KENYATTA UNIVERSITY

SCHOOL OF VISUAL AND PERFORMING ARTS

DEPARTMENT OF FINE ART AND DESIGN

GLAZE FORMULATION USING SELECTED GEOLOGICAL MATERIAL FROM NAKURU AND KIAMBU COUNTIES, KENYA.

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APRIL, 2016

DECLARATION

Declaration by the Student:

This project report is my original work and has not been presented for a degree in any other University.

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Signature: ………………………………………. Date: ……………………………………

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This Proposal has been submitted for review with our approval as University Supervisors.

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DEDICATION

This research is dedicated to my loving parents Mr. Robinson Ayieng'a Ming'ate and Mrs. Veronica Kemunto Ayieng'a and my entire family, whom through Gods grace have given a meaning to my live.

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I would like to thank God Almighty for enabling me to pursue this study. I would also like to express my sincerely gratitude to my immediate supervisors, Mr. Anthony Ngondo for his constant support, guidance, encouragement and constructive criticism during the entire period of my research, together with Dr. George Vikiru for his support, guidance and assistance in facilitating the completion of my research work after the demise of my previous supervisor, the late Dr. Margaret Matanda. I would therefore like to recognize and appreciate her millage, support and her major contribution in the supervision of my proposal that lead to this research work.

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ABSTRACT

The use of glazes and glaze formulation has evolved over time and glaze styles have been developed with characteristics of certain world regions, out of the use of locally available materials. A pilot study conducted in three studios within Nairobi to assess the use of local glazes/formulations revealed that the studios did not use local glazes or formulations and that there was need for research on local glazes and formulations. Based on the above, this study was concerned with using locally available geological material from Nakuru and Kiambu Counties to formulate glazes to be used on ceramic ware for ceramic artists in Kenya. The study set out to collect data of 52 geological materials for formulation; 29 from Nakuru County and 23 from Kiambu County. These materials underwent a wet milling grinding process using a porcelain ball mill at Kenya Industrial Research and Development Institute (KIRDI). After which, they went through a studio testing process of low and high firing tests with temperatures, of 1050^0C and 1200^0C on small slabs of Nyeri clay and thereafter an elimination of 13 samples for formulation. The 13 samples underwent a qualitative and qualitative certified chemical analysis test using an Atomic Absorption Spectrometer (Spectr AA- 10) at the Ministry of Mining. The test results were used in formulating 145 glaze recipes by introducing additives that generated glaze compositions which gave both functional and aesthetic qualities for application on ceramic ware. The results of the majority of the glaze formulations affirmed their use on ceramic ware. To confirm that the findings would be of benefit to practicing ceramic artists, two clay samples of ceramic studios within Nairobi; Jacaranda Workshop and Wakenii Creations were also tested and they received the glazes well. The geological materials studied were therefore found to be suitable for glaze formulation and could be put to use by local ceramic artists. Further research should be done into the improvement and generation of more colour range and textural effects of glaze formulations for mass production in ceramic manufacturing.

ACRONYMS AND ABBREVIATIONS

KIRDI -	Kenya Industrial Research and Development Institute.
CRS -	Crushed Refined Soda
SEAMIC -	Southern and Eastern African Mineral Centre
AMACO -	American Art Clay Co, Inc.
SiO_2 -	Silicon Dioxide
Al_2O_3 -	Aluminum Oxide
CaO -	Calcium Oxide
MgO -	Magnesium Oxide
Na_2O -	Sodium Oxide
K_2O -	Potassium Oxide
TiO_2 -	Titanium Dioxide
MnO -	Manganese Dioxide
Fe_2O_3 -	Iron (III) Oxide
LOI -	Loss on Ignition
Cd -	Cadmium
Pb -	Lead
ND -	Not Detected
L -	Low Temperature
H -	High Temperature
M -	Medium Temperature

Collorants

c1 - Copper Carbonate

c2 - Cobalt Oxide

c3 - Vanadium Pentoxide

c4 - Manganese dioxide

c5 - Copper Oxide

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OPERATIONAL DEFINITION OF TERMS

The following terms have been defined in the context of their use in the proposed study:

Alumina A naturally occurring oxide of aluminum that serves as a raw material for a broad range of advanced ceramic products and as an active agent in chemical processing.

Bentonite A type of clay, formed by decomposition of volcanic ash, having the ability to absorb large quantities of water and to expand to more than its usual volume.

Bone ash A mineral residue created by calcination of bones that is primarily used in the production of bone china.

Ceramic An inorganic, nonmetallic solid made by the process of heating and subsequent cooling.

Ceramic art Art objects such as pots, tiles, tableware and figurines made from clay and other raw materials by the process of pottery.

Colourant An ingredient that puts in colour to a basic glaze and is only added in little amount and is likely to be a metal.

Feldspar A rich rock-forming mineral naturally occurring as colorless or pale-colored crystals, consisting of aluminosilicates of potassium, calcium and sodium, formed by decomposition of granite or rocks.

Flux A mineral that helps glazes to flow when firing. It also helps in lowering the temperatures at which other minerals will naturally melt.

Frit A manufactured material that will form a glass when melted, usually has two or more raw materials put together.

Glass former	The major ingredient of a glaze and the one that requires additional melting from the fluxes and stiffening from the stabilizers. In most cases silica is mainly the main glass former.
Glaze	A layer of material that is fused onto the surface of a pot or ceramic piece used to seal the pores, decorate it, or both.
Kaolin	Fine white clay used to manufacture porcelain and bone china, also referred to as china clay.
Opacifier	An ingredient that assists the glaze in making it opaque by hindering the light to pass through and is mainly used in making white glaze.
Ore	A naturally occurring mineral from which a metal or a valuable mineral can be extracted.
Pottery	The art of assembling ceramic materials and creating wares from it.
Quartz	A naturally occurring crystal of silica either in pure form or with impurities, which cause it to have a wide range of colors and finishes.
Silica	Also known as silicon dioxide naturally occurring as quartz sand, flint, and agate. It is used usually in the form of prepared white powder chiefly in the manufacture of glass, ceramics, and abrasives.
Soda ash	Commercially manufactured anhydrous sodium carbonate.
Stabilizer	An ingredient that is used to expand the melting range of a glaze and strengthen the glaze.
Trona	A mineral mined as a prime source of sodium carbonate.
Vitrifying	To change or make into glass or a glassy substance, especially through heat fusion.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Glaze is a layer of material that is fused onto the surface of a pot or ceramic piece used to seal the pores, decorate it, or both. Burleson (2001), established that Egyptian potters were among the first to discover the first well-known forms of glaze when they applied naturally occurring clays; a combination of the clays, created objects with durable, smooth and shiny coatings. The prices of the objects were determined by the brilliant turquoise colour after firing. The clay was used to make beaded adornments, scarabs, ceremonial vessels and small sculptures. It was famously known as Egyptian paste and is still used to date by ceramists referred to as self glazing clay. In addition Burleson (2001), explains that the Egyptian paste transformed under fire for the reason that the Egyptian clays contained Sodium salts. Sodium being soluble in water was carried to the surface of the clay as the work dried and after evaporation, it re crystallized to leave a white chalky coating of somewhat pure sodium which melted at low temperature. During firing, the buildup sodium acted as a flux and fused with the clay surface to form an effortless glaze.

Further assessment by Burleson (2001), indicated that later (around 1st century B.C) Asian Potters started adding other earth materials such as feldspar and iron to basic glazes to generate a variety of steady glazes with diverse surface effects. Persian, Assyrian and Babylonian potters at around 600 B.C started adding Tin Oxide to Lead glazes that made the glazes whiter and enabled them paint coloured decorations onto tile reliefs, of which the latter created complex multi coloured tiles. During this early period of glaze development, glaze styles that were characteristic of certain world regions developed out of the use of locally available materials. Through sharing of information and materials, these styles were adopted by other cultures and the ranges of possibilities for ceramic glazes stretched out.

A pilot study conducted in three ceramic studios located within Nairobi (Jacaranda Workshop, Wakenii Creations and PCEA Eastleigh Community Centre) in Chapter 3 section 3.4 revealed that none of the studios used local glazes/ local glaze formulations, a factor that contributed to the development of this study. The ceramic studios imported glazes from Potters South Africa, Northern Ireland, America Amaco, South Africa and Pottery Crafts, Canada.

An instance of a ceramic bead project (NOOR) done by Somali women Refugees at Eastleigh Community Centre indicated difficulties in finding glazes locally. They stated that "so far all of the raw materials for the beading project have come from Kenya. The one component that we are lacking is the glaze. We will be experimenting with glazes that we must import from England. While we await the arrival of these glazes, we will be using some of the Eastleigh Pottery's supply." The scarcity of locally formulated glazes and limited documented background data on glaze development and technology in Kenya and East Africa on locally available materials therefore invoked a need to study and develop glaze formulation using local geological materials.

1.2 Statement of the Problem

A pilot study conducted in three ceramic studios located within Nairobi geared towards outlining glaze challenges faced by practicing ceramic artists showcased the difficulties they underwent in finding glazes. From the study, it was evident that local glazes and formulations were not available.

Jacaranda Workshop at Kileleshwa whose main products were beads and jewelry for export, imported their glazes from Pottery manufactures like Potters, South Africa and Northern Ireland. Wakenii Creations at Kahawa Wendani whose main products were beadwork, aesthetic pieces and table ware that were predominantly sold in the local market imported their glazes from Pottery manufactures like America Amaco, South Africa pottery crafts and Canada. PCEA Eastleigh Community Centre located at Eastleigh whose main products were crockery and beads for both local and international market, who also offer pottery lessons sourced their glazes from outside Kenya. The pilot study revealed that there is interest in welcoming local solutions through research that can assist them overcome the challenges.

The sentiments of the ceramic ventures indicated that the imported glazes had a direct effect on product pricing because of the duty they incurred in bringing the glazes and the fluctuation of currencies. They also experienced various challenges some of which included; delays of supplies, colour changes when renewing orders among others.

Gombe (1982), in her study recommended that there is need for technological development based on local environment and skills, identification of local resources of raw materials, cultural identity and preservation, industrial development built or supported by local resources for raw materials, skills, competence, socio economic demand and education. The researcher therefore saw the need to explore local geological materials from Nakuru and Kiambu Counties in formulating local glazes for ceramic application.

1.3 Objectives

The following objectives were used to guide this study:

i. To identify suitable geological materials for glaze formulation.
ii. To test fire the selected materials for glaze properties.
iii. To formulate glaze using selected additives on prospective samples.
iv. To apply successful glazes on a creative project.

1.4 Basic Assumptions

The following basic assumptions were used to guide this study:

i. Geological materials are among the most suitable materials for glaze formulation.
ii. Conducting a glaze test firing is the most suitable way to identify glaze properties in a geological material.
iii. Conducting a chemical analysis is the appropriate way to determine the additives to introduce in a geological material to formulate a stable glaze composition.
iv. Aesthetic sensibility, melting and bonding of a geological material to the clay body determines the success of a glaze and on what ceramic ware it will be applied on.

1.5 Justification

The importance of the study was to empower practicing ceramic artists in Kenya locate locally available materials that will enable then formulate affordable and authentic glazes within their space. By doing so, ceramic artists will have room for creativity when mixing ingredients and will create artistic and diverse glaze formulas, which will provide an improved product range locally.

The study will also contribute to academic knowledge of glazes and glaze formulas generated from geological material from Nakuru and Kiambu Counties and will avail this information to local/international ceramic practitioners and institutions for further research.

1.6 Scope and Delimitations

The study was limited to glaze formulation using locally available geological material collected from Nakuru and Kiambu Counties. The selection of the Counties was guided by an indication of a wealthy range of geological resources and availability of coloured range of geological rocks and clays, time, distance and finances. Samples were collected, processed, tested, analyzed, formulated, re-tested, rated and applied.

The glaze formulation was conducted in Fine Art and Design Department, Kenyatta University. Processing and grinding of samples was done using a Ball Mill in a wet milling process at Kenya Industrial Research and Development Institute (KIRDI). The chemical analysis of the processed samples was done at the Ministry of Mines and Geology. Test firing was done using an Electric Kiln at 1050^0 C low and 1200^0 C high temperatures on Nyeri Clay.

Testing was done on small test pieces. Application was done on a creative project. Two clay samples from ceramic studios within Nairobi (Jacaranda Workshop and Wakenii Creations) and tested the glaze findings, to assess their compatibility.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature on glaze classification, materials for glaze formulation with factors that determine the selection and suitability of a geological material for glaze formulation. The geology of Kenya and location of geological materials suitable for glaze formulation, processing and milling geological materials for glaze formulation, conducting test firing in glaze formulation, classification of chemical compositions and formulas of materials used in glaze formulation. Materials and additives that can be used to improve or correct certain defects in glaze formulation**,** factors that determine the success of a glaze and their suitability in application together with the conceptual framework.

2.2 Glaze Classification

Glazes can be classified according to the way they have been prepared; the safety, firing, use, application technique, the clay body they are used on, the temperature, colour, transparency, the texture and many other factors. Taylor and Bull (1986), classifies glazes as indicated below:

a) Raw or fritted
b) Lead or leadless
c) Once fired or twice fired
d) Hollow or flat ware
e) Tableware, tile, sanitary, electrical porcelain etc
f) Dipping, spraying, waterfall etc
g) Earthenware, Stoneware, hard porcelain, bone china, vitreous china, alumina etc
h) Fast fire or conventional fire
i) High expansion or low expansion
j) High temperature or low temperature
k) Oxidizing, neutral or reducing fire compositions
l) Transparent or opaque
m) Coloured or colourless
n) Glossy, matt, vellum or textured etc

o) Electrical conducting, scratch-resistance etc

This study has chosen temperature to classify its glazes, the low temperature glazes being of 1050^0C, mid temperature being 1150^0C and high temperature glazes being of 1200^0C for stoneware and earthenware. However there are other aspects like glossy, matt, texture that have been used in classifying the glazes used in this study.

2.3 Materials for Glaze Formulation

Barsoum (2003), states that the universe is made up of elements that in turn consist of neutrons, protons and electrons. There are roughly 100 elements, each possessing a unique electronic configuration determined by its atomic number Z, and the spatial distribution and energies of their electrons. This then establishes the opulence of the earth resources and differentiates every region in the world depending on the geology; which allows each region to examine the suitable geological materials within their region including Kenya.

According to Shearer (2005), in most cases materials used in glaze formulation are largely a combination that nature has assembled collectively. The ingredients are in most cases mined, refined, graded and packed and sold to potters, although a potter can also set out to explore and locate some of these ingredients with the guidance of geology knowledge on where to find them.

2.3.1 Factors that Determine the Selection and Suitability of a Geological Material for Glaze Formulation

According to Taylor and Bull (1986), raw materials for glaze manufacture are selected from processed and valuable minerals and from bulk industrial grade chemicals, acquired from earth resources. A low cost glaze is therefore based on the fact that its constituent raw materials are plentiful, painless to find and cost-effectively priced. Wilson (2008), further ascertains that when assessing the suitability of a particular raw material for making glaze compositions on a large scale various factors must be considered. Taylor and Bull (1986), put together those factors as expounded below:

a) The Cost – The affordability of producing the glaze.

b) The location of source – Accessibility of the location.
c) The availability resource –Abundance in nature of the given material.
d) The mineral impurities – The degree of purity of the main mineral used in produce glaze.
e) The Grain size (granulation) – The size reduction technique applied for the preparation of glaze (this factor is applicable on purchased additives, however wet milling is the most suitable technique in granulating geological materials in glaze formulation as discussed in section 2.4)
f) The behavior during mixing – The reaction when mixing.
g) The behavior in storage – The stability of chemical components during storage.
h) The behavior in suspension in water and on storage in the processed condition –The rate of sedimentation of the material.
i) The chemical composition and the consistency over a long time – Stability of chemical components within a period of time.
j) The behavior when melting in kiln – The reaction in firing.
k) The effects of use on environment – The safety of material to the environment.

These factors are bound to differ in weight depending on the nature of glaze being prepared, although every factor cannot be overlooked. Nonetheless, the cost of the initial material, the prediction of melting behavior, the availability and location was among the important factors in selecting geological materials for this study.

When speculating a melting behavior of a geological material, it is important that the material showcase a good balance of silica, alumina and fluxes. Zakin (2001), states that balanced glaze recipes have a good balance of silica, alumina and fluxes; these ingredients dictate the flowing, stability, melting points of the raw material as discussed in section 2.5. However a geological material that is rich in one or the other can be improved on by introducing another.

2.3.2 Geology of Kenya and Location of Geological Materials Suitable for Glaze Formulation

Geological materials are among the most suitable raw materials for glaze formulation. Raini Jackson (2013), in his article The County Council of Nakuru, Profile points out the County's geology, which has several stone quarries found at Mau, Bahati, Menengai and Kedowa. Ballast rocks for ballast crushing occur in patches in the County and are mined west of Gilgil town, Menengai slopes, Rhonda, West of Lake Nakuru and near Lamudiak river. Diatomite, a mineral used for insulation, building and as a stabilizer in the chemical industry is found and exploited at Kariandusi. Manganese is found along the Gilgil Nyahururu road to the north of the confluence of the Malewa and Oleolongo Rivers. Kaolin is found in Eburru. This is a light colored Kalaolimite rock clayed material which in its natural state is used in the manufacture of porcelain, wall tiles, paper, refectory ware, rubber, ceramics, felt pug for wire insulation and other purposes. Obsidian is found in Longonot and Eburru. Through this article it is evident that Nakuru County in the rift valley, Kenya has a wealthy geology. East African Rift System (EARS) being listed as one of the geologic wonders of the world contains geological materials that are plentiful and wealthy in silicates, alumina, feldspar, kaolin among other minerals that have been explored for glaze formulation in this study.

A newsletter from the Ministry of Mining by Southern and Eastern African Mineral Centre (SEAMIC) (2006), a *Special Issue* on *Mineral Potential of Seamic Member Countries* also points out on the earth resources of Kenya which include a wide range of minerals, both metallic and industrial, as well as varieties of gemstones. These minerals include barite, gypsum, gold, silver, lead, talc, titanium, salt, kyanite, corundum, a variety of gemstones, (mainly ruby and several varieties of garnet) dimension stones, diatomite, silica sand, heavy mineral sands, manganese, zinc, wollastonite, graphite, kaolin, copper, nickel, chromite, pyrite, various clays, rare earth elements and pyrochlore.

The newsletter groups the geology of Kenya into the following major geological successions as listed in the table 2.1 on the next page:

Table 2.1: A summary of Geological successions and mineral occurrences by Southern and Eastern African Mineral Centre (SEAMIC)

NO	Name	Description	Mineral Occurrence
1	Archean: Kavirondian system	Mudstones, Sandstones, Conglomerates, Granitic intrusions Nyanzian system: Shales, cherts, ironstones, Pyroclastics, Rhyolites, Andesites, Basalts.	Found in Western Kenya where metallic mineralization of base and precious metals are known to occur: gold, copper and silver have been mined in the past. They are also potential for ferrous and no-ferrous metals. Kimberlitic bodies have also been reported.
2	Proterozoic: Kisii series (Bukoban system)	Volcanics with sediments Mozambique Belt: quartzites, biotite/hornblende gneisses, schist, granitoid gneisses, amphibolites, migmatites. Intrusives: syntectonic granites.	Extensive in Central Kenya north to South in which minerals such as kyanite, corundum, graphite, wollastonite, marble, asbestos, fluorspar, magnesite, kaolin and a variety of gemstones are found together with minerals associated with basic and granitic rocks.
3	Palaeozoic/Mesozoic and Quaternary (Cretaceous, Jurassic, Triassic, Permian and Carboniferous)	The Karroo formations of the coastal hinterland, including the basal sedimentary formation in north eastern Kenya. Soils, alluvial beach sands, evaporates, fossil coral reefs and sandstones at the coast: alluvial and lacustrine sediments of the Rift Valley. There are also volcanic rocks of the rift valley from the younger volcanoes.	Widespread with rocks are sources and hosts of limestones, gypsum, clays, manganese and construction materials and possibly hydrocarbons. Base metal mineralization, lead-zinc-barite and copper are known to occur in the sedimentary basin along the coastal belt. Heavy mineral sands also occur along the coastal beach sands and recently deposits of about 3.2 billion tons of titanium bearing have been discovered.
4	Tertiary	Coastal sediments, Late Miocene and Pliocene volcanics, Terrestrial and lacustrine inland sediments. There are Early Tertiary formations not represented at surface.	The volcanic rocks associated with Rift System host a variety of minerals and construction materials. The volcano-sedimentary accumulations have deposits of clays, evaporites, trona (soda ash), diatomite, natural carbon dioxide, kunkar and gypsum. Gem quality rubies have also been discovered recently (Southern and Eastern African Mineral Centre, 2006).

