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Research Article

Innovative Shelter Assistance Service and Mud Brick Productions for Bambasi Woreda, Assosa Zone Benishangul-Gumuz Region, Western Ethiopia

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Abstract

Earth-based construction materials, particularly mud bricks, have been used for thousands of years and continue to play a vital role in the housing sector of developing regions. It is estimated that nearly 30% of the world's population currently lives in earthen dwellings, highlighting the ongoing relevance of this traditional building material. Mud bricks are inexpensive, environmentally friendly, energy-efficient, and rely on locally available resources, making them a sustainable alternative to conventional construction materials, especially in rural and low-income areas. This study investigates the suitability of locally available soil for mud brick production and examines the influence of sand content on the mechanical properties of mud bricks. Soil samples were collected from the Benishangul Gumuz Regional State, Ethiopia, an area characterized by geological formations such as meta-granite, schist, meta-basalt, and meta-diorite rock units. Granulometric analysis was conducted to determine the particle size distribution of the soil, while standard laboratory tests were used to evaluate the bending and compressive strength of mud bricks produced with varying sand contents. The granulometry results indicate that the soil consists of approximately 5–10% sand and 90–95% fines. This composition falls within the acceptable range recommended by previous studies for mud brick manufacturing, confirming the suitability of the soil for earthen construction. Experimental results further reveal that increasing the sand content beyond the optimal range leads to a noticeable reduction in both bending and compressive strength. This reduction is attributed to decreased material density and weakened inter-particle adhesion, which negatively affect the structural integrity of the mud bricks. The findings of this study emphasize the importance of proper soil selection and mix proportioning in mud brick production. Maintaining an appropriate balance between sand and fine particles is crucial to achieving adequate strength and durability. The results provide valuable technical guidance for the use of local soils in sustainable construction practices within the study area and similar geological contexts. Overall, the study supports the continued use of mud bricks as a viable, low-cost, and environmentally sustainable building material when properly designed and manufactured.

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Keywords

Mud Brick, Granulometry, Soil, Meta-Basalt

1. Introduction

1.1. Background

Earth-based construction materials, particularly mud bricks, have been used for thousands of years, and approximately 30% of the world's population still resides in earthen shelters. Mud bricks are inexpensive, environmentally friendly, and widely available, making them a sustainable alternative to conventional building materials [1, 2]. They have been extensively employed in construction worldwide, particularly in hot and arid desert climates such as those in many Arabian countries, where traditional production involves mixing soil and water into a workable paste. Despite their historical significance, limited research has examined the behavior and performance of historic mud brick and rammed earth structures, particularly in Latin America. This knowledge gap has contributed to the deterioration of heritage buildings, which form an essential part of architectural and cultural identity.

In Colombia, for instance, approximately 90% of heritage buildings are constructed using earth-based techniques, many of which are located in intermediate to high seismic risk zones. Earth construction methods, including mud bricks, rammed earth, and wattle-and-daub, were introduced during Spanish colonization and remain widely used in rural housing due to the accessibility of raw materials and low construction costs [3, 4]. The use of soil as a primary building material represents one of the technologies most adapted to environmental conditions and contemporary concepts of sustainable construction. Given the increasing environmental impact of conventional building materials, there is a growing need to develop alternatives that efficiently utilize natural resources. Earth-based construction minimizes ecosystem disturbance and exhibits one of the lowest ecological footprints among building materials [5, 6].

Mud bricks also offer several practical advantages over conventional materials, such as concrete masonry units, including minimal processing requirements, low cost, global availability of raw materials, reduced need for skilled labor, and satisfactory thermal performance in hot climates [7, 8]. This study evaluates the quality and suitability of locally available soils for mud brick production in the Benishangul Gumuz Regional State, western Ethiopia. The geology of the study area is characterized by meta-granite, schist, meta-basalt, and meta-diorite rock units [9, 10]. Laboratory analyses were conducted to assess soil properties relevant to mud brick manufacturing, providing insight into the potential use of local soils for sustainable and environmentally responsible construction applications.

