the physical-chemical contents of the soils used in plaster pastes are not studied to understand whether the colour of these pastes is affected by the addition of additives. Some studies comment only about toxicity of soils due to the presence of heavy metals such as lead, cadmium, arsenic.

Even though additives are put into the soil pastes they do not prevent erosion by rain water if not well protected neither do they make the plaster smooth or flow continuously like paints do. So in order to improve quality of the paste it requires an addition of binders but the question still remains whether the original colour of the soil paste would not change.

In this study, soil contents were identified but due to the inhibiting cost of binders the tests could not be carried out although in the literature binders used in paints are listed and these could be tried on soils It is important to learn to identify soil colour from Munsell colour charts so that before additives are mixed in the soil paste, the original colour is known and after the mixing it can be read again to see if there has been any changes in colour. If a change occurs then it could be due to the influence of the physical-chemical content.

.

CHAPTER THREE - RESEARCH METHODOLOGY

3.1 Introduction

Kothari (2004) defines research methodology as a way to systematically solve the research problem. Or it may be understood as a science of studying how research is done scientifically. This section discusses the research design, sample collection method, sample collection tools, sample analysis method, target locations, sample size, limitations of the study, and ethical considerations.

3.2 Research Design

Soils of various colour that are used by rural communities to plaster their homes are available in many locations in Zambia. For this study, Salanga village in Mwansabombwe, Luapula province was selected due to the number of different soil colours that were found in close proximity of 1km radius from which soil samples were collected (Sidhu, 2006).

3.3 Sample Collection Method

Most of the soil samples were quarried by use of hoes digging to an average depth of 600mm and recorded on a special data form (sample in the Appendix); apart from the black soil sample that was collected at about 400mm.

3.4 Samle Analysis Methodology

The study adopted a Laboratory test approach. Six samples were collected and brought to the laboratory in Lusaka from the sampling area in Kawambwa District around Salanga Village. Various laboratory methods were used for the parameters that were being determined. These methods included pH meter with combined electrodes, Walkley Black method for organic matter, precipitation method for sulfates, titrimetric method for chlorides and the Laboratory protocol for ore and soil sample digestion by the Atomic Absoption Spectrophotometry for the heavy metals. The quantitative method was adopted for analysis and calculations of results to assess the presence of metals and chemicals namely copper, iron, manganese and chromium including parameters such as pH, organic matter, sulfates, chlorides, as well as Particle Size

Distribution (PSD).The qualitative method was also used in the preparation of the study report. Munsel colour chart was used to identify soil colours and for chemical properties, titration and precipitation methods were used after which, Microsoft office excel was used for analysis of the data obtained and results were presented through tables, figures, and pie charts

3.5 Munsell Soil Colour Charts

In this study, only the Revised Standard Munsell soil colour charts were used to identify the soils samples. This was because Munsell colour charts top the list of methods that are available for identifications of soils and is widely used by many professions in the world.

3.6 How to Read a Munsell Soil Colour Chart

The Munsell colour system is a means to visually identify and match colour using a scientific approach Munsell (1973) wanted artists and scientists to have a system that made it easy to express colours in a concrete way. The result was a system that is used across many disciplines. Since colour is applicable across so many areas of studies, learning how to read these charts and numbers can be very helpful. The Munsell colour charts contain colours you would find in the field and reading of Munsell charts is by the following steps:

Step 1: *Understanding Colour Attributes*

The first step was to understand the three attributes of colour, Hue, Value and Chroma; also referred to as HVC. Hue is the colour such as red, green, blue, etc. In the Munsell system these are given letter codes, i.e. Red (R), Yellow-Red (YR), Green (G), Green-Yellow (GY). Value is how light or dark a colour is. In the Munsell system, value is indicated with a number, 2, 4, 6, and etc. The value scale runs vertically and moves from lightest at the top to darkest at the bottom in descending order, so a 2 is going to be darker than a 6. Chroma is how weak or strong a colour. In the Munsell system, chroma is indicated with a number, typically in the range of 2-14 upwards of 30 for colours in the fluorescent family. The chroma scale runs horizontally and moves from weak from the left to strong to the right, in ascending order, so a 2 is going to be weaker than a 6.

Step 2**:** *Reading Colour Notations*

There is an abundance of colours in the world; the colour order system allows for accurately identify and understand the relationship of these colours. In addition, when viewed on the charts, colours can be seen how they are related to one another visually. Each colour is designated with what is referred to as a colour notation; for example, 5R 7/2. As explained above, each of these indicators refer to the 3 attributes of colour. 5R is the Hue or colour, 7 is the Value or lightness or darkness and 2 is the Chroma (weak or strong). These colours can then be referenced on a Munsell colour chart to see what the notation looks like.

3.7 Interpreting Soil Colour

Colour can be a clue to mineral content of a soil. Iron minerals, by far, provide the most and the greatest variety of pigments in earth and soil as shown in Table 3.1 from the properties of minerals given by the Encyclopedia of Earth Sciences Series (2008). Soil colour does not affect the behaviour and use of soil; but, may indicate the composition of soil and give clues to the conditions of the soil (Brady et al., 2006).

Table 3.1 Properties of Minerals

Mineral	Formula	Size	Munsell	Colour
Goethite	Feooh	(1-2 M M)	10yr 8/6	Yellow
Goethite	Feooh	(~0.2m M)	7.5yr 5/6	Strong Brown
Haematite	Fe_2o_3	(~0.4m M)	5r 3/6	Red
Haematite	Fe_2o_3	(~0.1m M)	10r 4/8	Red
Lepidocrocite	Feooh	(~0.5 M)	5YR 6/8	Reddish-Yellow

Lepidocrocite	Feooh	(~0.1mm)	2.5yr4/6	Red
Ferrihydrite	$Fe (Oh)_3$		2.5yr3/6	Dark Red
Glauconite	$K(Si_x al_{4-X})(Al,Fe,Mg)O_{10}(Oh)_2$		5y 5/1	Dark Gray
Iron Sulfide	Fes		10yr 2/1	Black
Pyrite	Fes_2		10yr 2/1	Black (Metallic)
Jarosite	$K\ Fe_3\ (Oh)_6\ (So_4)_2$		5y 6/4	Pale Yellow
Todorokite	Mno_4		10yr 2/1	Black
Humus			10yr 2/1	Black
Calcite	$Caco_3$		10yr 8/2	White
Dolomite	$Camg\ (Co_3)_2$		10yr 8/2	White
Gypsum	$Caso_{4\times}\ 2h_2o$		10yr 8/3	Very Pale Brown
Quartz	Sio_2		10yr 6/1	Light Gray

Relatively large crystals of goethite give the ubiquitous yellow pigment of aerobic soils. Smaller goethite crystals produce shades of brown. Hematite (Greek for blood-like) adds rich red tints. Large hematite crystals give a purplish-red colour to geologic sediments that, in a soil, may be inherited from the geologic parent material. In general, goethite soil colours occur more frequently in temperate climates, and haematite colours are more prevalent in hot deserts and tropical climates.

3.8 The Identified Soil Colours

All the soil colours were established according to the Munsell Colour Chart method discussed in this chapter in conjunction with Charts in Appendix B and colours interpreted as shown in Table 3.2.

Table 3.2 Identified Original Soil Colours

SOIL IDENTIFICATION	COLOUR CODE	SOIL COLOUR
Soil Number S 1:	7.5YR 8/2	Light gray
Soil Number S 2:	7.5YR 6/6	Orange
Soil Number S 3:	10YR 2/2	Brownish-black
Soil Number S 4:	25YR 7/6	Yellowish
Soil Number S 5:	7.5YR 8/3	Light Yellow
Soil Number S 6:	Hue 10YR 3/1	Brownish- black

3.9 Soil pH

(i) **Test method:** A pH meter with combined electrode and a reference electrode was used in the analysis as a standard method for pH determination (Estefan et al., 2013). The method was preferred to the Litmus paper method since litmus method is not so accurate the two methods available at our disposal in the Laboratory.

(ii) **Apparatus:** A pH meter with combined electrode, Reference electrode, Saturated KCI potassium chloride, Measuring cylinder, Glass rod, Glass beakers, Internal timer, and a Plastic wash bottle.

(iii) **Reagents:** Deionized water, pH 7.0 buffer solution, and pH 4.0 buffer solution

(iv) **Procedure:** 50g of air dry soil of less than 2mm was placed in a 100ml glass beaker and 50ml of de ionized water using a graduated cylinder was added. The soil and the water were mixed well with a glass rod allowed to stand for 30 minutes. Stirring the suspension however, continued every 10 minutes during this period. The suspension was stirred again after 1 hour. The pH meter was then calibrated. To read the pH value, the combined electrode was put in the suspension about 3 cm deep and readings were taken after 30 seconds to one decimal. The combined electrode was removed from the suspension and rinsed thoroughly with deionized water in a separate beaker, and carefully dries with a tissue.

3.10. Organic Matter

(i) **Test method:** The Walkley Black Method was used to test for organic matter in the soil samples. This method is the most common procedure and it involves reduction of potassium dichromate ($K_2Cr_2O_7$) by organic carbon compound and determination of unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulfate Bahadori and (Tofighi, 2015). The method was preferred because it is more accurate compared to the Dry Matter method which is more of approximation.

(ii) **Apparatus:** A magnetic stirring bar, Glassware, pipette for dispensing and preparing reagents and Titration apparatus or burette

(iii) **Reagents:** The reagents applied in test were as follows:

- Potassium Dichromate Solution (K_2Cr2O_7), IN
- Sulphuric acid (H_2SO_4) concentrated (98%, sp. Gr. 1.84)
- Orthophosphoric acid (H_3PO_4), concentrated
- Ferrous Ammonium Sulfate was dissolved in de-ionized water, 5ml concentrated H_2SO_4
- Diphenylamine indicator $(C_6H_5)_2N$
- 1g diphenylamine indicator was dissolved in 100ml concentrated H_2SO_4

(iv) **Walkley- Black Method:** Two common methods for analysis of soil organic matter are the Walkley-Black acid digestion method and the weight loss on ignition method. The Walkley-Black method, used since the 1930's, uses chromic acid to measure the oxidizable organic carbon in a soil. Concern for the disposal of the chromium and the hazard of using this very strong acid by laboratory technicians, prompted the development of the Weight Loss on Ignition method in the early 1980's. The Weight Loss on Ignition method is based upon measuring the weight loss from a dry soil sample when exposed to high temperatures (360^{o}C). The weight loss that occurs at this temperature is then correlated to oxidizable organic carbon.

Both of these methods are approved and accepted by organizations such as the North Central States Soil Testing Committee. The Weight Loss on Ignition method is the most commonly used method of analysis by independent crop consultants and fertilizer and chemical retailers on routine soil samples. The Walkley-Black method has been the preferred method for GLP customers and researchers, but that trend is changing. Many GLP customers are now requesting the Weight Loss on Ignition method or even both methods.

Each method for determining soil organic matter has its advantages. The Walkley-Black method is more accurate and more precise on soils with less than 2.0% organic matter. On soils very high in organic matter, the Walkley-Black method may result in low test results, due to the incomplete oxidation of the organic carbon in the sample. The Loss on Ignition method is better suited to soils with greater than 6.0% organic matter. In this method there is no chemical reaction which could be limiting since we are only measuring weight loss of the sample at high temperatures A(gvise Laboratories, 2018). In this study, the Walkley-Black method was used simply as a preference by the researcher as it is said to be more accurate:

(v) **Procedure:** 1g air-dry soil was weighted into a 500ml beaker and 10ml 1N potassium dichromate solution was added using a pipette and 20ml of concentrated sulphuric acid H_2SO_4 was added using a dispenser then the suspension was mixed by swirling the beaker. The mixture was then left to stand for 30 minutes. 200ml of distilled water was added and then 10ml concentrated orthophospheric acid (H_3PO_4) using a dispenser and allowed the mixture to cool. When the mixture had cooled down, 10 – 15 drops of diphenylamine indicator was added; including a teflon-coated magnetic stirring bar, then placed on a magnetic stirrer. The mixture was then titrated with 0.5M ferrous ammonium sulfate solution until the colour changed from violet blue to green. Two blanks were prepared too, containing all the reagents but no soil and were treated exactly in the same way as the soil suspension.

(vi) **Errors:** Titration was one way in which error was possible because of the difficulty to tell when the mixture has changed colour. Care was also required at the time of adding reagents since some of them needed small quantities to be measured.

3.11. Sulfates

(i) **Test method:** The precipitation method was used to extract surface from soil extractants by Barium sulfate precipitation. This is a Spectrophotometric method with results read against a standard. The method does not loose some precipitation in the process as readings are direct. It is a quicker method although it is an expensive method. The method was preferred to the Gravimetric method which is has no standard for calibration although it is also a precipitation method. It does not give very accurate results compared to the first method due to loses of precipitates during the process.

(ii) **Apparatus:** The apparatus comprised a mechanical shaker and a muffle furnace

(iii) **Reagents:** The reagents that were used in the tests included the following:

- Methyl orange indicator 4-$NaOSO_2C_6H_4N:NC_6H_4$/-4-$N(CH_3)_2$
- 0.1g methyl orange indicator was dissolved in 100ml deionized water
- Hydrochloric acid solution (HCl), 1:1
- Equal portions of concentrated HCl with deionized water
- Barium Chloride Solution ($BaCl_2.2H_2O$) 1N
- 122g $BaCl_2.2H_2O$ was dissolved in deionized water, and made to 1L volume

(v) **Procedure:** The procedure used in this test comprised the following:

A - **Extraction:** Soluble SO_4^{2-} was obtained in a water extract from a saturated paste like for pH determination. The suspension was filtered on Whatman No.1 filter paper to exclude any soil particles.

B- **Measurement:** A soil extract containing 0.05 to 0.5 mg SO_4-S was pipetted into a 250ml pyrex beaker and diluted to 50ml volume and 1ml 1: 1 HCI solution was added including 2 – 3 drops methyl orange until the colour turned pink. The beaker was then placed on a hot plate and heated to boiling, then 10ml 1N $BaCL_2.2H_2O$ solution was added in excess to precipitate SO_4 as Barium Sulfate. This was boiled between 5 to 10 minutes and left to cool; there after the solution was filtered through ash less filter paper. The barium sulfate precipitated was collected on a filter paper, washed several times with warm d-ionised water until no trace of chloride remained. The presence of the chlorides was checked using silver nitrate $AgHO_3$ solution. After washing, the filter paper with the precipitate was placed into a pre-weighted and dried porcelain crucible (Wt_1), and put in an oven at 150 0C and left to dry for 1 hour. The crucible was then transferred to muffle furnace heated to 550 0C and left to dry ash for 2 – 3 hours. From the muffle furnace, the crucible was placed in a desiccator to cool, then the crucible was weighted on an analytical balance; this was (Wt_2).

3.12. Chlorides

(i) Test Method: Titrimetric method was used from which soluble Chloride (Cl) is obtained in the saturated extract as prepared for soluble Ca, Mg and anions and its concentration in the extract is determined by Silver Nitrate Titration.

(ii) **Reagents:** 1. Potassium Chromate solution (K_2CrO_4), 5% in water
50g of K_2CrO_4 was dissolved in 50Ml de-ionized water and drop wise, Silver Nitrate ($AgNO_3$) was added until a slight permanent red precipitate was formed ; it was then filtered and brought to 100mL volume with de-ionized water. 2. Silver Nitrate solution ($AgNO_3$), 0.001N3 – 4 g $AgNo_3$ was dried in an oven at 105 0C for 2 hours, cooled in a desiccator and stored in a tightly stoppered bottle. 1.696g dried $AgNo_3$ was dissolved in deionized water and brought to 1L volume. 3. Sodium Chloride solution (NaCl), 0.01 N and 2 -3g NaCl was dried in an oven at 110 0C for 3 hours, cooled in a desiccator and stored in a tightly stoppered bottle . 0.585g dried NaCl was dissolved in deionised water and brought to 1L volume.

(iii) **Procedure:** Soluble Cl^- was obtained in a water extract from a saturated paste like for pH determination. The suspension was filtered on Whatman NO. 1 filter paper to exclude any soil particles. 5-10mL soil saturation extraction was pipette in a wide mouth Erlenmeyer flask (150m-L) and 4 drops 5% K_2CrO_4 solution was added this was then titrated against 0.01N $AgNO_3$ until a permanent reddish-brown colour appeared. As a rule, two blanks containing all reagents but no soil were run and treated exactly the same way as for samples.

The readings of the blanks titration readings were subtracted from readings for all samples. Standardise $AgNO_3$ titrant establish reagent blank value by the titration method. A blank of 0.2 0.3mL was made as usual.

Calculation: $$\text{mg Cl}-/L = [\frac{(A-B) \text{ x N x } 35\ 450}{\text{mL sample}} \text{ x mg/L] x } 100\%$$

Where:

A = mL titration for sample,

B = mL titration for blank, and

N = Normality of $AgNO_3$

3.13. Iron

(i) **Test Method:** The test was done through a Laboratory protocol for ore and soil sample digestion to analyze Cu, Fe, Mn, Cr, and other metals in soil samples by Atomic Absoption Spectrophotometry as follows: 1 gram of soil sample was weighted using a weighing boat in triplicates, and transferred to a 250 ml beakers then 25 – 30 ml acid mixture (Aqua Regia: 3: 1 HCl : HNO3) was added.

(ii) **Apparatus:** 250ml beakers and an Atomic Absoption Spectrophotometer

(iii) **Procedure:** The procedure used in this test was as follows:

a) *Stages in Sample Preparation*

Each sample bag was mixed thoroughly so as to obtain homogeneity.

b) *Sample Division*

Decreasing the mass of the sample in this step is governed by the particle size and the mass of the material. Cardinal Rule – Crush Before You Divide the Sample.

c) *Conning and Quartering*

The reduction of sample bulk should always be carried out mechanically but instances do occur when the equipment is not available and the bulk sample must be reduced. Under such circumstances the simplest method is coning and quartering.

