

CLAY SOILS IN MCHINJI: POTENTIAL RAW MATERIALS FOR CERAMIC INDUSTRY

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ABSTRACT

Mchinji district is composed of a thick layer of superficial deposits which include vast dambos, colluvium, and alluvial plains with aplenty clay soils in their numerous valleys. Regardless of its high proportion, clay soils from Mchinji are only exploited for conventional pottery and local ceramic bricks. This is basically because the potentialities of these clay soil have not been evaluated. Up to the present moment, no study that evaluates the potential applications of these clay soils is available.

Ceramic suitability of clays in the selected sites of Mchinji was assessed utilizing empirical diagrams, involving grain size distribution, and chemical composition and by adopting a new approach basing on the methodology of the experimental design. It is found that the particle size distribution contains higher percentages of sand fractions, followed by clay fractions, and the lowest being silt. The chemical composition was found by XRF analysis which showed higher percentages of SiO_2, Al_2O_3, and Fe_2O_3. The low content in a fluxing agent is indicated by the low contents in Na_2O, K_2O, MgO, TiO_2, CaO, MnO, and P_2O_5.

The Mchinji clays are distributed in sandy clay loam and sandy clay in the grain size distribution diagram. These clays have ceramic suitability of checker bricks (perforated bricks) and clay roofing tiles. Taking into account the chemical composition, the clays have the suitability of red stoneware.

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ACRONYMS/ABBREVIATIONS

cm - centimetres
Fig. - figure
km - Kilometre

mm - millimetre
˚C - Degree Celsius
Ppm - Parts per million
PSD - Particle Size Distribution
XRF - X-ray fluorescence
XRD - X-ray diffraction
MUST - Malawi University of Science and Technology
GDS - Geological Survey
GPS - Global Positioning System

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1 INTRODUCTION

This chapter will provide an introduction to the study by first discussing the background and context, followed by the research problem, the research aims, objectives and questions, the significance, and finally the limitations.

1.1 Background

We depend heavily on ceramic products in our everyday life, whether they be delicate china teacups, tableware, burnt bricks, tiles, glass, or rough linings for high-temperature industrial furnaces(*Ceramic Raw Material*, 1982). It is amazing how shapeless lumps can be made into some of the most attractive objects in the world. This is where clay comes in Clay is the oldest known material for ceramics. Clay appears not to be the most important material on the earth's surface, yet they affect life on earth in far-reaching ways. Besides being used for ceramics. Worldwide clay has been used throughout history for various purposes such as building, and medicine(Behrami et al., 2021). Fortunately, clay the essential raw material for ceramics production is so cheap and plentiful. Clay is found generally beneath the topsoil, practically at most deposit sites in the world. Shackelford & Doremus, (2008) reported that clays, according to their deposits, are classified into two: Primary and secondary. Primary clay deposits are formed from the in-situ decomposition of igneous rock, while secondary clay deposits are formed from clay particles that have been transported from their original location by water or wind erosion and deposited in a new sedimentary deposit and can be easily found in different geological settings (Leeder, 2011).

The ceramic industry is very important to the world’s economy and it is one of the fields, besides construction, that relies heavily on clay as its raw material (A. C. K. Nascimento et al., 2020). Because of this reason, there is a necessity to find new sources of clay with potential for ceramic material production. As a result, scientists in the different fields have resorted to conducting, studies that involve analyzing the suitability of clay in found different areas for ceramic properties. Carter & Bennett, (1973) and the Ministry of Energy and Mines, (2007) classified clays as mineral resources that have an economic potential that could make an important contribution to the economy of a country. This shows that there's a chance that the economy of Malawi can diversify from agriculture to other industries. One of the industries could be the ceramic industry where clay can be used extensively.

Malawi clay deposits have been reported in several places including Linthipe-Dedza, Chintheche-Nkhotakota, and Nkhande-Ntcheu (Malunga, 2014). Some other notable places where clay is mined are headwaters of the Rivi-Rivi River in Ntcheu, Senzani, and Chitipa. Only the Linthipe deposit has been extensively investigated as of now it is known to be the largest clay deposit that holds kaolinitic clays (Technology and Action for Rural Advancement, 2016). Some clays are the locally available ceramic raw material in Malawi, they are in small or unknown sizes of deposits, of which it is extracted for local ceramic production (Malunga, 2014).

1.2 Problem statement

Clay soils are essential for raw materials for ceramic production. Natural clays normally occur together with other soil fractions and are found in most geographical settings (Fadil-Djenabou et al., 2015). Despite clay soils being abundant all over the world and can be easily found in different geological settings and despite the potential they have, in Malawi, they are only exploited for conventional pottery and local ceramic bricks, and some other small projects (Malunga, 2012). This is basically because the suitability of these clay soils as raw materials for ceramic production has not been evaluated (Manjate et al., 2018).

However, the only clay deposit that was studied in Linthipe, Dedza. The study focused relatively on big industries that use clay to manufacture building materials like cement (Technology and Action for Rural Advancement, 2016). This presents a problem to local industries that uses the clay to manufacture local ceramics such as clay pots, clay stoves, etc. that can contribute to the tourism industry and the economy of the country. As a result, the existing literature does not apply to the ceramics industry which is controlled by the artisanal and small-scale miners and depends on clay soils from nearby deposits. Since the artisanal and small-scale mining of these clay soils are made without any prior study and originates various problems during the manufacturing process, such as deformations and breakage of the final products (Manjate et al., 2018) . This study therefore would like to study and evaluate the potential of clays in Mchinji to increase the availability of potential clay mining sites in Malawi.

1.3 Objective of study

1.3.1 Main objective

Given to lack of research regarding the uses of clays that are found in different deposits

all over Malawi, this study aims to evaluate the suitability of the Mchinji clays as a raw material for t

1.3.2 Specific objective

The specific objectives of the study include the following:

1. To analyze the chemical characteristics of the clay soil in the selected sites in Mchinji.
2. To Identifying the clay particle size distribution.
3. To identify suitable ceramics based on PSD and Chemical composition.

1.4 Research Question

1. What is the particle distribution of the clay in Mchinji?
2. What is the suitable ceramic product suitable ceramic body associated with the PSD?
3. What is the chemical composition of Mchinji clays?
4. When subjected to chemical (XRF) analysis will it pass the physical property of the acceptable body?

1.5 Significance of study

- This study will contribute to the body of knowledge of clay deposits and their suitability for ceramics in Malawi.
- Provide knowledge to artisanal and small-scale miners on how best to utilize the clay deposits that are being studied.
- This study will help to address the current shortage of research on this topic and provide real-world alternative uses of the clays being studied.

2 LITERATURE REVIEW

2.1 Ceramics

Ceramics can be defined as solid compounds that are formed by the application of heat, and sometimes heat and pressure, comprising at least two elements provided one of them is a non-metal or a nonmetallic elemental solid. The other element(s) may be a metal(s) or another nonmetallic elemental solid(s) (Barsoum, 2003). The ceramic industry is very important to the world's economy because of the properties they have. The general properties of ceramics are described as follows: 1) They are brittle. 2)Dislocations are not important because they do not move. 3) They are polycrystalline and fracture along grain boundaries (Barry & Grant, 2007). Each ceramic product requires clays having particular and appropriate characteristics. They must not contain a swelling phase and their loss of weight and shrinkage, after drying and firing, have to be low (Michailidis et al., 2010).