1.2. Location and Accessibility

The study area is found in Benishangul Gumuz regional state, the Western part of Ethiopia, which is some 750 km away from Addis Ababa. Geographically, is bounded between 9 º44'59.99" 9 º74'99"N and, 34 ⁰29'59.99'' to 34⁰49'99.98'' E, respectively, with an average elevation of 1668 m m.a.s.l. Bambasi Woreda is bordered by the mao komo Special Woreda on the south west, Abramo and Oura Woreda in the north west, Buldiglu in the north east and Bengua in the southeast. As shown in the Figure 1, the study area is accessed through asphalted and graveled road.

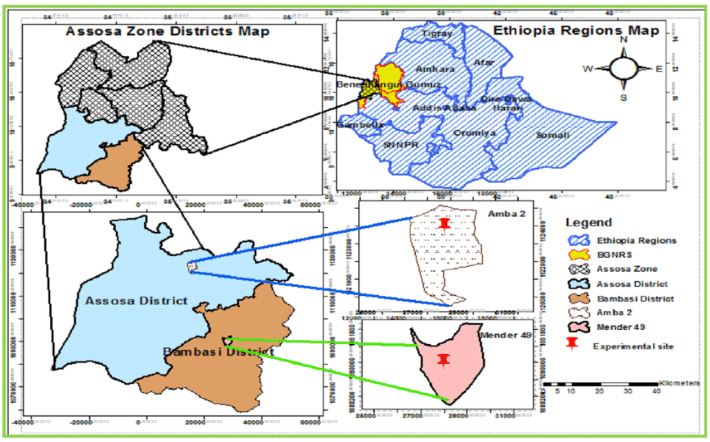

Figure 1. *Location and Accessibility of the Bambasi woreda (Adopted from Wassie Haile).*

2. Objective

The aim of this study was to,

The objective of this study is to evaluate and promote innovative shelter assistance services through the production and application of mud bricks for sustainable housing development in Bambasi Woreda, Assosa zone, Benishangul-Gumuz Regional State, Western Ethiopia.

Improve the proprieties of the mixtures of teff straw and clay. By conducting study related to the mixtures of Teff straw, clay for their use as building material. And this study tries to investigate the soil types of the study area.

3. Methodology

3.1. Materials and Methods

3.1.1. Materials

The materials used in this study for mud brick production were sand and mud as the main matrix, and hay/ straw/ fiber as fibrous materials. Materials necessary for mud brick productions are shown in Figure 2.

Figure 2. *necessary materials for mud brick productions.*

3.1.2. Methods

In this experimental program, physical tests were carried out on natural mud obtained from Bildigilu woreda. The objective of these tests was to analyze and investigate the physical properties of the material used in manufacturing the bricks. A sample of the soil material used for mud brick productions are shown in Figures 3 and 4.

Figure 3. *Pit samples Collected from Sonka Kebele site 01.*

Figure 4. *Pit samples Collected from Mutsa Kebele site 02.*

3.2. Procedures of Mud Brick Production

The manufacture of mud bricks requires careful consideration of soil composition, as the use of this material as a masonry unit is not yet fully regulated. One of the primary requirements is that the soil should not consist of pure clay, as excessive clay content leads to high drying shrinkage and the formation of cracks, which negatively affect the durability and mechanical performance of the bricks.

According to the Peruvian Technical Standard NTE E.080, suitable soil for mud brick production should fall within specific particle size distribution ranges. The recommended composition includes sand content between 5% and 10%, silt content between 35% and 55%, and clay content between 25% and 35%. In addition, soils containing organic matter should not be used, as organic materials adversely affect bonding and strength [11]. These proportions are intended to ensure adequate cohesion, workability, and dimensional stability of the mud bricks. It should be noted that these ranges may vary when stabilized mud bricks are produced using additives such as lime or cement.

In this study, soil selection was carried out in accordance with the above criteria. Visual inspection and preliminary field tests were first conducted to identify potentially suitable soils. Representative soil samples were then collected from the study area and subjected to laboratory analyses to confirm compliance with the recommended grading limits. Figure 5 illustrates the process of selecting suitable soil for mud brick production at the study site.