- Mix the sample thoroughly on a surface that is clean and will not be disturbed by the operations. A clean concrete floor or a large steel plate can be used.
- Mixing is done by transferring the sample from one point to another by shovel, always putting the shovel of the material on top of the cone. This process is done three times.
- Flatten the cone with the shovel and divide into four even quarters.
- Reject opposite quarters leaving half the sample.
- Remove the retained quarters and repeat the procedure until the required amount of material has been reached.
- Quarters can be made with a shaped wooden or metallic cross which is pressed into the heap.

(iv) **Elemental Analysis of Iron Ore Samples:**

- Weigh about 1 gram of sample.
- Add Aqua Regia about 30ml (a mixture of one part **concentrated** Nitric acid and three parts **concentrated** Hydrochloric Acid).
- Heat on Hot Plate (above 400 degrees Celsius) for 15 minutes or when it nears dryness.
- Wash the inside of the conical flask.
- Filter into 100ml volumetric flask.
- Make up to the mark of the volumetric flask.
- Thoroughly mix the filtrate and let it settle.
- Calibrate Atomic Absorption Spectrophotometer with Known working standards and ensure that you obtain a linear curve.
- Run the samples on the Atomic Absorption Spectrophotometer.

3.14. Copper

(i) **Tests Method** - The test was done through a Laboratory protocol for ore and soil sample digestion to analyze Cu, Fe, Mn, Cr, and other metals in soil samples by

Atomic Absoption Spectrophotometry as follows: 1 gram of soil sample was weighted using a weighing boat in triplicates, and transferred to 250 ml beakers of 25 – 30 ml acid mixture (Aqua Regia: 3: 1 HCl : HNO3).

(ii) **Apparatus:** 250ml beakers and an Atomic Absoption Spectrophotometer

(iii) **Procedure:** The procedure used in this test was in stages as follows:

a) Stages in Sample Preparation

Each sample bag was mixed thoroughly so as to obtain homogeneity.

b) Sample Division

Decreasing the mass of the sample in this step is governed by the particle size and the mass of the material. Cardinal Rule – Crush Before You Divide the Sample**.**

c) Conning and Quartering

The reduction of sample bulk should always be carried out mechanically but instances do occur when the equipment is not available and the bulk sample must be reduced. Under such circumstances the simplest method is coning and quartering. Mix the sample thoroughly on a surface that is clean and will not be disturbed by the operations. A clean concrete floor or a large steel plate can be used. Mixing is done by transferring the sample from one point to another by shovel, always putting the shovel of the material on top of the cone. This process is done three times. Flatten the cone with the shovel and divide into four even quarters. Reject opposite quarters leaving half the sample. Remove the retained quarters and repeat the procedure until the required amount of material has been reached. Quarters can be made with a wooden or metallic cross which is pressed into the heap.

(iv) **Elemental Analysis of Copper Ore Samples:**

- Weigh about 1 gram of sample.
- Add Aqua Regia about 30ml (a mixture of one part **concentrated** Nitric acid and three parts **concentrated** Hydrochloric Acid).
- Heat on Hot Plate (above 400 ^{o}C) for 15 minutes or when it nears dryness.
- Wash the inside of the conical flask.

- Filter into 100ml volumetric flask.
- Make up to the mark of the volumetric flask.
- Thoroughly mix the filtrate and let it settle.
- Atomic Absorption Spectrophotometer is calibrated with Known working standards to obtain a linear curve and run sample on AAS.

3.15. Manganese

(i) **Test Method:** The test was done through a Laboratory protocol for ore and soil sample digestion to analyze Cu, Fe, Mn, Cr, and other metals in soil samples by Atomic Absoption Spectrophotometry as follows: 1 gram of soil sample was weighted in triplicates using a boat, and transferred to a 250 ml beakers then 25 – 30 ml acid mixture (Aqua Regia: 3: 1 HCl : HNO_3) was added.

(ii) **Apparatus:** 250ml beakers and an Atomic Absoption Spectrophotometer

(iii) **Procedure:** The procedure used in this test was in stages as follows:

a) Stages in Sample Preparation

Each sample bag was mixed thoroughly so as to obtain homogeneity.

b) Sample Division

Decreasing the mass of the sample in this step is governed by the particle size and the mass of the material. Cardinal Rule – Crush Before You Divide the Sample.

c) Conning and Quartering

The reduction of sample bulk should always be carried out mechanically but instances do occur when the equipment is not available and the bulk sample must be reduced. Under such circumstances the simplest method is coning and quartering.

Mix the sample thoroughly on a surface that is clean and will not be disturbed by the operations. A clean concrete floor or a large steel plate can be used.

Mixing is done by transferring the sample from one point to another by shovel, always putting the shovel of the material on top of the cone. This process is done three times.

Flatten the cone with the shovel and divide into four even quarters.

Reject opposite quarters leaving half the sample.

Remove the retained quarters and repeat the procedure until the required amount of material has been reached.

Quarters can be made with a shaped wooden or metallic cross which is pressed into the heap.

(iv) **Elemental Analysis of Manganese Ore Samples:**

- Weigh about 1 gram of sample.
- Add Aqua Regia about 30ml (a mixture of one part **concentrated** Nitric acid and three parts **concentrated** Hydrochloric Acid).
- Heat on Hot Plate (above 400 degrees Celsius) for 15 minutes or when it nears dryness.
- Wash the inside of the conical flask.
- Filter into 100ml volumetric flask.
- Make up to the mark of the volumetric flask.
- Thoroughly mix the filtrate and let it settle.
- Calibrate Atomic Absorption Spectrophotometer with Known working standards and ensure that you obtain a linear curve.
- Run the samples on the Atomic Absorption Spectrophotometer.

3.16. Chromium

(i) **Test Method:** The test was done through a Laboratory protocol for ore and soil sample digestion to analyze Cu, Fe, Mn, Cr, and other metals in soil samples by Atomic Absoption Spectrophotometry as follows: 1 gram of soil sample was weighted using a weighing boat in triplicates, and transferred to a 250 ml beakers then 25 – 30 ml acid mixture (Aqua Regia: 3: 1 HCl : HNO3) was added.

(ii) **Apparatus:** 250ml beakers and an Atomic Absoption Spectrophotometer

(iii) **Procedure:** The procedure used in this test was in stages as follows:

a) Stages in Sample Preparation

Each sample bag was mixed thoroughly so as to obtain homogeneity.

b) Sample Division

Decreasing the mass of the sample in this step is governed by the particle size and the mass of the material. Cardinal Rule – Crush Before You Divide the Sample.

c) *Conning and Quartering*

The reduction of sample bulk should always be carried out mechanically but instances do occur when the equipment is not available and the bulk sample must be reduced. Under such circumstances the simplest method is coning and quartering.

- Mix the sample thoroughly on a surface that is clean and will not be disturbed by the operations. A clean concrete floor or a large steel plate can be used.
- Mixing is done by transferring the sample from one point to another by shovel, always putting the shovel of the material on top of the cone. This process is done three times.
- Flatten the cone with the shovel and divide into four even quarters.
- Reject opposite quarters leaving half the sample.
- Remove the retained quarters and repeat the procedure until the required amount of material has been reached.

Quarters can be made with a wooden or metallic cross which is pressed into the heap.

(iv) **Elemental Analysis of Chromium Ore Samples:**

- Weigh about 1 gram of sample.
- Add Aqua Regia about 30 ml (a mixture of one part **concentrated** Nitric acid and three parts **concentrated** Hydrochloric Acid).
- Heat on Hot Plate (above 400 ^{o}C) for 15 minutes or when it nears dryness.
- Wash the inside of the conical flask.
- Filter into 100ml volumetric flask.
- Make up to the mark of the volumetric flask.
- Thoroughly mix the filtrate and let it settle.

- Calibrate Atomic Absorption Spectrophotometer with Known working standards and ensure that you obtain a linear curve.
- Run the samples on the Atomic Absorption Spectrophotometer.

3.17. Particle Size Distribution (PSD)

(i) **Test Method:** The soil samples were dry sieved since the material was too fine and the results were reported in a table form. The percentage passing sieve no. 0.063 was obtained by subtracting the sum of fractions passing through all the sieves from the total mass of sample.

(ii) **Apparatus:** BS sieves: 16 mm, 9.52 mm, 8.00 mm, 6.00 mm, 4.00 mm, 2.00 mm, 1.18 mm, 0.60 mm, 0.425 mm, 0.30 mm, 0.15 mm, 0.063 mm, Pan, Sieve shaker and wire brush.

(iii) **Procedure:** The two classes of methods of determining the particle size distribution (PSD) of a given sample consist of classical and instrumental, both of which rely on physical segregation of particles followed by quantification by mass. Classical methods are sieving and pipette methods. Instrumental methods are optical determination of particles, electrical sensing zone or electro resistance particle counting (Coulter Counter), X-ray sedimentation (Sedigraph) and laser diffraction. All of these methods have distinct advantages and disadvantages and no one procedure gives exact results due to the nature and definition of soil particle size.

Considering the pros and cons from all the test methods for Particle Size Analysis described in Chapter two, the method for dry sieving was chosen because it was easy to carry out with the equipment available in the Laboratory as per the following procedure: Samples were washed on the 0.063 micro meter test sieve to remove clay and silt materials then, the soils were placed in the oven at 105 ^{0}C to dry and was then sieved after 24 hours in the oven.

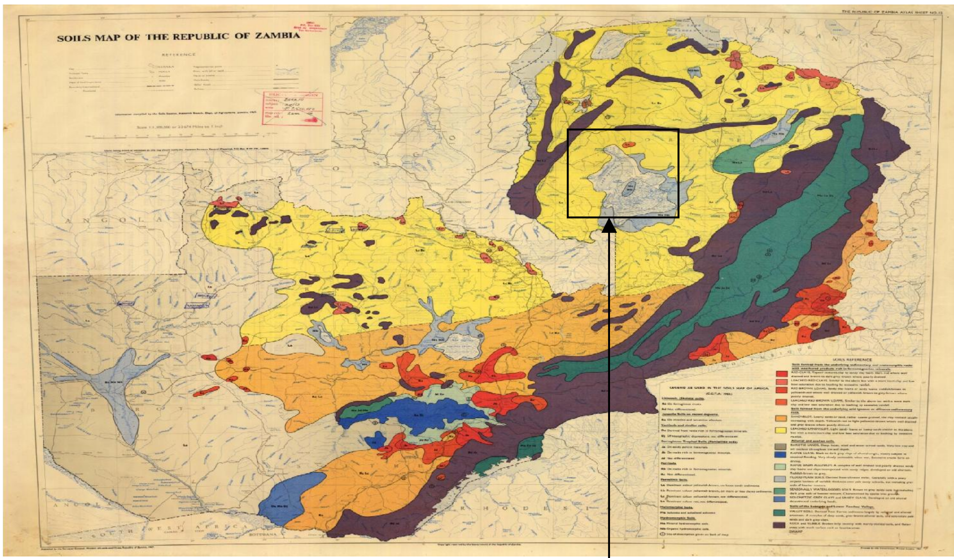
Sieves were arranged in a range as given in a descending order for particle size distribution performed in the Laboratory. The range of these sieves was then placed on the sieve shaker and clamped. The sieving of 500g of soil on the sieve shaker lasted 10 minutes for each soil sample. For each test, sieves were cleaned with a wire brush to remove any particles sticking in the sieve wire mesh. The amounts of soil retained and passing the sieves were added as appropriate and results calculated as given in tables in chapter four. The tests were done in order to determine the grain distribution in all the soils. Particle size analysis for soils is performed in order to determine the percentage of different grain sizes contained within a soil sample in accordance to the Unified Soil Grading Criteria

According to Henry (2014), particle size diversity is important to create good structure, and to reduce the amount of binder needed. Ideally you'd have a mix of nearly every grain size so that there are few large voids left because this creates a structure that resists movement, and also requires less binder to fill all those voids. Less binder equates to less cracking, and shrinkage cracks are one of the plasterer's number one enemies. Sand should not, however, contain silt – which is the particle size below sand, slightly coarser than clay. Silt fills the voids in place of the binder, resulting in weak plasters. Clay can also cause serious problems in lime-based plasters. So sand should be free of fine particles, and unwanted salt, chemicals or organic matter.

As a conservative rule the largest particles in the sand should be no more than half the thickness of your plaster, but preferably would be at least one quarter the thickness of your plaster (larger aggregate can provide better structure, resulting in a stronger plaster with less cracking). So if your plaster coat is a half inch, your largest aggregate would ideally be between 1/8 and 1/4 inch.

3.18. Target Location

A simple random sampling method was applied in the selection of sampling locations where by targeted locations had an equal probability of being chosen as a sample location. The soil samples were collected within a radius of 1km showing that there were varying soil differences in Kawambwa's Salanga Village shown on Figure: 3.1a and Figure 3.1b. In both Figures 3.1a and 3.1b the arrows point to the area shaded white on the Soils Map of Zambia shows the location where the soil sampling took place in Salanga Village, Kawambwa, Luapula Province.



Salanga Village Sampling area 1 km radius

Figure: 3.1a Kawambwa area Source: Ministry of Lands, soil section 1967

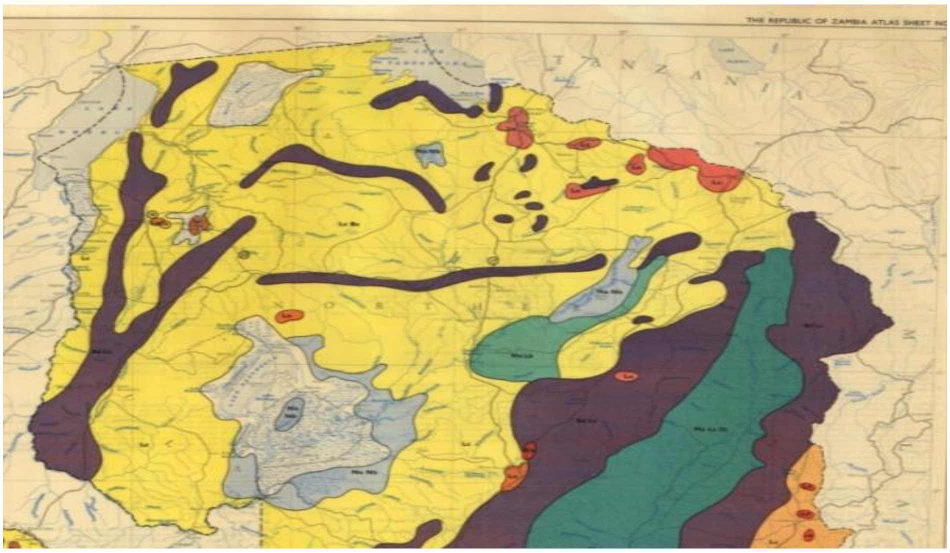


Figure: 3.1b Map of Sample Location

3.19. Sample Size

The sample size was at least 1x5 kg for each soil colour and total quantity depended on the colours available in that particular location as a result, six colours were found and collected.

3.20. Limitations of the Study

The number of locations and soil colours found in Kawambwa, Luapula province determined the limitations of the sample area size. The funds to use for the travel and other expenses had also an effect on the study since a sponsor was not found. The cost of binders and the extensive number of tests required for this objective could not enable tests to be carried out on soil samples to verify which ones might alter the original colour of the soils and whether the physical-chemical quantities present in soils were enough to cause a reactions with binders.

Figure: 3.2. Soil pigment samples – (Photo by Researcher: Brian C Mulenga 2016)

Figure 3.2 displays the six soil samples of different colours S1 – S6 that were used in the Laboratory for this study.

3.21. Ethical Considerations

Resnik (2011) defines ethics as norms for conduct that distiguish between acceptable and unacceptable behaviour. It may also be defined as a method, procedure or perspective for deciding how to act and for analyzing complex problems and issues. Many different disciplines, institutions and professions have norms for behaviour that suit their particular aims and goals. The study strived to respect guidelines for authorship, copyright and patenting policies, data sharing policies, and confidentiality.

CHAPTER FOUR - RESULTS AND FINDINGS

4.1. Introduction

Soils have many different properties, including texture, structure, water-holding capacity and pH; that is, whether the soils are acidic or alkaline. These properties combine to make soils useful for a wide range of purposes. The amount of sand, silt, clay and organic matter in a particular soil plays a large part in the way that it behaves, how it can be managed and what it be used for. In this study, soil samples from Salanga Village in Kawambwa, Luapula Province were subjected to Laboratory tests and results presented in Tables 4.1 – 4.16 as follows:

4.2. Results for Soil pH

Table 4.1 shows the results that were obtained from laboratory tests and each soil sample had five tests to obtain an average as given in the table.

Table 4.1 Shows Test results obtained – pH

Soil ID Luapula	**Sample size**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
	(g)						
S1	50g	5.9	5.97	6.4	6.06	6.21	**6.11**
S2	50g	4.93	6.04	6.77	5.62	5.66	**5.80**
S3	50g	4.88	5.01	5.33	5.14	5.17	**5.11**
S4	50g	4.68	5.33	5.77	5.61	5.62	**5.40**
S5	50g	4.83	5.21	5.58	5.25	5.39	**5.25**
S6	50g	6.03	6.26	6.64	6.35	6.46	**6.35**

The six soil samples were tested in the laboratory as described in Fig 4.1 showing that, the average soil pH to two decimal places ranged between 5.11 and 6.35. This means that, from the pH scale, the samples are partly forest soils and humid climate arable soils. The soil pH is also below the neutral 7 pH value and if interpreted from the common acids and alkalis, it is moderately to slightly acid.

The results increased the knowledge about the status of Salanga village soils in Kawambwa so that, a choice of the right binder to mix with the soil that will not react with these acidic soils to alter the original soil colours is made. Further investigations however, are encouraged to establish what would be the outcome of a binder-soil mixture.