2.2 Types of Ceramics

Ceramics are classified into three types, earthenware, stoneware, and porcelain (G. M. do Nascimento, 2016).

2.2.1 Earthenware

Earthenware is used extensively for pottery tableware and decorative objects. It is one of the oldest materials used in pottery. The clay is fired at relatively low temperatures (1,000 – 1,150˚C), producing a slightly porous, course product.

2.2.2 Stoneware

Stoneware is manufactured when the clay is fired at a high temperature (about 1200˚C) until vitrification of the raw material. Because stoneware is non-porous, a glaze is applied only for decoration. Stoneware is a study chip-resistant and durable material suitable for use in kitchens for cooking, storing liquids, and seven dishes and are also suitable for manufacturing tiles due to its non-porous nature.

2.2.3 Porcelain

Porcelain is a very hard translucent white ceramic. A small amount of glass, granite, and feldspar material is ground up with fine white kaolin clay. Porcelain is usually used for decorative glazes.

2.3 Clay as ceramic raw material

In ceramic industries, clays are widely used for the production of traditional ceramic products such as bricks, porcelain, sanitary wares, floor tiles, and roofing tiles (Grim, 1952; Murray, 1999; Temimi et al., 1998). They are generally mixed and blended to give standard composition and optimum properties for various ceramic applications (Bailey, 1974). Raw material selection plays a vital role in the final product design in ceramics. The structure, composition, and physical properties of the clays determine their applications in ceramic production. Each ceramic product requires clays with particular and appropriate characteristics (Andrade et al., 2011). The final ceramic product is strongly influenced by the following properties: particle size distribution, plasticity, drying shrinkage, green strength, dry strength, chemistry, and mineralogy (Andrade et al., 2011; Falih, 2010; Mandour et al., 1989; Onal & Sarikaya., 2009). The ceramic suitability of the natural clays also depends on the firing conditions: temperature, soaking time, heating rate, and atmosphere (Hajjaji, 2010).

2.4 Assessing the suitability of clay for ceramics

To assess the suitability of clay for manufacturing, ceramics such as bricks or roofing, floor, and wall tiles, use the particle size distribution, chemistry, and mineralogy of the raw material.

2.4.1 Particle size distribution (PSD)

The particle distribution refers to the relative proportion of sand, silt, and clay, irrespective of chemical or mineralogical composition. The particle size and its distribution of soil have a decisive influence on its molding properties and the resultant ceramic quality. Particle size refers to the mean or effective diameter of individual mineral grains or particles (Mueller et al., 2008).

The Particle size of raw materials influences considerably the behaviour of ceramic bodies during the technological process and also affects many properties of the finished products. The Particle size distribution of raw materials for clay products influences in particular the behavior of the material during the shaping and drying processes and affects the microstructure and the mechanical properties of fired materials.

To assess the suitability of clay using PSD, the use of empirical diagrams such as the ternary soil textures diagram (Bender & Händle, 1982), (fig 1) and the classic Winkler diagram (Manjate et al., 2018), (fig 2) are applied. The two ternary diagrams are

currently used to assess the validity of the particle size characteristics, to achieving a good quality c

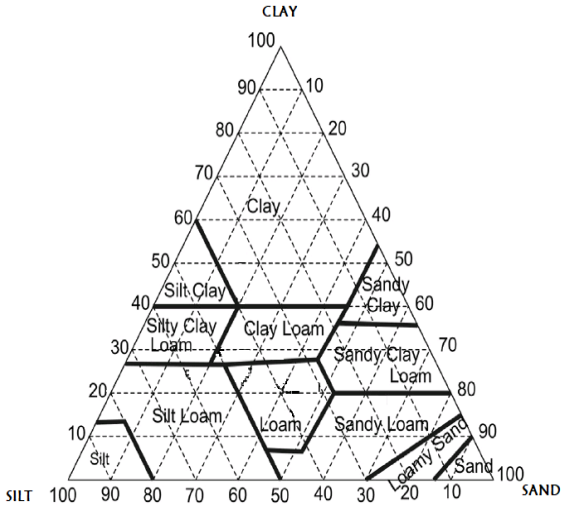


Figure 1: Showing clay, silt, and sand distribution,

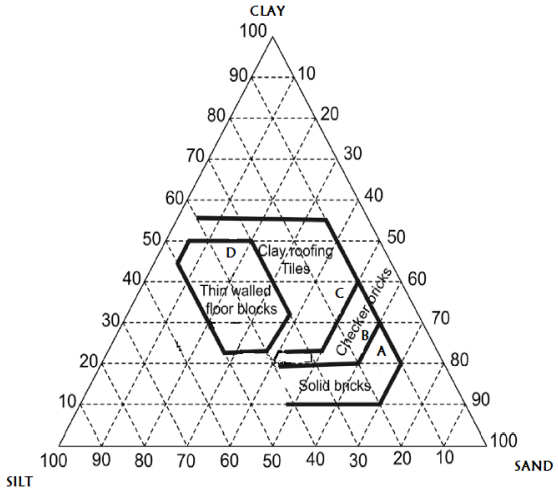


Figure 2: presenting the suitable mixtures of grain fractions for manufacturing ceramics. common bricks (A), vertically perforated bricks (B), roofing tiles and light blocks (C), and thin-walled hollow bricks and blocks (D).

Particle size is classified as Clay (Particle sizes of clay are smaller than 2µm), Silt (Particle sizes of silt ranges from 2 to 63µm), and Sand (Particle sizes of sand are greater than 63µm). Coarse-grained materials increase drying rate, decrease excessive plasticity, and reduce shrinkage and cracking (Michailidis et al., 2010). Clay that has a high amount of fine particles, allows the addition of the complementary shaping raw materials which provides improvements in certain aspects such as dimensional stability, better compaction, and a better finish (Cely-Illera, 2016).

2.4.2 Chemical Analysis

Clay is materials made from physical-chemical weathering phenomena, fine grain size generally consists of various minerals such as hydrated aluminum silicates, with ions mainly of calcium (Ca), titanium (Ti), magnesium (Mg), iron (Fe), Potassium (K) and sodium (Na) and other accompanying minerals like quartz, feldspars, carbonates, etc (Mukherjee, 2013). Natural clay includes oxides such as Alumina (Al_2O_3), Silica (SiO_2),

Iron oxide (Fe_2O_3), Calcium Oxide (CaO), Manganese oxide (MgO), Sodium oxide (Na_2O), and Pot

The physicochemical characteristics of material directly influence the final properties of structural products and determine the type of product to be manufactured (Cely-Illera, 2016). Alumina In combination with silica forms clay mineral mullite ($2Al_2O_{3.3}SiO_2$) at high temperatures which are responsible for developing strength in a fired product. a high percentage of alumina is an excellent raw material for manufacturing refractory products with higher value-added. Structural silica (SiO_2) within clay minerals gives strength in the fired ceramic products whereas free silica gives strength and rigidity. Iron oxide (Fe_2O_3) gives a strong red color to the fired products when fired at appropriate temperatures, its suitable requirement in brick manufacturing. Calcium Oxide (CaO) in a fine state and more than 2% will mask the red color given by iron, resulting in a buff-colored fired product. Manganese oxide (MnO) is an indication of Illitic clays and is beneficial for fired brick properties since it acts as a catalyst during the vitrification stage and aids in denser and stronger ceramics. Sodium oxide (Na_2O) is an indication of montmorillonite clays. Potassium oxide (K_2O) Indication of Illitic clays. Higher quantities of K_2O present in the clay will lead to lower vitrification temperatures but with a high firing shrinkage (Bender & Händle, 1982).