Figure 5. *Preparation of soil for mud brick production at site1.*

The selected soil is mixed with an appropriate amount of water to obtain a workable and homogeneous mixture. Adequate clay content is essential to provide cohesion and strength after drying; insufficient clay results in weak bricks with low structural integrity. Conversely, if the mixture lacks sufficient sand, excessive shrinkage may occur during drying, leading to cracking. Therefore, a balanced proportion of sand and clay is necessary to ensure dimensional stability and mechanical performance. A common field test is used to evaluate the suitability of soil for mud brick production [12]. This test involves taking a small quantity of the moistened soil mixture and manually forming approximately five to six spherical pellets with a diameter of about 2 cm. After the pellets are completely dried, they are subjected to a simple strength test by applying pressure using two fingers. If the pellets break into large fragments, the soil is considered suitable for mud brick preparation. If the pellets crack excessively during drying, the soil contains an excessive amount of sand. Conversely, if the pellets remain highly moldable and do not break easily, the soil contains too much clay. An intermediate behavior between these two extremes indicates an appropriate soil composition. Figures 6 and 7 illustrate the soil mixing, pellet testing, and overall procedures involved in mud brick production.

Figure 6. *Mixing the soil and the straw at the site.*

Figure 7. *Mixing the soil and the straw with water the site.*

Once suitable soil is selected, it is mixed with water to obtain a homogeneous paste and allowed to mature for approximately three days. This maturation period is essential for activating the clay minerals and improving the cohesion of the mixture. Following this process, preliminary test mud bricks are prepared. If visible cracks develop within the first 24 hours of drying, the soil is considered to contain excessive clay, and additional sand must be incorporated to improve dimensional stability. This preliminary testing stage is crucial, as it enables the determination of the optimal soil mixture prior to large-scale mud brick production. After the mixture proportions are finalized, the mud bricks are shaped either manually or using molds of various sizes and shapes. Traditionally, natural fibers such as straw are added to the mixture to enhance tensile strength and reduce the likelihood of shrinkage cracking during drying. The freshly molded mud bricks are then placed in a well-ventilated area and dried under natural sunlight. Complete drying typically requires between 10 and 20 days, depending on local climatic conditions. In humid or cold environments, the drying period may be extended, whereas in dry climates with strong sunlight, drying occurs more rapidly [13]. Before use in construction, mud bricks must be fully dried to achieve adequate strength and durability. In some traditional practices, the drying period may extend up to approximately 25 days to ensure complete moisture loss. Figures 8, 9, 10, and 11 illustrate the preparation procedures, molding process, and newly produced mud bricks prepared under laboratory conditions.

Figure 8. *Mold to cast the mud.*

Figure 9. *Casting the mud using the Mold.*

Figure 10. *removing the mold.*

Figure 11. *Exposing the mud brick to sunlight.*

4. Results and Discussion

4.1. Sample Description

Soil specimens used in this study were collected from the designated study area in Bambasi Woreda. Three test pits were excavated at selected locations, and Global Positioning System (GPS) coordinates were recorded to accurately identify the sampling sites. The upper layers of all test pits consisted mainly of disturbed and relatively dry soil. However, with increasing depth, noticeable variations in soil properties were observed, including changes in moisture content, grain size distribution, and overall composition. To preserve the natural moisture condition, all collected soil samples were immediately sealed in plastic covers to prevent moisture loss prior to laboratory testing. Sieve analysis was conducted to determine particle size distribution and the proportion of fines. The soil samples were washed through a No. 200 sieve to separate fine particles. The results indicated that the soil consisted of approximately 8.9% sand and 91.1% fines [13]. In addition, Atterberg limit tests, including liquid limit and plastic limit determinations, were performed to evaluate the plasticity characteristics of the soil.

4.2 Mud Brick Characterization Tests

A series of laboratory tests were conducted to characterize the soil and assess its suitability for mud brick production. The tests included:

1) Moisture content determination,
2) Grain size analysis, and
3) Atterberg limit tests.

4.2.1 Moisture Content

Moisture content plays a critical role in influencing the engineering properties of both coarse-grained and fine-grained soils when used for construction purposes. It significantly affects soil compaction behavior, settlement characteristics, and overall suitability as a construction material. In fine-grained soils, variations in moisture content are closely associated with swelling and shrinkage behavior, which directly impacts the dimensional stability and durability of mud bricks. Furthermore, the consistency and workability of fine-grained soils are largely governed by their moisture condition.

In this study, soil samples were collected and promptly submitted for laboratory analysis to determine their natural moisture content. Immediate testing ensured that the measured values accurately represented in-situ conditions, thereby providing reliable data for evaluating soil performance in mud brick manufacturing.

