ASSESSMENT OF BOREHOLE DRILLING STANDARDS COMPLIANCE AT UTEKON AND OLUKU BENIN CITY, EDO STATE, NIGERIA.

BY

IDOWU, Joshua

ENG2006230

THE DEPARTMENT OF CIVIL ENGINEEERING,

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN,

BENIN CITY,

NIGERIA.

APRIL, 2025.

`

ASSESSMENT OF BOREHOLE DRILLING STANDARDS COMPLIANCE AT UTEKON AND OLUKU BENIN CITY, EDO STATE, NIGERIA.

BY

IDOWU, Joshua

ENG2006230

A PROJECT SUBMITTED IN PARTIAL FUFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng) DEGREE IN THE DEPARTMENT OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA.

APRIL, 2025

`

PLAGIARISM

This work,**ASSESSMENT OF BOREHOLE DRILLING STANDARDS COMPLIANCE AT UTEKON AND OLUKU BENIN CITY, EDO STATE, NIGERIA,**by IDOWU, Joshua with Matriculation Number Eng2006230 of the Department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLIGIARISM TEST.

PROJECT COORDINATOR:

Name ……………………………………………………………………

Signature and Date…………………………………………………………

`

CERTIFICATION

This is to certify that this work was carried out by Idowu, Joshua Mat. No. ENG2006230, Department of Civil Engineering, Faculty Engineering, University of Benin City, Edo State, Nigeria.

SUPERVISOR: Engr. Dr. P. N. Ogbeifun

Name: ………………………………………………………………………………

Signature and Date ……………………………………………………………………

HEAD OF DEPARTMENT: Engr. Prof. Mrs. N. I. Ihimekpen

Name: ……………………………………………………………………………….

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

`

DEDICATION

I want to dedicate and thank God for the grace of life, strength and understanding to compile and complete this project, for nothing is impossible with God.

ACKNOWLEDGEMENT

I want to acknowledge God for the grace of life, strength and understanding to compile and complete this project, for nothing is impossible with God. I also want to extend my gratitude to my supervisor (Dr. Eng. Ogbeifun), for his exceptional guidance, unwavering support, and expert input throughout this project. His invaluable feedback and constructive critiques significantly enhanced this project, and I am deeply grateful for his supervision.

I am sincerely grateful for the tremendous leadership and continuous support of Engr. Prof. N. I. Ihimekpen, Head of Civil Engineering Department at University of Benin, whose excellent and profound dedication to academic excellence has been a continuous source of strength, hope and inspiration. I would also like to acknowledge my esteemed and dedicated lecturers: Engr. Prof. O.C. Izinyon, Engr. Prof. O.U. Orie, Engr. Prof. S.O. Osuji, Prof. A.N. Aniekwu, Engr. Prof. H.A.P. Audu, Engr. Prof. J.O. Okovido, Engr. Prof. E. Nwankwo, Engr. Dr. A.I. Agbonaye, Engr. Dr. R.O. Ogirigbo, Engr. Dr. IziengbeInerhunwa, Engr. Dr. N. Kayode Ojo, Engr. Dr. A. Rawlings, Engr. Dr. R. Ilaboya, Dr. L.O. Bobor, Engr. Dr. S.E. Okunofua, Engr. Dr. U, Ukeme, Engr. Dr. S.A. Adegbemileke, Engr. E. Oria Usifo, Engr. E. Musa, Engr. Mrs Ambrose Agabi, Engr. B. Omosefe, Mr. O. Osasu and Mr. C. Okolie, for their dedication to establishing professionalism within the department.

Lastly, I am deeply indebted to my family for their unwavering support throughout my academic journey. My mother, Idowu Mirrian, has been a constant source of love, encouragement, and strength. Her selfless sacrifices and prayers have motivated me to persevere. My sister, osahenruwen, has been loving and supportive, she has been one of my pillars in the area of finance. My grandfather, Prof. Osa Osemwota, has been my greatest support in terms of finance, and advice. My aunty, Omozusi for her big support for the whole family and myself, to my uncles Osemwota Osahon and Osemwota Osazee, I am deeply grateful for all the support and encouragement. To my friend's mother, Mrs. Aiyomogbezagha, for her love and support, I am also grateful to Miss Glory, my friend's aunty, Miss Inem Happy Sunday, and to all my friends, I am indeed grateful for their collective contributions to my academic success and appreciate the values they all instilled in me.

`

ABSTRACT

This study evaluates the compliance of borehole drilling practices with established standards at Utekon and Oluku in Benin City. A total of three boreholes were assessed, and data on drilling methods, casing, cementation, well completion were collected and soil logs used for sieve analysis to obtain D_{10} value used to obtain constant of permeability. The research aims to evaluate the level of adherence to industry guidelines and best practices in drilling of boreholes, with a focus on ensuring the sustainability and safety of groundwater resources.

A comprehensive field investigation was conducted, involving the collection and analysis of data from a representative sample of boreholes in the study area. The study assessed various aspects of borehole drilling, including drilling methods, casing, cementation practices and well completion.

The results of the study reveal significant deviations from standard practices in some aspects of borehole drilling, which could compromise the quality and sustainability of groundwater resources in the area. During investigation some drilling standards were ignored e.g. non-compliance to distance of borehole from structures such as septic tanks and inadequate site investigation and proper hydrological test conduction to know the depth of water table, the use of gravel packing was also ignored. Although the position of screen and the number of casings used were adequate.