4.3. Results for Organic Matter

The Table 4.2 shows the results that were obtained from laboratory tests as follows: Each soil sample had five tests to obtain an average as given in Table 4.2.

Table: 4.2. Shows Results obtained – Organic Matter

Soil ID Luapula	**Sample size**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average OM**
	(g)	ppm	ppm	ppm	ppm	ppm	(%)
S1	1g	0 - 18.9	0 - 13.8	0 - 20.7	0 – 20.6	0 – 18.9	**18.7**
S2	1g	0 - 18.7	0 - 14.9	0 - 20.6	0 – 19.6	0 – 20.2	**18.8**
S3	1g	0 - 21.9	0 - 14.7	0 - 27.5	0 – 19.0	0 – 19.7	**20.6**
S4	1g	0 - 18.6	0 - 17.9	0 - 19.6	0 – 20.3	0 – 19.8	**19.2**
S5	1g	0 - 21.5	0 - 17.8	0 - 19.7	0 – 20.8	0 – 20.1	**20**
S6	1g	0 - 11.0	0 - 17.9	0- 13.8	0 – 13.5	0 – 11.5	**13.5**

The actual measurement is of oxidisable organic carbon, and the data were converted to percentage organic carbon. However, as this proportion is not constant, results are reported as oxidisable organic carbon, or multiplied by 1.334 as organic carbon. The high carbon content may be attributed to high humus in the soil. This gives the soil a brownish gray colour.

The results increased the knowledge about the status of Salanga village soils in Kawambwa so that, a choice of the right binder to mix with the soil can be made. It is assumed that, if a binder is added to the soils, it might react with organic matter and have an effect on the colour of the soil. Further investigation would be necessary to establish whether original colour of the soil would be altered when a binder is added.

4.4. Results for Sulfates

The Table 4.3 shows the results that were obtained from laboratory tests as follows: Each soil sample had five tests to obtain an average as given in Table 4.3.

Table: 4.3. Shows Results obtained – Sulfates

Soil ID	**Sample size**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
Luapula	(g)	ppm	ppm	ppm	ppm	ppm	ppm
S1	2g	26.03	16.35	27.54	27.11	24.26	**24.26**
S2	2g	6.66	9.64	4.47	6.07	5.37	**5.37**
S3	2g	5.01	7.74	5.54	6.56	4.97	**4.97**
S4	2g	5.23	7.43	6.87	6.09	5.12	**5.12**
S5	2g	5.55	6.92	5.96	7.78	5.24	**5.24**
S6	2g	16.49	16.9	17.24	15.86	16.62	**16.62**

Soil type S1 has an average of 24. 26 ppm sulfates, and soil type S2 has an average of 5.37ppm sulfates, while soil type S3, S4, S5 and S6 have values of 4.97 ppm sulfates, 5.12 ppm sulfates, 5.24 ppm sulfates and 16.62 ppm sulfates respectively. The experiment confirmed the presence of sulfates in the soil samples however, samples S1 and S6 had high amounts of sulfates than the other four samples.

The results increased the knowledge about the status of Salanga village soils in Kawambwa so that, a choice of the right binder to mix with the soil can be made. It is assumed that, if a binder is added to the soils, it might react with sulfates and have an effect on the colour of the soil, its smoothness and flow. Further investigation would be necessary to establish whether original colour of the soil would be altered when a binder is added.

4.5. Results for Chlorides

The Table 4.4 shows the results that were obtained from laboratory tests as follows: Each soil sample had five tests to obtain an average as given in the Table 4.4.

Table: 4.4 Shows Results obtained - Chlorides

Soil ID Luapula	**Sample size**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
	(g)	ppm	ppm	ppm	ppm	ppm	ppm
S1	50g	11	9	10	17	14	**12.2**
S2	50g	9	8	11	14	13	**11**
S3	50g	10	9	11	11	11	**10.4**
S4	50g	11	11	13	12	13	**12**
S5	50g	17	12	10	12	15	**13.2**
S6	50g	11.6	12.2	11	10.4	12	**11.73**

Soil type S1 has an average of 12.2 ppm, S2 has an average of 11 ppm, S3 has an average 10.4 ppm, S4 has an average of 12 ppm, S5 has an average of 13.2 and S6 has an average of 11.73 ppm.

The experiment actually confirmed the presence of chlorides in the soil and this has added knowledge on the status of Salanga village soils in Kawambwa. It would be important to select a binder which will not react with chlorides. This is because the amount of chlorides present in the soil samples indicate that a reaction could take place if a binder is added to the soil and this could alter the soil colour.

4.6. Results for Iron

The Table 4.5 show the results that were obtained from laboratory tests as follows: Each soil sample had four tests to obtain an average as given in the Table 4.5 below.

Table: 4.5 Shows Results Obtained – Iron

Soil ID Luapula	Sample size	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Average**
	(g)	%	%	%	%	%
S1	1g	0.08	0.08	0.08	0.08	**0.08**
S2	1g	0.83	0.81	0.83	0.82	**0.82**
S3	1g	0.90	0.92	0.94	0.96	**0.93**
S4	1g	1.22	1.23	1.21	1.24	**1.23**
S5	1g	0.08	0.08	0.08	0.08	**0.08**
S6	1g	0.31	0.32	0.31	0.33	**0.32**

Sample S1 and S5 had 0.08 % iron, sample S2 had 0.82% iron, Sample S3 had 0.93 %, sample S4 had 1.23 %, and sample S6 had 0.32 % iron. The experiment, actually confirmed the presence of slight amounts of iron in the soil and this has added knowledge on the status of Salanga village soils in Kawambwa. It would be important to select a binder which will not react with iron. This is because the amount of iron present in the soil samples indicate that a reaction could take place if a binder is added to the soil and this could alter the soil colour.

4.7. Results for Copper

The Table 4.6 show the results that were obtained from laboratory tests as follows: Each soil sample had four tests to obtain an average as given in the Table 4.6.

Table: 4.6 Shows results Obtained – Copper

Soil ID Luapula	**Sample Size**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Average**
	(g)	%	%	%	%	%
SI	50	12.12	12.32	12.15	12.24	**12.21**
S2	50	5.68	5.17	5.72	5.69	**5.6**
S3	50	13.12	13.21	13.19	13.31	**13.21**
S4	50	15.03	15.08	15.10	15.01	**15.1**
S5	50	4.62	4.68	4.46	4.59	**4.6**
S6	50	12.92	12.89	12.81	12.90	**12.91**

Sample S1 had 12.21 %, copper, sample S2 had 5.6 % copper, Sample S3 had 13.21% copper, sample S4 had 15.1 % copper, S5 had 4.6 % copper, sample S6 had 12.91 % copper. Results reported to the Standard Deviation $\pm$ 4. The experiment actually confirmed the presence of copper in the soil samples.

The presence of copper in the soil and this has increased knowledge on the status of Salanga village soils in Kawambwa. It would be important to select a binder which will not react with copper. This is because the amount of copper present in the soil samples indicate that a reaction could take place if a binder is added to the soil.

4.8. Results for Chromium

The Table 4.7 show the results that were obtained from laboratory tests as follows: Each soil sample had four tests to obtain an average as given in the Table 4.7.

Table 4.7 Shows Results Obtained – Chromium

Soil ID Luapula	Sample Size	Test 1	Test 2	Test 3	Test 4	Average
	(g)	%	%	%	%	%
SI	1	< 0.002	< 0.002	< 0.002	< 0.002	**< 0.002**
S2	1	< 0.002	< 0.002	< 0.002	< 0.002	**< 0.002**
S3	1	< 0.002	< 0.002	< 0.002	< 0.002	**< 0.002**
S4	1	< 0.002	< 0.002	< 0.002	< 0.002	**< 0.002**
S5	1	< 0.002	< 0.002	< 0.002	< 0.002	**< 0.002**
S6	1	< 0.002	< 0.002	< 0.002	< 0.002	**< 0.002**

Sample S1 had **< 0.002** % Chromium, sample S2 had **< 0.002**% Chromium, Sample S3 had **< 0.002**% Chromium, sample S4 had **< 0.002**% Chromium, S5 had **< 0.002**% Chromium, sample S6 had **< 0.002**% Chromium. The experiment actually confirmed the presence of chromium in slight amounts in the soil samples.

The experimental results increased knowledge on the status of Salanga village soils in Kawambwa. Therefore, it would be important to select a binder which will not react with chromium. This is because the amount of Chromium present in the soil samples indicate that a reaction could take place if a binder is added to the soil.

4.9. Results for Manganese

The Table 4.8 show the results that were obtained from laboratory tests as follows: Each soil sample had four tests to obtain an average as given in the Table 4.8.

Table 4.8 Shows Results Obtained – Manganese

Soil ID Luapula	**Sample Size**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Average**
	(g)	%	%	%	%	%
SI	50	62.07	62.11	62.42	62.21	**62.17**
S2	50	66.71	70.02	66.88	66.79	**66.71**
S3	50	107.99	108.24	107.94	108.09	**107.99**
S4	50	54.72	54.68	55.21	55.13	**54.72**
S5	50	54.11	54.29	54.19	54.13	**54.11**
S6	50	324.67	321.86	322.81	324.12	**324.67**

Sample S1 had 62.17ppm, manganese, sample S2 had 66.71 ppm manganese, Sample S3 had 107.99 ppm manganese, sample S4 had 54.72 ppm manganese, S5 had 54.11 ppm manganese, sample S6 had 324.67 ppm manganese. The experiment actually showed the presence of significant amounts of manganese in the soil samples S3 and S6,while samples S1, S2, S4 and S5 had lower amounts of manganese.

The experimental findings increased the knowledge on the status of Salanga village soils in Kawambwa. It would be important to select a binder which will not react with manganese. This is because the amount of manganese present in the soil samples indicate that a reaction could take place if a binder is added to the soil and this could alter the soil colour.

4.10. Results for Particle Size Distribution (PSD)

Soil samples from the study area were tested for particle size distribution and the results found were tabulated in the Tables 4.9 – 4.14: and Figures 4.1 – 4.6 as follows:

Table 4.9 Particle Size Distribution Analysis **- Sample 1**

Sample Size:	500g				**Date :**	26 April 2016	
Soil ID:	**S1**				**Depth :**	1.5m	
Location:	Salanga Village				**Tested by:**	C. Silungwe	
					Tested by	C. Silungwe	
Sieve No.	**Sieve Opening**	**Sieve mass**	**Sieve/Soil mass**	**Retained soil mass**	**%Retained**	**Cumulative %Retained**	**% Finer**
	(mm)	(g)	(g)	(g)			
1	16.00	573.80	573.80	0.00	0.00	0.00	100.00
2	9.52	500.80	500.80	0.00	0.00	0.00	100.00
3	8.00	525.80	525.80	0.00	0.00	0.00	100.00
4	6.00	527.50	527.50	0.00	0.00	0.00	100.00
5	4.00	522.80	575.40	52.60	10.52	10.52	89.48
6	2.00	310.10	419.20	109.10	21.82	32.34	67.66
7	1.18	275.70	327.20	51.50	10.30	42.64	57.36
8	0.60	253.80	314.90	61.10	12.22	54.86	45.14
9	0.425	462.30	517.50	55.20	11.04	65.90	34.10
10	0.30	435.60	479.50	43.90	8.78	74.68	25.32
11	0.15	223.90	302.50	78.60	15.72	90.40	9.60
12	0.063	202.10	243.30	41.20	8.24	98.64	1.36
13	PAN	182.7	182.70	0.00	11.36	100.00	

Table 4.10 Particle Size Distribution Analysis **- Sample 2**

Sample Size: 500g **Soil ID:** **S2** **Location:** Salanga Village					**Date :** 26 April 2016 **Depth :** 1.5m **Tested by:** C. Silungwe		
Sieve No.	**Sieve Opening**	**mass of Sieve**	**mass of Sieve and soil**	**Mass of soil Retained**	**% Retained**	**Cumulative % Retained**	**% Finer**
	(mm)	(g)	(g)	(g)			
1	16.00	573.80	573.80	0.00	0.00	0.00	100.00
2	9.52	500.80	500.80	0.00	0.00	0.00	100.00
3	8.00	525.80	525.80	0.00	0.00	0.00	100.00
4	6.00	527.50	527.50	0.00	0.00	0.00	100.00
5	4.00	522.80	528.60	5.80	1.16	1.16	98.84
6	2.00	310.10	393.60	83.50	16.70	17.86	82.14
7	1.18	275.70	329.20	53.50	10.70	28.56	71.44
8	0.60	253.80	368.50	114.7	22.94	51.50	48.50
9	0.425	462.30	545.90	83.60	16.72	68.22	31.78
10	0.30	435.60	479.60	44.00	8.80	77.02	22.98
11	0.15	223.90	291.20	67.30	13.46	90.48	9.52
12	0.063	202.10	236.10	34.00	6.80	97.28	2.72
13	PAN	182.7	186.10	0.00	11.36	100.00	

Table 4.11 Particle Size Distribution Analysis – **Sample 3**

Sample Size: 500g **Soil ID:** **S3** **Location:** Salanga Village					**Date :** 26 April 2016 **Depth :** 1.5m **Tested by:** C. Silungwe		
Sieve No.	**Sieve Opening**	**mass of Sieve**	**mass of Sieve and soil**	**Mass of soil Retained**	**% Retained**	**Cumulative % Retained**	**% Finer**
	(mm)	(g)	(g)	(g)			
1	16.00	573.80	573.80	0.00	0.00	0.00	100.00
2	9.52	500.80	500.80	0.00	0.00	0.00	100.00
3	8.00	525.80	525.80	0.00	0.00	0.00	100.00
4	6.00	527.50	527.50	0.00	0.00	0.00	100.00
5	4.00	522.80	528.60	5.80	1.16	1.16	98.84
6	2.00	310.10	393.60	83.50	16.70	17.86	82.14
7	1.18	275.70	339.20	63.50	12.70	30.36	69.44
8	0.60	253.80	368.50	114.70	22.94	53.50	46.50
9	0.425	462.30	545.90	83.60	16.72	70.22	29.78
10	0.30	435.60	479.60	44.00	8.80	79.02	20.98
11	0.15	223.90	291.20	67.30	13.46	92.48	7.52
12	0.063	202.10	236.10	34.00	6.80	99.28	0.72
13	PAN	182.7	186.10	0.00	0.72	100	

Table 4.12 Particle Size Distribution Analysis – **Sample4**

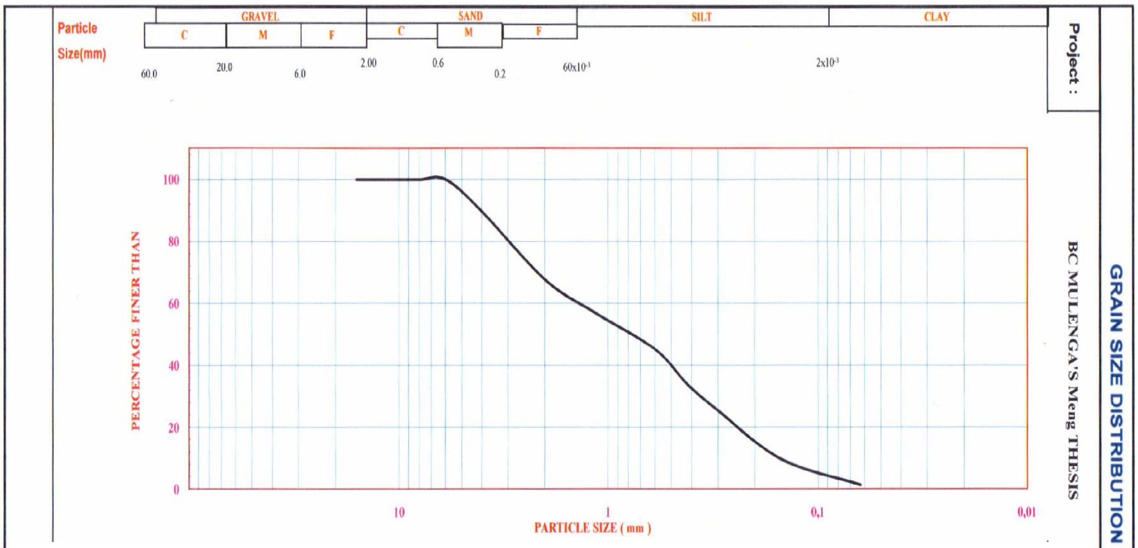
Sample Size: 500g **Soil ID:** **S4** **Location:** Salanga Village					**Date :** 26 April 2016 **Depth :** 1.5m **Tested by:** C. Silungwe		
Sieve No.	**Sieve Opening**	**mass of Sieve**	**mass of Sieve and soil**	**Mass of soil Retained**	**% Retained**	**Cumulative % Retained**	**% Finer**
	(mm)	(g)	(g)	(g)			
1	16.00	573.80	573.80	0.00	0.00	0.00	100.00
2	9.52	500.80	500.80	0.00	0.00	0.00	100.00
3	8.00	525.80	525.80	0.00	0.00	0.00	100.00
4	6.00	527.50	527.50	0.00	0.00	0.00	100.00
5	4.00	522.80	528.60	5.80	1.16	1.16	98.84
6	2.00	310.10	318.80	8.70	1,74	2.90	97.10
7	1.18	275.70	319.40	43.70	8.74	11.64	88.36
8	0.60	253.80	322.50	68.70	13.74	25.38	74.62
9	0.425	462.30	593.60	131.30	26.26	51.64	48.36
10	0.30	435.60	510.20	74.60	14.92	66.56	33.44
11	0.15	223.90	344.50	120.60	24.12	90.68	9.32
12	0.063	202.10	244.90	42.80	8.56	99.24	0.76
13	PAN	182.7	191.80	0.00	1.92	100	