The result is shown below in Table 1. It is calculated by Wt. Of water (g) times 100 over Wt. Of dry soil (g).

Moisture content = massof wet soil− mass of dry soil,

Sample of pt2= $4800.5g\_\ 3846.5g = 954g$, the weight of water in the soil sample is $954g$

Aver. Moisture content= $\text{weight of wet soil} / \text{weight of dry soil} * 100$, so $954/3846.5 * 100 = 24$

Table 1. Average moisture content, % of each soil sample of study area.

Serial No	Depth(m)	Location		Elevation(m)	Aver. moisture content
		E	N		
PT1	1.5	34º59’408’’	10º07’49.4’’	1569	27.3
PT2	1	34º59’47’’	10º08’26.1’’	1520	24.8
PT3	1.5	345915.5	10º07’40.8’’	1553	26.5

4.2.2 Grain Size Analysis

Grain size analysis was conducted to determine the particle size distribution of the soil and to support its classification for mud brick production. Soil particles larger than 0.075 mm (No. 200 sieve) were analyzed using standard sieve analysis techniques. This method involves a mechanical separation process in which soil fractions are screened through a series of sieves with progressively smaller openings to quantify the distribution of coarse particles.

The grain size distribution results were used to classify the soil according to the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) classification system. These classification systems provide a standardized basis for evaluating soil suitability in construction applications [14].

The laboratory test results indicate a high percentage of fine particles, consistent with the requirements for mud brick production when properly proportioned. Figure 12 presents the grain size distribution curves obtained from the laboratory analysis, including results from additional soil samples collected from the study area.

Figure 12. Shows sieve analysis.

The laboratory result of the AASHTO and USCS classification of the entire soil sample is given in the Table 2 and Figure 13 shows relation of Sieve size and percentage of retained soil sample below.

Table 2. *Shows the percentage of soil that are retained or passed using sieve analysis.*

Pit 1				
Sieve Size(mm)	**Wt Retd.**	**% Wt Retd**	**Cum Wt Retd.**	**% Passing**
37.5	0	0.00	0.00	100.00
25	0	0.00	0.00	100.00
19	0	0.00	0.00	100.00
12.5	0	0.00	0.00	100.00
9.5	0	0.00	0.00	100.00
4.75	1	0.20	0.20	99.80
2.00	3.5	0.70	0.90	99.10
0.425	30	6.00	6.90	93.10
0.075	128	25.60	32.50	67.50
Pan	337.50	67.50	100.00	`
Total retain(gm)	500			

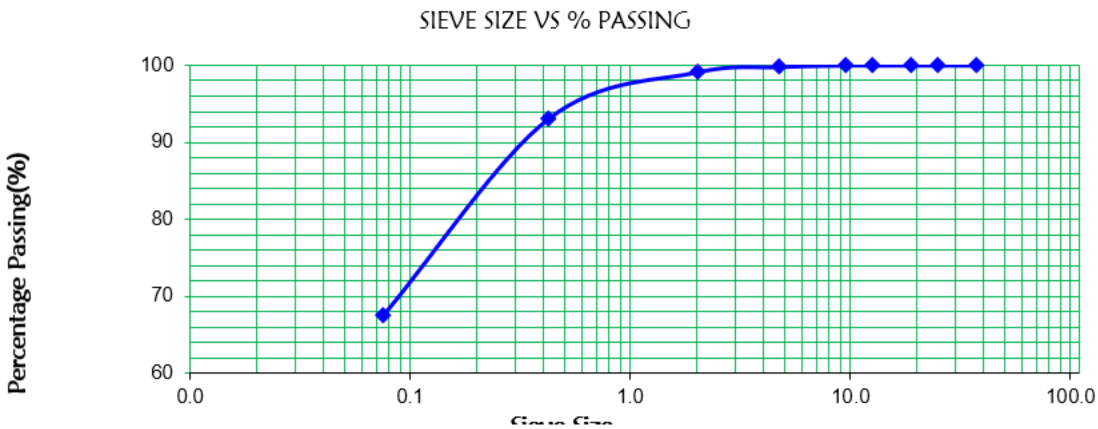

Figure 13. *Shows relation of Sieve size and percentage of retained soil sample.*