The findings of this study have significant implications for groundwater management in the study area. They underscore the importance of regular monitoring and effective enforcement of regulations to prevent contamination and ensure the long-term sustainability of groundwater resources as well provision of suitable water to developing communities by government. In conclusion, borehole drilling at Utekon and Oluku are based on individual experiences and not based on hydrological standards, and this may result in health issues in the long run.

`

TABLE OF CONTENTS

`

`

`

LIST OF FIGURES

`

`

`

`

LIST OF TABLE

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Well drilling is an important aspect of construction. It is very important to understand that good water is very important to health and other processes that utilizes the use of water. According to (Driscoll, 1986) well drilling is the process of creating a hole in the ground to access water or other fluids. It must be known from my little research on contamination of water in Nigeria, I came across a report by (Adebowale, 2018), which reads that about one in three households in Nigeria consume contaminated water, a survey by the National Bureau of Statistics (NBS). This survey was carried out in 2016/2017 by NBS in collaboration with the National Primary Healthcare Development Agency (NPHCDA) and the National Agency for the Control of Aids (NACA). This survey estimated that the North-East states had lower access to improved drinking water, which contributed to water borne diseases. It was estimated that over 52.4 percent has access to improved water, while in South-West over 87.3 percent have access to improved water, in the South-South regions (area of concentration for this project) according to over 79 percent have access to good and clean water according to (NOIpolls., 2020). It is important to understand the importance of good access to water. For this reason well drilling is an important subject to Help Bridge the huge gap between those with good access to water and those who do not have access to clean waters especially in rural areas. According to (NOIpolls., 2020), it is observed that a large population of people get their water from borehole. According to a conference held by the Federal Ministry of Information and National Orientation, as written by (Anyawu, 2024) it was recorded that according to some experts in the water resources sector opined that over 110,000 boreholes have been drilled within the Federal Capital Territory, FCT, while more than 330,000 metric tons of water are extracted daily from the holes and these expert warned that indiscriminate drilling of boreholes and extraction of water from the ground are capable of upsetting the equilibrium of the earth as well as causing violent tremors (slight earthquakes) in the FCT. With this estimation accounted to FCT alone, we can easily pin point the demand of borehole water around the country. For this reason, I am going to be carrying out a survey at different locations to observe the methodology, depth of drilling to obtain water if it follows standard.

1.2 Statement of Research problem

Well drilling is a fundamental aspect of water harvesting system. Due to failure of provision of public water system by government, individuals have resulted to drilling their personal well and this tends to pose serious issues due to the fact that the drilling process will not be supervised by a certified Engineer and most individuals who embark on well drilling have no technical know-how according standards, and this has resulted to high rate of consumption of contaminated water. Some Communities in Benin City, face significant challenges in accessing clean and reliable groundwater resources due to inadequate well drilling practices and lack of adherence to hydrological standards. This has resulted in increased risk of water contamination, posing serious health threats to residents and affecting the sustainability of the aquifer. Poor understanding of hydrogeological conditions also contributes to the problem. This study seeks to address these above highlighted issues by investigating the procedures for accessing groundwater resources for the purpose of preventing water contamination.

1.3 Aim and Objectives

The aim of this study is to investigate if standards for well drilling are followed carefully to prevent water contamination in the above mention communities.

The objectives are:

To draw the attention of well drillers on the importance of following hydrological standards to prevent water contamination.

1. To develop guidelines for sustainable well drilling and construction.

2. To ensure improved access to clean groundwater for residents through well drilling policies.
3. To prevent any related water borne diseases in these communities.

1.4 Scope of Study

The scope of this study focuses on assessment of groundwater resources at Utekon, Iyowa and Oluku areas. The scope of this study includes:

1. To investigate groundwater assessment in preventing water contamination.
2. To identify the different strata of soil formation of the well as well as their properties.

1.5 Justification of Study

Large population of Nigerians depend on well for water consumption. As earlier stated in background of study according to a survey by in 2016/2017 by NBS in collaboration with the National Primary Healthcare Development Agency (NPHCDA) and the National Agency for the Control of Aids (NACA) we can conclude that a large percentage of people solemnly depend on well for water consumption. Therefore, this study is justified by the fundamental importance to ensure adequate access to clean and reliable groundwater resources at Utekon, Iyowa and Oluku area, where non-conformance to well drilling standards result to risk of water contamination and health threats to consumers. According to (World Health Organization, 2011), contaminated water can have severe implications to public health, including the spread of waterborne diseases. For this reason this study aims to ensure adherence to well drilling practice standards and guidelines to improve access to clean and reliable groundwater resources and protecting public health.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The importance of groundwater in borehole drilling cannot be over emphasized. It is important to know that, water is the most important substance to human existence, not just water but clean and accessible water. For this reason, borehole drilling became a major channel for groundwater harvesting. In well drilling, the hydro-geological nature of the area where this drilling process is to be done is taken into consideration. A large population of people living in Benin City, depends on borehole water for drinking and carrying out domestic activities.

2.2 Hydrogeology and Groundwater

According to (Fetter, 2011) defines Hydro-geology as the branch of geology that deals with the study groundwater, its occurrence, movement, and quality in subsurface environment. With the study of the hydro-geological nature of an area, design and construction of water wells for drinking, water supply, irrigation schemes and other purposes can easily be done.