Table 4.13 Particle Size Distribution Analysis – **Sample 5**

Sample Size: 500g **Soil ID:** **S5** **Location:** Salanga Village					**Date :** 26 April 2016 **Depth :** 1.5m **Tested by:** C. Silungwe		
Sieve No.	**Sieve Opening**	**mass of Sieve**	**mass of Sieve and soil**	**Mass of soil Retained**	**% Retained**	**Cumulative % Retained**	**% Finer**
	(mm)	(g)	(g)	(g)			
1	16.00	573.80	573.80	0.00	0.00	0.00	100.00
2	9.52	500.80	500.80	0.00	0.00	0.00	100.00
3	8.00	525.80	525.80	0.00	0.00	0.00	100.00
4	6.00	527.50	528.40	0.50	0.18	0.18	99.82
5	4.00	522.80	523.70	0.90	0.18	0.36	99.64
6	2.00	310.10	318.60	8.50	1.70	2.06	97.94
7	1.18	275.70	326.80	51.10	10.22	12.28	87.72
8	0.60	253.80	380.40	126.60	25.32	37.60	62.40
9	0.425	462.30	571.20	108.90	21.78	59.38	40.62
10	0.30	435.60	499.10	63.50	12.70	72.08	27.92
11	0.15	223.90	226.60	2.70	0.54	72.62	27.38
12	0.063	202.10	240.50	38.40	7.68	80.30	19.70
13	PAN	182.7	192.50	0.00	19.70	100.00	

Table 4.14 Particle Size Distribution Analysis – **Sample 6**

Sample Size: 500g **Soil ID:** **S6** **Location:** Salanga Village					**Date :** 26 April 2016 **Depth :** 1.5m **Tested by:** C. Silungwe		
Sieve No.	**Sieve Opening**	**mass of Sieve**	**mass of Sieve and soil**	**Mass of soil Retained**	**% Retained**	**Cumulative % Retained**	**% Finer**
	(mm)	(g)	(g)	(g)			
1	16.00	573.80	573.80	0.00	0.00	0.00	100.00
2	9.52	500.80	500.80	0.00	0.00	0.00	100.00
3	8.00	525.80	525.80	0.00	0.00	0.00	100.00
4	6.00	527.50	528.40	0.90	0.18	0.18	99.82
5	4.00	522.80	523.70	0.90	0.18	0.36	99.64
6	2.00	310.10	318.60	8.50	1.70	2.06	97.94
7	1.18	275.70	343.50	67.80	13.56	15.62	84.38
8	0.60	253.80	403.40	149.60	29.92	45.54	54.46
9	0.425	462.30	533.10	70.80	14.16	59.70	40.30
10	0.30	435.60	482.70	47.10	9.42	69.12	30.88
11	0.15	223.90	317.20	93.30	18.66	87.78	12.22
12	0.063	202.10	253.50	51.40	10.28	98.06	1.94
13	PAN	182.7	192.20	0.00	1.94	100.00	



Classification

Symbol	Pit No.	Depth (m)	Classifi-cation (IS)	Gravel %	Sand %	Silt %	Clay %	$\Phi_{10\%}$ mm	$\Phi_{30\%}$ mm	$\Phi_{60\%}$ mm	Coeff. of Uniformity, $C_u = D_{60} / D_{10}$	Coeff. Of Curvature C_c $D_{30}/(D_{60} \cdot D_{10})$	Liquid Limit W_l	Plastic Limit W_p	Plasticity Index I_p	Remarks
	P1			32	66	1		-----	-----		-----	-----				SOIL NO.1

Grading

16,00	9,52	8,00	6,00	4,00	2,00	1,18	0,600	0,425	0,300	0,150	0,063	Sieve Size
100,00	100,00	100,00	100,00	89,48	67,66	57,36	45,14	34,10	25,32	9,60	1,36	% passing

Date: 07/12/2017

Figure 4.1 Graph for Particle Size Distribution Analysis – Soil **Sample 1**

Based on the Unified Soil Classification System (USCS) (ASTM D2487 – 11) and the Particle Size Distribution curve for Sample 1, the following observations were made:

- The Sample had 36% of grain size 2.0 – 6.0 mm fine gravel

- The Sample had 66% of grain size ranging from fine sand $60x10^{-3}$ - 2.0 mm coarse sand and

- The Sample had 1% silt – clay material

- Generally, the sand can be said to be well graded

- The sand could be good for plaster paste as a construction material

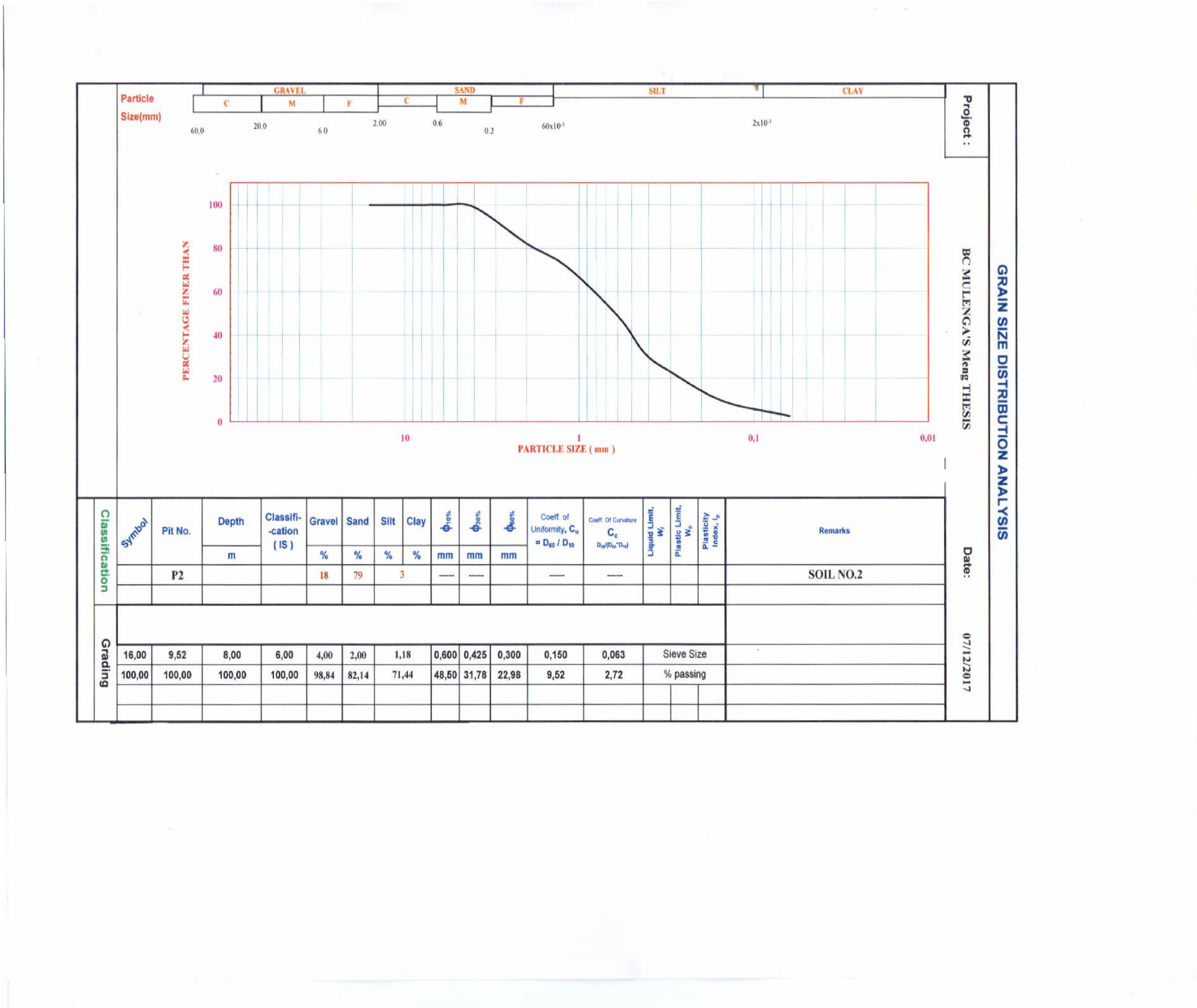


Figure 4.3 Graph for Particle Size Distribution Analysis – Soil **Sample 2**

Based on the Unified Soil Classification System (USCS) (ASTM D2487 – 11) and the Particle Size Distribution curve for Sample 1, the following observations were made:

- The Sample had 32% of grain size between 2.0 mm fine gravel
- The Sample had 66% of grain size ranging from fine sand 60 x 10^{-3} - 2.0 mm coarse sand
- The Sample had 3% silt – clay material
- Generally, the sand can be said to be well graded
- The sand could be good for plaster paste as a construction material

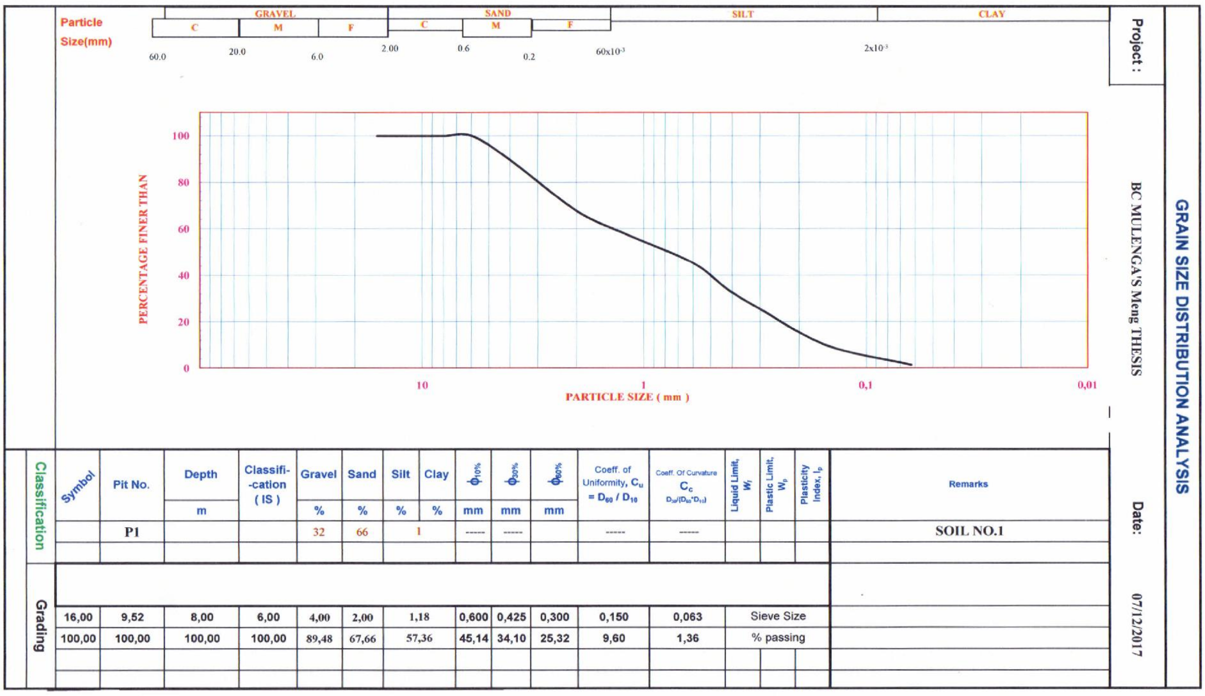
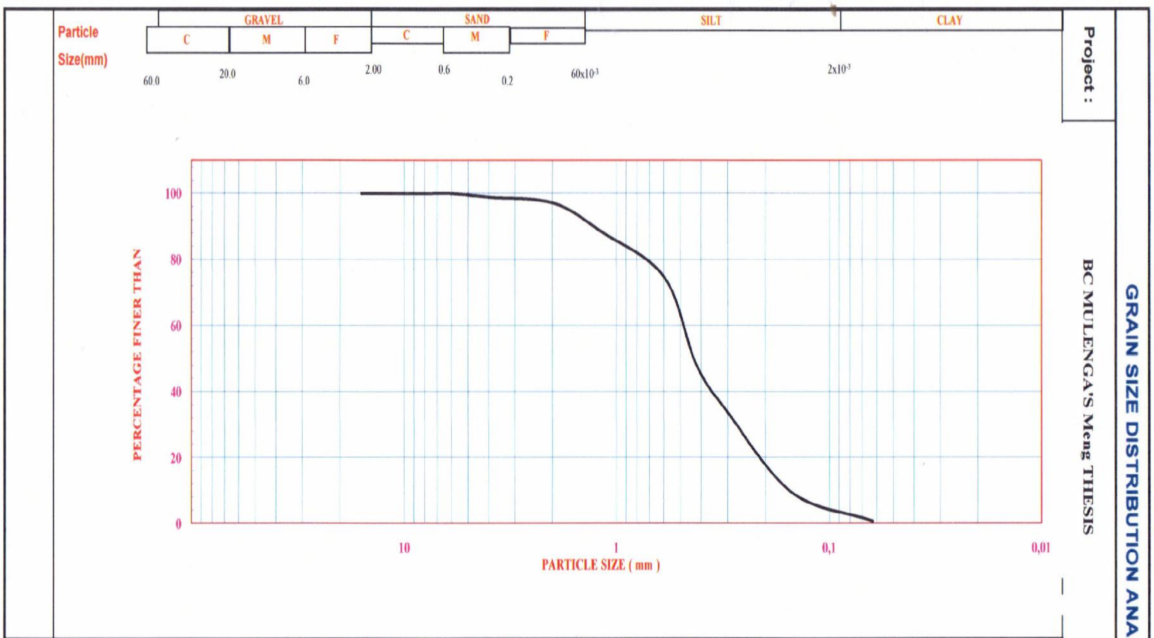


Figure 4.3 Graph for Particle Size Distribution Analysis – Soil **Sample 3**

Based on the Unified Soil Classification System (USCS) (ASTM D2487 – 11) and the Particle Size Distribution curve for Sample 1, the following observations were made:

- The Sample had 32% of grain size between 2.0 mm fine gravel
- The Sample had 66% of grain size ranging from fine sand 60 x 10^{-3} - 2.0 mm coarse sand
- The Sample had 3% silt – clay material
- Generally, the sand can be said to be well graded
- The sand could be good for plaster paste as a construction material



Classification

Symbol	Pit No.	Depth	Classifi-cation (IS)	Gravel	Sand	Silt	Clay	$\Phi_{10\%}$	$\Phi_{30\%}$	$\Phi_{60\%}$	Coeff. of Uniformity, $C_u = D_{60} / D_{10}$	Coeff. Of Curvature C_c $D_{30}^2/(D_{60}{*}D_{10})$	Liquid Limit, W_L	Plastic Limit, W_p	Plasticity Index, I_p	Remarks
		m		%	%	%	%	mm	mm	mm						
	P4			3	96	1		-----	-----		-----	-----				SOIL NO.4

Grading

16,00	9,52	8,00	6,00	4,00	2,00	1,18	0,600	0,425	0,300	0,150	0,063	Sieve Size
100,00	100,00	100,00	100,00	98,84	97,10	88,36	74,62	48,36	33,44	9,32	0,76	% passing

Figure 4.4 Graph for Particle Size Distribution Analysis – Soil **Sample 4**

Based on the Unified Soil Classification System (USCS) (ASTM D2487 – 11) and the Particle Size Distribution curve for Sample 1, the following observations were made:

- The Sample had 3% of grain size 2.0 mm fine gravel
- The Sample had 96% of grain size ranging from fine sand 60 x 10^{-3} - 2.0 mm coarse sand
- The Sample had 1% silt – clay material
- Generally, the sand can be said to be well graded
- The sand could be good for plaster paste as a construction material

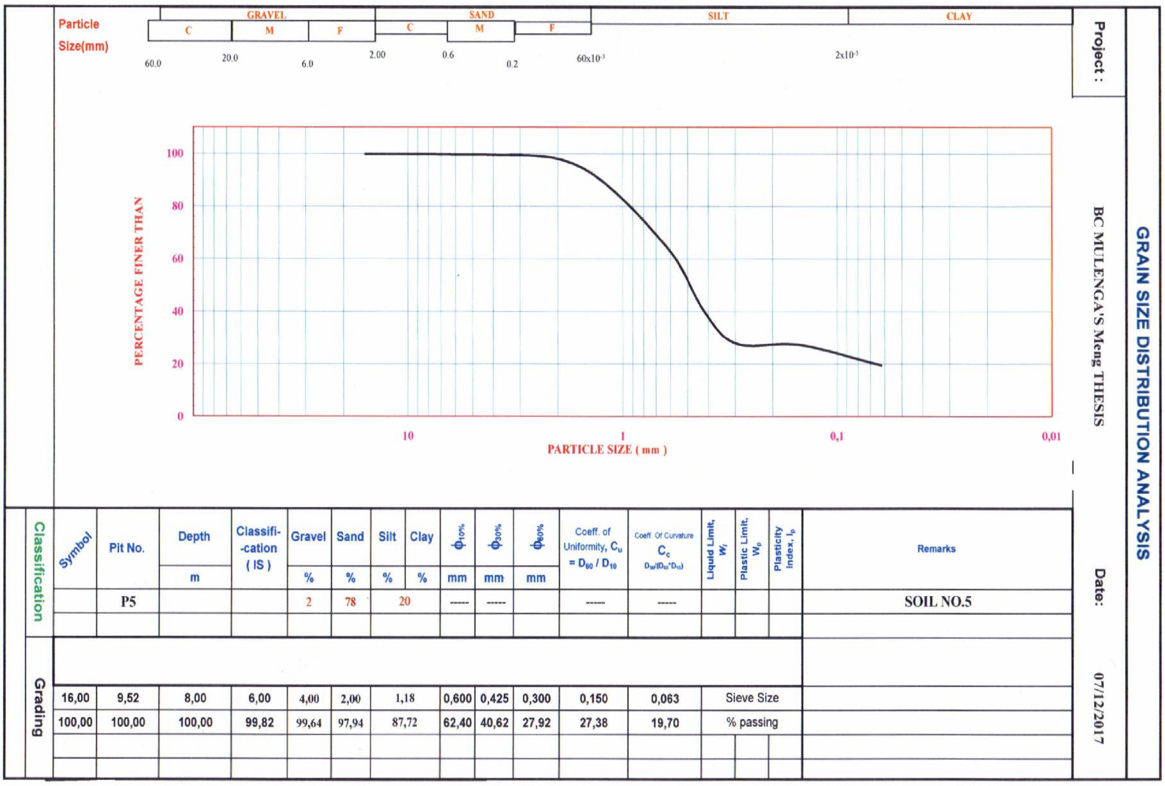


Figure 4.5 Particle Size Distribution Analysis – Soil **Sample 5**

Based on the Unified Soil Classification System (USCS) (ASTM D2487 – 11) and the Particle Size Distribution curve for Sample 1, the following observations were made:

- The Sample had 2% of grain size 2.0 mm fine gravel, hence, insignificant quantity of gravel
- The Sample had 78% of grain size ranging from fine sand 60 x 10^{-3} - 2.0 mm coarse sand
- The Sample had 20% silt – clay material
- Generally, the sand can be said to be sand with silt and clay
- The sand could be used for plaster paste as a construction material

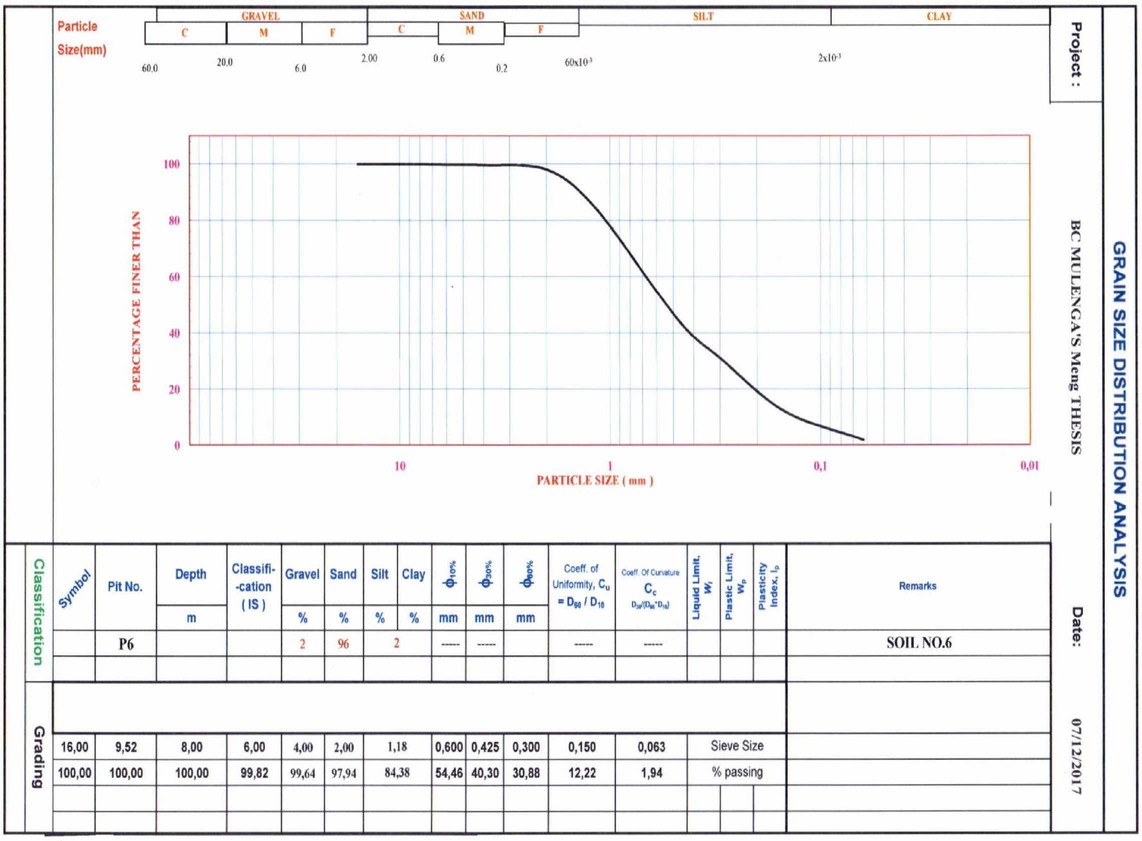


Figure 4.6 Graph for Particle Size Distribution – Soil **Sample 6**

Based on the Unified Soil Classification System (USCS) (ASTM D2487 – 11) and the Particle Size Distribution curve for Sample 6, the following observations were made:

- The Sample had 2% of grain size 2.0 mm fine gravel, hence, insignificant quantity of gravel

- The Sample had 96% of grain size ranging from fine sand 60 x 10^{-3} - 2.0 mm coarse sand

- The Sample had 2% silt – clay material

- Generally, the sand can be said to be well graded

- The sand could be good for plaster paste as a construction material

Table 4.15 Summary of results for chemical and heavy metals

Parameter	**pH**	**OM**	**SO4**	**Cl**	**Fe**	**Cu**	**Cr**	**Mn**
Soil ID		%	mg/L	ppm	%	%	%	%
S1	6.12	19.4	24.257	11.6	0.081	12.21	< 0.002	62.17
S2	5.80	20.1	5.368	11	0.657	5.64	< 0.002	55.47
S3	5.12	19.9	4.97	10.4	0.942	13.21	< 0.002	108.14
S4	5.40	19.2	5.124	12	1.225	15.1	< 0.002	54.92
S5	5.25	20.8	5.242	13.2	0.081	4.6	< 0.002	54.21
S6	6.35	10.5	16.622	13.2	0.317	12.91	< 0.002	323.38

4.11. Conclusion

In Table 4.15, the soil pH values were below the neutral pH 7 confirming that, all the soils were acidic. Organic matter figures shown indicated high carbon content which may be attributed to high humus in the soil. The experiment confirmed the presence of organic matter in the soil samples giving the soil a brownish gray colour.

For sulfates, figures shown indicate the presence of high sulfate content in samples 1 and 6 respectively; while the other four samples had same range of sulfate content.
For chlorides, figures shown indicate the presence of chloride in all the samples to be falling within the range from 10.4 to 13.2 confirming that, all soil types had chloride in it. The table also indicates the presence of heavy metals, iron, copper, manganese and chromium in various quantities.

CHAPTER FIVE – DISCUSSION

5.1 Introduction

In this chapter, the results and findings from Chapter four were discussed. A relationship between the findings and the literature was established. It was also hoped that, this was a starting point in studying about this particular material, 'the soil plaster paste,' in terms of trying to improve its quality. The findings would be of use in further studies on this subject. It must be noted that the study was of its own kind and was carried out for the first time in this country and around the world. The research objectives were therefore, discussed as follows:

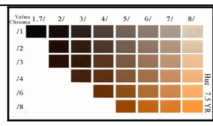
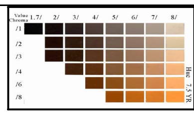
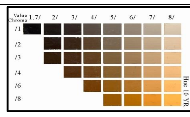
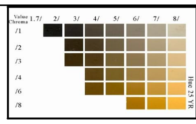
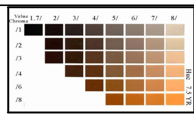
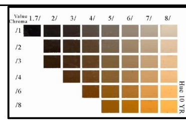
5.2 Discussion

5.2.1 The Soil Sample Colours

To establish the types of colours from soil samples that were collected from Salanga village the research area in Kawambwa, Luapula

From available literature it was found that, natural soils with very attractive colours are used all over the world. It is a material that was only used by poor local communities but was slowly becoming applicable in commercial buildings too. In most African countries it was found to be the most popular traditional building material used in the painting and decorating of houses. The literature referred to in this study was on Burkina Faso, Ghana, Tanzania, Zambia, Botswana, Zimbabwe, Malawi and Kenya all these countries showed that, these coloured soils were abundant and used extensively. Since these were natural soils, they were composed of various matter making them unfavourable for long term use unless they were treated with additives. Previous discoveries indicated that, improvements were necessary to reduce cracking and washing away easily by running water from roofs. That was why soils were mixed with cow dung, straw, and many other additives. Simply, these soils have advantages and disadvantages as given in the literature. The other difficulty was that, very little detailed literature was available on this subject. Nevertheless, Munsell Colour System and the Colour Charts provided in the Appendices were referred to in identifying the colours of the soil samples leading to scientific interpretations given in Table 5.1.

Table 5.1 Soil Colours Scientific Interpretation

SOIL IDENTIFICATION	MUNSELL COLOUR CODE	SOIL COLOUR	SCIENTIFIC INTERPRETATION	MUNSELL COLOUR CHART
Soil Number S 1:	7.5YR 8/2	Light gray	Quartz	
Soil Number S 2:	7.5YR 6/6	Orange	Goethite	
Soil Number S 3:	10YR 2/2	Brownish-black	Iron sulfide	
Soil Number S 4:	25YR 7/6	Yellowish	Goethite	
Soil Number S 5:	7.5YR 8/3	Light Yellow	Goethite	
Soil Number S 6:	Hue 10YR 3/1	Brownish-black	Goethite	

From the Munsell colour codes and charts, the identified colours were interpreted in a more scientific way as follows: Soil Number S1 Light gray was quartz soil, S2 Orange colour was scientifically goethite, S3 brownish-black was iron sulfide, S4 Yellowish was goethite, S5 Light yellow was goethite and S6 Brownish – black was goethite. The colour Charts could be viewed clearly at the Appendix B.

5.2.2 The Physical and Chemical Content

To determine the presence of chemicals and heavy metals in terms of physical chemical properties in the soil that could alter soil colour if a binder is added to the soil.

Based on these findings, relative to physical- chemical properties in the soil, the study established the following: The pH results shown in Figures 5.1 to Figure 5.6 indicated that, the soil pH was below the neutral pH 7. The experiment confirmed that, from the common acids and alkalis, all the soils were moderately to slightly acidic. For organic matter, figures shown in Figures 5.1 to Figure 5.6 indicated slight organic content which may be attributed to high humus in the soil. The experiment confirmed the presence of organic matter in the soil samples giving the soil a brownish gray colour. For sulfates, Figures 5.1 to Figure 5.6 indicated very little presence of sulfate content below 25 ppm in samples 1 and 6 respectively; while the other four samples had same range of sulfate content of less than 6 ppm. For chlorides, the numbers shown in Figures 5.1 to Figure 5.6 indicated the presence of chloride in all the samples to be falling within the range from 10.4 ppm to13.2 pp m confirming that, all soils had insignificant quantities of chloride. Metals also were very insignificant except for Manganese which ranged from 54.21 % to 323.38 % and this could be attributed to the fact that, Luapula Province has an abundance of manganese it the soils as evidenced from the results given in Figures 5.1 to Figure 5.6.