Table 3. *Dry Sieve Analysis (Test Method AASHTO T- 88).*

		pit2		
seive opeing (mm)	**weight of retained soil**	**%Retained**	**CC%Retained**	**%PASSING**
9.5	0	0.00	0.00	100.00
4.75	11	1.87	1.87	98.13
2	9	1.53	3.39	96.61
0.425	60	10.18	13.57	86.43
0.075	170	28.84	42.41	57.59
pan	337.5	57.25	99.66	0.34
	587.5			

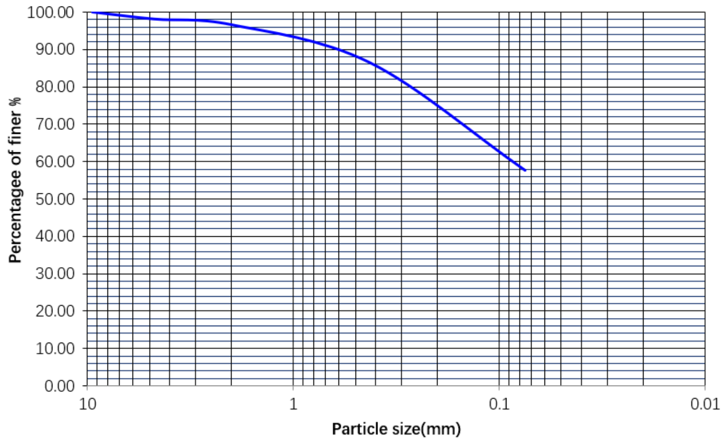

Figure 14. Grain size analysis curve of soil sample collected from the site.

For two samples i.e Figure 13 and Figure 14, the percent pass for 0.075 mm (No 200, Standard sieves), was more than 50%. Therefore, it is classified as fine grained soils in the USCS classification systems.

4.2.3. Atterberg Limits

Atterberg limits are defined as the critical water content boundaries that describe the transition of fine-grained soils from one consistency state to another. Specifically, soils passing through a 0.425 mm sieve are tested to determine their liquid limit (LL) and plastic limit (PL). These limits provide essential information about the soil's plasticity and workability and are widely used to predict engineering behavior such as shrinkage, swelling, and compressibility. Furthermore, Atterberg limits are used to classify fine-grained soils according to the Unified Soil Classification System (USCS) and the AASHTO system, which assists in assessing soil suitability for construction applications, including mud brick production.

(i). Liquid Limit

The liquid limit (LL) represents the water content at which a soil changes from a plastic to a liquid state. In this study, a flow curve was constructed by plotting the water content of the soil samples against the logarithm of the number of blows in the Casagrande cup test (Figure 14). Within the range of 21 to 34 blows, the plotted points approximately form a straight line. The water content corresponding to 25 blows is defined as the liquid limit of the soil.

All tested soil samples, except Sample 1, have their liquid limits presented in Appendix B. Soil Sample 1, which demonstrated slightly different behavior, is illustrated separately in Figure 15. The results indicate that the tested soils exhibit suitable plasticity characteristics for mud brick production when appropriately mixed with sand to balance workability and dimensional stability.

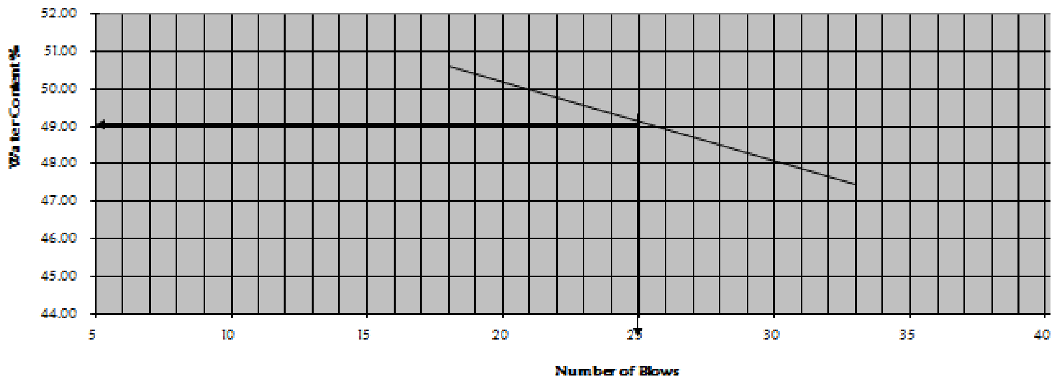

Figure 15. Plot of water content against the log.