Groundwater is one of the Nation's most important natural resources. Groundwater is a major contributor to flow in many streams and rivers (William M. Alley *et al.*, 1999). Groundwater is water that fills pores and fractures in the ground (Thomas Harter, 2003). The top of groundwater is called water table and between the water table and the land surface is the unsaturated zone. In unsaturated zone, moisture is moves downward to the surface or very deep (Thomas Harter, 2003).

2.3 Aquifers

Aquifers are geologic formation from which significant amounts of ground water can be pumped for domestic, municipal, or agricultural uses (Thomas Harter, 2003). In some cases, aquifers are vertically separated from each other by geologic formations that permit little or no water to flow in or out. Aquifers are classified into:

1. Confined
2. unconfined aquifer

   Th water level in borehole drilled into an unconfined aquifer will be at same depth as the water table in aquifer. Water in a confined aquifer is pressurized. It must be known that the water table in Benin is shallow which makes it easy to drill well. It is important to understand the porosity of a geological formation before drilling boreholes in such location. Porosity is the ability of a geological formation to store water is governed by its porosity, which is the ratio between the volume of voids and the total volume of geological material (Bruce Misstear *et al.*, 2006). Primary porosity is a characteristic of unconsolidated aquifers and some consolidated aquifers where the voids were formed at the same time as the geological material. In crystalline aquifers and in consolidated aquifers where the original pores have been infilled with cement, porosity results from openings formed at a later time due to fracturing and weathering. This is known as secondary porosity and typically comprises tectonic fractures and dissolution fissures according to (Bruce Misstear *et al.*, 2006).

2.4 Geology of Benin

It is important to know the geology of Benin, since my areas of study are located within Benin. Benin city is underlain by sedimentary formation, the formation is poorly bedded and occasionally cross bedded. The Benin formation locally covered with loose brownish sand which varies in thickness but attains a maximum thickness of 1970m near sea shore (Christopher N. Akujieze and G.E. Oteze, 2006). Under Benin, it is about 800m thick, almost all of which is water bearing. It is one of the most prolific aquifers in Nigeria. The water level varies from about 20m along sapele Road to 52m on Ikpoba Hill (Christopher N. Akujieze and

G.E. Oteze, 2006). Due to Benin formation, water table is usually shallow and this makes it easy to access groundwater.

2.5 Well Construction (Based on Hydro-logical Standards and Codes)

Well construction involves the different practices, in accordance with standards for well drilling to prevent water contamination. Well construction must be in accordance with the provisions of code, and based on the geologic and groundwater conditions known to exist as specified in hydro-geological report obtained from such site (Nigeria Industrial Standard, 2010). Well construction will be discussed under the following headings ;(Arjen Van Der Wal, 2010).

2.5.1 Preparations

All materials that are needed for installation and backfilling. The effective length of the PVC pipes should be measured and the last pipe should be cut to a length, allowing 1 meter to be left above ground level, after installation. The pipes should be numbered in order of installation (Arjen Van Der Wal, 2010).

2.5.2 Centralization of The Well Screen

To prevent the slots from becoming blocked with clay due to scraping of the well screen against the borehole wall during installation, the well screen should be centralized, this will allow the gravel pack to settle equally around the screen, leaving at least 1-inch of gravel all around the well screen. Centralization can be achieved by attaching spacer rings with an interval of 3 meter around the well screen (Arjen Van Der Wal, 2010).

2.5.3 Installation of the PVC pipe

In this stage, the PVC pipes are lowered into the borehole using a rope. The rope is used to prevent the casing and screen from slipping into the borehole while adding a new length of pipe. All prepared pipes should be installed and 1 meter is left of the pipe above the ground level so that the well screen is placed at the correct depth (Arjen Van Der Wal, 2010).

According to (ASTM D1785-21a, 2021), the standard specification for PVC pipe, schedules 40, 80, and 120 for use with the distribution of pressurized liquids only.

2.5.4 cleaning and flushing the well-screen(Arjen Van Der Wal, 2010)

After the installation of well-screen at the correct depth, the pipes and screen should be flushed in the case of fluid drilled boreholes. Water should be poured into the PVC pipes and allow dirty water to overflow out of the borehole. This process flushing with clean water until the water which is coming out of the borehole is clean, after which the gravel can be installed.

2.5.5 Installation of Gravel Pack

Gravel pack is poured in the annular space around the pipe, why the PVC pipe is moved from side to side to guarantee an easy passage for the gravel down to the screen. A measurement tape should be used to measure the depth to the top of the gravel and it should be filled to about 1-2 meter above the top of the well-screen (Arjen Van Der Wal, 2010). According to (Nigeria Industrial Standard, 2010), gravel used should come from clean sources and should be thoroughly sieved, washed, and disinfected before installation. Under no circumstances should crushed rock or laterite be used as gravel (Nigeria Industrial Standard, 2010). Gravel to be used should compose of sound medium to coarse sand and gravel hic should be clean, well-rounded gravel, uniform, water-washed and free from clay, silt, organic matter, gypsum, iron, manganese or other deleterious materials, the gravel should be selected based on formation analysis, materials should have an average specific gravity of not less than 2.5 and uniformity coefficient not greater than 2.0, the gravel should have a minimum thickness of at least 25mm and should be placed at a minimum of 5 meters below ground surface, and the gravel should be disinfected using water with a free chlorine residual of at least 50ppm (Nigeria Industrial Standard, 2010).