To assess clay suitability for manufacturing bricks or roofing, floor and wall tiles empirical diagrams involving chemical composition (Hajjaji, 2010), (Fig 3) is often in use (Hajjaji, 2010).

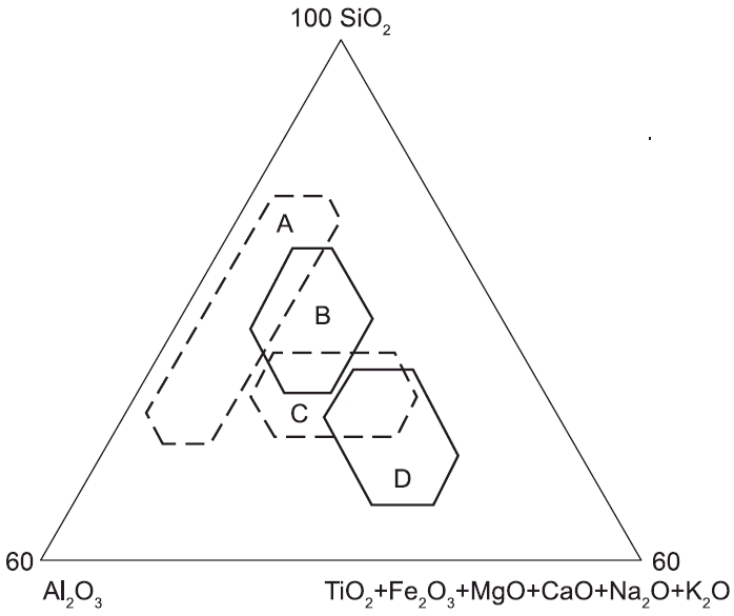


Figure 3: Clay chemical composition domains for preparing stoneware tiles (white (A) and red (B) bodies) and porous tiles (C and D).

2.5 The study area

2.5.1 General geology of the study area

Mchinji is located northwest of Bua River and is almost entirely underlain by the gneisses, granulites, quartzites, and schist of the basement complex. The basement complex is overlain by thick superficial deposits that include residual soils, alluvium, and colluvium (Thatcher & Wilderspin, 1968). Exposures of the basement complex are poor being restricted to the mountain ranges and a few small outcrops along streams or banks of dambos. The rocks are either fine-grained or coarse-grained. The fine-grained type is a source of the silica sands found in the dambos (Malunga, 2014). Mchinji sands are fine to very fine-grained and appear to be almost completely composed of quartz grains. In some parts, very small amounts of black minerals and iron oxides, and muscovite flakes can be observed.

Mchinji soils are classified as ferrallitic soils, weakly ferrallitic soils, ferrallitic with laterite and lithosols (Chinyama & Lowole, 1983). Ferrallitic soils are somewhat highly weathered, yellowish-red, or brown loamy structureless (Massive) soils, low inherent potential and are widely prevalent. Weakly ferrallitic soils are somewhat highly weathered, red, loamy, or clayey soils with some ferruginous property. Ferrallitic with laterite soils is massive laterite that occurs 100 centimeters from the surface. Lithosol is shallow and is mostly gravelly soil.

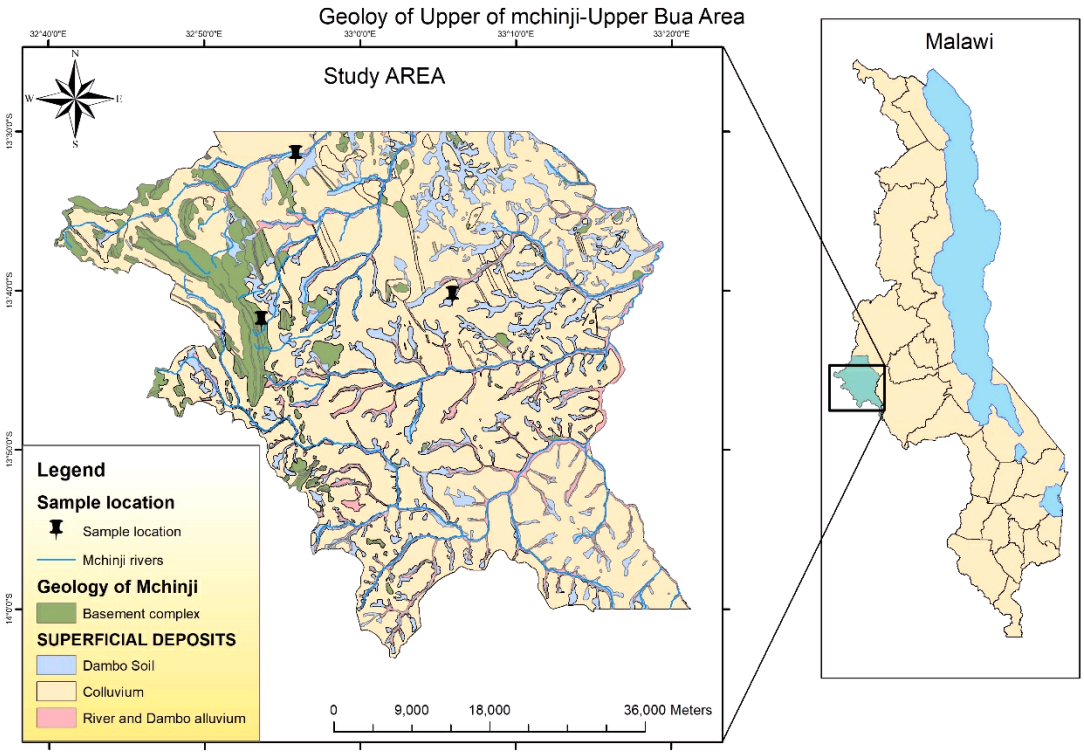


Figure 4: Map showing Geology of Mchinji.