(ii). Plastic Limit

The plastic limit (PL) is defined as the moisture content at which soil transitions from a semi-solid state to a plastic (flexible) state. This property is essential for evaluating the workability and handling characteristics of fine-grained soils used in mud brick production. The plastic limit provides information on the soil's ability to be molded without cracking or crumbling, which is critical for ensuring dimensional stability and durability of mud bricks [15].

In this study, the plastic limit was determined using standard laboratory equipment, including moisture cans, a precision balance, a glass plate, a wash bottle filled with distilled water, and a drying oven set at 105 ℃. Soil samples were carefully rolled and manipulated until they reached the point at which they began to crumble, indicating the plastic limit moisture content.

Figures 16, 17, and 18 illustrate the laboratory procedures for determining the liquid limit and plastic limit of the soil samples collected from the study area. The results indicate that the soils exhibit suitable plasticity characteristics for mud brick production when mixed in appropriate proportions, supporting their use as a sustainable building material in the region.

Figure 16. *Equipment used for Lab investigation Liquid limit of the soil samples.*

Figure 17. *Lab investigation Liquid limit of the soil samples.*

Figure 18. *Plastic limit of the soil samples.*

Table 4. *Shows Determination of Liquid Limit, Plastic Limit, Plastic Index and Classification of Soil.*

Pit 1 **TEST METHOD: AASHTO T89, T90 AND M145** **Liquid Limit W_L**			
Run Number	1	2	3
Tare Number	C	5	e2
A. Weight of Wet Soil + Tare	38.42	40.33	39.81
B. Weight of Dry Soil + Tare	31.25	32.41	32.56
C. Weight of Water (A – B)	7.17	7.92	7.25
D. Weight of Tare	16.23	16.11	18.41

Pit 1 **TEST METHOD: AASHTO T89, T90 AND M145** **Liquid Limit W_L**			
E. Weight of Dry Soil (B -D)	15.02	16.30	14.15
Water Content % (C / E x 100)	47.74	48.59	51.24
Number of Blows	33	23	18
Liquid Limit %	*49.0*		

Table 5. *shows PI specifications limit, plastic limit, and Liquid limit.*

Plastic Limit W_P			**Natural Moisture Content %**
Run Number	1	2	
Tare Number	C1	d5	
F. Weight of Wet soil + Tare	21.84	22.94	
G. Weight of Dry soil + Tare	21.01	21.91	
H. Weight of water (F – G)	0.83	1.03	
I. Weight of Tare	18.01	17.99	
J. Weight of Dry soil (G – I)	3.00	3.92	
Water Content % (H / J x 100)	27.6	26.3	
Plastic Limit % (Average)	*26.9*		

Table 6. *Atterberg limits analyzed and results for soil of pit of the study area.*

PI Specification Limit	**Pit2**				
	Liquid Limit				**Plastic Limit**
No. of Blows	33	26	22		
Container Number	H4	Front3	G2	C4	B2
Wt. of Container + Wet Soil (g) = (W1)	43.14	57.92	54.28	30.3	23.94
Wt. of Container + Dry Soil (g) = (W2)	32.74	44.25	41.67	26.61	20.51
Wt. of Container (g) = (W3)	11.5	18	18.23	18	13
Weight of Moisture (g) = (W1 - W2) = A	10.4	13.67	12.61	3.69	3.43
Weight of Dry Soil (g) = (W2 - W3) = B	21.24	26.25	23.44	8.61	7.51
Moisture Content (%) = (A / B) x 100	48.96	52.08	53.80	42.86	45.67
	52.52				44.26