2.5.6 Installation of the Sanitary Seal

After the installation of gravel and it is settled to the right depth after measurement, the sanitary seal can be installed. The cement grout is prepared, Bentonite grout is also prepared and are poured into the borehole (Arjen Van Der Wal, 2010). The neat cement grout should be a mixture of one bag, 50kg of Portland cement not more than 25litres of clean water and the use of bentonite, up to six percent by weight of cement to reduce shrinkage or additives (Nigeria Industrial Standard, 2010).

2.5.7 Filling the Annular space

The rest of the annular space is filled up by cutting and cement grout and always pour in the material slowly while moving the casing to prevent bridging of the material (Arjen Van Der Wal, 2010).

2.5.8 Installation of The Top Seal

A sanitary top seal of 3-5m thickness should be placed from 3-5m below ground to the surface and the top seal is usually made of cement grout (Arjen Van Der Wal, 2010).

2.5.9 Construction of Head works and Choice of Hand Pumps

Before this stage, the well is left alone before the installation of hand pump, the top of the PVC casing should be protected (Arjen Van Der Wal, 2010).

It is Important that drillers follow the above discussed well construction guidelines to obtain and access clean and reliable water. All guidelines as stated above are in accordance to codes that fundamental for well construction.

2.6 Well Development

Well development should be done according to the provided codes to avoid water contamination. Below are the guidelines for well development according to (Nigeria Industrial Standard, 2010);

1. According to (Nigeria Industrial Standard, 2010) every well should be developed, using any of the methods identified in the table below to remove the natural silts and clays, drill cuttings, or other foreign matter from the well.

Table 2.1: Water well development methods and their applicability by (Nigeria Industrial Standard, 2010)

Method	Rig or Equipment Required	Comments
Blowing	Air compressor	For handpump water wells
Bailing	Cable tool, bailer	Common for handpump water wells
Air lift pumping	Any rig with air compressor	Can be more effective in very porous aquifers and large diameter wells
Pumping	Any rig (including jetting, manual drilling) with pump	Can be used by jetting rigs or manually drilled wells
Backwashing	Any rig with air compressor or water well pump	Creates surging action without requiring surge blocks
Surging / air lifting pumping	Cable tool rig, air compressor, isolation tool	Effective in unconsolidated aquifers; only for screened water wells
Jetting	Rotary, air compressor, jetting tool	Best with wire wrap screens; only for screened water wells
Surging	Cable tool or rotary rig, surge block	Not recommended for aquifers with clay layers
Air lifting pumping / surging	Any rig with air compressor, air lift equipment with valve	Effective for water wells in sandstone aquifers

It is important that carry-out an efficient well development, the above development method as stated in (Nigeria Industrial Standard, 2010).

2. Development should continue until the water from the well is clean and silt-free

3. Where chemical conditioning is required, the specifications should include provisions for the method, equipment, chemical, testing for residual chemicals, and disposal of waste and disposal of waste and inhibitors.

   These listed guidelines above are fundamental for a sustainable well development which are according to hydro-logical codes and standards for well drilling.

2.7 Types of Wells

Wells have been a crucial source of water throughout history, providing access to essential water resources for daily consumption (Mark Walker, 2024). There are various types of wells, with each being designed for specific needs and environments. Well depths for drinking water based on factors such as soil type and local regulations, but a drinking well should be a minimum of 100ft below the ground surface or 10ft below the water table (Mark Walker, 2024). The followings are the common types of wells; (Mark Walker, 2024)

1. Dug Wells

Dug wells are shallow, they are wells that are excavated by hand or with machinery and these are often found in areas with soft or less-permeable materials like silt, sand, or clay, and are usually lined with bricks, stones, tiles, or other materials to prevent collapse. They are usually only 30 ft deep (Mark Walker, 2024).

2. Driven Wells

These wells are constructed by driving a pipe into the ground, and they often used in areas with shallow water sources. It is important to note that driven wells cannot be installed if the ground is made out of solid rock and only shallow water can be accessed with this method at 30 to 50 ft (Mark Walker, 2024).

3. Drilled Wells

Drilled wells are the most common and deepest type of well. They are constructed with either cable tools or rotary-drilling machines and can be more than 1000 ft deep and they have a lifespan of 30 to 50 ft (Mark Walker, 2024).

4. Artesian Wells

Artesian wells are a type of drilled well that taps into pressurized water sources beneath the ground at about 200 to 500 ft deep.

5. Interceptor Wells

Interceptor wells are used to prevent contamination of underground water resources from sources of pollution.

These types of wells discussed above are based on the standards given by (Mark Walker, 2024), it is important to follow the depth and standards for efficient well drilling.

2.8 Effect of Non-Conformance to Well Drilling Codes and Standards

Due to the increasing demands for reliable source of clean water, individuals have resorted to drilling their own personal domestic well. And also due to the alarming rate of few water engineers in the water sector, artisans who do not have the proper training skill for carrying out hydro-geological checks on site before well drilling commences, are now disguising and relying on experience only for well drilling without following standards and guidelines. This has poses serious issues and high risk to public health due to water contamination in the process of well construction by these artisans. There have been a considerable increase in the construction of boreholes over the years and this has raised alarm in the water sector and according to the report by (Anyawu, 2024), warned that due to the indiscriminate drilling of boreholes and extraction of water from the ground are capable of upsetting the equilibrium of the earth because the amount of borehole drilled keeps increasing every day.