The geology represents a wealthy resource of raw materials in Kenya that can be tested for glaze formulation. However this study has narrowed down to Nakuru and Kiambu Counties because of time, distance and resources.

2.4 Processing and Milling Geological Materials for Glaze Formulation

Rahaman (2003) indicates that, for characteristics of powder to have a remarkable effect on subsequent processing that produces a desired microstructure, they should be highly processed. Gonzlez-Gutirrez, Joamn, Gustavo Beulke, and Igor Emri (2012), in Powder Injection Molding of Metal and Ceramic Parts, suggests processing using high compression Roller mills, Jet mills or Ball mills for studio artists.

Taylor and Bull (1986), suggest that the most widely employed glaze manufacturing methods involve; mixing the ingredients, particle size reduction, dispersion in water, removal of unwanted materials and the addition of minor quantities of chemicals to modify certain physical properties of the glaze slip. The first three processes are carried out together during wet grinding. Therefore to achieve the desired microstructure for glaze formulation, this study used a wet milling process using a porcelain ball mill in granulating its geological samples.

Poor granulation will bear undesirable results therefore the ability of comminution will give desirable results although the success of glaze will depend on different factors. Taylor and Bull (1986), state that the most important factor in glaze formulation is granulation although other factors are also of equal importance; the factors are discussed in section 2.8.

2.5 Conducting Test Firing in Glaze Formulation

Glaze tests are best done on small pieces before application on large pieces. Burleson (2001) recommends test firing on small batch of clays to determine characteristics like opacity, fluidity and surface texture.

Nevertheless the main reasons for conducting glaze tests on smaller pieces for this study was, to examine the prospect of an individual material and in the case of glaze formulation, to examine the behavior of additives when formulating; all examinations based on appearance. This played a role in correcting glaze faults in a formula by either adding or reducing on specific ingredients.

The primary glaze test was done for instance to showcase the melting point of a material. The results gave glaze or glaze effects that required adjustments by adding additives. In the event of testing a low temperature of 1050^0C and a High temperature of 1200^0C were used to classify low and high temperature recipes.

According to Williams (2006), knowing which oxides produce which effects during firing and knowing what materials will successfully provide those oxides is the basis of developing, controlling and ensuring the safety and quality of one's glazes during testing. He states that the most important reason in learning and understanding the chemistry of glazes and oxides as discussed herein is so that one can save a lot of time, money, effort and frustration.

Among other fundamental factors in glaze testing for this study is the thickness of the glaze slurry and the measurement of ingredients. The measurement is extremely critical especially when ingredients are being introduced into a raw material. Clear labeling of containers is also essential as it allows you to avoid mix up. Burleson (2001) recommends that after mixing glaze it is advisable to allow it to rest overnight as some ceramic materials expand as water is absorbed into them, it is usual for glazes to thicken while resting and the proper thickness for application can only be adjusted after the rest. The disadvantage of applying glazes immediately after mixing is the risk of it expanding while on the clay surface and flake off or end up defected which can lead to poor judgment of the test result.

There are various glaze application techniques that can be used on glaze testing; dipping, brushing, pouring and spraying are the major ones. This study has used brushing technique on glaze tests and airbrush technique on project application; however in some cases brushing technique was used on application depending on the nature of material.

Burleson (2001), recommends that adding other additives as suspending agents like bentonite, veegum, macaloid, sodium carboxymethylcellulose that can assist in thickening the glaze slurry to prevent the ingredients from settling, acting as a binder and assisting in hardening the surface of unfired glaze is a step to achieving better test results. Deflocculants like darvan #7, darvan #11, sodium silicate, tri-sodium phosphate assist spraying and trailing glazes flow smoothly, flocculants like flocs, magnesium sulfate, vinegar assist pouring and dipping glazes to prevent settling, vehicles like glycerine, propylene glycol, liquid laundry starch assist brushing glazes achieve fluidity for brushing. There are also other acrylic emulsions used for commercial glaze additives that can be used for a variety application that include extending brush ability, suspending in the bucket, hardening unfired glaze surfaces; these emulsions are widely applicable on commercial uses that require a longer time frames of action. These additives were however not explored in this study.

2.6 Classification of Chemical Compositions and Formulas of Materials used in Glaze Formulation.

According to Taylor and Bull (1986), a superior and more accurate description of glaze is a material that is primarily composed of silica, fired with a balance of fluxes and stabilized with alumina. This description is more helpful as it begins to expose an outline to an in-depth understanding of glazes.

According to Zakin (2001), glazes can be classified by the amount of silica, alumina or modifiers that are contained in them. He indicates that balanced glaze recipes have a good balance of silica, alumina and fluxes. He advises that the reasonable way to balance is to have the glaze contain 55% to 80% feldspar and 6% to 10% clay and the rest of the materials that are not necessarily glass makers to have 15% to 35%. Such recipes are likely to be stable, useful and reliable.

Zakin (2001), establishes that high silica recipes are very stable, smooth, glassy and durable; they actually obtain most of the silica from the ground. While high alumina recipes are stable, durable and non-flowing; their surfaces are mostly dry and mat or strongly fluxed, smooth and enamel like with a colour that is somehow bleached.

There are also other recipes that contain non glassmaking material (they contain little silica and alumina). These recipes tend to be elaborate with a great deal of visual texture. They are very unstable, with poor durability; they experience excessive and erratic glaze flow and crazing. However they are very exciting and superior looking; very appealing on artistic and creative ceramic pieces.

Shearer (2005), points out on common oxides found in glazes and common minerals used in glaze making as indicated in Appendix III Appendix IV. Therefore a detailed chemical analysis was done on the samples in order to provide guidance on what additives to introduce on certain compositions and recipes to achieve certain results.

2.7 Materials or Additives that can be used to Improve or Correct Certain Defects in Glaze Formulation

A good stable opaque glaze formula should contain a glass former, a flux, a stabilizer, an opacifier and a colorant. Shearer (2005) defines a Glass former as the major ingredient of a glaze and the one that requires additional melting from the fluxes and stiffening from the stabilizers. In most cases silica is mainly the main glass former, while flux is an ingredient that facilitates melting glaze or helps in lowering the melting temperature in which the glaze will melt at. A stabilizer is an ingredient that is used to expand the melting range of a glaze and strengthen the glaze and an opacifier is an ingredient that assists the glaze in making it opaque by hindering the light to pass through and is mainly used in making white glaze. A colourant as an ingredient that puts in colour to a basic glaze and is only added in little amount and is likely to be a metal. These materials that contribute in adding certain attributes to a glaze formula are all listed in Appendix III. Even so this study selected additives based on availability as seen in Chapter 4 section 4.4.

Shearer (2005), further describes ceramics as a study of oxides as nearly all ceramic ingredients turn into oxides after blending in the kiln. These oxides are the ones that are responsible in providing certain characteristics that a ceramist may desire in a glaze. However some ceramic materials have different names and when an ingredient gains an atom of oxygen it changes the name, for instance Calcium gains oxygen to become Calcia. Calcium Carbonate is also referred to as Whiting or Limestone or Calcite or Chalk.

Taylor and Bull (1986), classify raw materials and additives for glaze formulation as listed in table 2.1 in the next page:

Table 2.2: Raw materials and additives for glaze formulation

NO	Material	Mineral
1	Silicon	Silica sand, Quartz, Flint, Silicates
2	Aluminium	Aluminium hydroxide, Alumina, Clay, Felspathic minerals, Anorthosite, Pegmatite, Stone, China Stone or Cornish Stone
3	The Alkali Metals	Lithium, Potassium, Sodium
4	Alkaline Earth Metals	Barium, Calcium, Strontium, Magnesium
5	Titanium	Titanium
6	Zirconium	Zirconium
7	Cerium	Cerium
8	Fluorine	Fluorine
9	Boron	Boron
10	Zinc	Zinc
11	Tin	Tin
12	Lead	Lead
13	Colorants in Ceramic glazes	Chromium, Cobalt, Copper, Iron, Manganese, Nickel, Vanadium

Zakin (2001), describes these materials and additives as elements found in ceramic materials and further breaks them down into elements that encourage melting, modify colour, make glazes opaque and assist them in chemical reaction as indicated in the Table 2.3:

Table 2.3: Elements that can be introduced in glaze compositions

NO	Description	Element
1	Elements that encourage melting	Potassium, Sodium, Calcium, Magnesium, Tatanium, Zinc, Lithium, Boron, Barium(toxic), Lead(toxic)
2	Elements that modify colour	Iron, Copper, Cobalt, Manganese, Nickel(toxic), Vanadium(toxic)
3	Elements added to glazes to make them opaque	Tin, Zirconium
4	Elements that take part in chemical reaction	Carbon(found in carbonates such as calcium carbonate, whiting) Oxygen(found in oxides such as iron oxide)

These elements provide a direction on additives that will solve certain anomalies that can be adjusted during glaze test. Different materials therefore provide different characteristics in glaze and the ability to diagnose and correct anomalies in glaze formulation is somewhat moderated by these elements. All the same this study selected a few of the additives that were available.

2.8 Factors that Determine the Success of a Glaze and their Suitability in Application

There are different factors that will assist in determining the success of a glaze; a good/successful glaze will articulate great aesthetic sensibility. Good/ successful glazes are likely to be stable, durable, non-flowing, smooth or with attractive visual textures. Taylor and Bull (1986), summarize the factors that influence the success of a glaze as listed below:

a) The composition of glaze(Chemical composition)
b) The raw materials
c) The granulation(size of particle after grinding)
d) The thickness of the applied glaze
e) The clay body(nature of the clay)
f) The source of firing either by combustion or electricity
g) The size of the kiln
h) The fluctuations in the heating curve during firing
i) The final firing temperature
j) The duration of firing
k) Oxidation and reduction(variation in the kiln atmosphere)
l) The curve of the cooling process

These factors also indicate that the same glaze compositions have the ability to produce different variations depending on an individual factor.

However glaze faults can also hinder glaze tests and therefore, it is important to beware of the faults before deriving any conclusion on unsuccessful glaze tests. Burleson (2001), points out the glaze faults as; Crawling, Crazing/Crackle, Pitting and Pin holing, Blisters, Shivering, Under firing and Over firing.

Nevertheless any glaze that does not exhibit attributes of endangering the users and is aesthetically appealing to the eye can be observed as a good or successful glaze. The most important factor is that the attributes it acquires suit the functionality of the item that the glaze will be applied on.

2.9 Conceptual Framework

The conceptual framework contained an independent variable which is the geological materials and a dependent variable which is the glaze formulations. The outcome will depend on three moderator variables which are: granulation; particle reduction of the geological material, temperature; low and high firing temperatures, and additives; to be used in glaze formulation.

This has been summarized by the framework structure below:

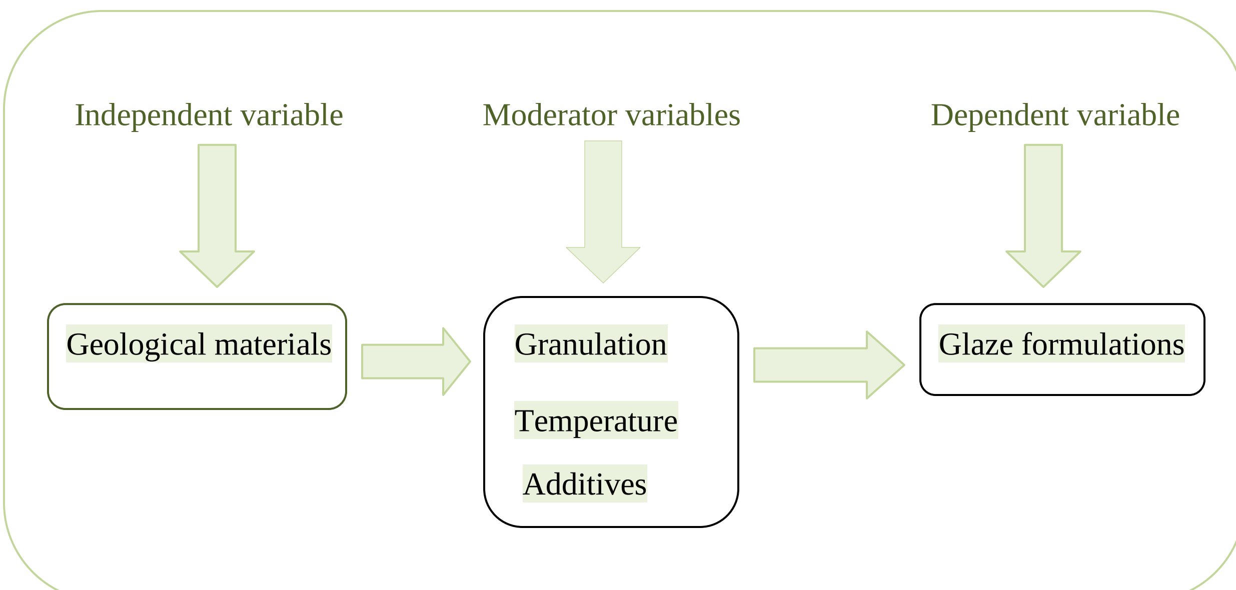

Figure 2.1 Conceptual Framework Structure

Designed and developed by the researcher

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter explains the research design, shows the study area and size, the pilot study, sampling techniques, validity and reliability, data collection tools and techniques, primary data, secondary data, data analysis tools and project application.

3.2 Research Design

The study explored an experimental studio based research design using geological materials from Nakuru and Kiambu Counties which used both qualitative and quantitative research methods. Mugenda (2003), illustrates the experimental research design as a useful tool in manipulating one or more variables, controlling and measuring any changes in other variables, therefore assisting in understanding the relationship between objectives and variables. The Solomon four group design, a type of experimental research design under controlled group design was viable for this study as it achieves the three purposes; assessing the effect of treatment, assessing the effect of pre-test and assessing the interaction between a pre-test and treatment conditions. The quantitative approach answers the scientific part in glaze formulation and developing glaze compositions for the research, while the qualitative approach answers the artistic part in appearance to suite the functionality or aesthetic value during application.

3.3 Study Area and Size

The study area was Nakuru and Kiambu Counties with 29 samples from Nakuru County and 23 Samples from Kiambu County from different locations as tabulated in table 3.1. The geological map of the counties is shown in Appendix I. The selection of these Counties was guided by an indication of a wealthy range of geological mineral resources found in Nakuru County and the availability of coloured range of geological clays and rocks found in Kiambu County.

Table 3.1: A List of Study Areas and Number of Samples

Nakuru County (A)				
Nakuru (N)			Gilgil (G)	
No.	**Area**	**No. of Samples**	**Area**	**No. of Samples**
1.	Mau/Kedowa	7	Kariandusi	2
2.	Bahati/Menengai	4	Eburru	9
3.	Njoro	6	Malewa	1
Total		17	Total	12
Total number of samples from Nakuru County = 29				
Kiambu County (B)				
Kiambu (K)			Thika (T)	
No.	**Area**	**No. of Samples**	**Area**	**No. of Samples**
1.	Kiambu Road	6	Ndarugo	5
2.	Kenyatta University	2	Utawala Bypass	8
3.	Clay works	2		
Total		10	Total	13
Total number of samples from Kiambu County = 23				
Total number of samples from Nakuru and Kiambu Counties = 52				

3.4 Pilot Study

A pilot Study conducted between 2nd and 15th January 2015 in view of sampling three ceramic studios that use glazes on their ceramic ware within Nairobi points out on absence of local glazes in their practice.

Jacaranda Workshop at Kileleshwa whose main products are beads and jewelry for export, imports glazes from Potters, South Africa and Northern Ireland as reported in an interview, photography and email. Wakenii Creations at Kahawa Wendani whose main products are beadwork, aesthetic pieces and tableware predominantly sold in the local market, imports glazes from America Amaco, South Africa pottery crafts and Canada as reported in an interview and photography. PCEA Eastleigh Community Centre located at Eastleigh whose main products are crockery and beads for both local and international market, who also offer pottery lessons source their glazes from outside Kenya as reported in an interview.

Table 3.2: Data collected on the use of glazes in production from Three Ceramic Studio in Nairobi

No.	Studio Names	Glazes used currently (Foreign Glazes)		Local Glazes/ Formulations	Accessibility of local glazes	Products
1	Jacaranda Workshop, Kileleshwa	Potters, South Africa (All) Potters, Northern Ireland	All	None	None	Bead work
2	Wakenii Creation, Kahawa Wendani	America, Amaco South Africa, pottery crafts Canada, pottery crafts	All	None	None	Bead work, Table ware & Aesthetic pieces
3	PCEA Eastleigh Community Centre, Eastleigh	Unrevealed sources. However they also used foreign glazes	All	None	None	Bead work, Table ware & Aesthetic pieces

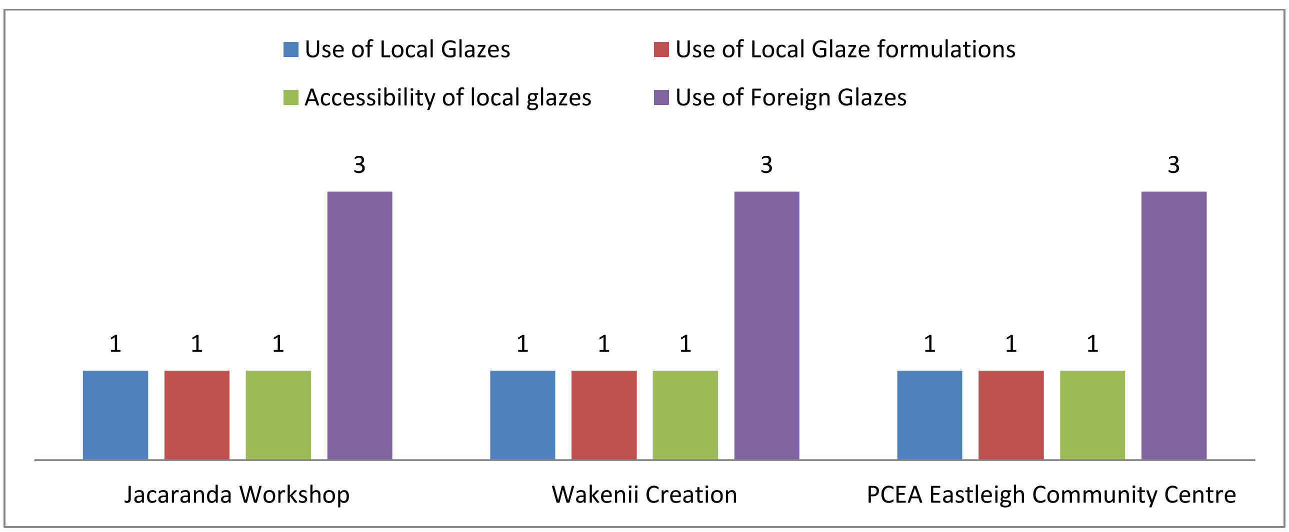

Figure 3.1 Use of glazes in three ceramic studios within Nairobi

Rating Key:

(1) None , (2) A certain percentage, (3) All

The purpose of the pilot study was to determine the availability of local glazes/ local glaze formulations and their use on ceramic products within the studios.

The data collected from the pilot study, revealed that the three studios within Nairobi did not use local glazes because they do not have access to local glazes. The findings of the pilot study assisted greatly towards developing a case study for this research, with intentions of documenting information on locally available geological materials and additives for glaze formulations in Kenya as documented in Chapter 4.

3.5 Sampling Techniques

This study applied two types of sampling techniques, cluster sampling technique in identifying and locating geological samples and purposive sampling in eliminating geological materials for glaze formulation. Mugenda (2003), describes cluster sampling as a technique used when it is not possible to obtain a sampling frame because the population is either very large or scattered over a large geographical area. It involves the selection of an intact group and each member becomes a unit of observation. This study therefore identified 52 samples from Nakuru and Kiambu Counties in forming its population of two clusters and further divided into regions with four clusters and then areas. The samples were numbered according to the regions as illustrated in Table 3.1, for instance Sample Code: AN:MK:1 was the first sample from Nakuru, Mau/Kedowa area, Sample No: AN:BM:2 was the second sample from Nakuru, Bahati/Menengai area.

Mugenda (2003), further states that the hindrance to cluster sampling is in achieving a reasonable degree of population validity between the selected cluster and the target population is often difficult. This limits generalization. Therefore it is important to keep in mind that the research of glaze formulation using geological materials in Kenya is not limited to the clusters selected for this study.

After obtaining the samples from the field, they were first categorized according to Counties, regions then areas as listed in Table 3.1. Then they underwent a primary test of 100% granulated geological material (sample) as excavated from the ground. In primary tests the samples were split into two major categories, low and high firing tests, with temperatures of 1050^0C as low temperature and 1200^0 C as high temperature.