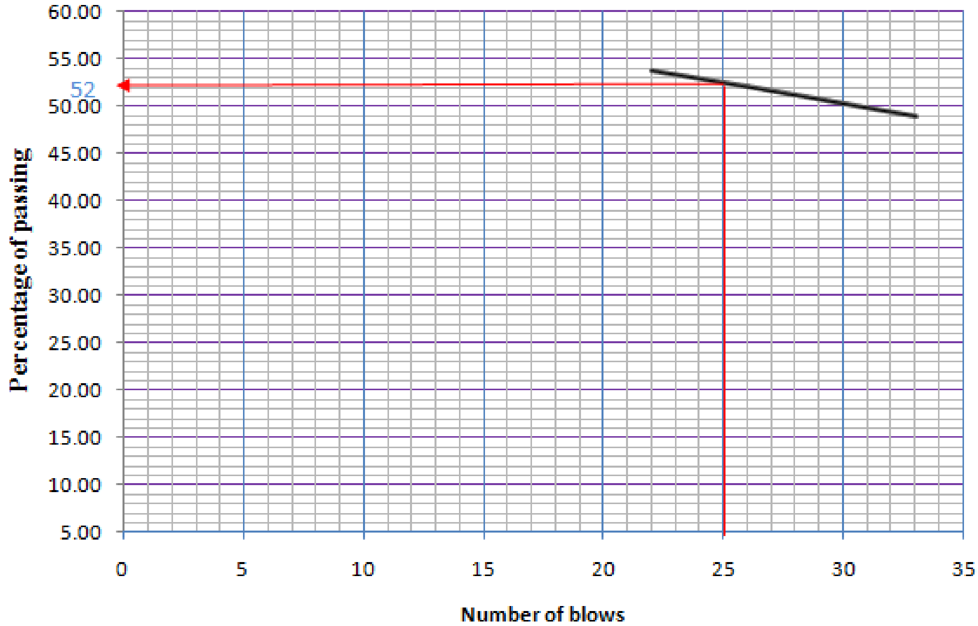

Figure 19. *Shows percentage of soil passed vs number of blows.*

Atterberg limit analysis shown Table 7 and Figure 19 shows percentage of soil passed vs number of blows liquid limit vs. plasticity index has been plotted and for two samples fall below A- line. Therefore, it is classified as silty and clay mixture. These kinds of soils have high water permeability capacity [16]. Therefore, the water which percolates through the weathered profile, when it reaches to the low permeable media, the seepage forces develops and ultimately leads to potential instability of the slope. From plasticity index of the soils of study area the all are grouped under low plastic, except the Pt3, because it is grouped higher plasticity.

Table 7. *Shows Atterberg limit analysis, liquid limit vs. plasticity index.*

No	Moisture content%	Atterberg limit			Description of plasticity properties	Classification of soil according to USCS.
		LL	PL	PI		
Pt1	28.55	49	26.9	22.1	In organic clay of low plasticity	clay soil of low plasticity
Pt2	22.5	52	32	20	In organic cay low plasticity	clay soil of low plasticity

From plasticity index of the soils of study area the all are grouped under low plastic, except the Pt3, because it is grouped higher plasticity. Figure 20 shows the general plastic limit and liquid limit of all samples that were collected at the site.

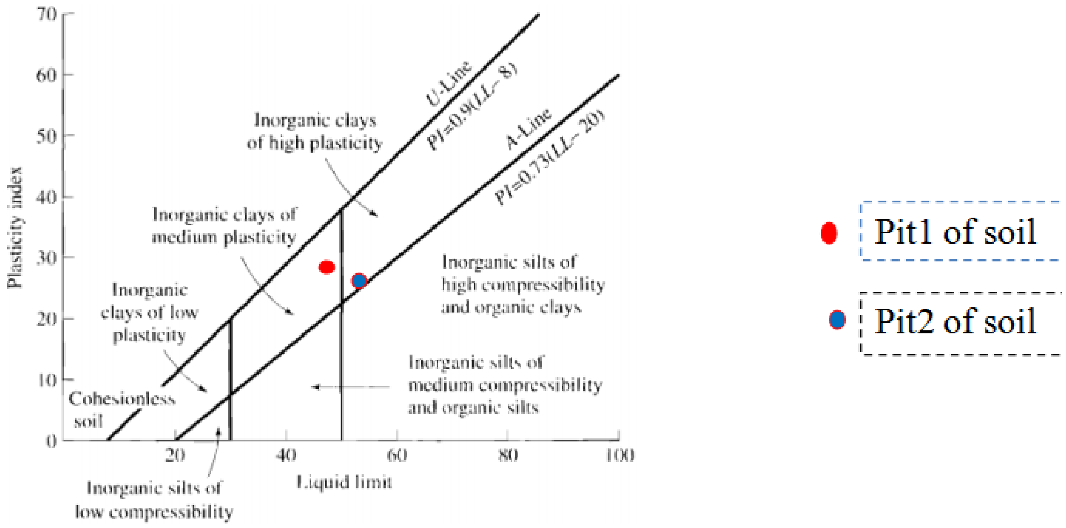

Figure 20. *Range of Liquid limit and Plastic Index for soil of study area by USCS classification*.