Most of these artisans do not have the skill to drill a sustainable well for the extraction of clean water for public consumption. The non-conformance to codes and standards for well drilling has resulted to serious water contamination which has resulted to water-borne diseases without consumers tracing it to failures in the part of artisans in following codes for drilling. The effect of non-conformance to well drilling codes and standards includes;

1. **Water contamination**

   It is impossible to prevent water contamination when well drilled are not according to codes and standards. There is high tendency of well to be contaminated by different contaminants that will poses serious health issues on the public. Water contamination is a serious issue that needs to be tackled by the government by providing clean public water. According to a study by (World Health Organization, 2019) it was found that contaminated water can transmit diseases such as cholera, typhoid and hepatitis.

2. **Groundwater pollution**

   One of the easiest way for ground water to be contaminated by non-conformance to drilling codes. When procedures and practices for well drilling are not adequately followed, chemicals and materials used in the process can introduce contaminants into groundwater which will definitely leave a lasting effect.

3. **Well failure**

   well do not fail unless they are not properly constructed. When standards are not followed for well construction, such well is bound to fail either immediately or in future time which will definitely lead to economic losses and reduce access to clean water.

4. **Environmental impact**

    Due to increasing borehole construction, over time there is a possibility of a seismic threat which will poses serious threat to lives and properties.

    This study tends to bring to light the effects of not following standards and codes, and also to ensure that the gaps of not adhering to these codes are removed in order to promote access to clean and reliable source of water. These effects were derived by my experience in line with substantial discussion I had with Prof. Osa. Osemwota, a retired professor from Urban and Regional Planning, Nigeria.

2.9 Challenges in Well Drilling

In well drilling, challenges arise which may affect the overall output of the water to be accessed. Some of these challenges are also a contributor to the non-conformance to well drilling standards and codes. Due to the economic imbalances, people prefer to go through route that suits their economic strength, and the moment there is economic constraints, every other thing is compromised. Some of the challenges in well drilling may include the followings:

1. **Financial constraints**

    One of the most important aspect of well drilling is finance. In Nigeria today, due to the economic breakdown, individuals who are in search of clean and accessible water, have resulted to using unskilled individuals who disguise as Engineers with the experience of well drilling. When there is no enough finance, people intend to find the cheaper means to obtain whatever they desire to obtain. It is important that the government should take it upon themselves to provide adequate and accessible water for citizens.

2. **Increase in unskilled personnel**

One of the challenges associated with well drilling, is the increase in unskilled personnel who disguise as expert of well drilling and this is a serious challenge that should be tackled and prevented.

3. **Inadequate regulation**

Lack of regulation is one of the challenges associated with well drilling. In Nigeria today, there are no regulations of well drilling, and this has seriously contributed to the reasons for increase in water contamination because personnel who drilled this well are not properly regulated and controlled.

These are some of the few challenges I derived in the process of this study.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

My area of study for this project (well drilling) were Utekon (6.559497 latitude and 5.621047 longitude) and two areas at Oluku (River Road with latitude 6.437528/longitude 5.601228 with Lat/Long 6.436648/5.601393) which are located within Benin City and Benin City is located within the rainforest zone of Nigeria with mean annual rainfall in the range of 1500mm to 2500mm and the mean monthly temperature varying from 25°C to 28°C. The Benin region is underlain by sedimentary formation of the south sedimentary Basin and constitute part of the Benin formation which is made up of over 90% massive, porous, and coarse with thick clay/shale interbeds having high ground water retention capacity. The geology is generally marked by top reddish earth, composed of ferruginized or literalized clay sand. Benin City has two distinct seasons. These are the Wet (rainy) season and dry season. The amount of rainfall contributes to the depth of water level for borehole construction. These are regions I will be considering in the course of this project. The maps below were generated from a map for the study area respectively. Three different samples were collected at these different locations and each samples comprised of different logs of different soil at different depth.

The red marker highlights Utekon, with surrounding areas like Ogheghe, Iguomo, and key roads such as the A122 highway and Ekenwan Road clearly labeled.