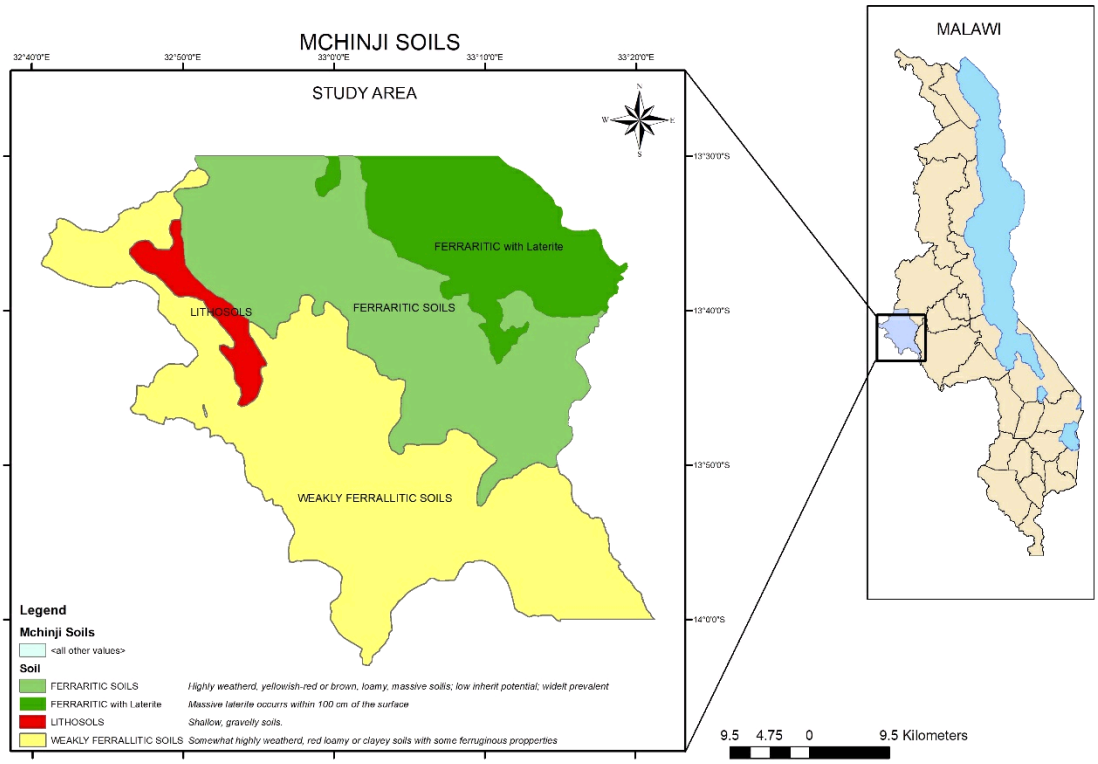


Figure 5: Map showing Mchinji soils.

2.5.2 Clay deposits in Mchinji

Thatcher & Wilderspin (1968) found that Mchinji has small and localized deposits of clay suitable for brick making which is found in most parts of the area with the probable exception of the Mchinji Hills. The area east of Bua and Namitete appears to be the most promising for clays that are suitable for brick making. Despite that, Mchinji has other areas in which clay is extracted for manufacturing clay stoves (fig 6) and clay kitchen utensils (fig 7).



Figure 6:Showing clay stoves manufactured by women artisan groups in Mchinji.



Figure 7: Showing women using some of the clay in Mchinji.

2.5.3 Location of the study area

The study area of this research project is three villages, Nyoka village T.A Nyoka (13˚ 41'50.0"S 32˚54'0"E), Chapuma village T.A Mkanda (13˚31'39.9"S 32˚55'55.2"E), and Chikoza Village T.A Mduwa (13 40'35.5"S 33 06'13.1"E). Nyoka village and Chapuma village are situated along S118 road located 13km and 40 km northwest of Mchinji boma. Chikoza village is located 41 km west of Mchinji boma. Most of the inhabitants are farmers with few involved in small-scale trading. Very few, mostly women, mould and produce traditional ceramics, using natural clay, to earn a living. It is interesting to note that Mchinji clays are locally called "dothi la Mtapo" and each village has its deposit where the clay is derived from. So far there is no known published work on the properties of this clay deposit.

3 METHODOLOGY

This chapter is a documentary of how data was collected and analyzed. This is scientific research that adopted an experimental method, based on qualitative and quantitative analysis of Mchinji clays. The qualitative study will discuss physical characteristics observed in the field, which included the appearance of the sampled clays. Quantitative analysis is aimed at finding the chemical characteristics and particle size distribution and Firing transformation of the samples collected.

3.1 Experimental procudure

The study adopted the experimental method. This involves data collection, fieldwork, and chemical analysis.

3.2 Data collection

There are two types of data on which the project is based on which are primary and secondary data

3.2.1 Primary data

Sampling procedure

With knowledge of the presence of clay deposits in Mchinji, that are small and localized, led to recognizance, through the District commissioner's (DC) office of which 7 villages were found. From these seven villages, three villages were chosen at random where samples were collected.

SAMPLE NAME	Village	SAMPLE TYPE	EASTINGS	NORTHINGS
Nyoka	Nyoka	Soil	8485519	488540
Chapuma	Chapuma	Soil	8504748	492518
Mduwa	Chikoza	Soil	8488411	510662

The samples were collected at the base of Mchinji mountain in Nyoka Village, T.A Nyoka; along Luweredzi river in Chapuma Village, T.A Mkanda; and along Dwamu river in Chikoza Village T.A Mduwa. This includes sample collection of clay soils in their deposits Table 1 below shows locations on which samples were collected. Three sampling points are giving out three soil samples.

Table 1 shows coordinates of sample points

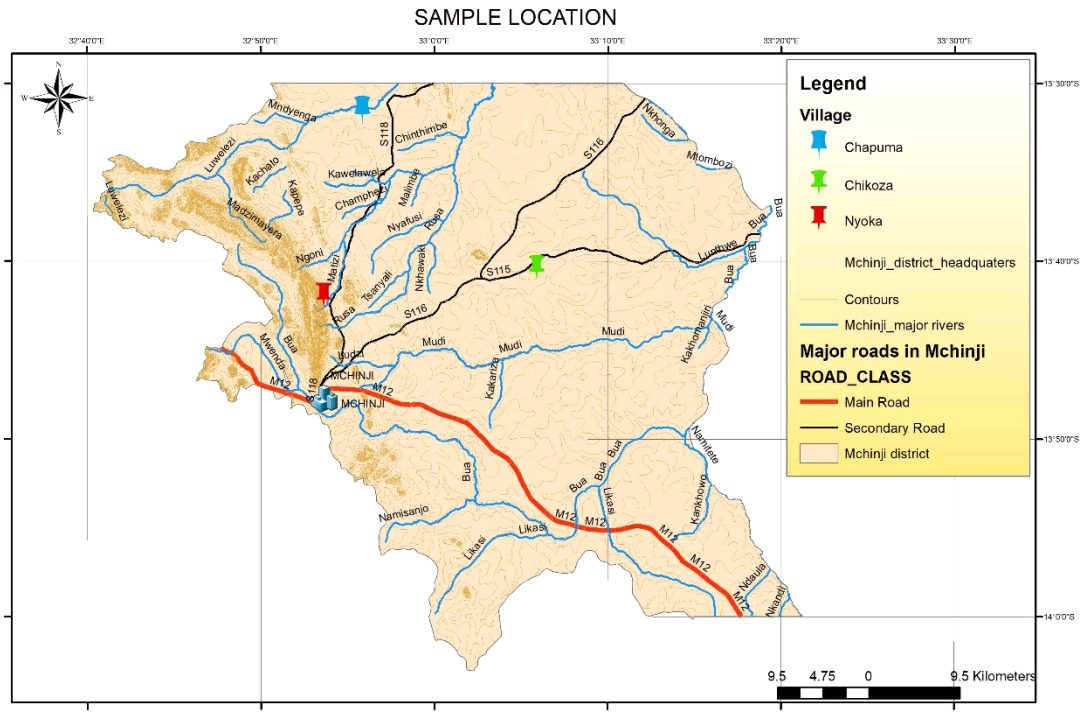


Figure 8: showing sample locations

3.2.2 Secondary data

The data was compiled from journal articles, books related to the ceramic properties of clay. This data was used to come up with a conclusion in this study by comparing it with what other researchers have found.