Cone 5, which has a temperature of 1050^0 C, is used by most of the glaze manufacturing companies as low temperature glaze, AMACO is one such manufacturer. 1200^0 C is considered mid temperature glaze by most manufactures and is suitable as high temperature for earthen ware clay, which is the clay that is commonly used in Kenya and 1200^0 C is also kind to the kiln elements and is considered affordable for ceramic production.

At this stage of test firing the purposive sampling technique was introduced in eliminating tests that proceeded to formulation using additives. Mugenda (2003), defines purposive sampling as a sampling technique that allows a researcher to use cases that have the required information with respect to the objectives of his or her study. Cases of subjects are therefore handpicked because they are informative or they process the required characteristics. The criteria for selection of samples was based on the observation in appearance, mainly considering how the sample bonded with the clay body, its melting behavior, colour and textural effects.

A further formulation tests were done during progressive test using 13 selected samples and the tests were done in two categories as listed below:

Category 1: A progressive test in glaze formulation with 85% granulated geological material (sample) excavated from the ground and 15 % additives.

Category 2: A progressive test in glaze formulation with 70% granulated geological material (sample) excavated from the ground and 30 % additives.

Testing was generally conducted on small test pieces. After which, some successful glaze recipes were handpicked and applied on the project. A naming system was then developed based on the name of the quarry, name of the rock sample, the colour of the sample or either of the two.

3.6 Validity and Reliability

To ensure validity and reliability of the glaze formulation, the study used controlled weight operators when measuring the ratios of each material. However, during formulation, the geological material was never at any point below 70% of the glaze formula and the additives did not exceed 30% of the glaze formula to control the cost of production.

To ensure validity and reliability of the glaze formulas, temperatures were similar for testing across all samples and a similar clay body was used on high temperature and low temperature test pieces.

To guarantee proper analysis of samples; processing was done by wet milling the samples to consistent granules to give a desired microstructure using a ball mill at Kenya Industrial Research and Development Institute (KIRDI)

To guarantee reliability of the findings of the study, clay bodies of bisque fired items from Jacaranda Workshop and Wakenii Creations were used to test if the glaze findings were compatible with their clay bodies.

3.7 Data Collection Tools and Techniques

The study used the following tools and techniques of data collection:

- Structured identification tables (checklist) or observation tables in observing the appearance of the geological materials during testing.
  Key, (1997) describes this kind of observation as a systematic direct observation. He says that in many cases, systematic direct observation of behavior in this case visual is the most desirable measurement method. In using this data collection tool an investigator identified the behavior of interest and devised a systematic procedure for identifying, categorizing, and recording the behavior in either a natural or "staged" situation.
- Photography and maps were used to capture details of the location and physical properties of the raw material.
- Atomic Absorption Spectrometer (AAS) was also a tool of data collection and the results of the chemical analysis certified by the Ministry of Mines and Geology.

3.7.1 Primary Data

Primary data was obtained from:

- A pilot study to develop a case study as seen in Chapter 3, section 3.3.

- Data that was recorded in observation tables when identifying and collecting geological materials as seen in Appendix II.
- Low and high temperature primary test (100% granulated sample) data, that was recorded in observation tables as seen in Appendix III.
- A qualitative and quantitative chemical analysis of the 13 samples as seen in Chapter 4, section 4.4.
- Data from formulation of progressive tests as seen in Appendix IV.
- Data from application of glazes on items and vertical pieces as documented in Chapter 4, section 4.5.

3.7.2 Secondary Data

This study incorporated data that was collected from the libraries, books, online publications, journals, reports, surveys and published government records. The researcher collected information on glaze processing, preparation, formulation and application and borrowed ideas on how to conduct the study.

3.8 Data Analysis

The data analysis was done by processing the data that was collected and recorded on:

- Observation tables from the field
- Low and high temperature primary tests (100% granulated sample)
- A qualitative and quantitative chemical analysis of the 13 samples that were selected for formulation
- Progressive tests (glaze formulations)
- Application of glazes

This information was processed using tables, pie charts and graphs as shown in Chapter 4.

CHAPTER FOUR: PRESENTATION AND ANALYSIS OF DATA

4.1 Introduction

This chapter presents and analyzes data that was obtained from each objective, using tables, graphs and pie charts.

4.2 Data Presentation and Analysis for Objective 1

The cost of the initial material, the prediction of melting behavior, the availability and location was among the important factors in selecting suitable geological materials for this study as stated in Chapter 2, section 2.3.1. When locating geological material, it was important that they showcased a good balance of silica, alumina and fluxes. This meant that the material possessed melting behavior. However a few cases were selected beyond that measure.

52 geological samples were identified as suitable geological materials for glaze formulation and were collected from Nakuru and Kiambu Counties as documented in Appendix II.

29 geological samples which is an equivalent of 56% were collected from Nakuru County while 23 geological samples which is an equivalent of 44% were collected from Kiambu as indicated in figure 4.1 below:

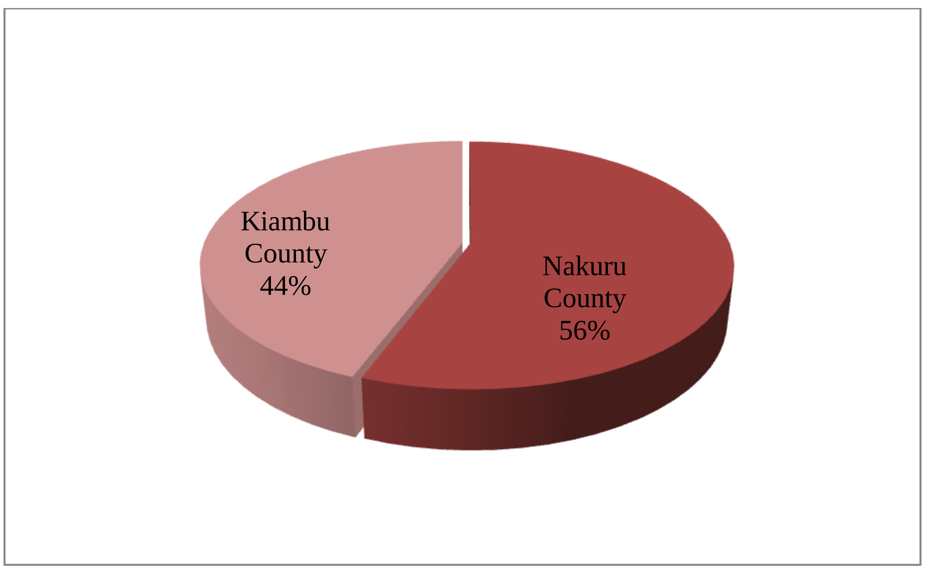

Figure: 4.1. Geological samples from Nakuru and Kiambu Counties represented in percentages

Nakuru County was divided into two regions; Nakuru region with 17 Samples and Gilgil region with 12 samples. Kiambu County was also divided into two regions; Kiambu region with 10 Samples and Thika region with 13 samples. Their percentage in data is illustrated in figure 4.2 below:

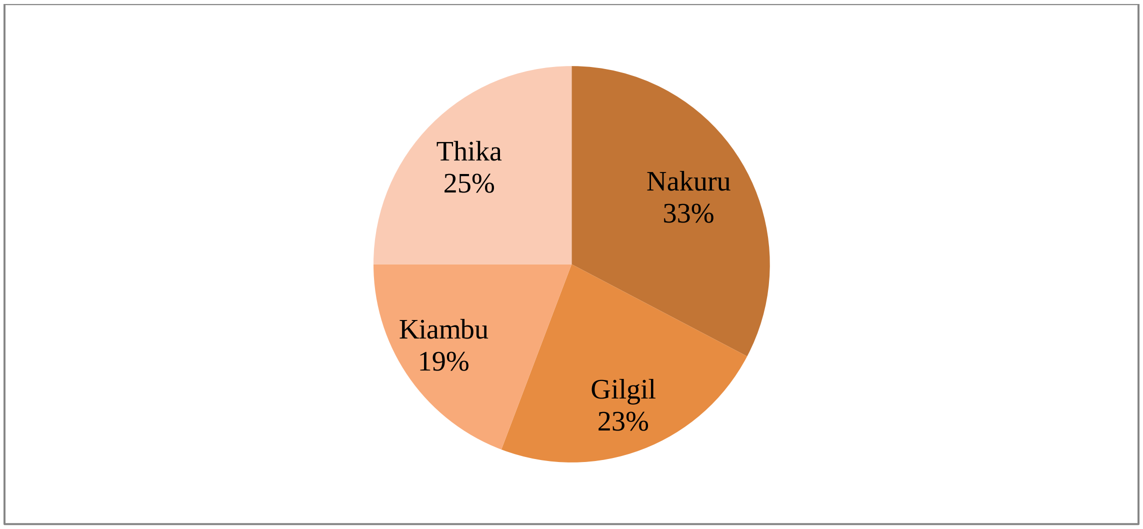

Figure: 4.2. A representation of Geological samples from Nakuru, Gilgil, Kiambu and Thika Region

Nakuru region was divided into three areas, Mau/Kedowa with 7 samples at 41%, Bahati/Menengai with 4 samples at 24% and Njoro with 6 samples at 35% as represented in figure 4.3 below:

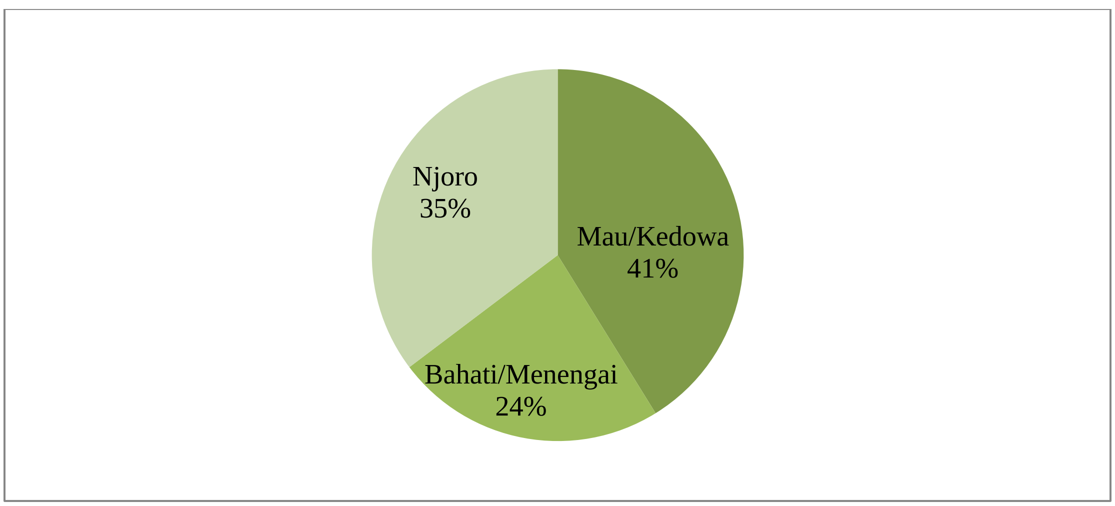

Figure: 4.3. A representation of Geological samples from Mau/Kedowa, Bahati/Menengai and Njoro

Gilgil region was divided into three areas, Kariandusi with 2 samples at 17%, Eburru with 9 samples at 75% and Malewa with 1 sample at 8% as represented in figure 4.4 below:

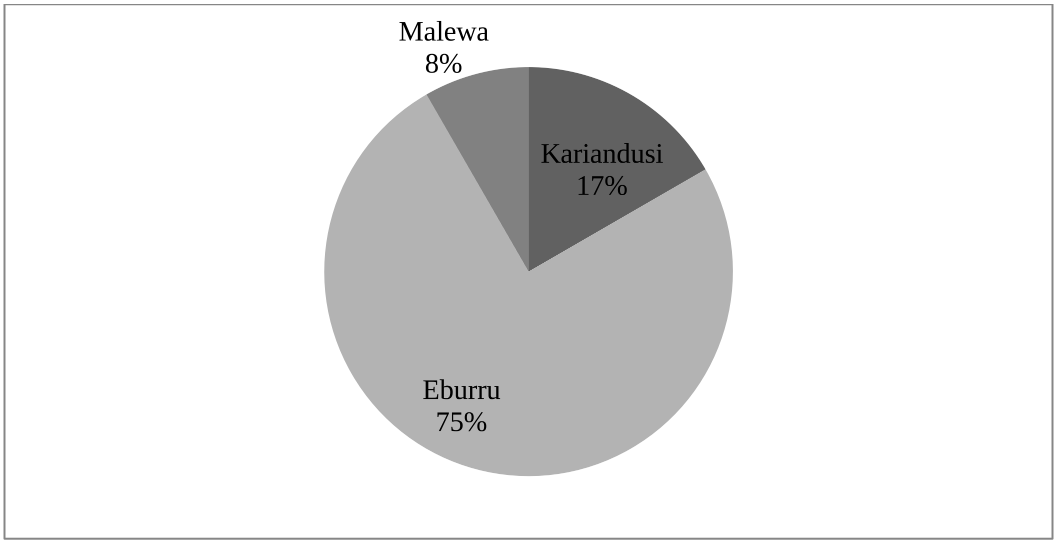

Figure: 4.4. A representation of Geological samples from Malewa, Eburru and Kariandusi

Kiambu region was divided into three areas, Kiambu road with 6 samples at 60%, Kenyatta University with 2 samples at 20% and Clay works with 2 at 20% samples as represented figure 4.5 below:

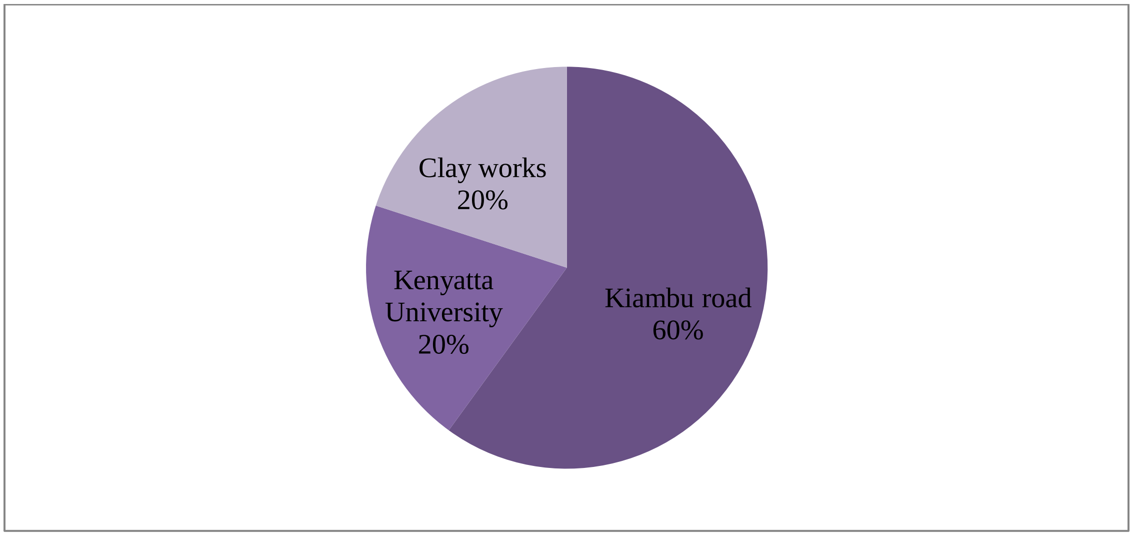

Figure: 4.5. A representation of Geological samples from Kiambu road, Clay works and Kenyatta University

Thika region was divided into two areas, Ndarugo with 5 samples at 38% and Utawala Bypass with 8 samples at 62% as represented in figure 4.6 below:

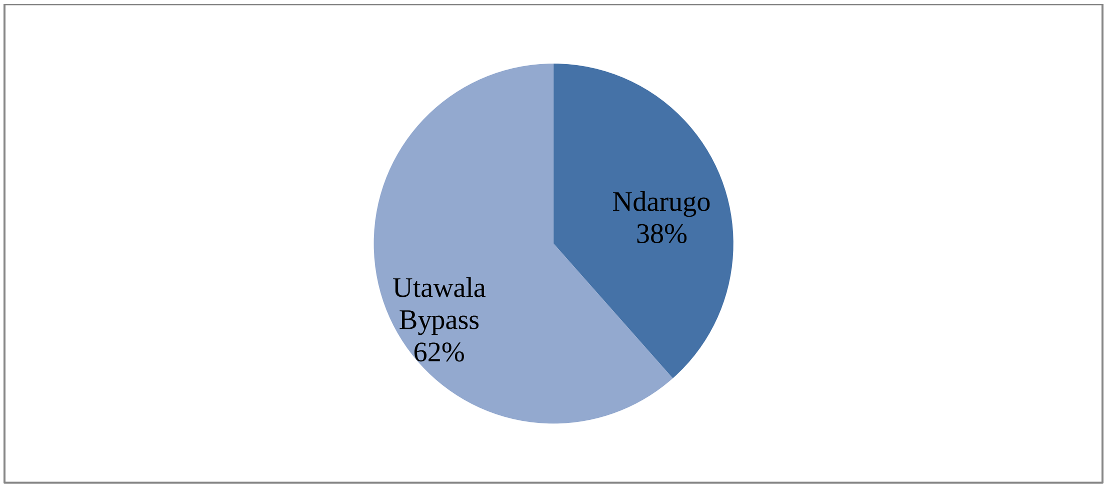

Figure: 4.6. A representation of Geological samples from Ndarungo and Utawala Bypass

In comparing the 4 regions in the analysis of figure 4.7, 4.8, 4.9 and 4.10, there was a balance in selection of samples that proceeded to glaze formulation region wise. However some areas appeared to have more samples than others due to variety in nature of sample.