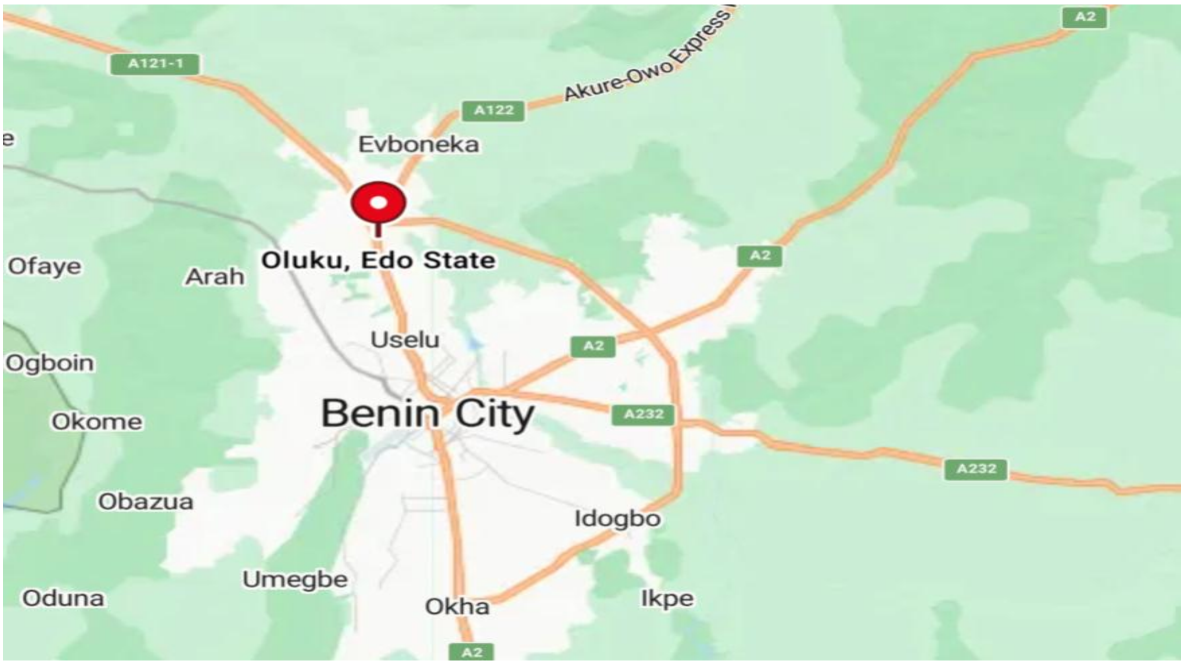

Figure 3.1: GPS Maps showing location of my study area with the co-ordinate.

The red marker highlights Oluku.

3.2 Materials for Well Drilling

The materials to be used in borehole drilling in order to maintain the water quality includes; Bentonite, Casing, Gravel pack, Well screen, Grout, Drilling Fluids Additives (Baryte, Chalk, Sodium carbonate, Lime, Lignite), Mud mixer and Tanks.

3.2.1 Bentonite

Bentonite is a type of absorbent clay that originates from volcanic ash sediments. Bentonite is renowned for its unique properties such as swelling, high viscosity, and thermal stability. The most crucial feature that makes Bentonite an invaluable resource in well drilling is its ability to expand when in contact with water. The swelling property of Bentonite helps in creating a stable, viscous, and impervious mud barrier. This barrier helps in sealing and lubricating the borehole walls, reducing soil permeability, and preventing fluid loss during drilling. For optimal performance of Bentonite, the type and quantity of Bentonite used, the composition of other additives in the drilling fluid, and specific conditions of the drilling operation, play a significant role (Vahit, 2023)

3.2.2 Casing and Well Screen (International Committee of the Red Cross, 2010)

Boreholes are constructed by inserting lengths of protective permanent casing. These are lowered or pushed into the hole by the drilling rig to the required depth. Casing normally extends up to the surface, with a certain amount of about 0.7 meter, standing above ground level. Lengths of casing may be obtained in mild steel, stainless steel, and plastic (such as UPVC, Polypropylene, and glass-reinforced plastics). Plastic casings are more fragile and deformable than steel casings and so should be used mainly for low- yield and shallow boreholes (International Committee of the Red Cross, 2010).

Table 3.1: Typical Casing Collapse Strength (International Committee of the Red Cross, 2010)

CASINNG MATERIAL	CASING WALL THICKNESS	COLLAPSE STRENGTH
UPVC	12.4 mm	660 KPa
Polypropylene	12.7 mm	690 KPa
Glass-reinforced plastic	6 mm	690 KPa
Mild steel	9.4 mm	11.1 MPa

The different types of screen, designs and application according to (Nigeria Industrial Standard, 2010) are shown in table 3.2

Table 3.2: Types of screen (Nigeria Industrial Standard, 2010)

Screen Type	Design	Applications
Slotted	Slots cut horizontally or vertically in casing	
Louvered and Bridge slot	Openings are mechanically punched into steel which forces a lip of steel outwards	Primarily consolidated formations
Continuous Slot Screen (wedge wire)	Wedge shaped wire wrapped around longitudinal supports	Primarily unconsolidated formations
Composite	Screens with filter packing material integrated.	Primarily unconsolidated formations
Well points	May be continuous slot type, slotted or wire gauze covered openings	Unconsolidated formations

When borehole has been dug alongside a water-bearing zone, the casing installed in it must have apertures that allow water to enter as efficiently as possible while holding back material from the formation. These perforated sections are known as well screen (International Committee of the Red Cross, 2010). According to (Nigeria Industrial Standard, 2010);

1. Casings should either be bitumen coated steel, Unplastized Polyvinyl Chloride (uPVC) or other appropriate materials.
2. In constructing any well, all water-bearing zones that are known to contain polluted, saline, or other non-potable water shall be adequately cased and cemented off so that pollution of overlying and underlying groundwater zones should not occur.
3. The casing in wells sunk into unconsolidated rock formations (such as gravel, sand or shale) should extend at least 300mm into the water-bearing formation.
4. Upon completion of the well, the well shall be sufficiently free of obstacles including formation materials to allow for the installation and proper operation of pumps and associated equipment.

Table 3.3: Casing Diameters and Screen Openings (International Committee of the Red Cross, 2010) page.58

Expected Pumping Rate, Litres/Sec	Borehole Diameter	Collapse Strength
0.3	6	100
0.5	6	100
0.8	6	300
1	6	400
1.5	6	500
2	6	750
2.8	6	1,000
4.2	6	1,500
5.6	8	2,000
7	8	2,500
8.3	8	3,000
11	10	4,000

According to the specification of (Nigeria Industrial Standard, 2010), for water well deeper than 100m, bitumen coated steel casing of the underlisted specification should be used:

1. The casing should be new, seamless or electric-resistance welded galvanized or black steel pipe. Galvanizing should be done in accordance with requirements of ASTM A-120.
2. The casing, threads and couplings shall meet the specifications ASTM A-53, A-120 OR A-589.
3. The minimum wall thickness for a given diameter should be as specified in the table 5.
4. stainless steel casing, threads, and couplings should conform in specifications to the general requirements in ASTM A-530 and also should conform to the specific requirements in ASTM standard that best describes the chemical makeup of the stainless steel casing that is intended for use in the construction of the well.
5. Stainless steel casing should have a minimum wall thickness that is equivalent to ISO standard
6. Steel casing shall be equipped with a drive shoe if the casing is driven in a consolidated rock formation.