3.3 Field collection tools and instruments

The tools that were used in the field, during data collection include hoe, GPS, sample bags, field notebook, pen, and pencil. The hoe was used to break and remove the surface soils to collect a fresh sample, it was chunks of soil. On each sample point, soils were put in a sampling bag. Samples at Nyakankhe Village, T.A Nyoka were collected along a valley 30 centimeters below the ground. Samples in Mshanga Village, T.A Mkanda were collected in the flood plains of Luwerezi river, from the point where the villagers mine clay to use for making clay pots. It was about 1 meter below the surface. Lastly, samples at Chikoza Village T.A Mduwa were collected along Dwamu

river, where the villagers extract their clay to sell and for making clay pots. When the sample was c

Finally, the samples were delivered to Zomba Geological Survey (GSD) for XRF analysis and other samples were delivered to Agrilab in Blantyre (Limbe) for particle size distribution (PSD).

3.4 Fieldwork

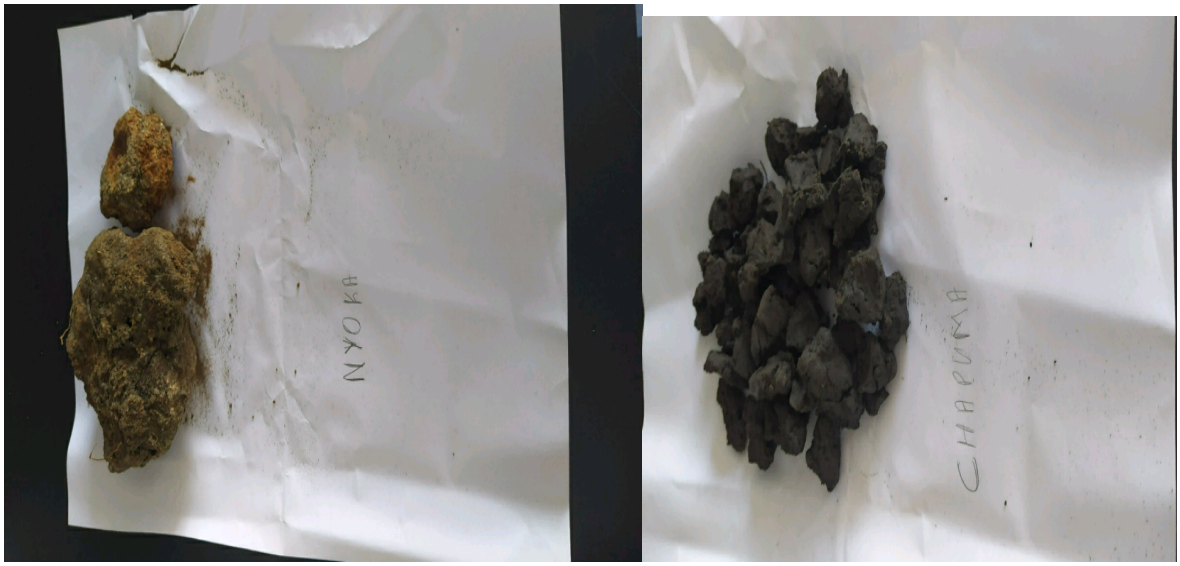
Smearing and shape test

This involved taking some loose soil from the possible ceramic raw material and put an appropriate amount of water into it to make a sticky paste. After the soil was saturated with water, the soil paste was mixed by hand. The paste was rolled in the hand enough so that the ball is formed dried out a little bit. This process helps to feel for any coarse particles and check if the clay is semi-plastic to plastic in nature (Mueller et al., 2008).

3.5 Laboratory work

3.5.1 Particle size distribution (PSD)

After the fieldwork, the samples were prepared before they were analyzed in the laboratory. The preparation. Involved dry wet samples, and crushing lumps of soil in preparation for sieve analysis.



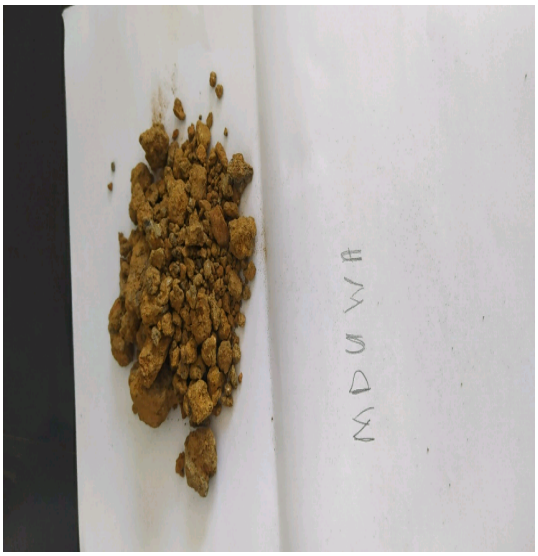


Figure 9: Samples

Particle size distribution (PSD) was obtained by sieving for the coarse and fine sand fractions using dry-sieve opening mesh ASTM 10, #4, #10, #12, #, #18, #40, #60, #, #140, and # 200 respectively using the STDS-200 Shaker and following the procedure described, among others, by Braja M. Das (2002). The silt- and clay-sized fractions were obtained by sedimentometry using Robinson's pipette method at Agrilab, an organization under Farming and Engineering services (FES) in Blantyre.

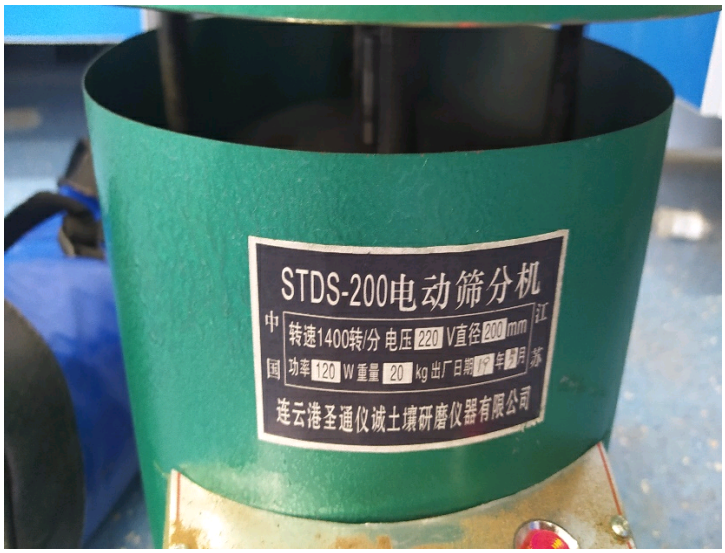




Figure 10: equipment uses for sieve analysis.

3.5.2 Chemical analysis

The samples were analyzed in Zomba at the Geological Survey Department (GSD) for chemical analysis. Chemical compositions of samples were performed by X-ray fluorescence (XRF) using Spectro Xepos XRF 2017 device. The major elements expressed as oxides and trace elements are given in parts per million (PPM). the required trace elements in this study were converted to oxides using the oxide conversion factors. The necessary oxides (SiO_2, Al_2O_3, Fe_2O_3, MnO, TiO_2, MgO, CaO, Na_2O, K_2O, and P_2O_5) Weight percentages are rounded up to 100%.