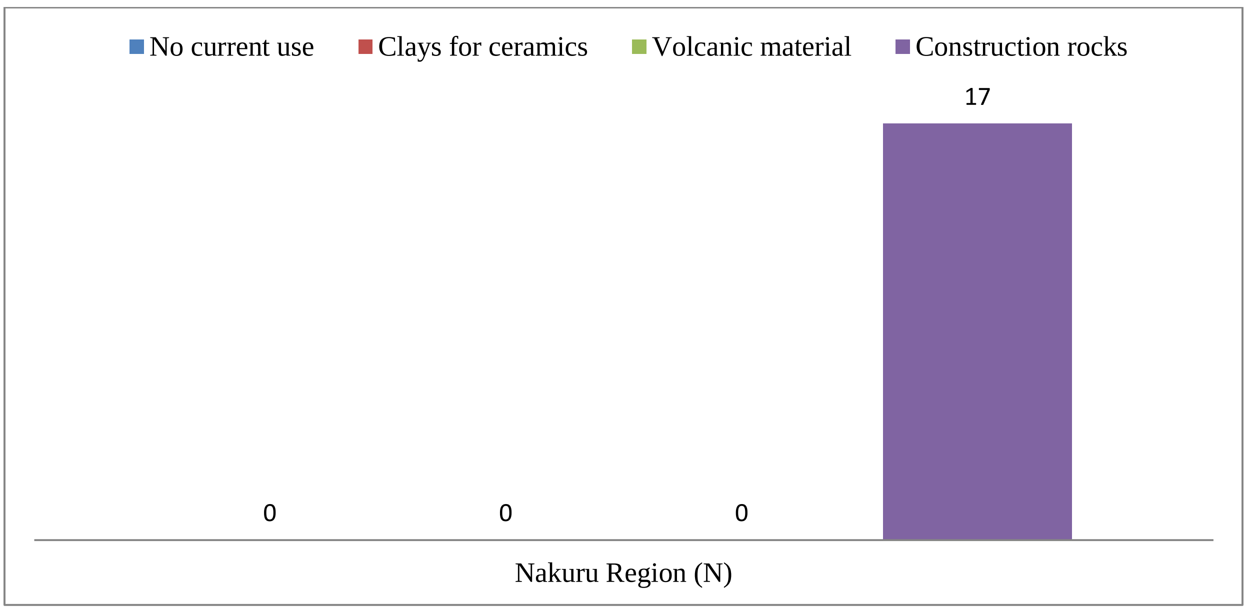

Figure: 4.7. Nature of samples, by local name or use, from Nakuru Region

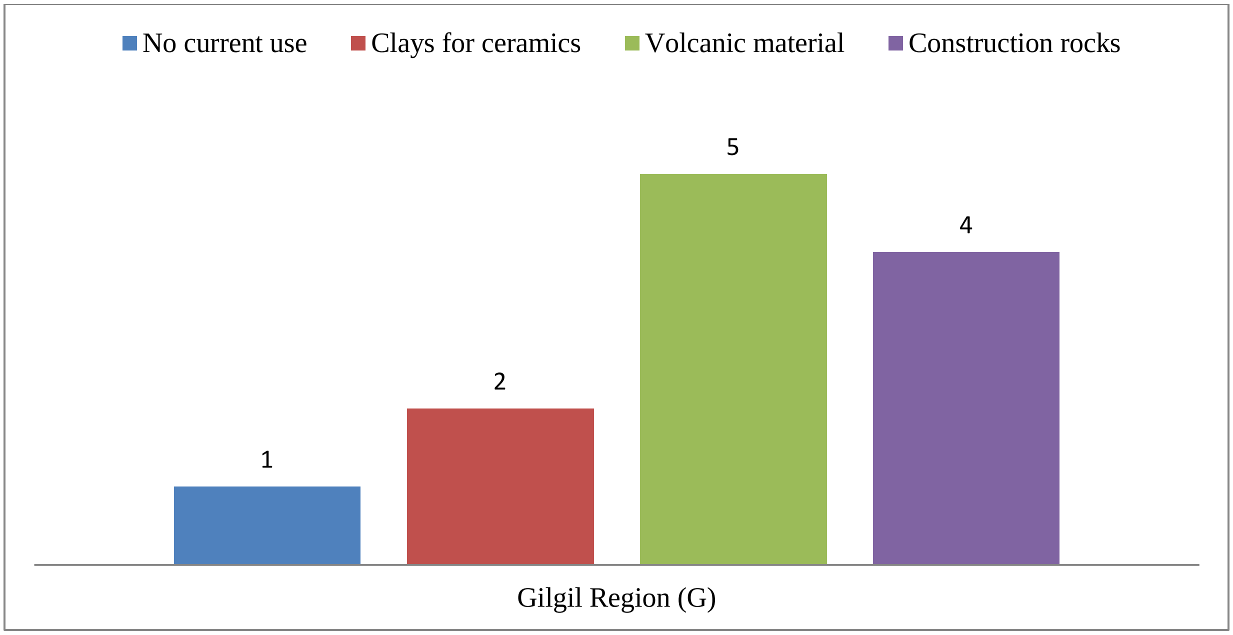

Figure: 4.8. Nature of samples, by local name or use, from Gilgil Region

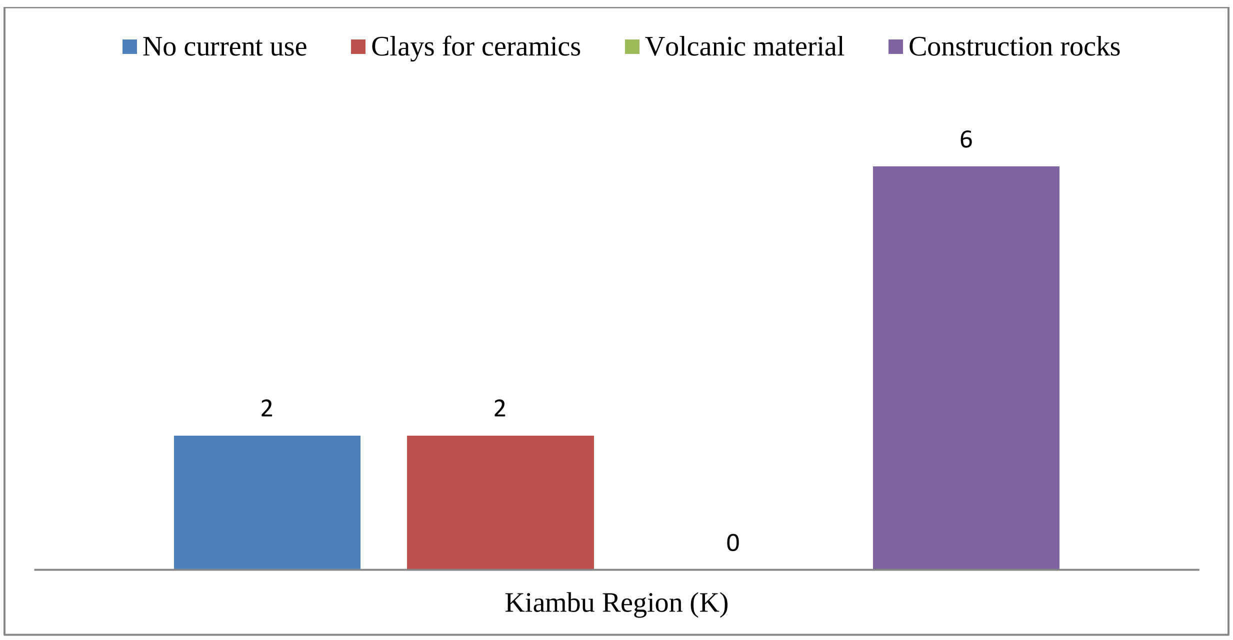

Figure: 4.9. Nature of samples, by local name or use, from Kiambu Region

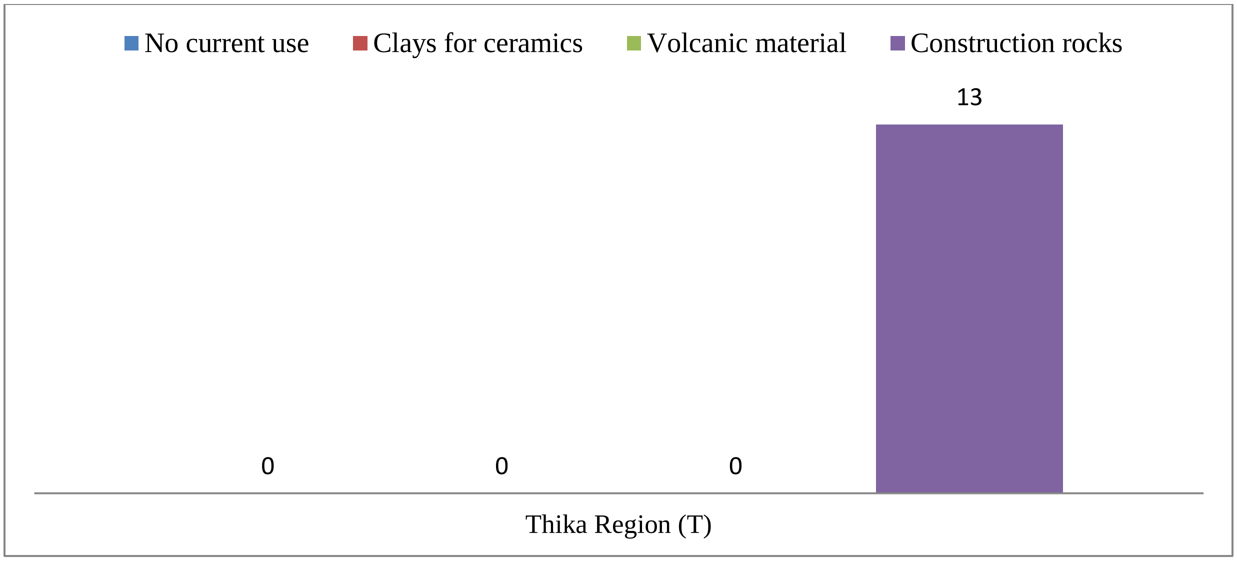

Figure: 4.10. Nature of samples, by local name or use, from Thika region

From the observations of the four regions, Gilgil region seemed to have a wider range of geological material. In comparison, the analysis shows that majority of the samples collected in both Nakuru and Kiambu Counties were used in construction. However a very minimal number was used for ceramics as illustrated.

4.3 Data Presentation and Analysis for Objective 2

The geological samples were collected from the ground and taken to KIRDI for processing in order to acquire a desired microstructure for testing. There were three major machines used in processing samples at KIRDI as listed below:

- **Steel Ball Mill:** Used in breaking down the rock samples (this only applied for hard rock samples in order to reduce them to smaller chunks that could be processed by the porcelain ball mill).
- **Porcelain Ball Mill:** Used in wet milling processing by grinding samples to fine powder desired for glaze formulation.
- **Vibro Sieve:** Used in eliminating particles that were not able to be finely ground during wet milling and getting rid of some iron particles from the sample (containing 120 micro meter mesh).

This machinery is represented in Appendix IX in pictorials. After processing, the granulated samples were brought to the studio for testing and elimination. They then, underwent a primary test firing of 100% granulated raw sample on a 1050^0C low and 1200^0C high temperature in order to select materials with good glaze formulation properties. The information on tests is well represented in Appendix III.

With the help from the data obtained from Appendix III, a rate was determined by observation in appearance of the fired test result and the samples were rated according to compatibility with clay body and aesthetic appearance, using a psychometric observation scale as generated from Mugenda (2008), on likert scale of 1 – 5 as indicated below:

Rating Key:

(1) Excellent (E), (2) Very Good (VG), (3) Good (G), (4) Average (A), (5) Poor (P)

The table below represents an interpretation of appearance and rates. While the chart in the next page represents rates of 104 primary tests of both low and high temperatures.

Table 4.1: Interpretation of appearance and rates

Low temperature Key	**Rate**	**High temperature Key**	**Rate**
Showcases melting behavior at low temperature	1:Excellent	Melts uniformly at high temperature	1:Excellent
Merges well with clay body	2:Very Good	Melts with minor defects	2:Very Good
Bright coloured tone on low temperature	3:Good	Bright coloured tone on high temperature/ Crack effect	3:Good
Shows signs of rejecting the clay body	4:Average	Melts with defects	4:Average
Peels off the clay surface at low temperature	5:Poor	Peels off the clay surface at high temperature	5:Poor

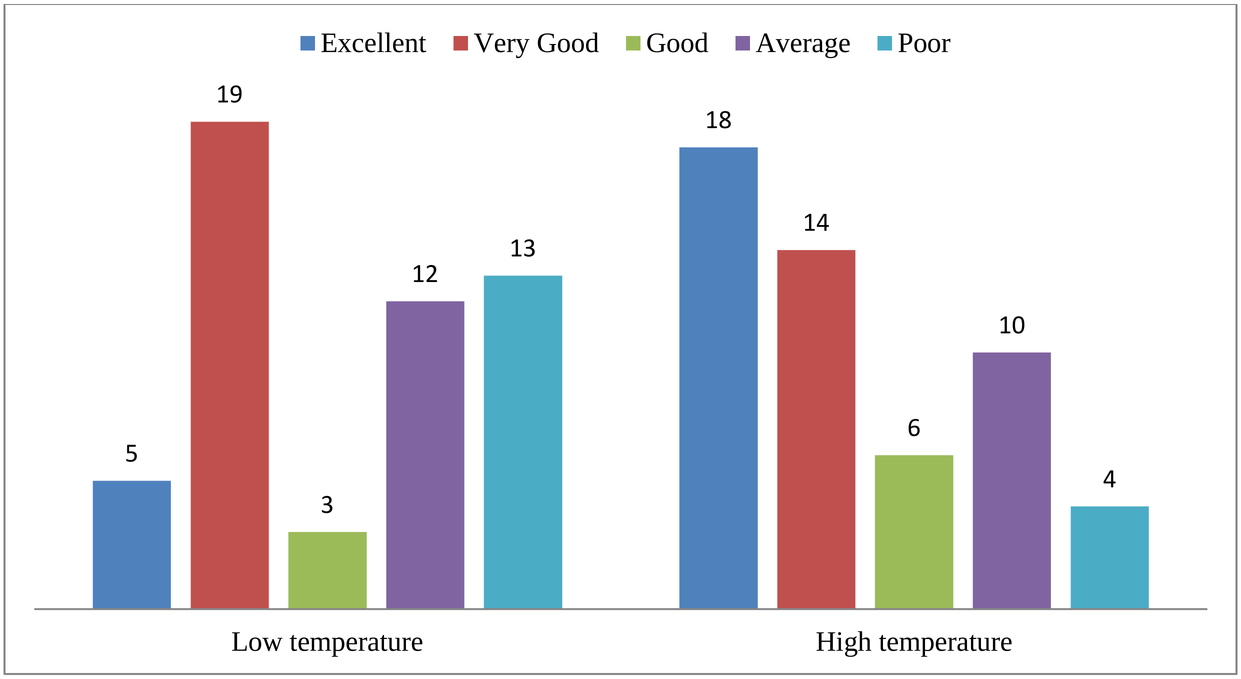

Figure: 4.11. Primary tests analysis (100% granulated sample)

The analysis indicated that most of the samples could be used for glaze formulation. Out of 104 primary tests only 17 samples were rated poor, 13 of which were low temperature and 4 were high temperature. This meant that most samples appeared to be of high temperature. Following the analysis of the above, 18 high temperature glazes were coded "excellent" as they had the potential to be applied on items without formulation. This is because they melted on the test pieces uniformly. 5 samples were also coded "excellent" for low temperature as they showcased melting behavior.

The results of these tests were used in selecting ¼ of the geological samples that proceeded to objective 3, for glaze formulation.

4.4 Data Presentation and Analysis for Objective 3

13 geological samples were selected to proceed to objective three, which was to formulate glaze using selected additives on prospective sample. A decision on elimination was settled based on the outcome of the rate system with a selection of at least one sample from each location. However more samples were selected from Gilgil based on the fact that its samples were diverse in material form as seen in an analysis of geological samples in nature of sample (by local name or use) analysis chart in figure 4.7, 4.8, 4.9 and 4.10. They also created different surface textures in comparison to the rest of the samples.

It was necessary to conduct a qualitative and quantitative chemical analysis on the 13 samples as seen in the table below, in order to understand their chemical composition before proceeding to formulation. The reason for doing the analysis was to guide the researcher in making a decision on what additives to introduce on the compositions. Some glazes required slight adjustments while others required major ones.

A major and important observation that could not go without notice in the chemical analysis was the lack of lead and cadmium in all the 13 samples. This meant that all the samples were safe for table ware and other functional items. The Laboratory tests are represented in the table below and a certificate from the Ministry of mining on the same attached in Appendix XII:

Table 4.2: A list of 13 Laboratory tests from selected samples

Laboratory tests: Atomic Absorption Spectrometer (Spectr AA- 10)

	Ref.	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**TiO_2**	**MnO**	**Fe_2O_3**	**LOI**	**Cd**	**Pb**
i	**AN:MK:4**	52.83	13.32	0.95	0.15	2.88	8.50	0.91	0.08	6.69	13.66	ND	ND
ii	**AN:BM:4**	57.40	15.11	0.96	0.13	8.10	8.70	0.72	0.16	5.98	0.80	ND	ND
iii	**AN:N:6**	54.10	13.41	0.69	0.13	6.76	7.70	0.89	0.19	11.70	4.36	ND	ND
iv	**AG:K:1**	75.31	4.31	0.82	0.27	1.26	1.90	0.19	0.02	3.60	12.50	ND	ND
v	**AG:E:1**	66.58	8.33	0.62	NILL	7.52	7.50	0.30	0.20	6.64	0.29	ND	ND
vi	**AG:E:5**	58.74	11.97	1.01	0.10	2.37	10.0	0.64	0.10	6.33	9.00	ND	ND
vii	**AG:E:6**	65.52	9.51	0.43	NILL	2.05	8.60	0.34	0.10	6.00	7.90	ND	ND
viii	**AG:E:8**	78.04	14.20	0.10	NILL	0.19	0.40	0.14	NILL	0.65	6.56	ND	ND
ix	**AG:M:1**	64.09	11.69	0.52	NILL	6.99	7.80	0.63	0.20	6.62	1.19	ND	ND
x	**BK:KR:5**	51.66	16.60	0.91	0.48	5.93	5.30	0.30	0.20	5.37	4.29	ND	ND
xi	**BK:KU:2**	24.72	13.05	0.18	NILL	0.50	0.97	0.98	3.20	40.50	15.30	ND	ND
xii	**BT:N:4**	64.90	10.52	0.65	0.16	3.00	6.30	0.25	0.20	6.24	6.27	ND	ND
xiii	**BT:U:6**	51.85	13.60	0.67	0.49	7.28	5.80	0.35	0.08	4.74	2.47	ND	ND

Additives for formulation were also selected based on availability as listed below:

Table 4.3: A list of additives used in glaze formulation for this study

Additives		
No.	**Name**	**Category**
1	Silica	Glass former
2	Kaolin	Stabilizer
3	Soda Ash	Flux
4	Feldspar	Flux
5	Granulated glass	Flux
6	Calcium carbonate	Flux
7	Aluminum Oxide	Flux
8	Sodium Carbonate	Flux
9	Sodium Chloride	Flux
10	Magnesium Oxide	Flux
11	Zinc Oxide	Flux
12	Table salt	Flux
13	Building cement	Flux
14	Nyeri Clay	Stabilizer
15	Zinc Oxide	Flux
16	Copper Oxide	Collorant
17	Copper Carbonate	Collorant
18	Magnesium dioxide	Collorant
19	Copper Oxide	Collorant
20	Vanadium Pentoxide	Collorant

The formulation by adding additives was target towards improving the composition of the sample and developing glazes. The additives were sourced from Athi river mining, chemical stores within Nairobi and Chemistry Department, Kenyatta University.

4.5 Data Presentation and Analysis for Objective 4

A range of ceramic ware was agreed upon and glazes were selected for application on items based on the outcome of the tests. Names of glazes were derived from the location of samples as documented in Appendix IV. Some glazes were best suited on functional items or both, while others were purely suitable for decorative items. The selection is illustrated in the table below:

Table 4.4: A list of Ceramic Items used for Application on the Final Project

ITEMS

NO	**GLAZE NAME**	**ITEM**	**NO. OF PIECES**
1	Tembwa Magical	Tea set	14
2	Nyororo Black	Soup bowl set	5
3	Thongo Green	Hand build form	1
		Water jar and tumblers	5
4	Ndusi Mite	Hand build form	1
5	Obsidian	Sugar, tea and coffee pots	8
		Salt and pepper shakers	2
		Jewel pot	1
		Bead work	1
6	Burru ash	Jar	1
		Bead work	2
7	Burru sand	Wine bottle and wine glasses	5
8	Burru white	Flower vase	1
9	Lewa grey	Casserole, plates and side plates	14
10	Rima blue	Hand build form	1
11	KU Metallic	Slab vase	1
12	Rugo blue	Soup bowls	6
		Candle holders	2
13	Gingo Purple	Soup Bowls	6
14	Combinations	Slab work	1
		Bead work	6
		Murals	3
		Decorative piece	1
Total			**86**

Application of glazes was done on both the final project and vertical test. The vertical tests were done in order to verify the test sample before application on the final project and to observe the behavior of glaze on a vertical flow. The application analysis of the 13 selected glazes is listed in an analysis in the next page:

i. **AN:MK:4: Tembwa Magical**

Figure 4.12: Tea Set

Item	**Tea Set**
Finish/Test	Glossy/ 2H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 17 cm x 30 cm, Kettle, 13 cm x 17 cm, Milk pot, 8 cm x 11 cm, Cups, 4 cm x 4 cm, Egg holders
Observation on Vertical test piece	The application gave better results when it was thickly applied
Observation on Tea Set	Application looked good on tea cups. The glaze mixture for the tea cups rested for a week before application. However when the same glaze mixture was used after resting for two hours but mixed with laboratory silica instead on the studio silica gave different results on the Kettle and milk pot.

ii. AN:BM:4: Nyororo Black, Project application

Figure 4.13: Soup bowls

Item	**Soup Bowls**
Finish/Test	Glossy/ 1H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 11 cm x 22 cm, Big bowl and 7 cm x 14 cm
Observation on Vertical test piece	The application gave better results when it was thickly applied
Observation on Soup bowls	Application looked good and the items received glaze proportions that appeared evenly distributed.

iii. (a) AN:N:6: Thongo Green, Project application

Figure 4.14: The Bride

Item	**Hand built form**
Finish/Test	Matt/ 4L Temp, 1050^0C
Application Technique	Airbrush
Use	Decorative
Dimensions	(Height x width) 40 cm x 29 cm
Observation on vertical test piece	The application looked good.
Observation on The bride	Application looked good and the glaze appeared evenly distributed; however on the hand build form developed some cracked effect that looked aesthetically appealing.