These specifications must be followed as stated by (Nigeria Industrial Standard, 2010), for efficient drilling process in preventing water contamination.

Table 3.4: Minimum wall thickness for steel casing (Nigeria Industrial Standard, 2010)

Nominal Diameter (mm)	Wall Thickness (mm)
100	3.607
125	3.962
138	4.166
150	4.7
200	6.35
250	7.087
300	8.382
350 and larger	9.525

For water well less than 100m deep, uPVC casing of the underlisted specification should be used in accordance with (Nigeria Industrial Standard, 2010):

1. The casing shall be new.
2. The casing and joints should meet or exceed all the specifications of ASTM F-480-81 except that the outside diameters should not be restricted to those listed in F-480.
3. The top of the casing shall be terminated by the driller at 300mm protruded above ground surface.
4. For wells in which the casing will extend into consolidated rock, thermoplastic casing should be equipped with a coupling, or other device approved by the manufacturer of the casing, that is sufficient to protect the physical integrity of the uPVC casing during the processes of seating and grouting the casing and subsequent drilling operations.
5. uPVC casing should not be driven into consolidated rock.

These specifications are strictly for uPVC casing for water well less than 100m deep based on (Nigeria Industrial Standard, 2010) specification.

3.2.3. Gravel-pack

After the casing and screen string have been inserted, natural materials will tend to fall from the walls of the borehole into the annular space, forming a natural backfill or gravel pack that helps to filter incoming water. The screen slot sizes should be such that only the finer content of this backfill is allowed into the borehole. The introduction of a natural or artificial gravel pack into a borehole will reduce the effective open area of the screen (International Committee of the Red Cross, 2010).

Gravel used in gravel-packed wells should come from clean sources and should be thoroughly sieved, washed and disinfected before being placed in the well, the gravel pack shall have a minimum thickness of at least 25mm and should be placed at a minimum of 5 meters below ground surface (Nigeria Industrial Standard, 2010).

3.2.4. Grouting

To achieve proper sanitary seal protection effectively. According to the specification of (Nigeria Industrial Standard, 2010)**,** the followings are the outlined specifications:

i. The annulus of the well should be grouted to a minimum depth of 5m in basement and 10m in the sedimentary formations below ground surface and as necessary to seal off, from producing zone, all aquifers or zones with water containing organic or other contaminants of such type and quantity as to render water from those aquifers or zones unsafe or harmful or unsuitable for human consumption and general use.

ii. Grout should be placed around the casing by using any one or combinations of the methods; Gravity, pressure or pumping.

iii. If an outer casing is installed, it should be grouted by either the pumping or pressure method.

iv. The liquid and solid components of all grout mixtures shall be thoroughly blended prior to placement below ground surface.

v. The well should be grouted immediately after well development.

vi. No additives which would accelerate the process of hydration should be used in grout for uPVC well casing.

vii. Where grouting is required by the provisions of this section, the grout shall extend outward from the casing wall to a minimum thickness equal to either one-third of the diameter of the outside dimension of the casing or 50mm. The approved grouting materials includes; Neat Cement Grout, Bentonite Grout, Sand Cement Grout, and Clay grout (Nigeria Industrial Standard, 2010). These specifications must be duly followed in order to obtain optimum result and also to prevent water contamination which is the aim of this study. The above guidelines are based on Nigeria standard for well drilling.

3.2.5. Drilling Fluids

Drilling fluids are necessary in well drilling. Only clean water should be used in the make-up of drilling fluids whether employed alone or in combination with drilling additives. Only high grade clay or commercial chemicals that meet the requirements of Nigerian Industrial Standards (NIS) should be used in the make-up of any drilling fluid. Drilling fluid with a mixture of water and unprocessed mud, clay, or other material should not be permitted. When and only if it becomes necessary to add clay or chemicals to the drilling fluid, it must be borne in mind that it is desirable to maintain a mud system containing a minimum of clay and fine sand and to obtain representative lithology samples and minimize sealing of well with mud cake or mud invasion into formation (Nigeria Industrial Standard, 2010).

3.2.6 Mud Mixer and Tanks

Mud mixer and tanks are essential components in horizontal directional drilling, designed to blend and store drilling fluid used during operations. These tanks combine water with additives to create a consistent, high-quality mud that supports borehole stability, cools the drill bit, and transports cuttings.

3.3 Methods of Borehole Drilling

In the course of this project, I focused on certain regions in Benin city. These regions with their coordinates includes; Utekon (6.559497 latitude and 5.621047 longitude) and Oluku (River Road with latitude 6.437528 and longitude 5.601228). The method of borehole drilling to be used is Rotary drilling method. This method, involves the use of a drill bit that continues to rotate as it drills down soil formation. This method is most suitable and efficient for areas which I have chosen as my study area due to the depth of water table.