3.6 Data analysis

3.6.1 Particle size distribution

The Analysis interpretation of the results was done using the soil ternary diagram (Fig 1), and Winkler diagram (Fig 2), to find the soil type and the type of structural ceramic that is suitable for the PSD of the obtained samples.

3.6.2 Chemical composition analysis

This uses XRF data and the empirical diagram (fig 3), to show the nature of the ceramic body once it is prepared. The major elements expressed as oxides and trace elements are given in parts per million (PPM). the required trace elements in this study were converted to oxides by multiplying the percentages with the oxide conversion factors which involves multiplying the weight percentage by the numerical value which is different for each element (Al-Mishwat, 2016). The necessary oxides (SiO_2, Al_2O_3, Fe_2O_3 , MnO, TiO_2, MgO, CaO, Na_2O, K_2O, and P_2O_5) Weight percentages are rounded up to 100%.

3.7 Ethical considerations

This was through acknowledging the necessary traditional authority of the villages where the samples were collected. The Traditional authorities were acknowledged through the Mchinji District Commissioner about the survey to be conducted in the villages.

3.8 Study limitations

There were a lot of challenges that were experienced during the undertaking of the project which may result in not accomplishing some goals of the project.

- Lack of equipment: It was first decided that the samples would be analyses for mineralogical composition (XRD), chemical composition (XRF), and PSD. Due to this, the study has used PSD and XRF data only. The suitability of clays for ceramic application is assessed using the mineralogical and mainly technological characteristics to achieve more accurate results.

4 RESULTS AND DISCUSSION

4.1 Particle size distribution

The particle size distribution of the studied samples is shown in table 2. The results show variation in particle sizes, having sand fractions from about 46.95% to 52.19%, silt fractions from about 13.17% to 17.16%, and clay fractions from about 30.65% to 36.75%. Results show that sand fraction has the higher amount in all three samples followed by silt and clay size fraction.

Table . Showing PSD results

Sample ID	Sand (%)	Silt (%)	Clay (%)
Nyoka	52.19	17.16	30.65
Chapuma	46.95	16.30	36.74
Mduwa	56.09	13.17	30.75

The relative proportions of sample ID “Nyoka” and “Mduwa” belong to sandy clay loam, and sample ID “Chapuma” belongs to sandy clay in the ternary soil textures diagram (Figure 11). Referring to the point location representing the clay grain size fractions in Winkler’s diagram (Figure 12), the studied raw materials are suitable for manufacturing vertically perforated (checker) bricks and clay roofing tiles. Where sample ID Nyoka (red) and Mduwa (green) are suitable for perforated bricks and sample ID Chapuma, are suitable for roofing tiles.

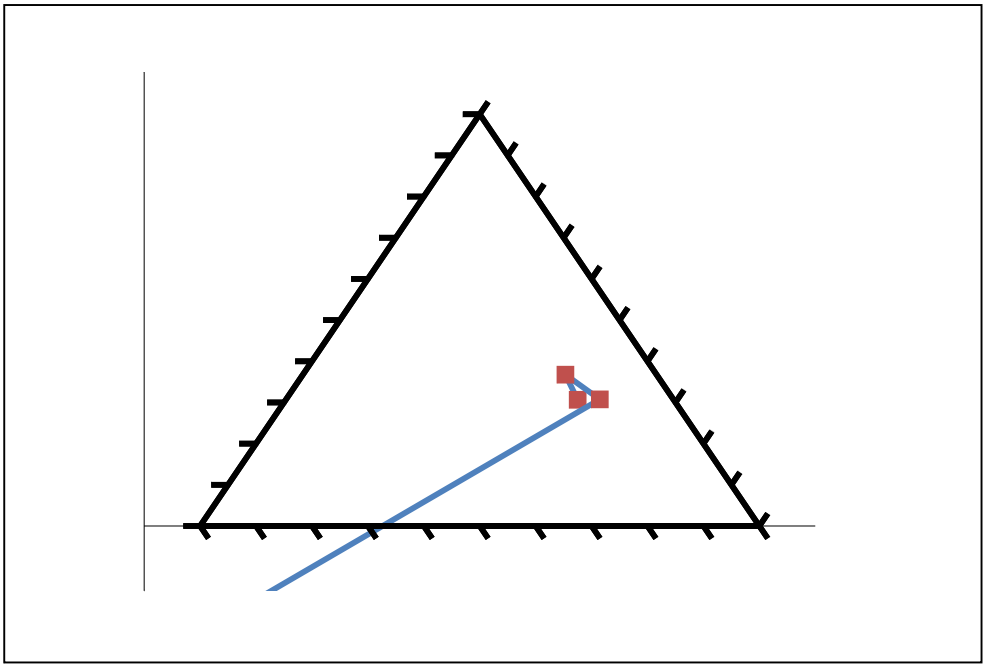


Figure 11: Soil classification diagram showing Nyoka (Red), Chapuma (Blue), and Mduwa (Green)

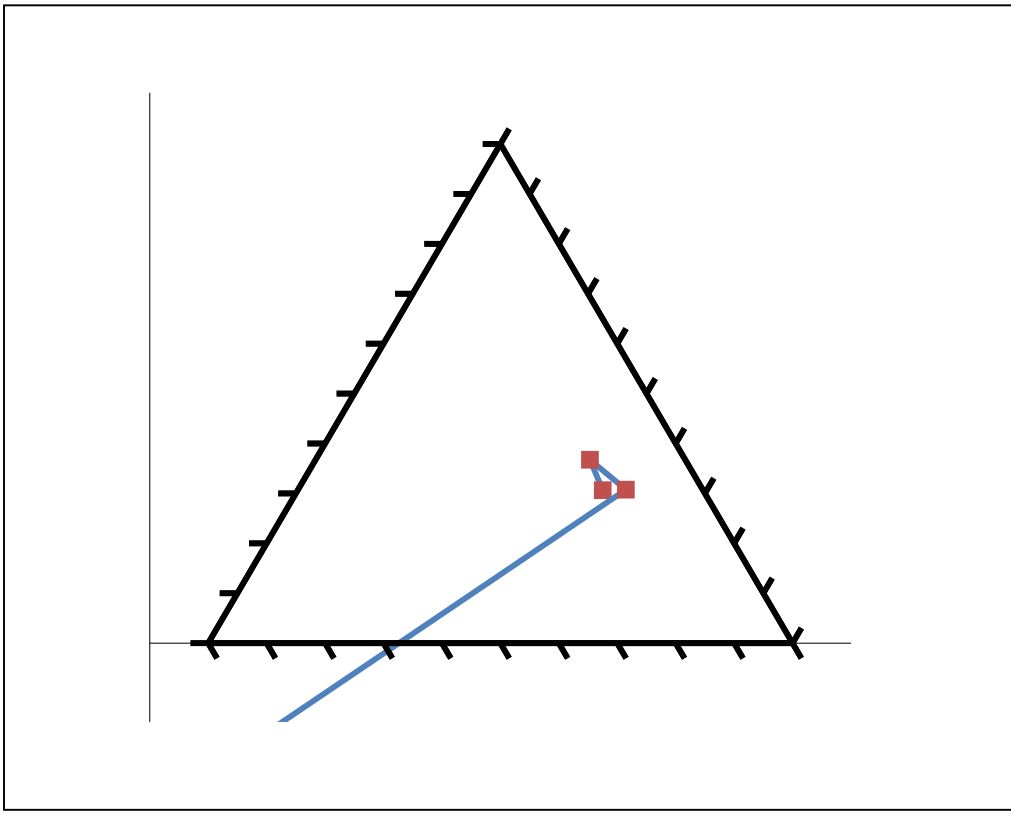


Figure 12 Winkler diagram showing Nyoka (Red), Chapuma (Blue), and Mduwa (Green)

4.2 Chemistry of the samples

The chemical analysis of the samples is presented in Table 3. The main components in all the clays were SiO_2, Al_2O_3, and Fe_2O_3, whereas the minor components were MnO, TiO_2, MgO, CaO, Na_2O, K_2O, and P_2O_5.