Experimental findings of chemical Physical content in the six soil samples

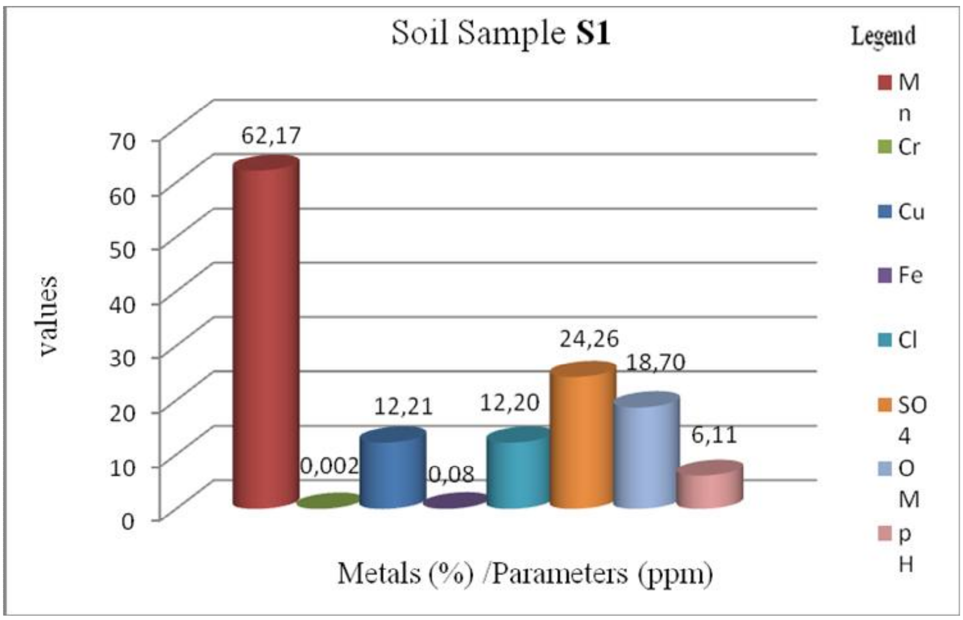


Figure 5.1 Representation of the metals and other physical parameters in S1

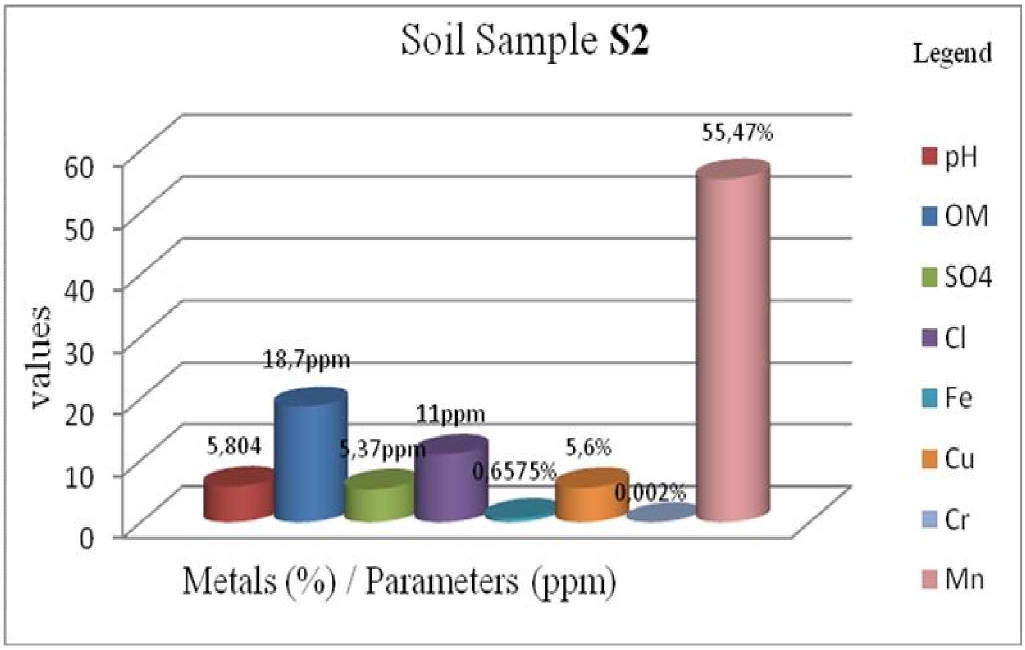


Figure 5.2 Representation of the metals and other physical parameters in S2

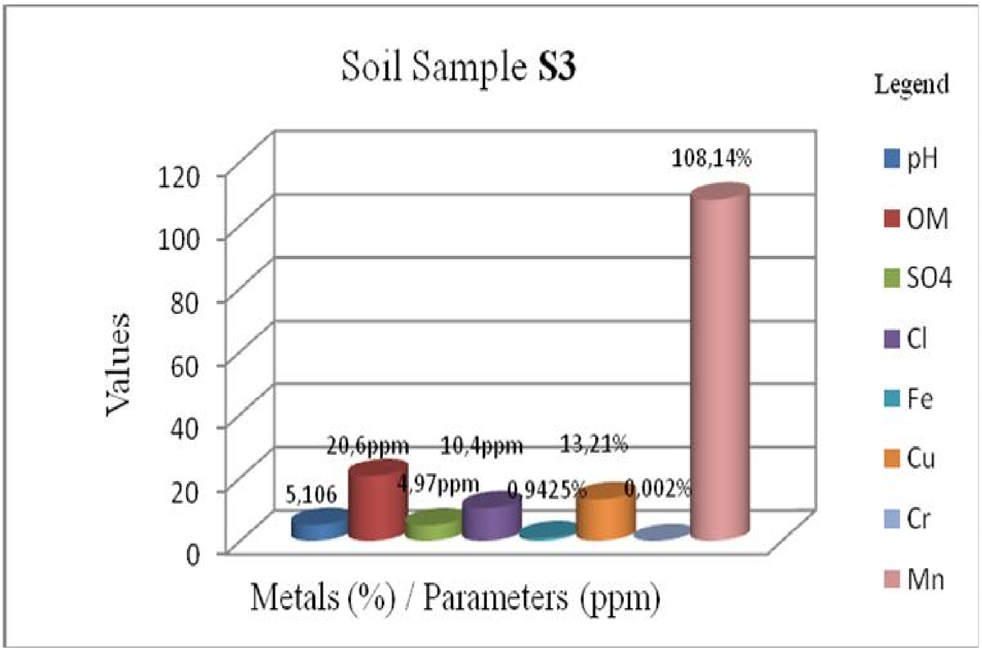


Figure 5.3 Representation of the metals and other physical parameters in S1

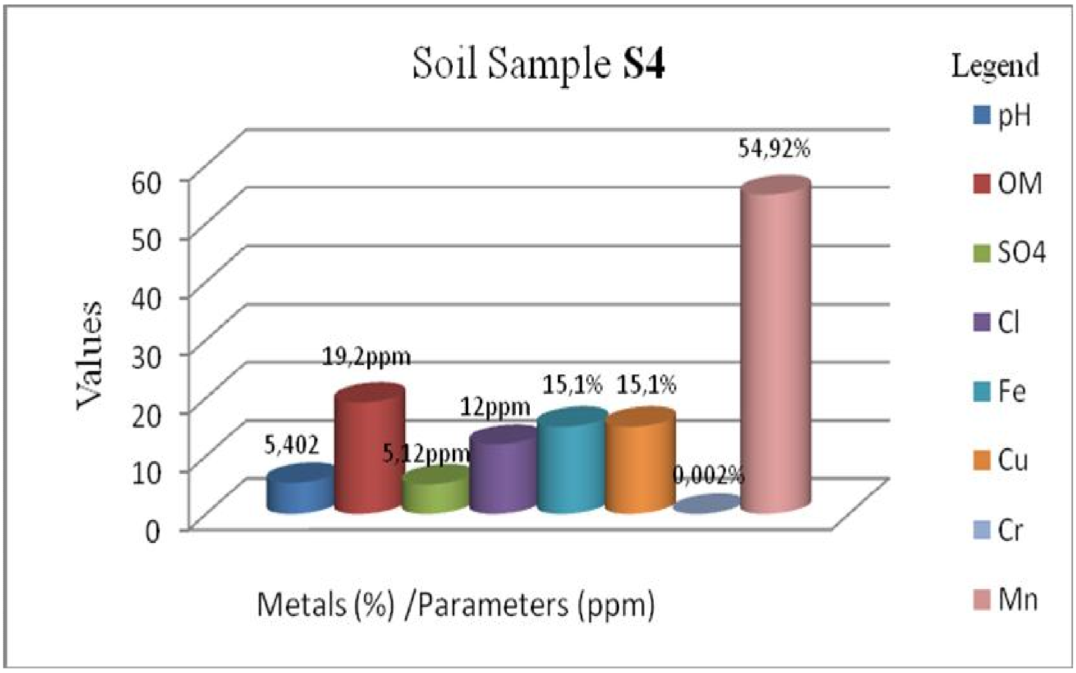


Figure 5.4 Representation of the metals and other physical parameters in S1

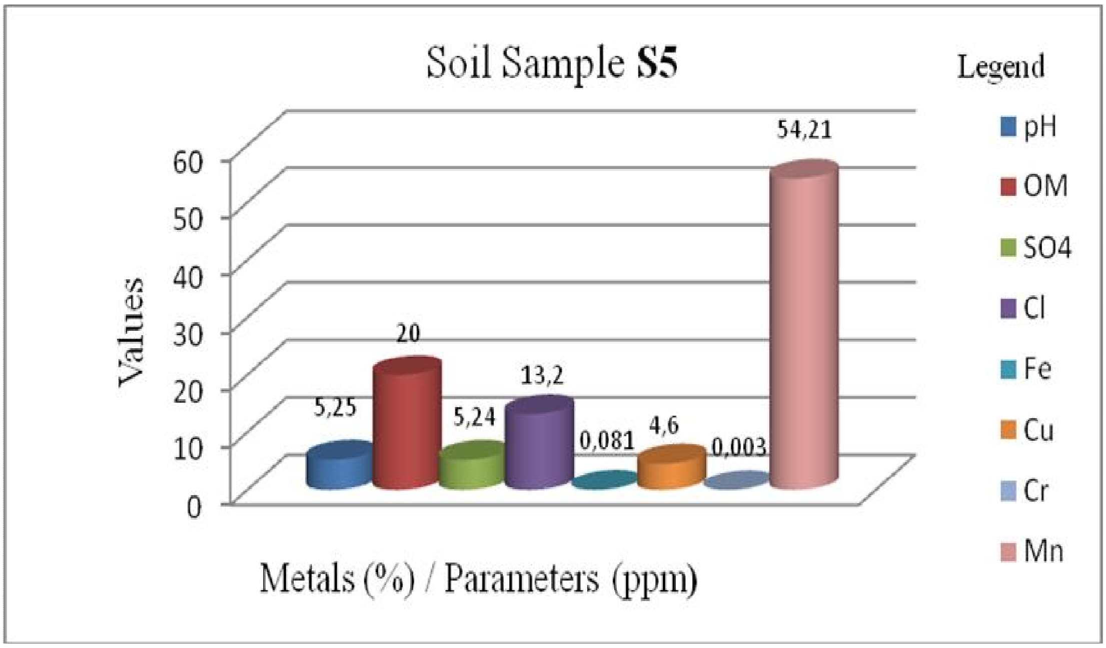


Figure 5.5 Representation of the metals and other physical parameters in S1

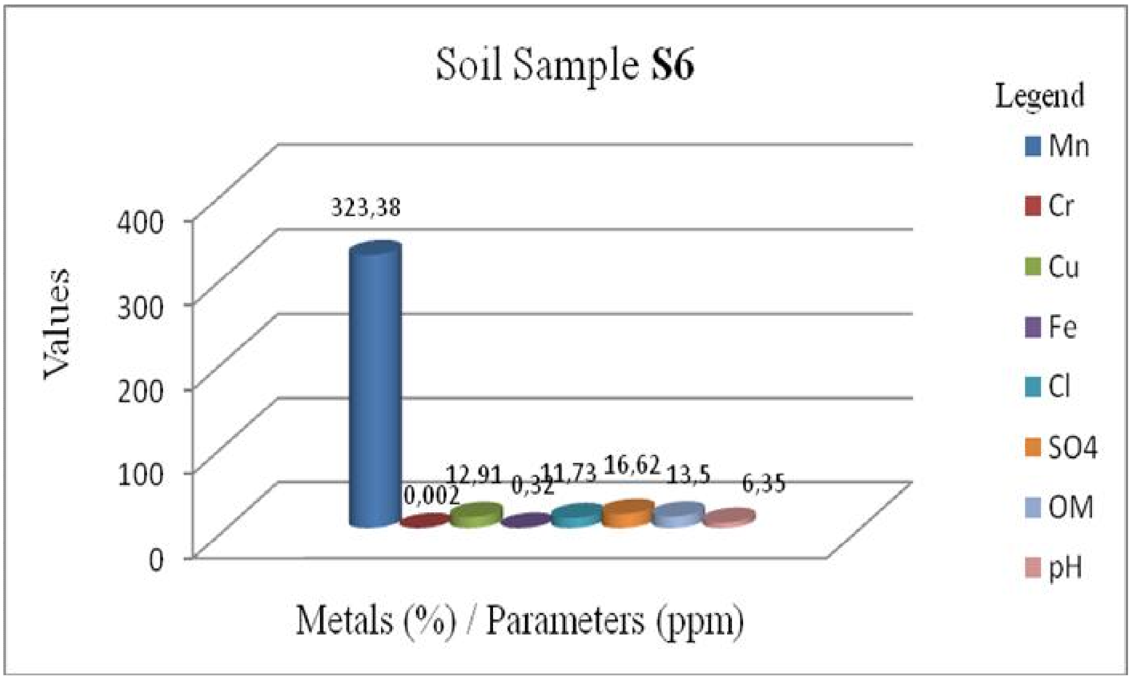


Figure 5.6 Representation of the metals and other physical parameters in S1

Figure 5.6 indicated the presence of heavy metals, iron, copper, and chromium in insignificant quantities except for manganese which was above 320 %. Therefore, the study achieved the purpose of determining the physical- chemical presence of pH, OM, SO_4, and Cl including heavy metals Fe, Cu, Mn, Cr in the soil samples.

5.5.3 The Conventional Additives

To establish if current conventional additives can apply to the developed soil plaster without altering natural properties

Conventional additives and binders were found to be too expensive from paint manufacturers for the purpose of this study because ordinary citizens would not manage to buy them since they were the main target of the research. From the literature available, clay is the best and cheapest form of additive and binder because it is affordable and readily available; however, addition of additives such as cow dung, straw and other traditional materials were encouraged, in the communities where it existed.

According to Lekshmi et al (2016), mud mortar stabilized with 5% cement and had a compressive strength of 2.07 N/mm^2 which is less than that of raw mud. The mud mortar stabilised with 10% cow dung got a compressive strength (3.534 N/mm^2) comparable to that of the raw mud mortar whereas that stabilised with 20% cow dung
showed a decrease in compressive strength from 3.188N/mm^2 (7 day) to 2.916 N/mm^2) 28 day. This decrease in compressive strength may be due to the increased fibre content in the cow dung. In the case of fibre reinforced mortar the mud mortar stabilized with 4% lime (1.834N/mm^2) and0.5% WCF had more compressive strength than that with 5% cement (1.667 N/mm^2) but the values were less than the recommended values for required for masonry mortar. From Lekshmi's research it was deduced that, even with additions of cement to mud mortar the strength of the mud mortar did not improve as required.

The purpose of this objective was to try and obtain a cheap soil plaster paste that could be used to improve quality of the paste and if found, it should be accessed by rural communities too. However, from just the beginning it seemed that current additives and binders used in pain manufacture are too expensive for the intended purpose.
From the soil tests that were carried out in the Laboratory, it was deduced that, soils of various colours actually are acidic with pH ranging from 5.106 – 6.108. Manganese ranged from 54.21 to 323.38 %, while the other metals were negligible.

5.6 Conclusion

5.6.1 *Limitations to the Third Objective*

The funds to use for the travel and other expenses had also an effect on the study since a sponsor was not found. The cost of binders and the extensive number of tests required for this objective could not enable tests to be carried out on soil samples to verify which ones might alter the original colour of the soils and whether the physical-chemical quantities present in soils were enough to cause a reactions with binders

5.6.2 *Quality*

Soils are one of our most important natural resources. They also are important for the beauty their many colors add to our landscapes. Most of us overlook this natural beauty because we see it every day. Often these colors blend with vegetation, sky, water, etc. Soil colors serve as pigments in bricks and pottery. Soil colour is usually due to 3 main pigments: black from organic matter, red from iron and aluminium oxides, white from silicates and salt.

It was noted that, when the quality improvement is done or found for soil plaster pastes, then a cost analysis may be effectively established. This meant that, the right binders and additives should be researched in order to conclusively answer the questions of quality improvement and cost implications that rural communities always want to avoid.

CHAPTER SIX – CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

In this chapter the conclusions and recommendations of the research are provided. The study was to evaluate the contents of the soil samples that were obtained from Kawambwa District, at Salanga Village, in terms of physical and chemical content.

6.2. Conclusion

Despite limitations in terms of funding and other logistics the study went on well because from the evaluation of the soils carried out in the Laboratories all the targeted physical – chemical properties of the soils under investigation were established. The colours of the soils were also established with the help of Munsell Colour Charts. The cost of binders and the extensive number of tests required for this objective could not enable tests to be carried out on soil samples to verify which ones might alter the original colour of the soils and whether the physical-chemical quantities present in soils were enough to cause a reactions with binders.

The high cost of additives and binders defeat the purpose of using them in soil pastes because the final product should not be expensive again for the class of rural communities that are being targeted to be included in accessing this soil paste. The additives that are not expensive are straw, hairs, fresh cow dung since these are easier to find tests done in the literature review show that original colours of the paste does not change. Improving our local materials is a must because from the literature review, it has been established that only traditional building methods that have been used for thousands of years are still saving majority of the people in Zambia in terms of housing.

Clay soils were regarded as the best and cheapest binder in natural soils that is affordable to local communities because it could be quarried without specialised equipment but only with local knowledge and simple equipment. It found close to the sites within the village or peri-urban areas at no cost at all.

6.3. Recommendations

The researcher was actually of the view that research work to establish a suitable binder or binders and additives to local soils that will improve the quality of plaster for rural communities be taken a step further by more research work.

There must be enough resources to support the research and it requires a lot of time to carry out various tests with different additives and binding materials

REFERENCES

Abidin, Z. N., (2010), Environmental concerns in Malaysian construction industry. Pulau Pinang, Malaysia: Universiti Sains Malaysia.

Afolabi, A. (2012), 'Site and services as a strategy for achieving adequate housing in Nigeria in the 21st century'. International Journal of Humanities and Social Science 2 (2), 126-132.
African Vernacular Architecture http://www.pinterest.com/pin440086194814493618,

Agarwal, A. (1981), Mud, Mud: The potential of Earth-based material for Third World housing, London

Agvise Laboratories (2018), 'Soil Organic Matter (A choice of methods)' https://www.agvise.com/ educational-articles/soil-organic-matter-a-choice-of-methods/

Akadiri P. O., Chinyio E. A., Olomolaiye P.O., (2012), 'Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector School of Technology, University of Wolverhampton, Wulfruna Street, Wolverhampton WV1 1LY, UK; E-Mail: E.Chinyio@wlv.ac.uk

Amanda S. (2013), 'Building a Greener World - a Shift to a Sustainable Architecture', https://medium.com/@ECONYL/building-a-greener-world-a-shift, accessed, May 22, 2017

Ann S. (2013), "The Decorated Walls in Tiébélé." - http://handeyemagazine.com/content/decorated- walls- tiébélé . Accessed March 5, 2013.
Asif et al (2007). Life cycle assessment: A case study of a dwel ling home in Scotland. Building and Environment, Vol 42, pp. 1391-1394.

Aubert J.-E., Marcom A., Oliva P. and Segui P. 2015, 'Chequered earth construction in southwestern France' J. Cult. Herit. **16** 293-298

Bahadori M. Tofighi H., (2015)' A Modified Walkley-Black Method based on Spectrophotometric procedure.' Published on lined

Bischof V. (2013), Gurunsi Painted Homes, -
https://victoriabischof.weebly.com/uploads/1/7/2/0/17209968/africanpaper.pdf

Black W., (1947) 'The Walkley Black Method', (Walkley, 1947; FAO, 1974)

Blueegg, G.M (2011): "Glossary of Water - based Paints" Encyclopedia of Chemical Technology; Vol. 3 Pate Scince Publishers, NewYork, pp. 564-569.

Brady, Nyle C. & Ray R. Weil Elements of the Nature and Properties of Soils, page 95. Prentice Hall, 2006

Building Materials and Technology Promotion Council Ministry of Urban Development & Poverty Alleviation, Government of India G-Wing, Nirman Bhawan, New Delhi • 110 Oil

Cai and Sun (2014), 'Brief Discussion on Green Building Materials,' *IOP Conf. Ser.: Mater. Sci. Eng.* **62** 012010

Cai, W., Wu Z. and Wang H. (2011), Effect of green roof on urban human settlement and indoor environment for green buildings. Proceedings of the International Conference on Electric Technology and Civil Engineering, pp. 3102-3105, 22-24 April, Lushan, China

Carole C. (2016), 'Earthern Plasters the Healthiest,' https://www.abundantedge.com/articles-1/2016/6/17/earthen-plasters-the-healthiest-and-most-beautiful-way-to-finish-your-home. accessed 17 June 2016

Central Statistics Office, CSO (2004), Summary Statistics on Small Areas – Volume I and Civil Engineering and Urban Planning: An International Journal (CiVEJ) Vol.3, No.2, June 2016

Chapinduka E. N. and Cloete C.E , (2007),' Lack of affordable housing finance in Malawi's major urban areas,'Department of Construction Economics, University of Pretoria, Pretoria, South Africa, https://www.researchgate.net/publication/241701609, accessed Feb 13 2019

Clayworks (2014), 'Natural clay plaster wall finishes,' https://clay-works.com/wp-content/uploads/2014/06/Clayworks-Product-Description.pdf. accessed 6 June 2014.

Cof K. (2016), Tiébélé Burkinabé Village With Painted Houses,
https://safarijunkie.com/culture/tiebele-burkinabe-village-painted-houses/| accessed March 15th, 2016

Collins English Dictionary - Complete & Unabridged (2012) Digital Edition, William Collins Sons & Co. Ltd.

Copsey N. (2008), ‘Earth plastering, analysis and specification for conservation, repair and restoration works,’ http://www.nigelcopsey.com/reports/consultancy/consultancy_earth. accessed 8 December 2008

Crew C. (2007), ‘Earth Plasters and Aliz**,** www.networkearth.org/naturalbuilding/aliz.html. accessed, October 19-28, 2007

Crown Paints Kenya PLC (2017), https://www.crownpaints.co.ke/product/crown. accessed 22 September 2017

Curtiss K. (2016), ‘Kassena Homes, Tiébélé, Burkina Faso, West Africa.’ https://www.globalcitizen.org/en/content/who-uses-sht-to-build-a-house/ accessed Jan. 16, 2016

Dancing Rabbit Eco-village, (2016), ‘Natural Building Materials, Techniques & Technologies at Dancing Rabbit’https://www.dancingrabbit.org/about-dancing-rabbit-ecovillage/eco-living/building/natural-building/earthen-plaster/

Daniela C. (2015), ‘University of Western Australia, https://theconversation.com/cheap-tough-and-green-why-arent-more-buildings-made-of-rammed-earth-38040

Darling, E.K., Cros, C., Wargocki, P., Kolarik, J., Morrosin, G., Corsi, R. (2012). “Impacts

Davide B., Resnik J. D. (2011), **“**What is Ethics in Research and why is it important, ”NIEHS Alexander Drive, Research Triangle Park, USA

Davoust A. (2013), "Traditional Tiebele, Burkina Faso." Last modified 2011 Accessed March 5,2013 http://www.travelsinparadise.com/travelarticle/tiebele - burkina - faso.html.

De Silva et al (2004), Improving the maintainability of buildings in Singapore. Building and Environment, 2004; 39(10):1243–51.

Delinière R, Aubert JE, Rojat F, Gasc- Barbier M. (2014), Physical, mineralogical and mechanical characterization of ready- mixed clay plaster. Build. Environ, 80, p. 11-17.

Department of Surveys and Mapping (DSM) (2001), *Botswana National Atlas*, Gaborone, DSM.

Department of Surveys and Mapping (DSM) (2001), Botswana National Atlas, Gaborone, DSM.

Dethier, J. (1981), "Down to earth: adobe structure – an old idea, a new future", New York facts on file, USA.

Deuble, M.P., and R.J. de Dear. 2012. Green occupants for green buildings: The missing link? Building and Environment, 56(2012): 21-27.