Therefore, it can be concluded from the above analysis that the soils of the study area have some clay content. However, it is in small amount thus soils in general possess low cohesion, same has been deduced from the laboratory results also. According to their grain size, soil particles are can be classified as shown the Figure 21 below.

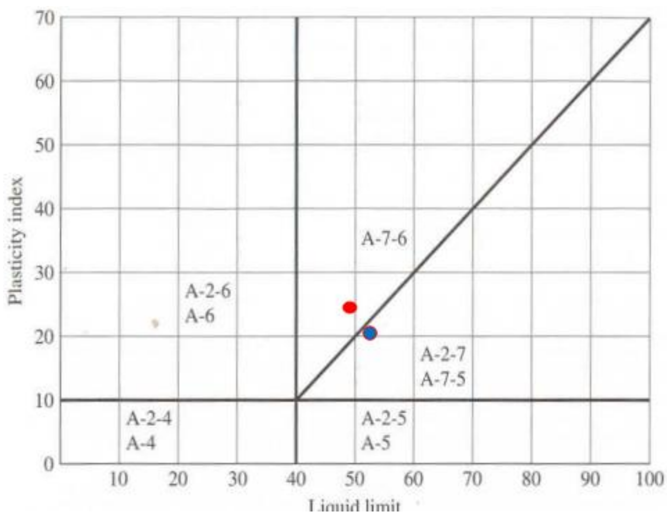

Figure 21. *Range of Liquid limit and Plastic Index for soil of study area by AASHTO classification.*

Soil particles classification according to AASHTO soil classification.

Based on AASHTO soil classification the laboratory result of the soil samples can be grouped as silty clay soils [7]. Therefore the general rating of the sub grade is excellent too good for construction of bricks as shown in Table 8.

Table 8. *Shows AASHTO soil classification.*

No	Moisture content%	Atterberg limit			Description of plasticity properties	Classification of soil according to USCS.	AASHTO Soil classification
		LL	PL	PI			
Pt1	28.55	49	26.9	22.1	In organic clay of low plasticity	clay soil of low plasticity	A-2-7

No	Moisture content%	Atterberg limit			Description of plasticity properties	Classification of soil according to USCS.	AASHTO Soil classification
		LL	PL	PI			
Pt2	22.5	52	32	20	In organic cay low plasticity	clay soil of low plasticity	A-2-7

5. Conclusion

During the preparation of mud brick samples, variations in the consistency of the soil mixture were observed, particularly with increasing straw content. Granulometric analysis indicated that the soil used for mud brick production consists of approximately 5–10% sand and 90–95% fines. This composition, supported by comparisons with previous studies, falls within the recommended range for mud brick manufacture, confirming the suitability of the soil for this purpose. The study also demonstrated that increasing the sand content in the mud brick mixture leads to a reduction in both compressive and flexural strength. This decrease is attributed to a lower material density and reduced particle adhesion, which negatively affect the structural performance of the bricks.

The mean values of compressive and flexural strength were analyzed, and the corresponding standard deviations were calculated at a 90% confidence level. The results exhibited considerable dispersion, which can be attributed to factors such as surface irregularities of the bricks and variations introduced during manual shaping and drying. Despite these variations, the findings indicate that the locally available soil, when appropriately proportioned and supplemented with natural fibers like straw, can produce mud bricks with sufficient mechanical performance for sustainable construction in the study area. Overall, this study confirms that mud bricks remain a viable, low-cost, and environmentally friendly building material, provided that proper soil selection, proportioning, and preparation techniques are employed.

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
PL	Plastic Limit
GPS	Global Positioning System
LL	Liquid Limit
PL	Plastic Limit
m.a.s.l	above mean sea level
USCS	Unified Soil Classification System

Conflicts of Interest

The authors declare no conflicts of interest.

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