Sample ID	Nyoka	Chapuma	Mduwa
SiO_2	51.16	60.09	41.57
Al_2O_3	24.91	24.14	23.72
Fe_2O_3	15.71	9.65	30.59
MnO	0.08	0.2	0.35
TiO_2	1.63	3.43	1.43

MgO	1.27	0.48	0.01
CaO	1.24	1.09	0.43
Na_2O	0.02	0.02	0
K_2O	3.77	0.9	1.88
P_2O_5	0.02	0	0.03
TOTAL	99.81	100	100.01

Table 4: Chemical compositions of samples

Taking account of the clay chemical composition and the discernible domains of Figure 4, the considered clay may be used as feeding material for red stoneware tiles. This applies to sample ID Nyoka and Module. Sample ID Chapuma does not fall in any defined zone of the ternary diagram. This is due to the low Al_2O_3 supported by the high amount of SiO_2.

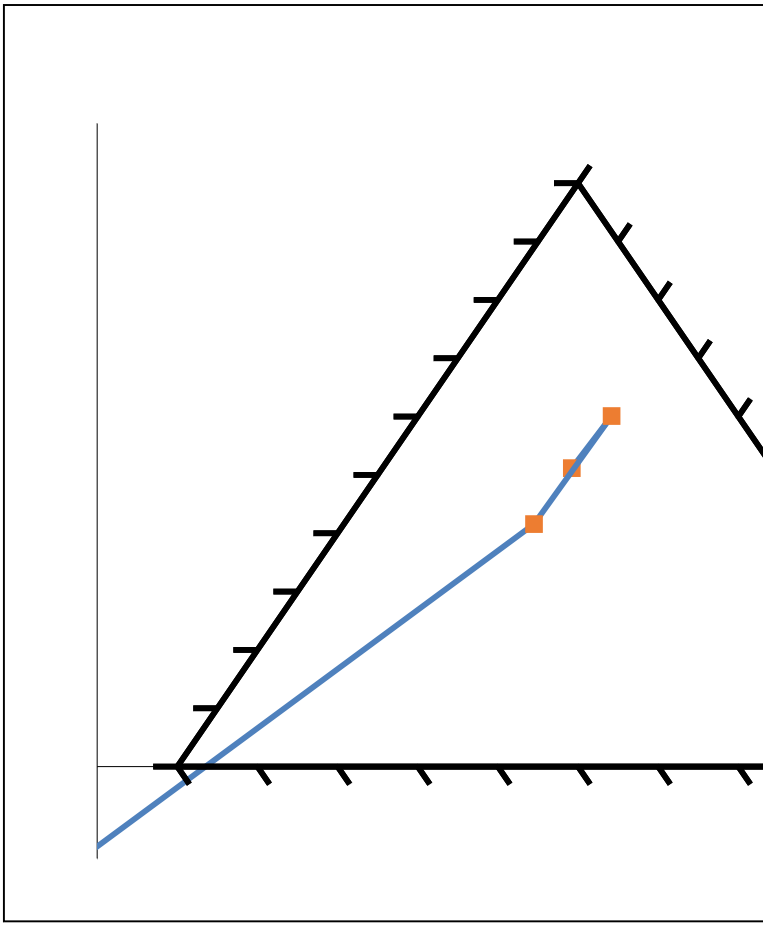


Figure 13: Chemical composition domains for preparing stoneware tiles, Nyoka (red), Chapuma (blue), and Mduwa (green).

The alkali and alkaline oxides (K_2O, CaO, MgO, Na_2O) act as a flux; thus their high content induces early vitrification (Bender & Händle, 1982). These help the low material to reach the melting point at lower firing temperatures. The higher Fe_2O_3 content in the samples is suggested to have originated from the weathering and alteration of basalt rocks (Masheane et al., 2016). The Fe_2O_3 gave reddish color clay-based products after firing in reducing conditions. The presence of relatively low CaO in all the clays (less than 2 %) is an indication of non-calcareous clays.

5 CONCLUSION

The Mchinji clays from Nyoka village, Chapuma village, and Chikoza village were studied for their particle size distribution and chemical properties. The following conclusions are drawn:

1. The Winkler diagram indicates that Nyoka and Mduwa can be used for bricks (common or vertically perforated) formulation. Chapuma can be used for clay roofing tile formulation.
2. Projection of the chemical composition of the studied clays on the ternary (empirical) discriminant clarifies their suitability for ceramic products where Nyoka and Mduwa are stonewares.

However, it must be emphasized that according to Machailidis et al. (2010), conclusions based only on chemical characteristics may lead to misjudgment concerning the suitability of clays for ceramic application. Mineralogical and mainly technological characteristics (e.g., firing tests) are necessary for correct conclusions.

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REPUBLIC OF MALAWI

GEOLOGICAL SURVEY DEPARTMENT

5/12/2021

58	Ce	Cerium	315.6	ppm	6.8
59	Pr	Praseodymium	48.3	ppm	2.4
60	Nd	Neodymium	155.3	ppm	1.0
62	Sm	Samarium	4.3	ppm	0.9
70	Yb	Ytterbium	< 2.4	ppm	-
72	Hf	Hafnium	4.8	ppm	0.6
73	Ta	Tantalum	< 0.8	ppm	-
74	W	Tungsten	2.0	ppm	0.8
79	Au	Gold	< 0.1	ppm	-
80	Hg	Mercury	< 0.1	ppm	-
81	Tl	Thallium	< 0.2	ppm	-
82	Pb	Lead	34.4	ppm	0.4
83	Bi	Bismuth	< 0.3	ppm	-
90	Th	Thorium	19.0	ppm	0.4
92	U	Uranium	3.8	ppm	0.5

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Appendix B

5/12/2021

Sample Name	CHAPUMA	Dilution Material	-
Method	Geochem Traces cups (A2)	Sample Mass	5.0000
Sample Folder	May 2021	Dilution Mass	-
Sample Type	Powder	Dilution Factor	-
Sample Status	AAAAXXXX	Measurement Date	5/12/2021 1:00 PM
Operator	Admin User	Evaluation Date	5/12/2021 1:00 PM