DIN 18947, DIN. 2013 'Earth plasters – Terms and definitions, requirements, test methods (in German),

Dobson S. (2015), Cheap, 'Tough and green: why aren't more buildings made of rammed earth?,' http://theconversation.com/cheap-tough-and-green-why-arent-more-buildings-made-of-rammed-earth-38040, accessed April 29, 2015

Dubuisson M. (2018), https://www.anton-paar.com/us-en/products/applications/mar-resistance-of-paint-coatings-by-nanoscratch-testing/ Anton Paar TriTec SA

Edwards D. (2013),'What's in your paint?' accessed 6 January 2013 https://www.dunnedwards.com/colors/specs/posts/whats-in-your-paint,

Ejiga et al (2012) Sustainability in traditional African architecture: A springboard for sustainable urban cities. In: Sustainable Futures: Architecture and Urbanism in the Global South, Kampala, Uganda, 2 7 – 30 June 2012.

Emsley J., (2011) 'Nature's Building Blocks: An A-Z Guide to the Elements,' Oxford University Press, New York, 2nd Edition

Encyclopedia of Earth Sciences Series, (2008), Editors: Ward Chesworth, ISBN: 978-1-4020-3994-2 (Print) 978-1-4020-3995-9 (Online)

Environmental Earth Sciences, (2014), Volume 71, Number 2, Page 931

Estefan G., Sommer R., Ryan J. (2013), Methods of Soil, Plant and Water Analysis, third Edition

Faria P, Santos T, Aubert J-E (2015) Experimental characterization of an earth eco-efficient plastering mortar. Journal of Materials in Civil Engineering (in press)

Faria, P., Santos, T., and Aubert, J. (2016), Journal of Materials in Civil Engineering, January, Vol. 28, No. 1

Fitzpatrick R.W. (2012) Forensic earth science: Getting the dirt on crime. e-Science Faculty of Sciences, The University of Adelaide. Issue 2, 6-13; 56-65

Froeschle L. M.. (1999), Environmental Assessment and Specification of Green Building Materials," The Construction Specifier, October 1999, p. 53.

Georgiev G, Theuerkorn W, Krus M, Kilian R (2013) Cattail-reinforced clay plasters in building heritage preservation and new constructions. In: Correia M, Carlos G, Rocha S, editors.

Goldberg R. (2017), https://www.houseplanninghelp.com/hph178-natural-clay-plaster-wall-finishes-with-clare-whitney-from-clayworks/ accessed May 25, 2017

Goossens, D. (2008), Techniques to measure grain-size distributions of loamy sediments: a comparative study of ten instruments for wet analysis. Sedimentology 55, 65-96.

Grant, Sandy & Elinah (1995), Decorated Homes in Botswana, Mochudi, Phutadikobo Museum

Gurunsi Architecture (2013), 'The Next Big Thing...." Last modified 2012. Accessed March 5, 2013. http://ghanarising.blogspot.com/2012/02/gurunsi- architecture- next- big- thing.html

GRZ (1996), National Housing Policy: Enabling shelter strategy. Government Printers: Lusaka

Hadjri K., Osmani M., Baiche B., Chifunda C., (2007),'Attitude towards earth building for Zambian housing provision', Proceedings of the Institution of Civil Engineers Eng. Sustain., 160 (ES3) (2007), pp. 141-149

Hamard, E., Morel, J.C., Salgado, F., Marcom, A., Meunier, N., (2013) A procedure to assess the suitability of plaster to protect vernacular earthen architecture. J. Cult. Herit. 14, 109e11

HATAB (2016), ‘Hospitality and Tourism Association of Botswana’-Land and Marine Publications ltd, Botswana

Haynes, W. M. ed., (2015) ‘*CRC* Handbook of Chemistry and Physics, CRC Press/Taylor and Francis, Boca Raton, FL, 95th Edition, Internet Version, accessed (ATSDR, 2013), 4770 Buford Hwy NE, Atlanta, GA 30341

Henry M. (2014), Binders for Natural Plasters (Part 1),’ http://thesustainablehome.net/binders-for-natural-plasters-part-1/

Henry M. 2015, Natural Building Techniques, Natural Plasters, February 20, 2015 - http://thesustainablehome.net/sand-for-natural-plasters

Hospitality and Tourism Association of Botswana, (HATAB, 2016), http://www.hatab.bw/’ index.php/about-botswana/architecture.html

http://ghanarising.blogspot.com/2012/02/gurunsi□architecture□next□big□thing.htm

http://handeyemagazine.com/content/decorated□walls□tiébélé

http://listserv.repp.org/pipermail/strawbale_listserv.repp.org/2007-March/000699.html

http://photo.lacina.net/photo-1962- traditional- kassena- house -kassena- tribe- ghana.html

http://photo.lacina.net/photo□1962□traditional□kassena□house□kassena□tribe□ghana.html

http://the laststraw.org/earth-plastering-guidelines-finishes

http://www.chemistryexplained.com/elements/A-C/Chromium.html#ixzz4zd603vHg

http://www.chemistryexplained.com/elements/C-K/Copper.html#ixzz4rQS27Jmh

http://www.gateway□africa.com/tribe/kassena_tribe.html.

https://greenbuildingelements.com/2008/11/19/natural-building-101-how-to-make-and-apply

https://www.amusingplanet.com/2013/01/decorated-mud-houses-of-tiebele-burkina.html

https://www.featurepics.com/online/traditional-african-house-picture263609.aspx

Lenntech B. V. (2017), www.lenntech.com/periodic/elements/cr.html

https://www.naturalpigments.com/azurite-fine-grade-pigment.html

https://www.naturalpigments.com/green-bice-pigment.html

https://www.naturalpigments.com/naples-yellow-light-pigment.html https://www.naturalpigments.com/natural-red-oxide-indian-red-pigment.html

https://www.naturalpigments.com/Realgar-pigment.html

https://www.naturalpigments.com/vermilion-pigment.html

https://www.researchgate.net/publication/264312936_Environmental_impacts_of_natural_and_conventional_building_materials_A_case_study_on_earth_plasters, accessed Aug 25, 2017

Population and Housing Census (2001), Gaborone Government Printers.

International Journal of Straw Bale and Natural Building Strategies of the 1996 National Housing Policy

ISO/TC 35/SC 9 General test methods for paints and varnishes

ISO/TC 35/SC 9: 2009, General test methods for paints and varnishes**,** International Organization for Standardization- https://www.iso.org/committee/47996/x/catalogue

Ivanov O. (2011), (Ed.),' Applications and Experiences of Quality Control,' Publisher, InTech Open

Jamal H. (2017) Composition of Paints,www.aboutcivil.org/Composition%20of%20paints, accessed Feb 03, 2017

Judi H. M., et al. (2011), 'Quality Control Implementation in Manufacturing Companies,' Industrial Informatic Programme, Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia 43600 Bangi, Selangor Darul Ehsan,

Kamana C.P. and Escultura E. (2011), Building green to attain sustainability. International Journal of Earth Sciences and Engineering, 4(4): 725-729.

Kanyemba. J. (2004). Preserving Traditional Building materials and Construction Methods by the use of Performance Based Building Codes. Proc of the Strategies for a Sustainable Built Environment

Kati (2012) "Uses for bamboo in sustainable building.'ttp://www.greenbuild.org.

Kaushik (2012), Decorated Mud Houses of Tiébélé, Burkina Faso, www. https://www.amusingplanet.com/2013/01/decorated-mud-houses-of-tiebele-burkina.html

Kaushik et al (2007), “Stress– Strain Characteristics of Clay Brick Masonry Under Uniaxial Compression”. Journal of Materials in Civil Engineering, Vol-19(9), pp-728–739, 2007

Kennedy J. F., (2003), ‘The Grassroots Journal of Straw Bale and Natural Building; HC 66 Box 119, Hillsboro NM 88042; ph 505-895-5400, fax 505-895-3326;

Kenya information Guide (2015), ‘Maasai Huts- who builds them and how? accessed 13 May 2015, https://www.tanzania-experience.com/blog/maasai-huts-who-builds-and-how/

Kilian et al (2013), Cattail- reinforced clay plasters in building heritage preservation and new constructions. In: Correia M, Carlos G, Rocha S, editors. Vernacular Heritage and Earthen Architecture. CRC Press, p. 415–20.

Kopeliovich D. (2014), ‘Composition of paints,’ accessed 25 January 2014 http:/www.substech.com/dokuwiki/doku.php?id=composition of paints

Kothari, C.R. (2004). Research Methodology: Methods and Techniques. 2nd Edition, New Age International Publishers, New Delhi.

Kuchena J. (2004). Appropriate low cost building materials/construction Research Institute for the Built and Human Environment

Lacina D. (2004), ‘Traditional Kassena House,’ ‘http://photo.lacina.net-1962 - traditional kassena- house - kassena- tribe-ghana.html.

Lamble et al (2011), Ozone deposition velocities, reaction probabilities and product yields for green building materials. Atmospheric Environ, 45(38) , p. 6965–6972

Lekshmi M. S. et al. (2016), Cochin University of Science and Technology, Kochi 682 022, Kerala State, India

Lembeck B. (2007),‘ Paint, ttp://www.enviropaedia.com/topic/default.php?topic_id=183’,

Liblik, J. (2015), ‘Protective effect of clay plaster for the fire design of timber constructions.’ Master thesis. Tallinn University of Technology, Tallinn. Estonia,

Lima J. and Faria P. (2014), Earthen plasters: The potential of the clayey soils of Barrocal Region in Algarve. In: 40th IAHS World Congress on Housing – Sustainable Housing

Construction, (CD- Rom ID-217, ISBN 978-989-98949-1-4).

Little S. (2014), https://freshome.com/2014/09/19/10-reasons-you-should-use-sustainable-building-materials/

Loffer L. (2017), https://www.wagnermeters.com/moisture-meters/wood-info/what-is-equilibrium-moisture-content/

Loffer L. (2017), The Advantages of Wood as a Building Material https://www.wagnermeters.com/moisture-meters/wood-info/advantages-wood-building/

Lyamuya P. and Alam K. (2013), Earth Construction in Botswana: Reviving and Improving the Tradition. Paper presented at Commonwealth Association of Architect's 20th General Assembly and Conference February 19-24, Dhaka.

Mahlke F. (2013), Earth Plastering Guidelines for Finishes – TLS #43- September 24, 2013

Martin R. (1976), Towards a new architecture. In: In-situ? Zambia Institute of Architects:

Mc Intosh P. (2014), 'Natural Building Collective' accessed 9 September 2016 https://naturalbuildingcollective.wordpress.com/2014/11/09/

McCave I.N., Hall, I.R., Bianchi, G.G., (2006), Laser vs. settling velocity differences in silt grainsize measurements: estimation of palaeocurrent vigour. Sedimentology 53, 919-928.

McIntosh P. (2014), Understanding Earth: The beginnings of a Natural Builder, https://naturalbuildingcollective.wordpress.com/2014/04/20

Minke G. (2013) Earth as a construction material,The International Journal of the Straw Bale and Natural Building - TLS #43, August 2, 2013

Minke, G. (2011). 'Shrinkage, abrasion, erosion and sorption of clay plasters'. Inf. La Construc. 63, 153e158.

Minke, G. (2009) Building with Earth: Design and Technology of a Sustainable Architecture, Berlin, Birkhauser.

Mires and Peat, (2013-14), Volume 13 Article 09, 1–13. http://www.mires-and-peat.net/, ISSN 1819-754X© 2014 International Mire Conservation Group and International Peat Society

Mishra G. (2017), Types of building materials, their properties and uses in construction works, https://theconstructor.org/building/types-of-building-materials-construction/699/

Molinaroli, E., De Falco, G., Rabitti, S., Portaro, R., (2000), Stream-scanning laser system, electric sensing counter and settling grain size analysis: a comparison using reference materials and marine sediments. Sedimentary Geology 130, 269-281.

Montana, G., Randazzo, L. and Sabbadini, S. Environ Earth Sci (2014) 71: 931. https://doi.org/10.1007/s12665-013-2499-4

Montana, G., Randazzo, L., Sabbadini, S., 2014. Geomaterials in green building practices: comparative characterization of commercially available clay-based plasters. Environ. Earth Sci. 71, 931e945

Moody P. W. and Thi C. P. (2008), Soil constraints and management package (SCAMP): guidelines for sustainable management of tropical upland soils, Publication Code MN130,

Mora E.P. (2007), 'Life cycle, sustainability and the transcendent quality of building materials' Build. Environ., 42 (2007), pp. 1329-1334

Moreira J. (2017), The beauty and benefits of natural clay plaster- https://giynow.com/2017/03/20/the-beauty-and-benefits-of-natural-clay-plaster/

Muchawonweyi, K. (2004). Alternative construction materials and technology: Special focus on low costhousing. Unpublished BEng Dissertation. NUST.

Mudroch, A., Azcue, J.M., Mudroch, P., 1997. Manual of Physico-Chemical Analysis of Aquatic Sediments. Lewis Publishers, New York, NY.

Mudscape Housing (2011), 'Experimental Study on the Physical Properties of Mud Mortar in Comparison with the Conventional Mortars' accessed August 9, 2011 available from: openarchitecture network. Org/projects/9960

Muller, H.W., Dohrmann, R., Klosa, D., Rehder, S., Eckelmann, W., 2009. Comparison of two procedures for particle-size analysis: Kohn pipette and X-ray granulometry. Journal of Plant Nutirtion and Soil Science 172, 172-179.

Munsell A, (1973), 'Munsell Soil Colour Charts', https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-soil-color-charts/

Mwango A.M. (2006), 'Informal Housing Delivery. Assessing its Potential Contribution in Formalising local building materials: Copper belt University, Zambia

Nassrulla T. (2016), https://www.tanzania-experience.com/blog/maasai-huts-who-builds-and-how/accessed 10th August 2016

National Housing Authority, NHA (2004), Projects. Available online at http://www.nha.co.zm [Accessed December 2004]

Natural Pigments, 2015; https://www.naturalpigments.com/watercolor/pigment-powders.html

Ngowi, A.B. (1997), 'Improving the traditional earth construction: A case study of Botswana'. Construction and Building Materials 11 (7): 1–7.

Oamide, I. (2012). 'Site and services as a strategy for achieving adequate housing in Nigeria in the 21st century'. International Journal of Humanities and Social Science 2 (2), 126-132. of clay plaster on indoor air quality assessed using chemical and sensory measurements." Building and Environment, 57, 370-376.

Onyegiri I. ; Ugochukwu I.B. (2016), 'Traditional Building Materials as a Sustainable Resource and Material for Low Cost Housing in Nigeria,'Advantages, Challenges and the Way forward,Int'l Journal of Research in Chemical, Metallurgical and Civil Engg. (IJRCMCE) Vol. 3, Issue 2

Ortiz O., Pasqualino J.C., Castells F., 'Environmental performance of construction waste: comparing three scenarios from a case study in Catalonia, Spain,Waste Manag'. 30 (2010) 646–654

Oshike E.E. (2015), 'Building with earth in Nigeria: a Review of the Past and Present Efforts to Enhance Future Housing Developments,'International Journal of Science, Environment and Technology, Vol. 4, No 1, 2015, 646 – 660

Owens B. and Sigmon J. (2010), LEED & green building codes.

Pan N.-F., R.J. Dzeng and M.D. Yang (2011), Decision making behaviors in planning green buildings. Proceedings of the International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, pp. 1710-1713, 19-20 February, Changsha Hunan, China.

Payne, G. K. (1977), 'Urban Housing in the Third World,' London: International Text Book

Peckenham E. (2016), 'Green Building Materials,' https://inhabitat.com/11-green-building-materials-that-are-way-better-than-concrete/ plastering.pdf, accessed 8 Fbruary 2016.

Prudenti R. D. (2013), Kansas State University, uncategorized archives

Richards S. (2012). 'Vernacular' accommodations: wordplay in contemporary- traditional

Ruppert J. (2013), 'Earth Plastering Guidelines for Finishes; Bales, Building Science, Plaster, Technical, Walls, – The International Journal of the Straw Bale and Natural Building–TLS 43

Russell B. (2010), The Use of Green Materials in the Construction of Buildings' Structure, http://www.aia.org/practicing/groups/kc/AIAB081061. accessed, 2nd January 2015.

Ryan. D. (2013), "The Tiebele house decorations of Burkina Faso, Africa." Accessed March 5, 2013. http://beautifuldecay.com/2013/01/18/ the - tiebele- house- decorations- of- burkina-faso- africa/.

Sassu and Ngoma (2002), 'Rural mud wall building (nyumba yo mata or ndiwula) in Malawi. Housing Report # 43, Report Date 05-200206 - Earthquake Engineering Research Institute (EERI) and International Association for Earthquake Engineering (IAEE)

Schylter, A (2003), Multi-Habitation: urban housing and everyday life in Chitungwiza, Zimbabwe, Nordic Africa Institute, Uppsala

Schreckenbach H. (2004), 'Building with Earth', Publisher, Dachrerband., Weimer, Germany

Sev A. (**2009)**, How can the construction industry contribute to sustainable development? A conceptual framework. Sustain. Dev. *17*, 161–173.

Shein, E.V. Eurasian Soil Sc. (2009) 42: 284. https://doi.org/10.1134/S1064229309030053, accessed 28 March 2009

Silavwe, G. W. (1998), Effects of Rural-Urban Migration on Urban Housing in Zambia.
Singh S. (2016), Sustainable Development: A Literature Review, International Journal of Indian Psychology, Volume 3, Issue 3, No. 6, DIP: 18.01.104/20160303

Siuluta, O. M. (2002), 'Building with Earth in Zambia'. School of Built Environment

Smartdove, Q. E. (2008): Basic Categorizations and Characterizationsof Paints Greenworold Publishers, Arizona. ISBN 5634010232.pp.60-69

Smith F.T. (2013), "Gurensi Wall Painting." African Arts. 11. no. 4 (1978): http://www.jstor.org/stable/3335342 accessed March 5, 2013-Schunior A. 2013 "The Decorated Walls in Tiébélé." Last modified September 8, 2011 Accessed March 5, 2013 http://handeyemagazine.com/content/decorated- walls- tiébélé
Soil Survey Staff (1993), Soil Survey Manual. Agricutlural Handbook No. 18, USDA-NRCS, U.S. Government Printing Office, Washington, DC.