(b) AN:N:6: Thongo Green, Project application

Figure 4.15: Jar and Tumblers

Item	**Jar and Tumblers**
Finish/Test	Glossy/ 2H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 15.5 cm x 17 cm, Jar and 9 cm x 8 cm, Tumblers
Observation on Vertical test piece	The application gave better results when it was thickly applied
Observation on Jar and Tumblers	Application looked good and all items appeared to have received good proportions of glaze especially from the outside, but some pieces received too much glaze at the base that looked like bubbles. The remedy is to be careful in application and avoid too much glaze in some areas especially the bottom.

iv. **AG:K:1: Ndusi Mite, Project application**

Figure 4.16: The Passage Gourd

Item	**Hand built form**
Finish/Test	Matt/ 4Lc5 Temp, 1050^0C
Application Technique	Airbrush
Use	Decorative
Dimensions	(Height x width) 18 cm x 22 cm
Observation on Vertical test piece	The application looked good.
Observation on The Passage Gourd	Application looked good but paler in colour with a rougher surface texture than the vertical test piece.

v. (a) AG:E:1: Obsidian, Project application

Figure 4.17: Sugar, Coffee, Tea pots with Salt and Pepper Shakers

Item	**Sugar, Coffee, Tea pots with Salt and Pepper Shakers**
Finish/Test	Glossy/ 3L Temp, 1050^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 15 cm x 14 cm, 13 cm x 12 cm, 10 cm x 9 cm, Sugar, Coffee, Tea pots and 8 cm x 7 cm, 6 cm x 5 cm, Salt and Pepper Shakers
Observation on Vertical test piece	The application looked good, with minor cracks
Observation on Sugar, Coffee, Tea pots with Salt and Pepper Shakers	Application looked good. Appeared to have very minor cracks because it was thinly applied in comparison to the vertical piece.

(b) AG:E:1: Obsidian, Project application

Figure 4.18: Jewel Pot

Item	**Jewel Pot**
Finish/Test	Glossy/ 3Lc1 Temp, 1050^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 14 cm x 17 cm
Observation on Vertical test piece	The application looked good.
Observation on Jewel Pot	Application looked good.

vi. **AG:E:5: Burru Ash, Project application**

Figure 4.19: Jar

Item	**Jar**
Finish/Test	Glossy/ 5H Temp, $1200^{0}C$
Application Technique	Airbrush with drops using brush
Use	Functional
Dimensions	(Height x width) 19 cm x 15 cm
Observation on Vertical test piece	The application looked good.
Observation on Jar	Application looked good, despite the glaze having difficulties in sticking on the clay body

vii. AG:E:6: Burru Sand, Project application

Figure 4.20: Wine Bottle with Wine Glasses

Item	**Wine bottle with Wine Glasses**
Finish/Test	Glossy/ 2H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 19 cm x 12 cm, Wine bottle, 5.5 cm x 5.5 cm, Wine Glasses
Observation on Vertical test piece	The application looked good.
Observation on Wine bottle with Wine Glasses	Application looked good.

viii. AG:E:8: Burru White, Project Application

Figure 4.21: Flower Vase

Item	**Flower Vase**
Finish/Test	Matt/ 7Hc2 Temp, 1200^{0}C
Application Technique	Airbrush
Use	Decorative
Dimensions	(Height x width) 21 cm x 18 cm
Observation on Vertical test piece	The application looked good.
Observation on Flower Vase	Application looked good and stable on both the item and vertical piece. It was also noted that the glaze could be improved on as it appears to have not reached maturity.

ix. AG:M:1: Lewa Grey

Figure 4.22: Plates and Side Plates

Item	**Plates and Side Plates**
Finish/Test	Glossy/ 1H Temp, $1200^{0}C$
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 3 cm x 25 cm, Plate, 2 cm x 18 cm, Side Plate.
Observation on Vertical test piece	The application looked good.
Observation on Plates and Side Plates	Application looked good.

x. BK:KR:5: Rima Blue, Project application

Figure 4.23: The Lady from the North

Item	**Hand built form**
Finish/Test	Textured/ 3M Temp, 1150^0C
Application Technique	Brush
Use	Decorative
Dimensions	(Height x width) 13 cm x 29 cm
Observation on Vertical test piece	The application looked good but had some difference in textures from the horizontal tests.
Observation on The Lady from the North	Application looked good with heavy textures.

xi. BK:KU:2: KU Metallic, Project application

Figure 4.24: Slab Vase

Item	**Slab Vase**
Finish/Test	Textured/ 3H Temp, 1200^{0}C
Application Technique	Brush
Use	Decorative
Dimensions	(Height x width) 31 cm x 15 cm
Observation on Vertical test piece	The application looked good.
Observation on Slab Vase	Application looked good with heavy textures at the bottom due to deliberate thick application.

xii. (a) BT:N:4: Rugo Blue

Figure 4.25: Chinese Bowls

Item	**Chinese Bowls**
Finish/Test	Glossy/ 4H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 8.5 cm x 13 cm, Big Bowl, 6 cm x 9cm, Small Bowl
Observation on Vertical test piece	The application looked good.
Observation on Chinese Bowls	Application looked good and the items received glaze proportions that appeared evenly distributed

(b) BT:N:4: Rugo Blue

Figure 4.26: Candle Holders

Item	**Candle Holders**
Finish/Test	Glossy/ 4H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 10cm x12 cm, Big Holder, 8cm x 10cm, Small Holder
Observation on Vertical test piece	The application looked good.
Observation on Candle Holders	Application looked good and the items received glaze proportions that appeared evenly distributed. However application was thickly applied intentionally and it began to showcase textures that were interesting on decorative items.

xiii. BT:U:6: Gingo Purple, Project Application

Figure 4.27: Soup Bowls

Item	**Soup Bowls**
Finish/Test	Glossy/ 2H Temp, 1200^0C
Application Technique	Airbrush
Use	Functional
Dimensions	(Height x width) 13.5 cm x 18.5 cm, Big Bowl, 7.5 cm x 10.5 cm, Small Bowl
Observation on Vertical test piece	The application looked good when thickly applied.
Observation on Soup Bowls	Application looked good in some bowls and received glaze proportions that appeared evenly distributed. However application on some parts of the bowls appeared to be contaminated.

xiv. (a) **Combinations of Ndusi Mite and Obsidian glazes, Project application**

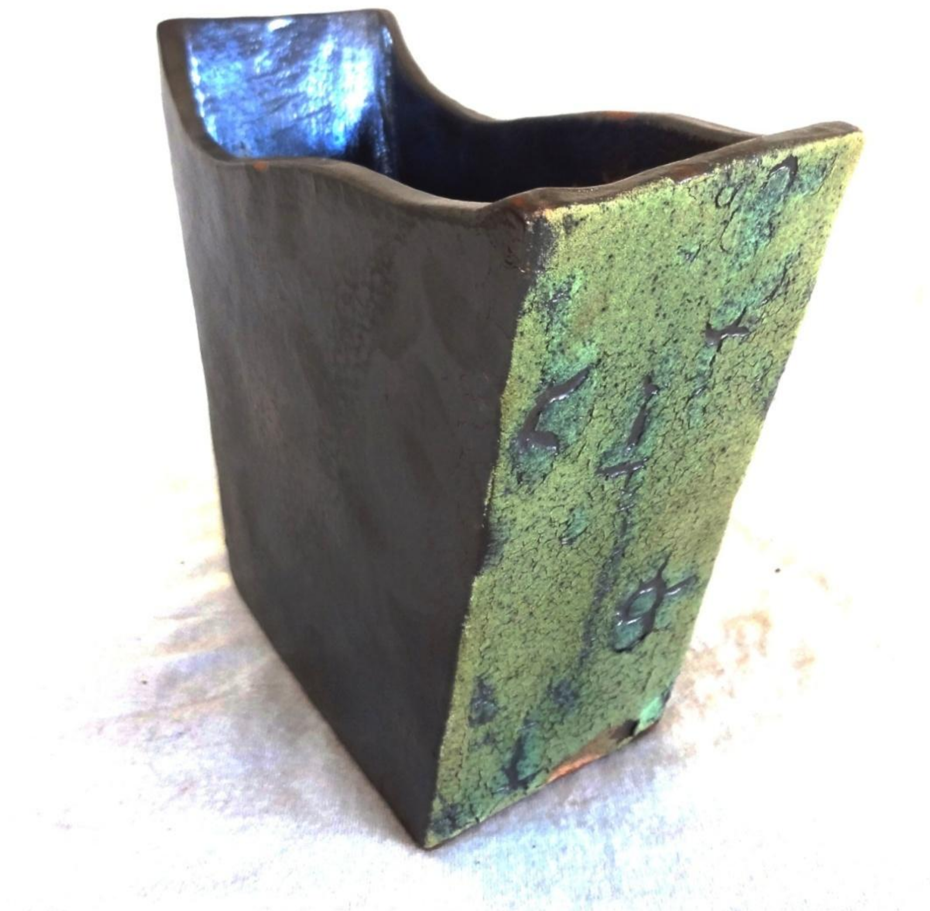

Figure 4.28: Ndusiana

Item	**Slab Work**
Finish/Test	Glossy Textured/ 3Lc1 + 4Lc5 Temp, 1200^0C
Application Technique	Airbrush
Use	Decorative
Dimensions	(Height x width) 20 cm x 23 cm
Observation on Vertical test piece	The application looked good.
Observation on Ndusiana	Application looked aesthetically appealing.

(b) Combinations of Burru White, Ndusi Mite and Rima glazes, Project application

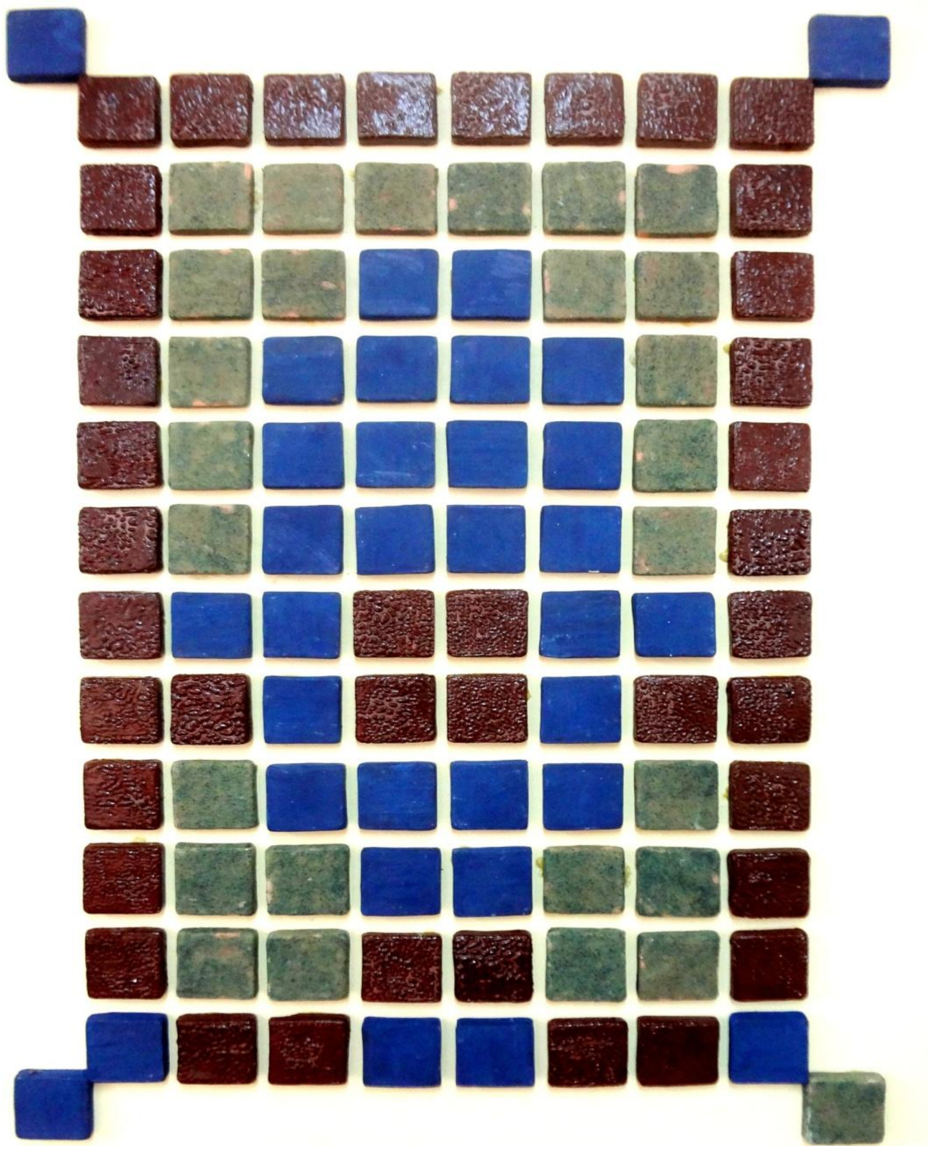

Figure 4.29: Stuart (The One-Eyed Minion)

Item	**Architectural installation**
Finish/Test	Glossy Textured/ Combination of three tests
Application Technique	Brushing
Use	Decorative
Dimensions	(Height x width) 102 cm x 67 cm
Observation on Vertical test piece	The application looked good.
Observation on Stuart (The One-Eyed Minion)	Application looked good.

(c) Combinations of Ndusi Mite and Obsidian glazes, Project application

Figure 4.30: The Talking Jar

Item	**Architectural installation**
Finish/Test	Glossy Textured/ Combination of two tests
Application Technique	Air brush
Use	Decorative
Dimensions	(Height x width) 65 cm x 44 cm
Observation on Vertical test piece	The application looked good.
Observation on The Talking Jar	Application looked good.

(d) Combinations of 3 Obsidian glazes, Project application

Figure 4.31: Historia ya Kenya

Item	**Architectural installation**
Finish/Test	Glossy/ Combination of 3 Obsidian tests
Application Technique	Air brush
Use	Decorative
Dimensions	(Height x width) 52 cm x 101 cm
Observation on Vertical test piece	The application looked good.
Observation on Historia ya Kenya	Application looked good.

(e) Combinations of Tenmbwa Magical, Rima Blue and KU Metallic glazes, Project application

Figure 4.32: Decorative Piece

Item	**Architectural installation**
Finish/Test	Glossy Textured/ Combination of three glazes
Application Technique	Air brush
Use	Decorative
Dimensions	(Height x width) 65 cm x 47 cm
Observation on Vertical test piece	The application looked good.
Observation on Decorative Piece	Application looked good.

(f) Combinations of glazes, Project application

Figure 4.33: Beadwork

Item	**Beadwork**
Finish/Test	Glossy/ Combination of tests
Application Technique	Air brush and Brushing
Use	Decorative
Dimensions	Assorted
Observation on Vertical test piece	The application looked good.
Observation on Beadwork	Application looked good.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter contains a summary of interpretation and discussion of findings, conclusions and recommendations based on the data analysis from the study objectives discussed in Chapter 4.

5.2 Summary of Interpretation and Discussion of Findings

The summary of interpretation and discussion of findings is discussed in two sections, in 5.2.1 for geological materials for glaze formulation and section 5.2.2 for testing and application.

5.2.1 Interpretation and Discussion of Findings for Geological Materials used in Glaze Formulation

Given the historic geology and mineral potential of Kenya, the uniqueness of the Great Rift Valley and its formation of lavas among others, has given forth a rich geology for glaze formulation. From the data represented in Chapter 4 it is evident that the geological materials have a diversity of aesthetic surfaces for potters within Kenya and East Africa as seen in Chapter 4 section 4.5. East African Rift System (EARS) being one of the geologic wonders of the world can be a great gift to ceramists within the region. For instance when collecting data at Kariandusi prehistoric site it was important to note that some of the lava rocks that this study used for glaze formulation were made and used as tools by Homo erectus as seen in the images below.

Fig 5.1: Kariandusi Prehistoric Handaxes, made and used by Homo erectus.

Source: Kariandusi Prehistoric Site

These resources that the early man used as tools can now be meaningful raw materials that can be used in glaze formulation for ceramics in Kenya. If more research can be injected in the art of surface decoration for pottery in Kenya and Africa the possibilities are unlimited.

Another data analysis in Chapter 4 section 4.3 points out that majority of the rocks mined in Nakuru and Kiambu Counties were used in house and road construction, they gave desirable results and some of them were used in application. This means that Potters can explore such sites that are within their area of operation and use such rocks in glaze formulation. These rocks are available at very low costs, they are considered affordable, accessible and plentiful because of the nature of the work they are mined for.

Other geological materials that are not necessarily construction stones can also be explored by potters. The geological map of Kenya in Appendix I, has documented different kinds of geological materials in other parts of Kenya that can be explored and researched on. The Western, Eastern, North Central, North Western, North Eastern and Coastal parts of Kenya have a wide variety of geological materials, some of similar structure and other different types that can be explored for glaze formulation.

5.2.2 Interpretation and Discussion of Findings for Testing and Application

The analysis on testing was very impressive, especially on small test pieces. Majority of them looked excellent for application on the first and second test and appeared not to require much in terms of formulation as observed in Appendix IV.

The vertical tests were done to assist in understanding the flow of the glaze on a vertical flow. These tests were to assist in verifying the glaze test before applying them on the main project. A few observations were made on the vertical pieces as indicated in Chapter 4 section 4.5 application analysis and majority of the observation was in adjusting the thickness in application which was corrected on the main project. Otherwise all the vertical tests received glazes well and gave desirable results.

The safety of glazes before application on the project was also catered for; the chemical test as seen in chemical analysis in Chapter 4 section 4.4 confirmed the safety of the geological material especially for table ware.

Another notable finding was on application of items. Some item gave unexpected results. However in glaze application, there are many factors that can trigger changes as discussed in Chapter 2, literature review. Very minor contaminations can completely change the outcome of the glaze. Tembwa Magical: a glaze from Kaptembwa quarry, for example in Chapter 4, figure 4.12 applications, had an instance where two batches of glaze were mixed of the same recipe. The first one used the studio silica in preparation and rested for one week before application while the second one used laboratory silica in preparation and rested for only two hours before application. The outcome of the glaze formulation in the same firing environment gave totally different results on the application of the Kettle and milk pot from the tea cups as documented. The same case scenario was repeated on Lewa Grey: a glaze from Malewa quarry using plates and side plates, figure 4.22 but nothing of the sort happened.

Glazes are therefore full of uncertainties and in some cases, like the one of Tembwa Magical, might give results that can never be achieved a second time. In such cases, concrete outcomes can only be arrived at after several other tests have been conducted.

Other minor observations were on excessive glazing (too much glaze) especially at the base of some items like the tumblers in application and glaze defects in a few cases. In glazing such is bound to happen but can be avoided if the ceramist has prior knowledge on the behavior of the glaze.

5.3 Conclusions

This study was majorly interested in the visual aspect of glaze formulation in terms of appearance, in either functional finishing or aesthetic decoration. In view of providing local formulations that can be used locally.

The study set out to:

- Step 1: Identify geological materials for glaze formulation from Nakuru and Kiambu Counties; it identified a total of 52 geological samples.
- Step 2: Conduct test firings on the 52 geological samples for glaze formulation properties and select the desired ones; 104 tests of low and high temperature were rated and ¼ was selected for formulation.

Step 3: Formulate glaze using selected additives on prospective samples. Here 145 tests were conducted and most formulations looked good for application, especial the high temperature. However only one in some cases two formulations was selected from each glaze for application.

Step 4: Apply successful glazes on a creative project. This gave desirable results and was applied based on the functionality of the ceramic ware.

The steps above enabled the researcher to develop a variety of glaze formulations using geological samples from Nakuru and Kiambu County, with at least one glaze formulation being picked for application.

Using geological materials that are within their reach, ceramists can therefore collect, and by using a mortar and pestle or a studio grinder, grind and sieve using mesh 100, test and or formulate glaze recipes for surface decoration in small quantities. However manufactures can also process and package locally these geological materials for ceramic artists.

Indeed the study showcases that our local resources are sufficient for ceramic production. A lot of research however needs to be done to refine these materials, for them to be of benefit to Kenya.

5.4 Recommendations

Research in knowledge is a continual process that will never have an end. Therefore, the researcher has some recommendations for ceramists, ceramic manufactures and further recommendation for improving on the study. But in addition to that, the researcher would like to point out some limitations in this research. Time and finances were considered an impediment in exploring more possibilities.

i. Recommendations for Ceramists

The glaze recipes developed within this study have been formulated to assist ceramic artists in Kenya to formulate local glazes. If they desire glaze recipes that are uniquely Kenyan, then they can collect and make use of the compositions formulated in this study to prepare studio glazes for their ceramic ware. However, ceramists can also collect geological materials that are within their environs and formulate their own glaze recipes for surface decoration in small quantities.

They can also improve on these recipes to suite their taste. Nonetheless, their possibilities of glaze range for local formulations are not at all limited to the geological material and glaze compositions for this study.

ii. Recommendations for Ceramic Manufactures

On the same note ceramic manufactures can also process and package locally these geological materials for ceramic artists or more so use them in large scale production of ceramic ware. If ceramic manufactures were to be involved in processing these materials, then production of ceramic ware can be made easy for ceramicists locally and perhaps ceramic innovation in Kenya can begin to disentangle. Consequently, Ceramic manufacturing in Kenya can also be taken a notch higher with further research in the field. This study among has therefore revealed the availability of raw materials for local ceramic production. More production of ceramic material and ware by local ceramic manufactures will lead more job opportunities for Kenyans at large.

iii. Recommendations for improving on the study

An improvement of the study by other researchers could also generate other greater possibilities. Artistically, further research can be done on widening the colour ranges and textural effects. Alterations of recipes and different firing environments are among the adjustments that can be made to improve on the compositions for this study. Scientifically extractions of elements like iron among others can be made by chemists to change or improve on the geological materials. Further research in glaze formulation using geological materials from Kenya can be done in other areas of Kenya as Nakuru and Kiambu counties were only a case study for this research.