Results - CHAPUMA

The error is the statistical error with 1 sigma confidence interval

		Element	Concentration		Abs. Error
11	Na_2O	Sodium oxide	< 0.016	%	-
12	MgO	Magnesium oxide	0.3625	%	0.0057
13	Al_2O_3	Aluminium oxide	18.13	%	0.02
14	SiO_2	Silicon dioxide	45.27	%	0.02
15	P_2O_5	Phosphorus pentoxide	< 0.00007	%	-
16	SO_3	Sulfur trioxide	0.1291	%	0.0006
17	Cl	Chlorine	0.01543	%	0.0001
19	K_2O	Potassium oxide	0.6733	%	0.0006
20	CaO	Calcium oxide	0.8199	%	0.0006
22	TiO_2	Titanium dioxide	25760	ppm	10
23	V	Vanadium	190.9	ppm	1.5
24	Cr	Chromium	82.6	ppm	0.3
25	MnO	Manganese(II) oxide	1474	ppm	1
26	Fe_2O_3	Iron(III) oxide	7.246	%	0.003
27	Co	Cobalt	23.7	ppm	3.5
28	Ni	Nickel	42.4	ppm	0.6
29	Cu	Copper	28.0	ppm	0.5
30	Zn	Zinc	65.4	ppm	0.4
31	Ga	Gallium	22.4	ppm	0.3
32	Ge	Germanium	0.3	ppm	0.1
33	As	Arsenic	0.8	ppm	0.2
34	Se	Selenium	1.9	ppm	0.1
35	Br	Bromine	1.0	ppm	0.1
37	Rb	Rubidium	29.0	ppm	0.1
38	Sr	Strontium	81.8	ppm	0.2
39	Y	Yttrium	58.3	ppm	0.2
40	Zr	Zirconium	886.7	ppm	0.6
41	Nb	Niobium	34.0	ppm	0.2
42	Mo	Molybdenum	< 0.1	ppm	-
44	Ru	Ruthenium	< 0.2	ppm	-
45	Rh	Rhodium	< 0.2	ppm	-
46	Pd	Palladium	< 0.2	ppm	-
47	Ag	Silver	1.6	ppm	0.2
48	Cd	Cadmium	< 0.2	ppm	-
49	In	Indium	< 0.3	ppm	-
50	Sn	Tin	3.7	ppm	0.4
51	Sb	Antimony	3.6	ppm	0.4
52	Te	Tellurium	10.8	ppm	1.0
53	I	Iodine	19.8	ppm	1.2
55	Cs	Cesium	51.7	ppm	2.7
56	Ba	Barium	1213	ppm	5
57	La	Lanthanum	172.5	ppm	5.1

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58	Ce	Cerium	234.9	ppm	6.6
59	Pr	Praseodymium	< 1.0	ppm	-
60	Nd	Neodymium	114.5	ppm	0.9
62	Sm	Samarium	< 1.5	ppm	-
70	Yb	Ytterbium	< 2.5	ppm	-
72	Hf	Hafnium	21.8	ppm	0.9
73	Ta	Tantalum	3.2	ppm	1.3
74	W	Tungsten	1.5	ppm	0.6
79	Au	Gold	< 0.1	ppm	-
80	Hg	Mercury	< 0.1	ppm	-
81	Tl	Thallium	< 0.2	ppm	-
82	Pb	Lead	22.4	ppm	0.3
83	Bi	Bismuth	< 0.3	ppm	-
90	Th	Thorium	13.7	ppm	0.2
92	U	Uranium	1.8	ppm	0.2

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Appendix C

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5/12/2021

Sample Name	MDUWA	Dilution Material	-
Method	Geochem Traces cups (A2)	Sample Mass	5.0000
Sample Folder	May 2021	Dilution Mass	-
Sample Type	Powder	Dilution Factor	-
Sample Status	AAAAXXXX	Measurement Date	5/12/2021 12:07 PM
Operator	Admin User	Evaluation Date	5/12/2021 12:07 PM

Results - MDUWA

The error is the statistical error with 1 sigma confidence interval

	Element		Concentration		Abs. Error
11	Na_2O	Sodium oxide	< 0.0027	%	-
12	MgO	Magnesium oxide	< 0.0050	%	-
13	Al_2O_3	Aluminium oxide	17.83	%	0.02
14	SiO_2	Silicon dioxide	31.25	%	0.02
15	P_2O_5	Phosphorus pentoxide	0.0194	%	0.0011
16	SO_3	Sulfur trioxide	0.1408	%	0.0007
17	Cl	Chlorine	0.00550	%	0.0000
19	K_2O	Potassium oxide	1.413	%	0.001
20	CaO	Calcium oxide	0.3203	%	0.0004
22	TiO_2	Titanium dioxide	10730	ppm	10
23	V	Vanadium	356.0	ppm	1.1
24	Cr	Chromium	77.8	ppm	0.3
25	MnO	Manganese(II) oxide	265.9	ppm	0.4
26	Fe_2O_3	Iron(III) oxide	23.00	%	0.01
27	Co	Cobalt	< 0.3	ppm	-
28	Ni	Nickel	74.5	ppm	1.0
29	Cu	Copper	102.7	ppm	0.9
30	Zn	Zinc	59.8	ppm	0.6
31	Ga	Gallium	25.1	ppm	0.4
32	Ge	Germanium	< 0.3	ppm	-
33	As	Arsenic	7.4	ppm	0.3
34	Se	Selenium	0.9	ppm	0.1
35	Br	Bromine	< 0.2	ppm	-
37	Rb	Rubidium	67.0	ppm	0.3
38	Sr	Strontium	94.9	ppm	0.3
39	Y	Yttrium	45.2	ppm	0.3
40	Zr	Zirconium	624.5	ppm	0.7
41	Nb	Niobium	15.7	ppm	0.3
42	Mo	Molybdenum	37.5	ppm	0.4
44	Ru	Ruthenium	< 0.2	ppm	-
45	Rh	Rhodium	< 0.2	ppm	-
46	Pd	Palladium	< 0.2	ppm	-
47	Ag	Silver	1.5	ppm	0.3
48	Cd	Cadmium	1.0	ppm	0.5
49	In	Indium	1.0	ppm	0.6
50	Sn	Tin	3.3	ppm	0.4
51	Sb	Antimony	2.6	ppm	0.5
52	Te	Tellurium	11.7	ppm	1.0
53	I	Iodine	18.3	ppm	1.2
55	Cs	Cesium	58.5	ppm	3.0
56	Ba	Barium	624.7	ppm	4.7
57	La	Lanthanium	190.3	ppm	5.6

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5/12/2021

58	Ce	Cerium	257.8	ppm	7.2
59	Pr	Praseodymium	33.7	ppm	2.3
60	Nd	Neodymium	96.5	ppm	0.8
62	Sm	Samarium	< 1.5	ppm	-
70	Yb	Ytterbium	< 4.2	ppm	-
72	Hf	Hafnium	14.8	ppm	1.5
73	Ta	Tantalum	7.0	ppm	2.6
74	W	Tungsten	< 1.4	ppm	-
79	Au	Gold	< 0.1	ppm	-
80	Hg	Mercury	< 0.1	ppm	-
81	Tl	Thallium	< 0.2	ppm	-
82	Pb	Lead	40.3	ppm	0.6
83	Bi	Bismuth	< 0.3	ppm	-
90	Th	Thorium	28.1	ppm	0.9
92	U	Uranium	7.2	ppm	0.6

2 / 2

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Appendix D

Good day,

I acknowledge receipt of your samples on 07/05/2020 at Agrilab for analysis of the following Parameters:

Soil:

Particle Size Distribution

Number of Samples: 3

Your expected results date is 28/05/2020.

Please feel free to contact me should you need any more information

Regards,

Ashleigh White

Laboratory Administrator

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