Soils Section, Research Branch, Department of Agriculture, (1967), Zambia.
Publisher: Surveyor General, Ministry of Lands and Mines, Republic of Zambia.

Sojkowski J. (2011), 'Malawi vernacular Architecture. http: //www.architectureweek.com/0807/ culture_1-2.html Accessed 21/01/2007.
Sojkowski J. (2002), 'Zambian vernacular. http: // www.architectureweek.com/0807/ culture_1-2.html Accessed 21/01/2007.

Sojkowski J. (2015), "African Vernacular Architecture," Arch Daily. Accessed 23 Jun 2018. https://www.archdaily.com/638933/why-i-created-a-database-to-document-african-vernacular-architecture/ ISSN 0719-8884

Sojkowski J. (2015), Vernacular Architecture in Zambia, Copperbelt University

http://victoriabischof.weebly.com/uploads/1/7/2/0/17209968/africanpaper.pdf accessed 20 February 2013,

Standeven H. A. L. (2013) Oil-Based House Paints from 1900 to 1960: An Examination of Their History and Development, with Particular Reference to Ripolin Enamels, Journal of the American Institute for Conservation, 52:3, 127-139, DOI:

Standeven H. A. L. (2011)”House Paint 1900 – 1960: History and Use**.”**

STM D5178-16, Standard Test Method for Mar Resistance of Organic Coatings, ASTM International, West Conshohocken, PA, 2016, www.astm.org, Earthscan.

Suryakanta (2014), ‘What are the effects of atmospheric conditions on plastering work?’

Taubner, H., Roth, B., Tippkotter, R., 2009. Determination of soil texture: Comparison of the sedimentaion method and laser-diffraction analysis. J. Plant Nutr. Soil Sci. 172, 161-171.

Tilbury J. (2011), House made out of termite mound, http://www.mudhutmama.com/ August 2, 2013

Tilbury J. (2014), Traditional Homes: Zambia**,** www.mudhutmama.com TLS #43, accessed, August 2, 2013

Tortnum R. (2015), Ed., Journal of Contemporary Painting, vol. 2, issue 1 .

Turner (1976), Mitchell & Bevan (1992), Payne (2001), ‘High cost conventional building materials’

Turner, J. F. C. (1976), ‘Housing by people – towards autonomy in building environment’,

Ukaegbu C. J. (2013), Determination of the various defects attributed to the manufacture, surface preparation and application of textured paints. BSC. Thesis, Abia State University

UN- HABITAT (2005). Financing Urban Shelter: Global Report on Human Settlements Nairobi: UN- Habitat understanding-earth-iii-plaster-and mortars mixes

UNESCO, Culture, World Heritage (2017), List, https://whc.unesco.org/en/list/1544, accessed Sunday, 9 July 2017

United Nations Center for Human Settlements (Habitat) 1989, Urbanisation and Sustainable Development in the 'Third World: an Unrecognised Global Issue, Habitat, Nairobi, Kenya.

United Nations Population Funds, State of the world population 2007, The United Nations, New York, 2007.

USG (2014), ‘The Gypsum Construction Handbook, 7th Edition, by John Wiley and Sons, Inc.

Verma S. K. et.al. (2017), ‘Int. Journal of Engineering Research and Application’.

www.ijera.com, ISSN : 2248-9622, Vol. 7, Issue 7, (Part -9) July 2017, pp.32-37, accessed July 2017

Vital Systems Natural Building and Design (VSNBD, 2017),http:/www.vitalsystems.net/ November 2017.

Walker, P., Keable, R., Martin, J. and Maniatidis, V. (2005) Rammed Earth: Design and Construction Guidelines. UK: BRE Bookshop.

Wanek C. (2012), 'The New Straw Bale Home,'Straw bale central', http://www.strawbalecentral.com/newSBHome.html. accessed 29 January 2012

Wuana, A. and Okieimen, F.E. (2011) Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. ISRN Ecology, 2011, Article ID: 402647.

WCED (1987), World Commission on Environment and Development, United Nations

Webster M.(2017), https://www.merriam-webster.com/dictionary/pigment

Weismann A., (2008) 'Using Natural Finishes: Lime and Earth Based Plasters, Renders & Paints'Green Books Ltd

Welch, N.H., Allen, P.B., Galindo, D.J., (1979), Particle-Size Analysis by Pipette and Sedigraph. Journal of Environmental Quality, Vol. 8, no. 4, 543-546.

White P. J., Broadley M. R. (2001), Wellesboume, Warwick CV35 9EF, UK

Willaert R .(2014), 'Gurunsi Earth Houses of Burkina Faso,' 'kassena village, tiébélé, urkina fasoimage. https://www.designboom.com/architecture/gurunsi-earth-houses-of-burkina-faso/'accessed 13 February 2013,

Worby M. (2014), https://naturalbuildingcollective.wordpress.com/2014/03/09/using-natural-materials-a-comparison/

World Bank Group (1998), Nigeria Developing Housing Finance - http://documents.worldbank.org/curated/en/pdf/110897-WP-P131973-PUBLIC-Housing

World Green Building Council (2016-2018), 'What is Green Building,' http://www.worldgbc.org/what-green-building

Zebron D. (2011), Vernacular Architecture in Zambia**,** Puyallup, WA, USA

Ziggy, (2008), Earth plasters, http://www.theyearofmud.com/

APPENDICES

APPENDIX A

RESEARCH DATA FORM 1

PROVINCE……………………………….DISTRICT…………………………………………

SAMPLE LOCATION……………………………………CORDINATES…………………….

DATE SAMPLED:………………………….SAMPLED BY ………………………………….

SAMPLE DETAILS:

SOIL COLORS:		**QUANTITY SAMPLED:**	**ID**
WHITE	☐	……………………………kg	……………..
BROWN	☐	……………………………kg	……………..
YELLOW	☐	……………………………kg	……………..
BLUE	☐	……………………………kg	……………..
GREY	☐	……………………………kg	……………..
BLACK	☐	……………………………kg	……………..
RED	☐	……………………………kg	……………..
OTHER	☐	……………………………kg	……………..

SAMPLE STORAGE:

COOLER BOX (SAMPLE ID)…………………………………………………………………

IN BLACK PLASTIC……………………………………………………………………………..

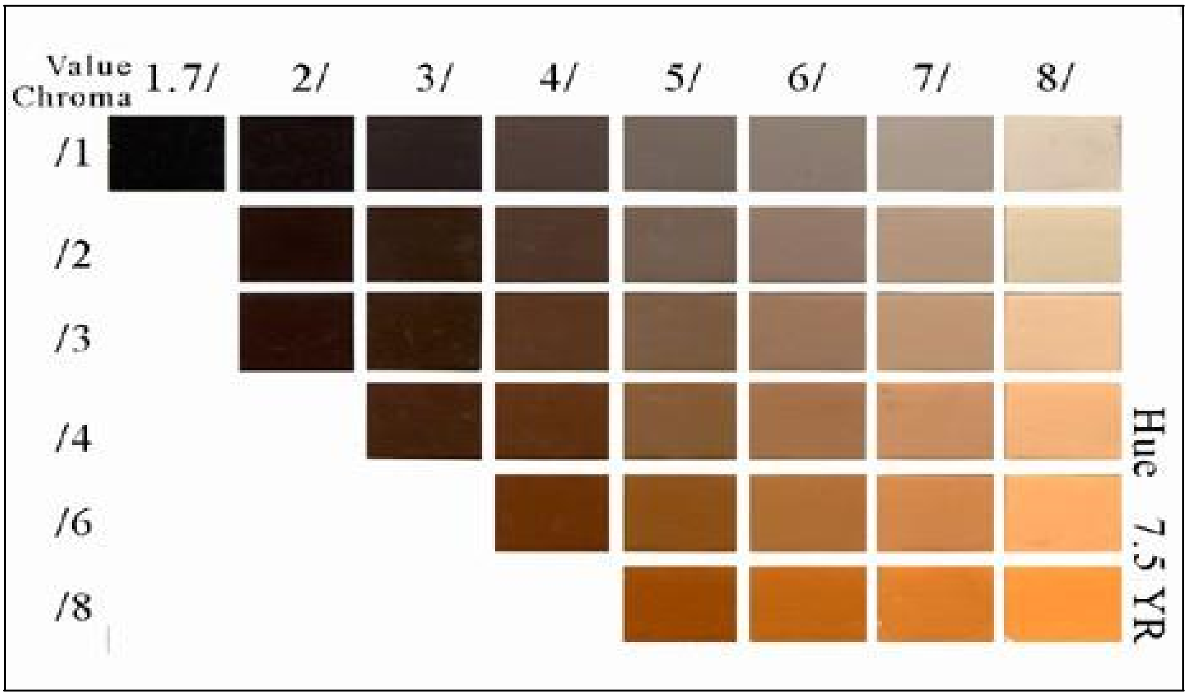
OPEN AIR………………………………………………………………………………………….

SITE NOTES:……………………………………………………………………………..

APPENDIX B

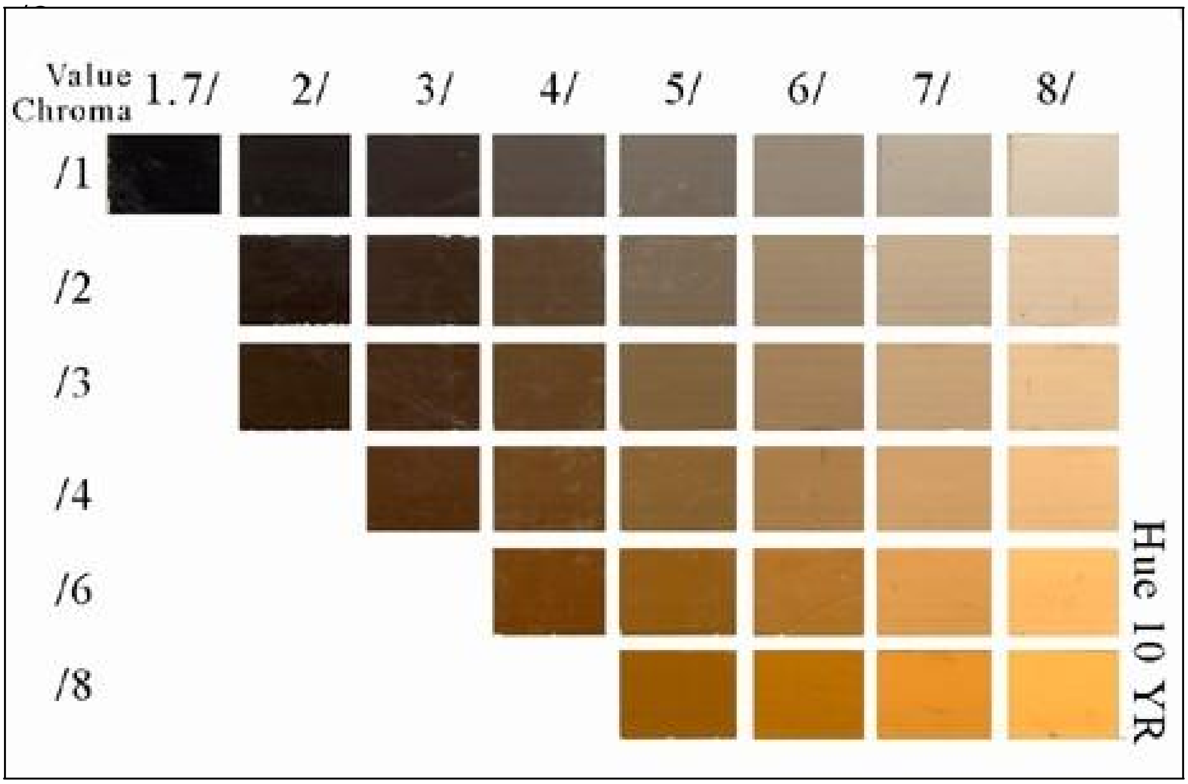
Hue 7.5 YR

Value / Chroma	1.7/	2/	3/	4/	5/	6/	7/	8/
/1	black 1.7/1	2/1	3/1	4/1	brownish gray 5/1	6/1	light brownish... 7/1	light... 8/1
/2		brownish black 2/2	3/2	4/2	grayish brown 5/2	6/2	...gray 7/2	...gray 8/2
/3		very dark brown 2/3	dark... 3/3	brown 4/3	dull 5/3	brown 6/3	7/3	light... 8/3
/4			...brown 3/4	4/4	5/4	dull orange 6/4	7/4	...yellow... 8/4
/6				4/6	bright... 5/6	orange 6/6	7/6	...orange 8/6
/8					...brown 5/8	6/8	yellow orange 7/8	8/8



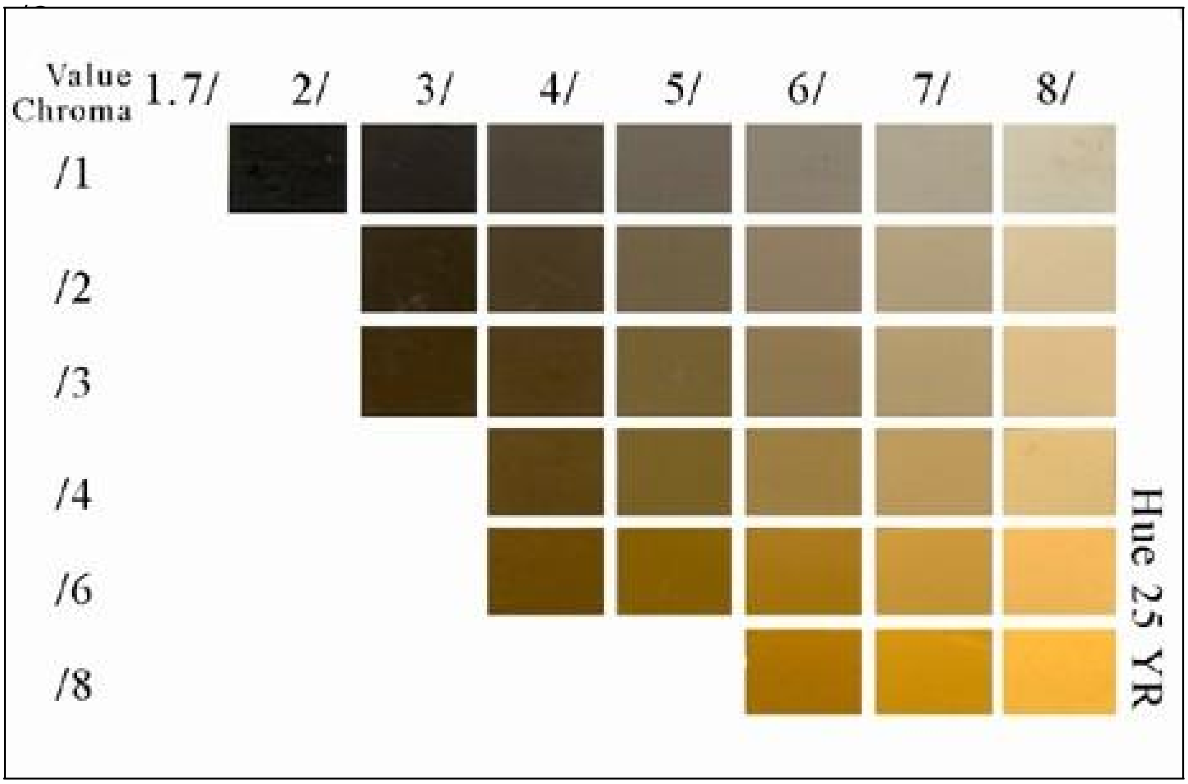
Hue 10 YR

Value / Chroma	1.7/	2/	3/	4/	5/	6/	7/	8/
/1	black 1.7/1	2/1	3/1	brownish gray 4/1	5/1	6/1	light gray 7/1	8/1
/2		brownish black 2/2	3/2	grayish yellow brown 4/2	5/2	6/2	7/2	8/2
/3		2/3	dark... 3/3	dull yellowish brown 4/3	5/3	dull yellow orange 6/3	7/3	light yellow.... 8/3
/4			...brown 3/4	brown 4/4	5/4	6/4	7/4	...orange 8/4
/6				4/6	yellowish... 5/6	bright 6/6	yellowish 7/6	8/6
/8					...brown 5/8	brown 6/8	yellow orange 7/8	8/8



Hue 2.5 Y

Value / Chroma	1.7/	2/	3/	4/	5/	6/	7/	8/
/1		black 2/1	brownish... 3/1	yellowish gray 4/1	5/1	6/1	light gray 7/1	8/1
/2			...black 3/2	dark grayish yellow 4/2	5/2	grayish yellow 6/2	7/2	8/2
/3			dark olive brown 3/3	olive 4/3	yellowish... 5/3	dull... 6/3	light... 7/3	pale.... 8/3
/4				brown 4/4	...gray 5/4	...yellow 7/3	...yellow 7/4	...yellow 8/4
/6				4/6	5/6	bright 6/6	yellowish 7/6	8/6
/8						brown 6/8	yellow 7/8	8/8



Hue 5 Y

Value / Chroma	1.7/	2/	3/	4/	5/	6/	7/	8/
/1		black 2/1	3/1	4/1	gray 5/1	6/1	light gray 7/1	8/1
/2		olive black 2/2	3/2	4/2	grayish olive 5/2	6/2	7/1	8/2
/3				dark 4/3	5/3	olive... 6/3	light... 7/3	pale.... 8/3
/4				olive 4/4	olive 5/4	...yellow 6/4	...yellow 7/4	...yellow 8/4
/6					5/6	6/6	yellow 7/6	8/6
						6/8	7/8	8/8