5.5 Areas of Further Research

This study covered glaze formulations using geological materials from Nakuru and Kiambu County. It was not within its scope to explore geological materials from other counties. It was also not expected to study colour possibilities, surface textures, and combinations with clay bodies.

The researcher therefore recommends that further research be carried out on:

1) Glaze formulations on geological materials from other counties in Kenya. The Western, Eastern, North Central, North Western, North Eastern and Coastal parts of Kenya have a variety of geological materials that are not necessarily of the same structure as the ones from Nakuru and Kiambu counties that can be looked into.
2) Glaze formulation on other material from Nakuru and Kiambu counties that this research might not have covered due to limitation of time, money.
3) Colour possibilities and colour ranges that can be achieved from certain recipes; for instance a research can pick one recipe and explore the possibilities of colour in the recipe, they could further extract elements of colour from the recipe and introduce new elements of colour in the same recipe to derive varieties from the sample.
4) Surface texture is another area that can be researched on. Modifying recipes and introducing other elements could be explored with intentions of developing different surface textures.
5) Combinations with clay bodies' is also another area that can be researched on. This can be done either by mixing the glaze recipes in clay slurry, that can be referred to as terra sigilata and using them to burnish leather hard pots or by mixing the glaze materials with clays as practices by Egyptians and discussed in Chapter 1 section 1.1 and, even further introducing modern technology like 3D printing in prototyping ceramic ware using the paste.
6) Firing of glaze formulations in different environments is also a viable area that this research did not look at that can also be explored.

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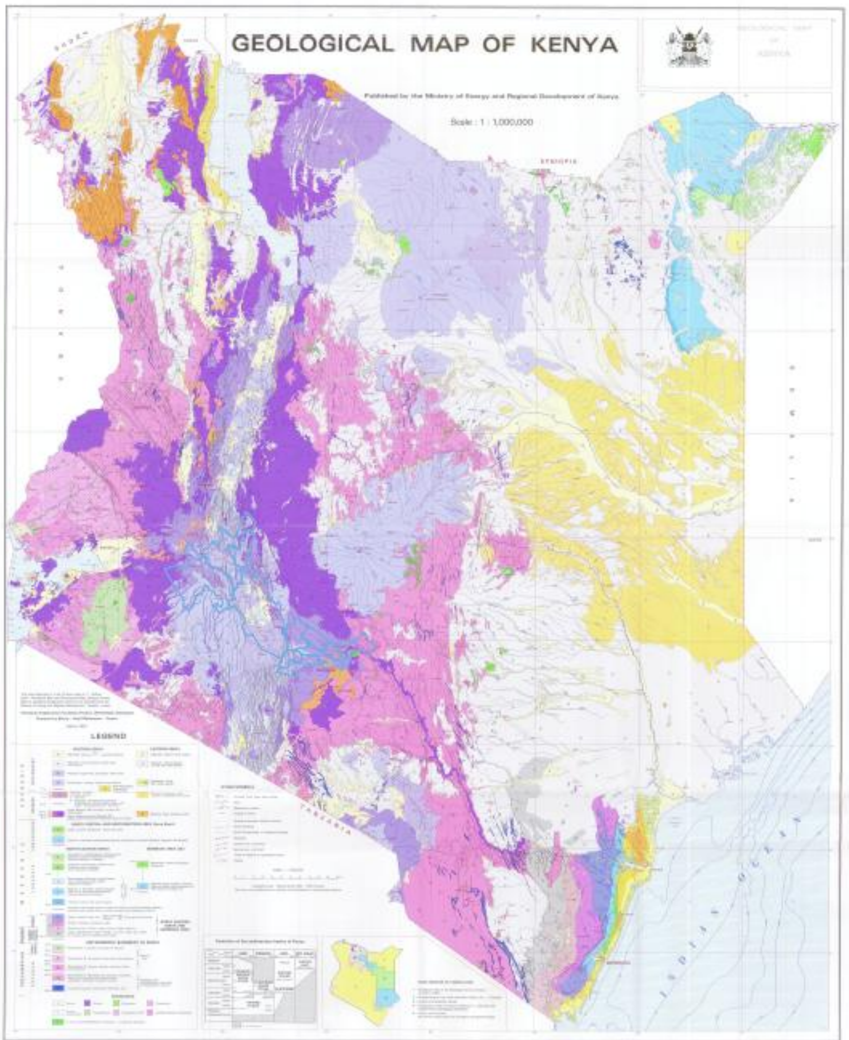
APPENDICES

Appendix I: Geological Map of Kenya and Study Area



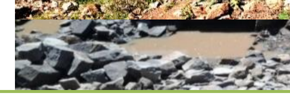
Nakuru and Kiambu Counties

Appendix II: Data Collected when Identifying Geological Samples

The data below was collected from Nakuru and Kiambu Counties. It contains a map of the location where the sample was collected from with a table that contains sample code (SC), local name or use (LN/U), colour in raw state (CRS), physical properties (PP) and appearance in raw state (ARS). The data was recorded by observation using observation tables as listed below:

i. Data obtained from Nakuru County, Nakuru region, Mau/Kedowa area

Satellite Map of the location

Location	S C	LN/U	CRS	PP	RS
Mau/Kedowa, Kiptenden Quarry	**AN:MK:1**	Construction stone	Green Stone	Hard rock	
Mau/Kedowa, Kiptenden Quarry	**AN:MK:2**	Construction stone	Black Stone	Hard Rock	
Mau/Kedowa, Kapsenda Quarry	**AN:MK:3**	Construction stone	Grey Stone	Hard rock	
Mau/Kedowa, Kaptembwa Quarry	**AN:MK:4**	Construction stone	Yellow Stone	Medium Hard rock	
Mau/Kedowa, Jarogoror Quarry	**AN:MK:5**	Construction stone	White Stone	Medium Hard Rock	
Mau/Kedowa, Kabao Quarry	**AN:MK:6**	Construction stone	Red Stone	Hard rock	
Mau/Kedowa, Kabao Quarry	**AN:MK:7**	Construction stone	Black Stone	Hard Rock	

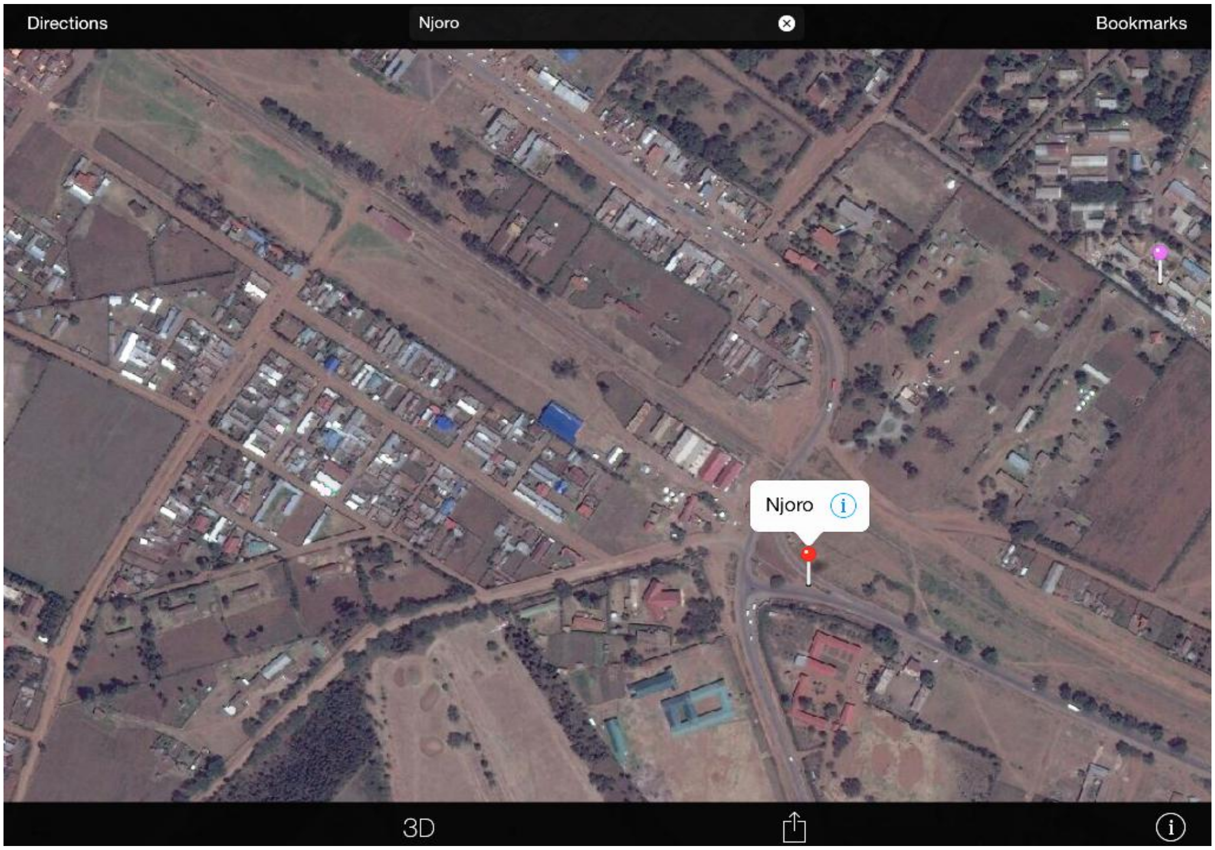
ii. Data obtained from Nakuru County, Nakuru region, Bahati/Menengai area

Satellite Map of the location

Location	S C	LN/U	CRS	PP	RS
Bahati/Menengai Creator, Wanyororo B	**AN:BM:1**	Construction stone	Light Grey	Medium Hard Rock	
Bahati/Menengai Creator, Wanyororo B	**AN:BM:2**	Construction stone	Brown Stone	Medium hard rock	
Bahati/Menengai Creator, Wanyororo B	**AN:BM:3**	Construction stone	Red Stone	Medium hard rock with shinny pebbles	
Bahati/Menengai Creator, Wanyororo B	**AN:BM:4**	Construction stone	Black Stone	Very light medium hard rock that feels like coal	

iii. Data obtained from Nakuru County, Nakuru region, Njoro area

Satellite Map of the location



Location	S C	LN/U	CRS	PP	RS
Njoro, Naishi, Kona Mbaya Quarry	**AN:N:1**	Construction stone	Green Stone	Hard Rock with tiny black markings	
Njoro, Naishi, Kona Mbaya Quarry	**AN:N:2**	Construction stone	Grey Stone	Hard Rock	
Njoro, Naishi, Kona Mbaya Quarry	**AN:N:3**	Construction stone	Black Stone	Hard Rock	
Njoro, Lamudiac Quarry	**AN:N:4**	Construction stone	Yellow Stone	Medium Hard Rock	
Njoro, Mithongo Quarry	**AN:N:5**	Construction stone	Dark Grey	Hard Rock	
Njoro, Mithongo Quarry	**AN:N:6**	Construction stone	Light Green	Hard rock with tiny black markings	

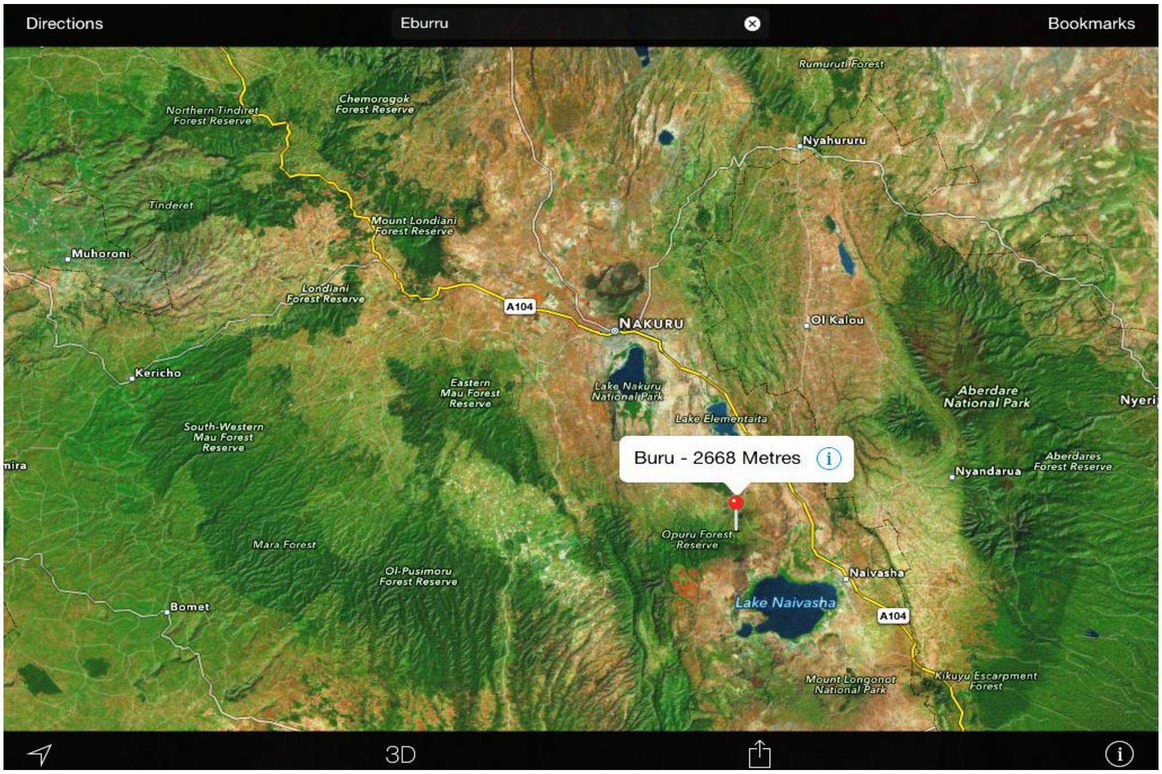
iv. Data obtained from Nakuru County, Gilgil region, Kariandusi area

Satellite Map of the location

Location	S C	LN/U	CRS	PP	RS
Kariandusi, Prehistoric Site	**AG:K:1**	Diatomite	White	Very Soft Rock	
Kariandusi, Prehistoric Site	**AG:K:2**	Construction stone	Grey	Soft rock with condensed sand like particles	

v. Data obtained from Nakuru County, Gilgil region, Eburru area

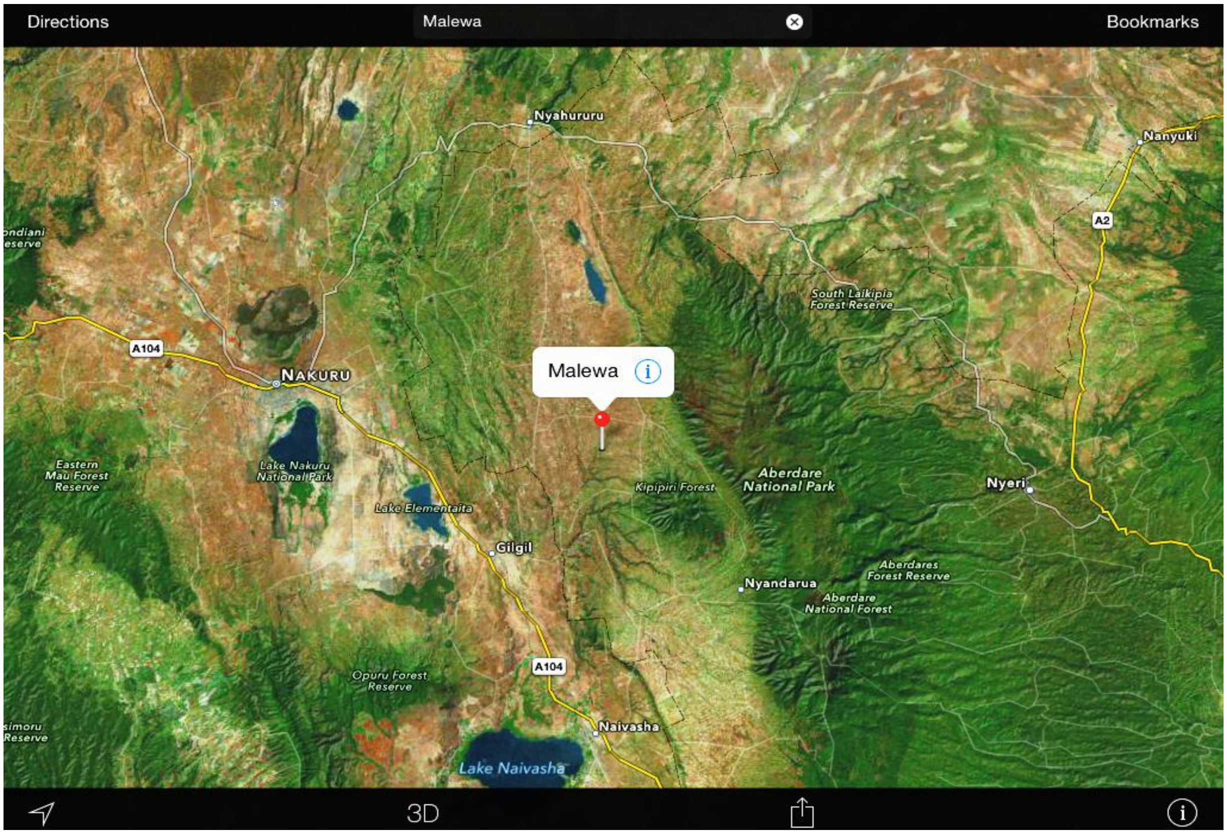
Satellite Map of the location



Location	S C	LN/U	CRS	PP	RS
Eburru, Kamathatha Pipeline No 136	**AG:E:1**	Obsidian Rock	Shiny Black	Glass like hard rock	
Eburru, Kamathatha Pipeline No 136	**AG:E:2**	Pumice	Grey	Very light soft rock with pores	
Eburru, Kamathatha Site A Quarry	**AG:E:3**	Construction stone	Orche Yellow	Medium Hard Rock	
Eburru, Kamathatha Site A Quarry	**AG:E:4**	Construction stone	Black	Medium Hard Rock	
Eburru, Kamathatha Site B Quarry	**AG:E:5**	Volcanic Ash	Dark Grey	Ash like	
Eburru, Kamathatha Site B Quarry	**AG:E:6**	Volcanic Sand	Pale Grey	Sand like	
Eburru, Kamathatha Site B Quarry	**AG:E:7**	No current use	Light Grey	Medium Hard Rock with a white coating	
Eburru, Kwa Mzungu	**AG:E:8**	Kaolin	White	Medium Hard Rock	
Eburru, Kwa Mzungu	**AG:E:9**	Fire Clay	Red & White	Hard Rock	

vi. Data obtained from Nakuru County, Gilgil region, Malewa area

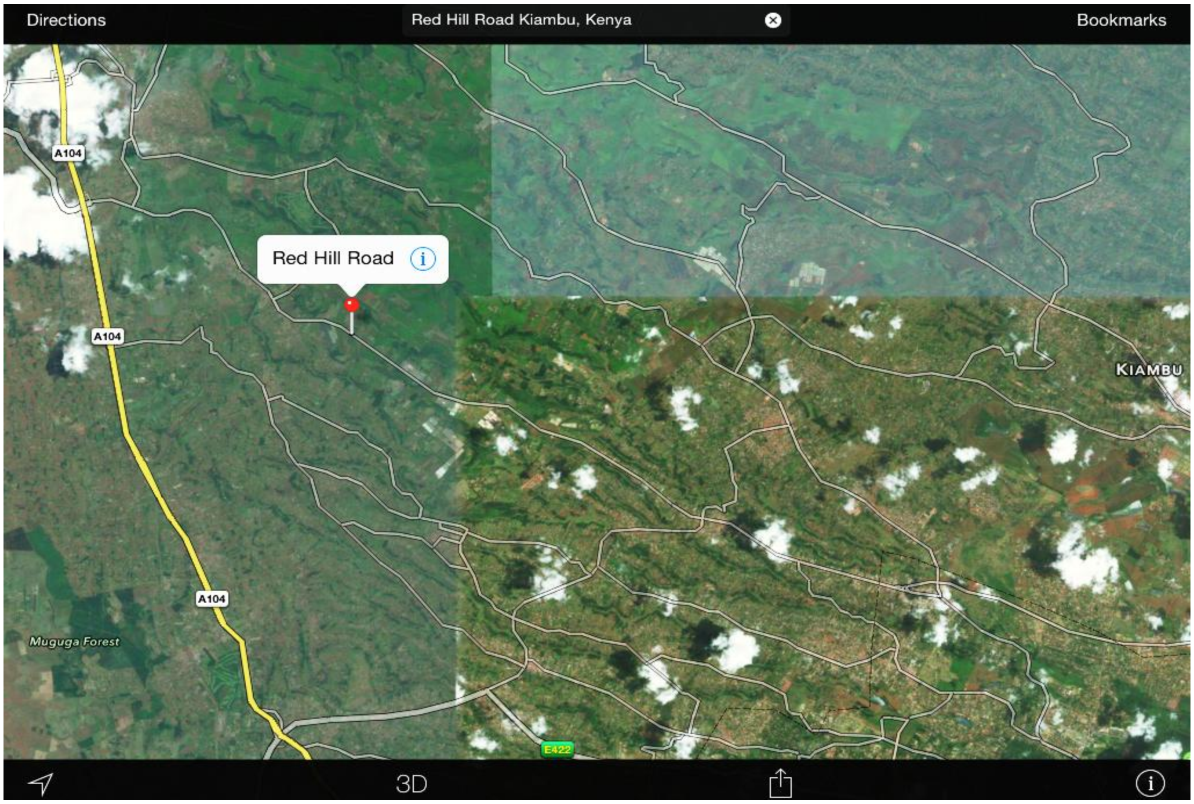
Satellite Map of the location



Location	S C	LN/U	CRS	PP	RS
Malewa, Kamatira , Gilgil Nyahururu Road	**AG:M:1**	Construction stone	Grey	Hard Rock with sand pebbles	

vii. Data obtained from Kiambu County, Kiambu region, Kiambu road area

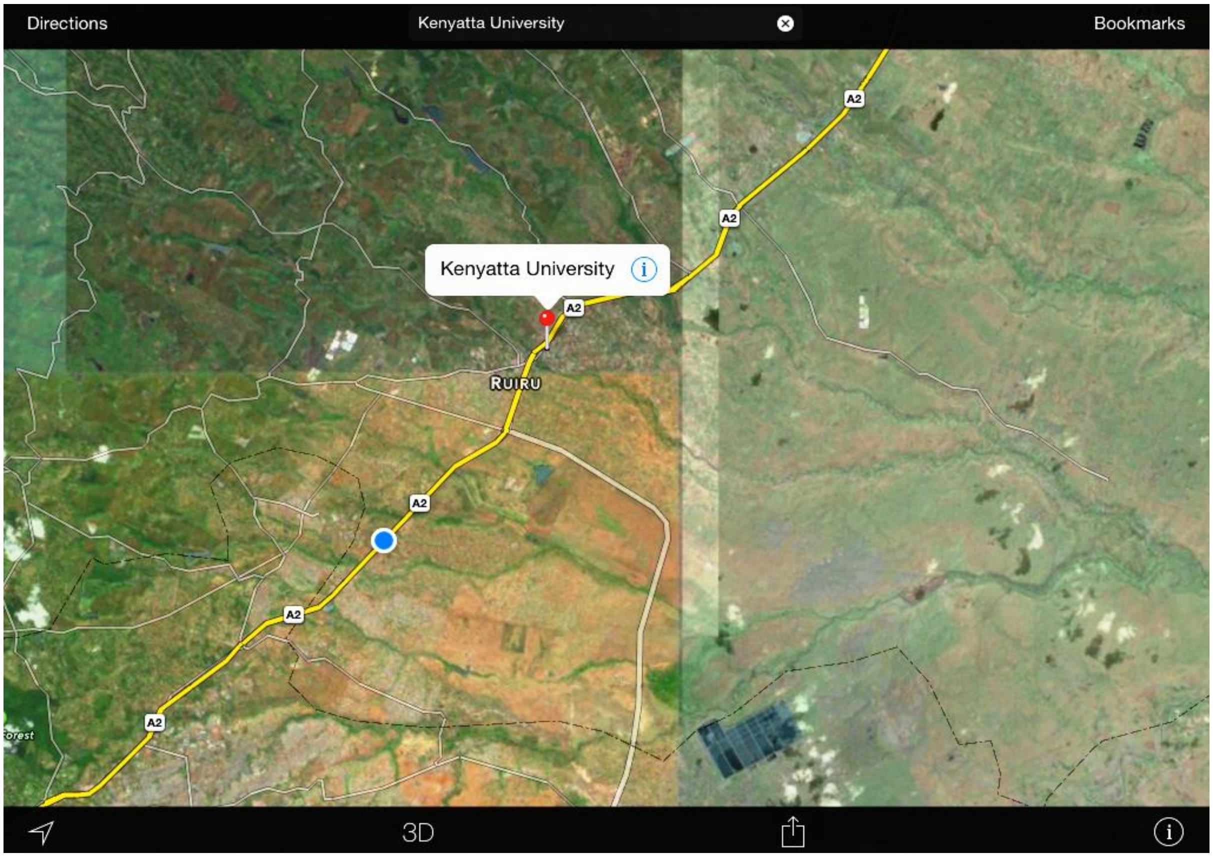
Satellite Map of the location



Location	S C	LN/U	CRS	PP	RS
Kiambu Road, Ruaka/Redhill	**BK:KR:1**	Construction stone	Deep Red	Condensed red soil	
Kiambu Road, Mirima Quarry	**BK:KR:2**	Construction stone	Brown	Medium Hard Rock	
Kiambu Road, Mirima Quarry	**BK:KR:3**	Construction stone	Dark Grey	Medium Hard Rock	
Kiambu Road, Mirima Quarry	**BK:KR:4**	Construction stone	Purple Brownish	Medium Hard Rock	
Kiambu Road, Mirima Quarry	**BK:KR:5**	Construction stone	Blue	Very Hard Rock	
Kiambu Road, Mirima Quarry	**BK:KR:6**	Construction stone	Dark Red	Medium Hard Rock	

viii. Data obtained from Kiambu County, Kiambu region, Kenyatta University and Clay works area

Satellite Map of the location



Location	S C	LN/U	CRS	PP	RS
Kenyatta University, School of Engineering	**BK:KU:1**	No current use	Greenish grey	Medium hard rock	
Kenyatta University, School of Engineering	**BK:KU:2**	Murram	Brown and black	Hard Murram	
Clay works, Thika Road	**BK:CW:1**	Clay cotton soil	Black	Cotton soil	
Clay works, Thika Road	**BK:CW:2**	Clay cotton soil	Yellowish	Cotton soil	

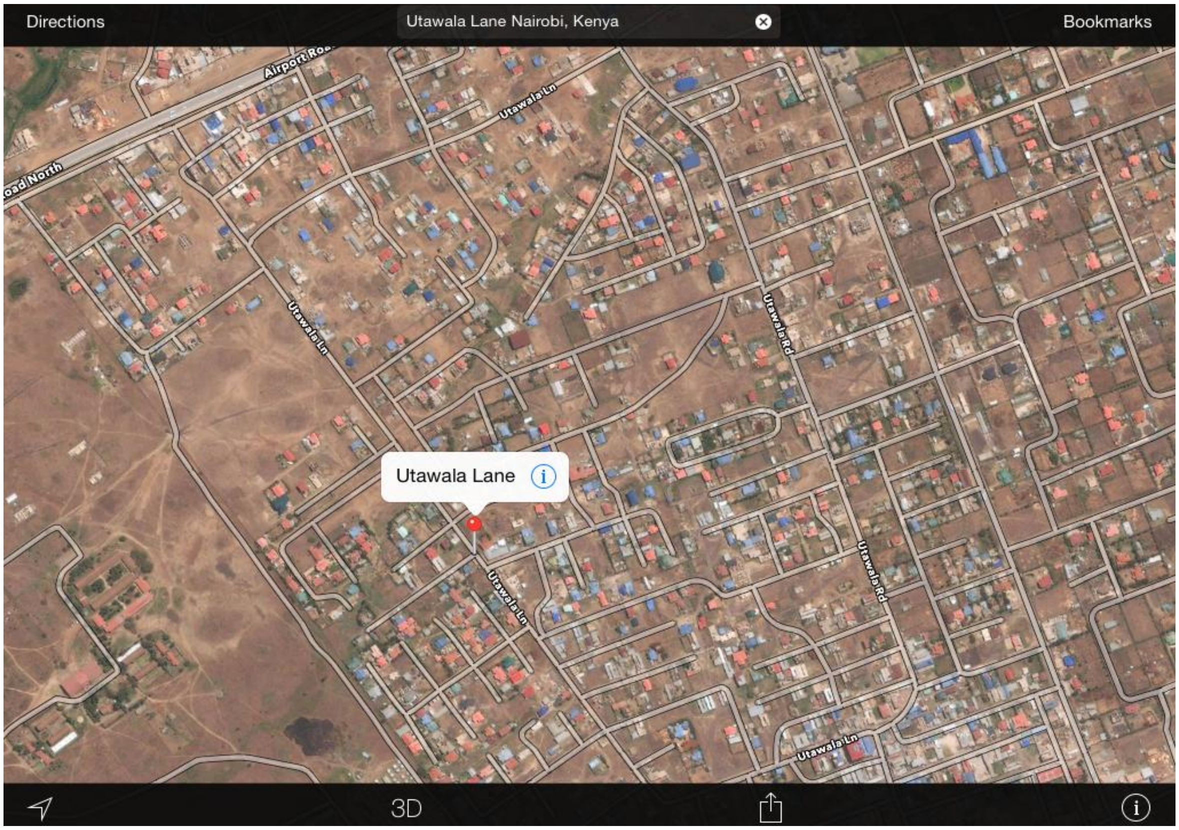
ix. Data obtained from Kiambu County, Thika region, Ndarugo area

Satellite Map of the location

Location	S C	LN/U	CRS	PP	RS
Thika, Ndarugo, Seven Star Quarry	**BT:N:1**	Construction stone	Brown Stone	Medium hard rock	
Thika, Ndarugo, Niesta Quarry	**BT:N:2**	Construction stone	Khaki Stone	Medium hard rock	
Thika, Ndarugo, Break Stone Quarry	**BT:N:3**	Construction stone	White Stone	Medium Hard rock	
Thika, Ndarugo, Nature Stone Quarry	**BT:N:4**	Construction stone	Blue Stone	Medium hard rock	
Thika, Ndarugo, Site A Quarry	**BT:N:5**	Construction stone	Grey Stone	Medium hard rock	

x. Data obtained from Kiambu County, Thika region, Utawala Bypass area

Satellite Map of the location



Location	S C	LN/U	CRS	PP	RS
Utawala Bypass, Migingo Quarry	**BT:U:1**	Construction stone	White	Soft Rock	
Utawala Bypass, Migingo Quarry	**BT:U:2**	Construction stone	Grey	Hard Rock	
Utawala Bypass, Migingo Quarry	**BT:U:3**	Construction stone	Pale Grey	Hard Rock	
Utawala Bypass, Migingo Quarry	**BT:U:4**	Construction stone	Light green	Hard Rock	
Utawala Bypass, Migingo Quarry	**BT:U:5**	Construction stone	Green	Soft Rock	
Utawala Bypass, Migingo Quarry	**BT:U:6**	Construction stone	Purple	Very Hard Rock	
Utawala Bypass, Migingo Quarry	**BT:U:7**	Construction stone	White	Very Hard Rock	
Utawala Bypass, Migingo Quarry	**BT:U:8**	Construction stone	Green, grey and yellow	condensed sand particles	

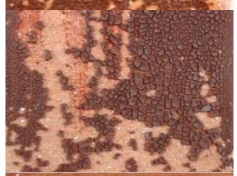
Appendix III: Data Collected from 104 Primary Glaze Tests of Low and High Temperature

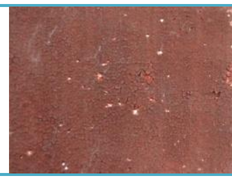
Primary test of 100% granulated sample						
Sample No	1050^0C: Low Temperature			1200^0C: High Temperature		
	Observation	**Appearance**	**Rate**	**Observation**	**Appearance**	**Rate**
AN:MK:1	Showcases melting behavior at low temperature		1	Melts with defects		4
AN:MK:2	Peels off the clay surface at low temperature		5	Melts with defects		4
AN:MK:3	Peels off the clay surface at low temperature		5	Melts uniformly at high temperature		1
AN:MK:4	Merges well with clay body		2	Melts uniformly at high temperature		1
AN:MK:5	Merges well with clay body		2	Melts with minor defects		2
AN:MK:6	Peels off the clay surface at low temperature		5	Peels off the clay surface at high temperature		5
AN:MK:7	Shows signs of rejecting the clay body		4	Melts with minor defects		2
AN:BM:1	Merges well with clay body		2	Melts with minor defects		2
AN:BM:2	Merges well with clay body		2	Melts with minor defects		2
AN:BM:3	Merges well with clay body		2	Melts uniformly at high temperature		1

AN:BM:4	Merges well with clay body		2	Melts with minor defects		2
AN:N:1	Merges well with clay body		2	Melts with minor defects		2
AN:N:2	Shows signs of rejecting the clay body		4	Melts with defects		4
AN:N:3	Shows signs of rejecting the clay body		4	Melts with defects		4
AN:N:4	Shows signs of rejecting the clay body		4	Melts with minor defects		2
AN:N:5	Shows signs of rejecting the clay body		4	Melts with defects		4
AN:N:6	Merges well with clay body		2	Melts uniformly at high temperature		1
AG:K:1	Bright coloured tone on low temperature		3	Bright coloured tone on high temperature		3
AG:K:2	Merges well with clay body		2	Melts uniformly at high temperature		1
AG:E:1	Showcases melting behavior at low temperature		1	Melts with defects		4

AG:E:2	Showcases melting behavior at low temperature		1	Melts with minor defects		2
AG:E:3	Shows signs of rejecting the clay body		4	Melts uniformly at high temperature		1
AG:E:4	Merges well with clay body		2	Melts uniformly at high temperature		1
AG:E:5	Shows signs of rejecting the clay body		4	Melts uniformly at high temperature		1
AG:E:6	Merges well with clay body		2	Melts uniformly at high temperature		1
AG:E:7	Showcases melting behavior at low temperature		1	Melts uniformly at high temperature		1
AG:E:8	Bright coloured tone on low temperature		3	Bright coloured tone on high temperature		3
AG:E:9	Bright coloured tone on low temperature		3	Bright coloured tone on high temperature		3
AG:M:1	Showcases melting behavior at low temperature		1	Melts uniformly at high temperature		1
BK:KR:1	Peels off the clay surface at low temperature		5	Peels off the clay surface at high temperature		5

BK:KR:2	Shows signs of rejecting the clay body		4	Melts uniformly at high temperature		5
BK:KR:3	Shows signs of rejecting the clay body		4	Melts with minor defects		2
BK:KR:4	Peels off the clay surface at low temperature		5	Melts with minor defects		2
BK:KR:5	Shows signs of rejecting the clay body		4	Melts with minor defects		2
BK:KR:6	Shows signs of rejecting the clay body		4	Melts uniformly at high temperature		1
BK:KU:1	Peels off the clay surface at low temperature		5	Crack effect		3
BK:KU:2	Peels off the clay surface at low temperature		5	Crack effect		3
BK:CW:1	Peels off the clay surface at low temperature		5	Peels off the clay surface at high temperature		5
BK:CW:2	Peels off the clay surface at low temperature		5	Peels off the clay surface at high temperature		5
BT:N:1	Merges well with clay body		2	Melts uniformly at high temperature		1
BT:N:2	Merges well with clay body		2	Melts uniformly at high temperature		1

BT:N:3	Shows signs of rejecting the clay body		4	Melts with minor defects		2
BT:N:4	Merges well with clay body		2	Melts uniformly at high temperature		1
BT:N:5	Merges well with clay body		2	Melts uniformly at high temperature		1
BT:U:1	Peels off the clay surface at low temperature		5	Melts with defects		2
BT:U:2	Peels off the clay surface at low temperature		5	Melts with defects		4
BT:U:3	Merges well with clay body		2	Melts uniformly at high temperature		1
BT:U:4	Merges well with clay body		2	Melts with minor defects		2
BT:U:5	Peels off the clay surface at low temperature		5	Melts with defects		4
BT:U:6	Merges well with clay body		2	Melts with minor defects		2
BT:U:7	Peels off the clay surface at low temperature		5	Melts with defects		4

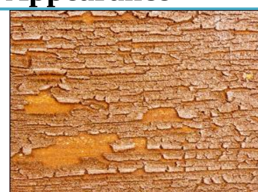
BT:U:8	Merges well with clay body		2	Melts with minor defects		2

Appendix IV: Data Collection of Formulations from Progressive Glaze Tests on Selected Geological Samples

i. AN:MK:4: Tembwa Magical

Tembwa Magical is a natural glaze named after the granulation of a Yellow medium hard rock. It is currently used in house construction as a decorative brick found in Kaptembwa quarry, Mau/Kedowa area.

Formulation of Tembwa Magical: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^0C	Sample: 85% Granulated Glass: 15%		Looks under fired
3H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks over fired

3M Temp 1150^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A great matt finish that can be used on aesthetic pieces.
4L Temp 1050^{0}C	Sample: 70% Soda Ash: 10% Granulated Glass: 10% Silica: 10%		A great low temperature matt finish that can be used on aesthetic pieces.
4H Temp 1200^{0}C	Sample: 80% Feldspar: 5% Granulated Glass: 5% Silica: 5% Sodium Carbonate: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.

ii. AN:BM:4: Nyororo Black

Nyororo Black is a natural glaze named after the granulation of a black medium hard rock that is light in weight and has a feel of coal. It is currently used in house construction is found in Wanyororo B quarry, Bahati/Menengai area.

Formulation of Nyororo Black: Compositions, appearance and observation

Test	Composition	Appearance	Observation
1L Temp 1050^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Can be used on aesthetic pieces.
1H Temp 1200^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Can be used on aesthetic pieces

2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 10%		Can be used on aesthetic pieces
3H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Kaolin: 5%		A good high temperature glaze that can be used on both functional and aesthetic pieces
4L Temp 1050^0C	Sample: 70% Silica: 10% Soda Ash: 10% Granulated Glass: 10%		A great low temperature matt finish that can be used on aesthetic pieces.
4H Temp 1200^0C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces

iii. AN:N:6: Thongo Green

Thongo Green is a natural glaze named after the granulation of a light green hard rock with dark markings. It is currently used in house construction and is found in Mithongo quarry, Njoro area.

Formulation of Thongo Sapphire: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Can be used on aesthetic pieces

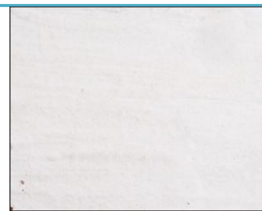
1H Temp 1200^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A great matt finish that can work on aesthetic pieces
2H Temp 1200^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 10%		Shinny and great results for low temperature, can be used on aesthetic pieces.
3H Temp 1200^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks over fired
3M Temp 1150^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A test done to correct 3H defect of over firing. Can be used on aesthetic pieces.
4L Temp 1050^{0}C	Sample: 70% Silica: 10% Granulated Glass: 10% Sodium Carbonate: 10%		A great matt finish that can work on aesthetic pieces
4H Temp 1200^{0}C	Sample: 80% Feldspar: 5% Silica: 5% Granulated Glass: 5% Sodium Carbonate: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.

iv. AG:K:1: Ndusi Mite

Ndusi Mite is a natural glaze named after the granulation of a diatomite, a white soft chalky. It is currently used in industrial mining and is found near Kariandusi Prehistoric, Kariandusi area.

Formulation of Ndusi Mite: Compositions, appearance and observation.

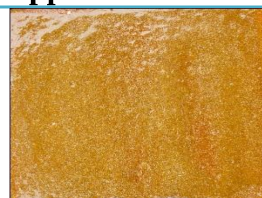
Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
3L Temp 1050^0C	Sample: 85% Granulated Glass: 15%		Looks under fired
3H Temp 1200^0C	Sample: 85% Granulated Glass: 15%		Looks under fired

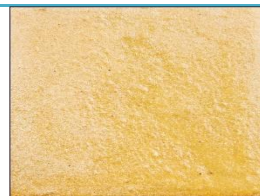
4L Temp 1050^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		Looks under fired but merges well with clay body
4H Temp 1200^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		Can be used on aesthetic pieces
4Lc1 Temp 1050^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		4% addition of Copper Carbonate gave character to 4L results. Can be used on aesthetic pieces
4Lc2 Temp 1050^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		4% addition of Cobalt Oxide did not work well with 4L results
4Lc3 Temp 1050^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		4% addition of Vanadium Pentoxide appears to introduce a less opaque surface to 4L results
4Lc4 Temp 1050^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		4% addition of Manganese dioxide did not work well with 4L results but appears to have potential
4Lc5 Temp 1050^{0}C	Sample: 70% Soda Ash: 5% Feldspar: 5% Granulated Glass: 10% Sodium Carbonate: 10%		4% addition of Copper Oxide gave a very good character to 4L results. Can be used on aesthetic pieces

v. AG:E:1: Obsidian

Obsidian is a natural glaze named after the granulation of an obsidian rock, a shinny dark black, glass like hard rock formed by the formation of cooling laver. This rock was collected from a site that exposed the rock during the construction of the pipeline no 136 found in Kamathata, Eburru area.

Formulation of Obsidian: Compositions, appearance and observation.

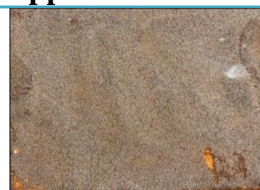
Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^0C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on aesthetic pieces and functional if the cracking effect is corrected
3H Temp 1200^0C	Sample: 85% Feldspar: 10% Kaolin: 5%		Looks over fired
3M Temp 1150^0C	Sample: 85% Feldspar: 10% Kaolin: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.

4L Temp 1050^{0}C	Sample: 70% Silica: 10% Granulated Glass: 10% Sodium Carbonate: 10%		A good low temp glossy glaze that can be used on aesthetic pieces.
4H Temp 1200^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks over fired
3Lc1 Temp 1050^{0}C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on both functional and aesthetic pieces.
3Lc2 Temp 1050^{0}C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.
3Lc3 Temp 1050^{0}C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.
3Lc4 Temp 1050^{0}C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.
3Lc5 Temp 1050^{0}C	Sample: 85% Granulated Glass: 10% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on aesthetic pieces.

vi. AG:E:5: Burru Ash

Burru Ash is a natural glaze named after the granulation of a dark grey ash like volcanic material. It is currently mined in Volcanic caves in Kamathata site B quarry Eburru area used by large scale farmers in Naivasha for green house farming.

Formulation of Burru Ash: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on aesthetic pieces.
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on aesthetic pieces.
3L Temp 1050^0C	Sample: 85% Granulated Glass: 15%		Looks under fired
3H Temp 1200^0C	Sample: 85% Feldspar: 5% Silica: 5% Kaolin: 5%		A good high temp glossy glaze that can be used on aesthetic pieces.
4L Temp 1050^0C	Sample: 70% Soda Ash: 5% Granulated Glass: 10% Sodium Carbonate: 10%		Looks under fired

4H Temp 1200^0C	Sample: 85% Granulated Glass: 5% Sodium Carbonate: 10%		A good high temp glossy glaze that can be used on aesthetic pieces.
5H Temp 1200^0C	Sample: 70% Soda Ash: 10% Granulated Glass: 10% Sodium Carbonate: 10%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.

vii. AG:E:6: Burru Sand

Burru Sand is a natural glaze named after the granulation of a pale grey sand like volcanic material that looks like a pumis rock. It is currently mined in Volcanic caves in Kamathata site B quarry Eburru area used by large scale farmers in Naivasha for green house farming and it's also used as a construction material.

Formulation of Burru Sand: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both aesthetic and functional pieces.
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired

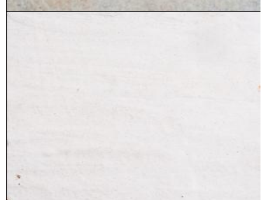
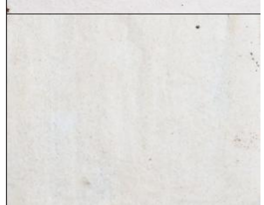
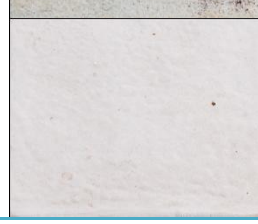
2H Temp $1200^{0}C$	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both aesthetic and functional pieces.
3L Temp $1050^{0}C$	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks under fired
3H Temp $1200^{0}C$	Sample: 85% Granulated Glass: 15%		A good high temp glossy glaze that can be used on aesthetic pieces.
4L Temp $1050^{0}C$	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		Looks under fired
4H Temp $1200^{0}C$	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp glossy glaze that can be used on aesthetic pieces.

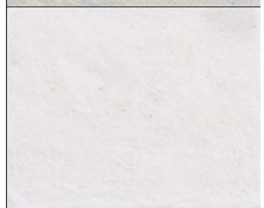
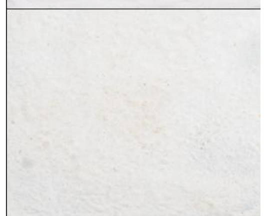
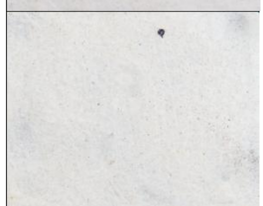
viii. AG:E:8: Burru White

Burru White is a natural glaze named after the granulation of a white soft rock. It is currently mined in volcanic caves in Eburru Kamathata area used by large scale farmers in Naivasha for planting flowers in green houses.

Formulation of Burru White: Compositions, appearance and observation.

Test	**Composition**	**Appearance**	**Observation**
1L Temp $1050^{0}C$	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired

1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
3L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks under fired
3H Temp 1200^0C	Sample: 85% Granulated Glass: 15%		Looks under fired
4L Temp 1050^0C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		Looks under fired
4H Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired
5L Temp 1050^0C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		Looks under fired

5H Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, but can be used in application. Showcases a matt effect.
6L Temp 1050^{0}C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		Looks under fired
6H Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, but can be used in application. Showcases a matt effect.
7L Temp 1050^{0}C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		Looks under fired
7H Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, but can be used in application. Showcases a matt effect.
7Hc1 Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, with undesirable effect.
7Hc2 Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, but can be used in application. Showcases a matt effect.
7Hc3 Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, with undesirable effect.

7Hc4 Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, but can be used in application. Showcases a matt effect.
7Hc5 Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks under fired, with undesirable effect.

ix. AG:M:1: Lewa Grey

Lewa Grey is a natural glaze named after the granulation of a grey hard rock, with sand like pebbles. It is currently used in house construction and is found in Malewa quarry, Gilgil Nyahururu road.

Formulation of Lewa Grey: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good low temp glossy glaze that can be used on both functional and aesthetic pieces.
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good low temp matt glaze that can be used on both functional and aesthetic pieces.
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.

3L Temp 1050^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good low temp glaze that can be used on both functional and aesthetic pieces.
3H Temp 1200^{0}C	Sample: 85% Granulated Glass: 15%		Looks over fired
3M Temp 1150^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good low temp matt glaze that can be used on both functional and aesthetic pieces.
4L Temp 1050^{0}C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		A good low temp matt glaze that can be used on both functional and aesthetic pieces.
4H Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		Looks over fired

x. BK:KR:5: Rima Blue

Rima Blue is a natural glaze named after the granulation of a blue hard rock. It is currently used in house construction and is found in Mirima quarry, Kiambu road.

Formulation of Rima Blue: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.

2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks under fired
3H Temp 1200^0C	Sample: 85% Granulated Glass: 15%		Looks over fired
3M Temp 1150^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good mid temp textured glaze that can be used on aesthetic pieces.
4L Temp 1050^0C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on both functional and aesthetic pieces.
4H Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3Mc1 Temp 1150^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Can be used on aesthetic pieces, however it has a defect.

3Mc2 Temp 1150^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good mid temp light textured glaze that can be used on aesthetic pieces.
3Mc3 Temp 1150^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good mid temp light textured glaze that can be used on aesthetic pieces.
3Mc4 Temp 1150^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good mid temp light textured glaze that can be used on aesthetic pieces.
3Mc5 Temp 1150^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Can be used on aesthetic pieces, however it has a defect.

xi. BK:KU:2: KU Metallic

KU Metallic is a natural glaze named after the granulation of hard murram, with black and brown spots, dug from Kenyatta University, School of Engineering construction site, second layer of the ground.

Formulation of KU Mettalic: Compositions, appearance and observation.

Test	**Composition**	**Appearance**	**Observation**
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp textured glaze that can be used on aesthetic pieces.

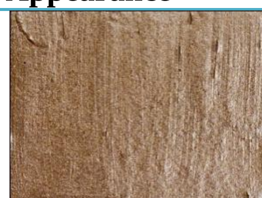
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp textured glaze that can be used on aesthetic pieces.
3L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks under fired
3H Temp 1200^0C	Sample: 85% Granulated Glass: 15%		A good high temp textured glaze that can be used on aesthetic pieces.
4L Temp 1050^0C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		Looks under fired
4H Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp matt glaze that can be used on aesthetic pieces.
5H Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp light textured glaze that can be used on aesthetic pieces.
6H Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp matt glaze that can be used on aesthetic pieces.

7H Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp matt glaze that can be used on aesthetic pieces.

xii. BT:N:4: Rugo Blue

Rugo Blue is a natural glaze named after the granulation of a blue medium hard rock. It is currently used in house construction and found in Nature Stone quarry, Ndarugo, Thika.

Formulation of Rugo Blue: Compositions, appearance and observation.

Test	**Composition**	**Appearance**	**Observation**
1L Temp 1050^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good low temp matt glaze that can be used on aesthetic pieces.
1H Temp 1200^{0}C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
2H Temp 1200^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good low temp glossy glaze that can be used on both functional and aesthetic pieces.

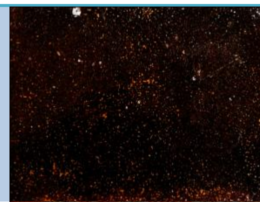
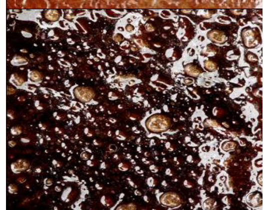
3H Temp 1200^0C	Sample: 85% Granulated Glass: 15%		A good high temp glossy glaze that can be used on aesthetic pieces.
4L Temp 1050^0C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on both functional and aesthetic pieces.
4H Temp 1200^0C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp glossy glaze that can be used on aesthetic pieces.

xiii. BT:U:6: Gingo Purple

Gingo Purple is a natural glaze named after the granulation of a purple, hard. It is currently used in house construction, found in Migingo quarry, Utawala bypass area.

Formulation of Gingo Purple: Compositions, appearance and observation.

Test	Composition	Appearance	Observation
1L Temp 1050^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		Looks under fired
1H Temp 1200^0C	Sample: 85% Soda Ash: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
2L Temp 1050^0C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		Looks under fired

2H Temp 1200^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Silica: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
3L Temp 1050^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		Looks under fired
3H Temp 1200^{0}C	Sample: 85% Granulated Glass: 15%		Looks over fired
3M Temp 1150^{0}C	Sample: 85% Feldspar: 5% Granulated Glass: 5% Kaolin: 5%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.
4L Temp 1050^{0}C	Sample: 80% Silica: 5% Feldspar: 5% Granulated Glass: 5% Sodium Carbonate: 5%		A good low temp glossy glaze that can be used on both functional and aesthetic pieces.
4H Temp 1200^{0}C	Sample: 70% Granulated Glass: 20% Sodium Carbonate: 10%		A good high temp glossy glaze that can be used on both functional and aesthetic pieces.

Appendix V: Current Mining Activities

Current list of Companies and Organizations linked to Mining in Kenya compiled from the online sources

No	Company/Organization	Location	Mineral
1	Magadi Soda Company Limited	Magadi	Harvests Trona (a naturally occurring mineral that contains sodium carbonate compounds) that is found at the surface of the Lake Magadi
2	Cortec Mining Kenya Limited	Mrima Hill, Kwale, Coast Region	Tantalum, Niobium and Rare Earth Element Mining
3	International Gold Exploration	Migori, Archaean Greenstone Belt in south-west Kenya	Gold Mining
4	Kenya Fluorspar Company	Kimwarer, Choff and Kamnaon, Kerio Valley, Eldoret	Fluorspar
5	Mercurials Interlink	Nairobi	Contract Mining
6	Mines and Geological Department	Madini House, Machakos Road, Nairobi	Industrial Minerals Mining, Support activities for other mining and quarrying, Contract Mining, Other specialized construction activities, Technical testing and analysis, General public administration activities, Mining Industry, Regulation, Library and archives
7	Swensson & Simonet Minerals Kenya Ltd	Nairobi	Precious and Semi-Precious Stone Mining Mining Engineering
8	Tarshish Holdings	Nairobi	Contract Mining
9	Achelis (Kenya) Limited	Funzi Road, Industrial Area, Nairobi	Contract Mining
10	Athi River Mining Ltd	Chiromo Road, Westlands, Nairobi	Contract Mining
11	Ministry of Environment and Natural Resources	Nairobi	Mining Industry Regulation
12	Tiomin Resources Inc (Kenya)	Diani, Ukunda, Kwale district, Coastal Region	Mining ilmenite, rutile, and zircon

Appendix VI: Common Oxides found in Glazes

Shearer, (2005), a list of the common oxides found in glazes

	Name	Common Name	Category	Chemical Abbreviation
1	Silicon Dioxide	Silica	Glass Former	SiO_2
2	Aluminium Oxide	Alumina	Stabiliser	Al_2O_3
3	Boric Oxide		Glass Former,Stabiliser, Flux	B_2O_3
4	Barium Oxide	Baria	Flux	BaO
5	Calcium Oxide	Calcia	Flux	CaO
6	Potassium Oxide	Potash	Flux	K_2O
7	Sodium Oxide	Soda	Flux	Na_2O
8	Lithium Oxide	Lithia	Flux	Li_2O
9	Magnesium Oxide	Magnesia	Flux	MgO
10	Lead Oxide	Litharge	Flux	PbO
11	Strontium Oxide		Flux	SrO
12	Zinc Oxide		Flux	ZnO_2
13	Stannous Oxide	Tin	Opacifier	SnO_2
14	Titanium Dioxide	Anatase	Opacifier	TiO_2
15	Zirconium Oxide	Zirconia	Opacifier	ZrO_2
16	Copper Oxide		Colorant	CuO
17	Copper Carbonate		Colorant	$CuCo_3$
18	Cobalt Oxide		Colorant	CoO
19	Cobalt Carbonate		Colorant	$CoCO_3$
20	Manganese Dioxide		Colorant	MnO_2
21	Iron Oxide (red)		Colorant	$Fe2O_3$
22	Rutile		Colorant	TiO_2
23	Vanadium Pentoxide		Colorant	V_2O_5
24	Nickel Oxide		Colorant	NiO

Appendix VII: Common Minerals used in Glaze Making

Shearer, (2005), Common minerals used in glaze making.

	Name	Common name	Category	Chemical Abbreviation
1	Silica	"Flint, Quartz"	Glass former	SiO_2
2	Orthoclase	Potash Feldspar	Complete glaze material	$K_2O.Al_2O_3.6SiO_2$
3	Albite	Soda Feldspar	Complete glaze material	$Na_2O.Al_2O_3.6SiO_2$
4	Lithium Feldspar	Petalite	Complete glaze material	$Li_2O.Al_2O_3.8SiO_2$
5	Bone Ash	Bone Ash	"Flux, glass former"	$Ca_3(PO_4)_2$
6	Kaolin	China Clay	Stabilizer	$Al_2O_3.2SiO_2.2H_2O$
7	Calcite	"Limestone, Whiting"	Flux	$CaCO_3$
8	Colemanite	Gerstley Borate	Flux	$2CaO.3Ba_2O_3.5H_2O$
9	Dolomite		Flux	$CaMg(CO_3)_2$
10	Lead Bisilicate		Flux	$PbO.2SiO_2$
11	Lithium Carbonate		Flux	Li_2CO_3
12	Magnesium Carbonate		Flux	$MgCO_3$
13	Barium Carbonate		Flux	$Ba\ CO_3$
14	Nepheline Syenite		Flux	$K_2O.3Na_2O.4A_{l2}O_3.8SiO_2$
15	Wollastonite		Flux	$CaSiO_2$
16	Talc		Flux	$3MgO.4SiO_2.H_2O$
17	Zinc Oxide	Zincite	Flux	ZnO_2

Appendix VIII: Some Site Photos

Naishi Quarry, Njoro

Kariandusi prehistoric site

Eburru, Kamathatha, Site B Quarry

Mau/Kedowa, Kabao Quarry

Mau/Kedowa, Kiptenden Quarry

Eburru, with the harvest of Pumice

Eburru, Kamathatha, Volcanic Sand

Mithongo Quarry, Njoro

Kamathatha Caves, Volcanic Ash

Migingo Quarry, Utawala

Appendix IX: Processing of Geological Materials at KIRDI

Steel Ball Mill

Porcelain Ball Bill

Sample is ready for sieving

Taking the sample through the Vibro Sieve

Appendix X: Studio Work

Granulated samples in preparation for test firing

Preparing items for glaze application

Appendix XI: Application


Air brush application

Application on tests ready for firing

Appendix XII: Certificate of Chemical Analysis, Ministry of Mining

MINISTRY OF MINING

Telegrams: "MINERALOGY"
Nairobi Telephone: 020-558034
Fax No. 554366:e-mail:cmg@bidii.com
When replying please quote ref No & date

MINISTRY OF MINING
MACHAKOS ROAD
P O. Box 30009-00100 GPO
NAIROBI

Ref. No. ORIGINAL CERT 1385-1400/15

Date…31st August, 2015

ASSAY CERTIFICATE

SENDER'S NAME	:	**AYIENG'A BARONGO LILIAN**
DATE	:	**21.07.2015**
SAMPLE TYPE	:	**ROCKS**
SAMPLE NO	:	**1385-1400/15**

RESULTS

Lab No.	Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI	Cd	Pb
1385/15	BK:KR:5	51.66	16.60	0.91	0.48	5.93	5.3	0.30	0.20	5.37	4.29	ND	ND
1387/15	BT:U:6	51.85	13.60	0.67	0.49	7.28	5.80	0.35	0.08	4.74	2.47	ND	ND
1388/15	BT:N:4	64.90	10.52	0.65	0.16	3.00	6.30	0.25	0.20	6.24	6.27	ND	ND
1390/15	AG:E:8	78.04	14.20	0.10	NILL	0.19	0.40	0.14	NILL	0.65	6.56	ND	ND
1391/15	AG:K:1	75.31	4.31	0.82	0.27	1.26	1.90	0.19	0.02	3.60	12.50	ND	ND
1392/15	AG:E:5	58.74	11.97	1.01	0.10	2.37	10.0	0.64	0.10	6.33	9.0	ND	ND
1393/15	AG:E.1	66.58	8.33	0.62	NILL	7.52	7.50	0.30	0.20	6.64	0.29	ND	ND
1394/15	AG:E:6	65.52	9.51	0.43	NILL	2.05	8.6	0.34	0.10	6.00	7.90	ND	ND
1395/15	AG:M:1	64.09	11.69	0.52	NILL	6.99	7.80	0.63	0.20	6.62	1.19	ND	ND
1396/15	AN:N:6	54.10	13.41	0.69	0.13	6.76	7.70	0.89	0.19	11.70	4.36	ND	ND
1397/15	AN:MK:4	52.83	13.32	0.95	0.15	2.88	8.50	0.91	0.08	6.69	13.66	ND	ND
1398/15	AN:BM:4	57.40	15.11	0.96	0.13	8.10	8.70	0.72	0.16	5.98	0.80	ND	ND
1399/15	BK:KU:2	24.72	13.05	0.18	NILL	0.50	0.97	0.98	3.20	40.50	15.30	ND	ND

Note: The results are expressed in percentage (%) unless otherwise indicated.
ND means not detected.

FOR: COMMISSIONER OF MINES & GEOLOGY.

J.W. KATWEO
FOR: COMMISSIONER OF MINES AND GEOLOGY

Appendix XII: Research Authorization, National Commission for Science, Technology and Innovation

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

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Ref: No. **NACOSTI/P/15/68497/8734**

Date: **21st December, 2015**

Lillian Barongo Ayienga
Kenyatta University
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NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Glaze formulation using selected geological material from Nakuru and Kiambu Counties, Kenya,"*** I am pleased to inform you that you have been authorized to undertake research in **Kiambu and Nakuru Counties** for a period ending **18th December, 2016.**

You are advised to report to **the County Commissioners and the County Directors of Education, Kiambu and Nakuru Counties** before embarking on the research project.

On completion of the research, you are expected to submit **two hard copies and one soft copy in pdf** of the research report/thesis to our office.

DR. M. K. RUGUTT, PhD, HSC.
DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kiambu County.

The County Director of Education
Kiambu County.