Benin City is located in the Mid-Western region of Southern Nigeria. The city is sited on the coastal lowland of South-Western Nigeria. The land surface is flat plain that is only interrupted by Ikpoba river valley in the north Ogba river-valley in the south-west of the city. It has a humid tropical climate with a mean daily temperature of 28°C and a long raining season (an advantage in borehole drilling in terms of depth of water level). Rainfall is usually high and lasts from March to October and the total precipitation in the city was estimated to be 1,804.7mm in 2005 (Agheyisi, 2007)**.** These climatic conditions usually favor the development of groundwater and high precipitation is a major source of groundwater recharge in Benin metropolis. For borehole construction in Benin City, surface methods are generally the most suitable and commonly used. These methods are simple, cost-effective and reliable for estimating aquifer thickness and locating the best drilling spots. As carefully explained above, taking the meteorological characteristics into consideration, we can conclude that surface methods are mostly practiced in Benin City, due to the fact that the water table level is shallow.

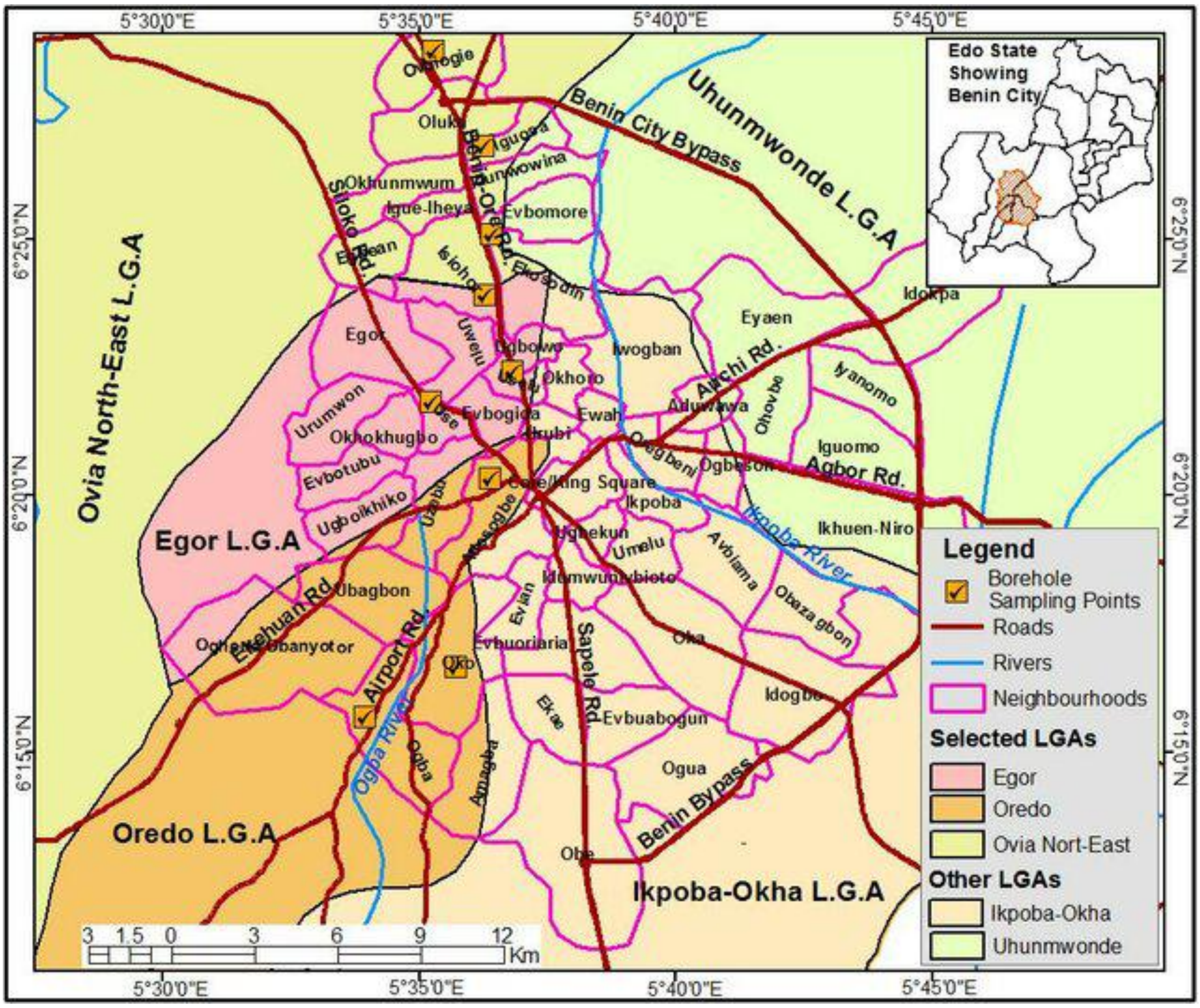

Figure 3.2: Map Of Benin City Showing Local Government Areas And Borehole Water Sampling Locations (D. E. Ogbeifun *et al.*, 2019)

The followings are the common well drilling methods according to (International Committee of the Red Cross, 2010):

3.3.1 Hand-auger drilling

Auger drills, which are rotated by hand, cut into the soil with blades and pass the cut material up a continuous screw or into a bucket. Excavated material must be removed and the auguring continued until the required depth has been reached. Auger drilling by hand is slow and limited to a depth of about 10 meters (maximum 20m) in unconsolidated deposits

3.3.2 Jetting

A method whereby water is pumped down a string of rods from which it emerges as a jet that cuts into the formation. Drilling may be aided by rotating the jet or by moving it up and down in the hole. Cuttings are washed out of the borehole by the circulating water. Jetting is useful only down to relatively shallow depths (International Committee of the Red Cross, 2010).

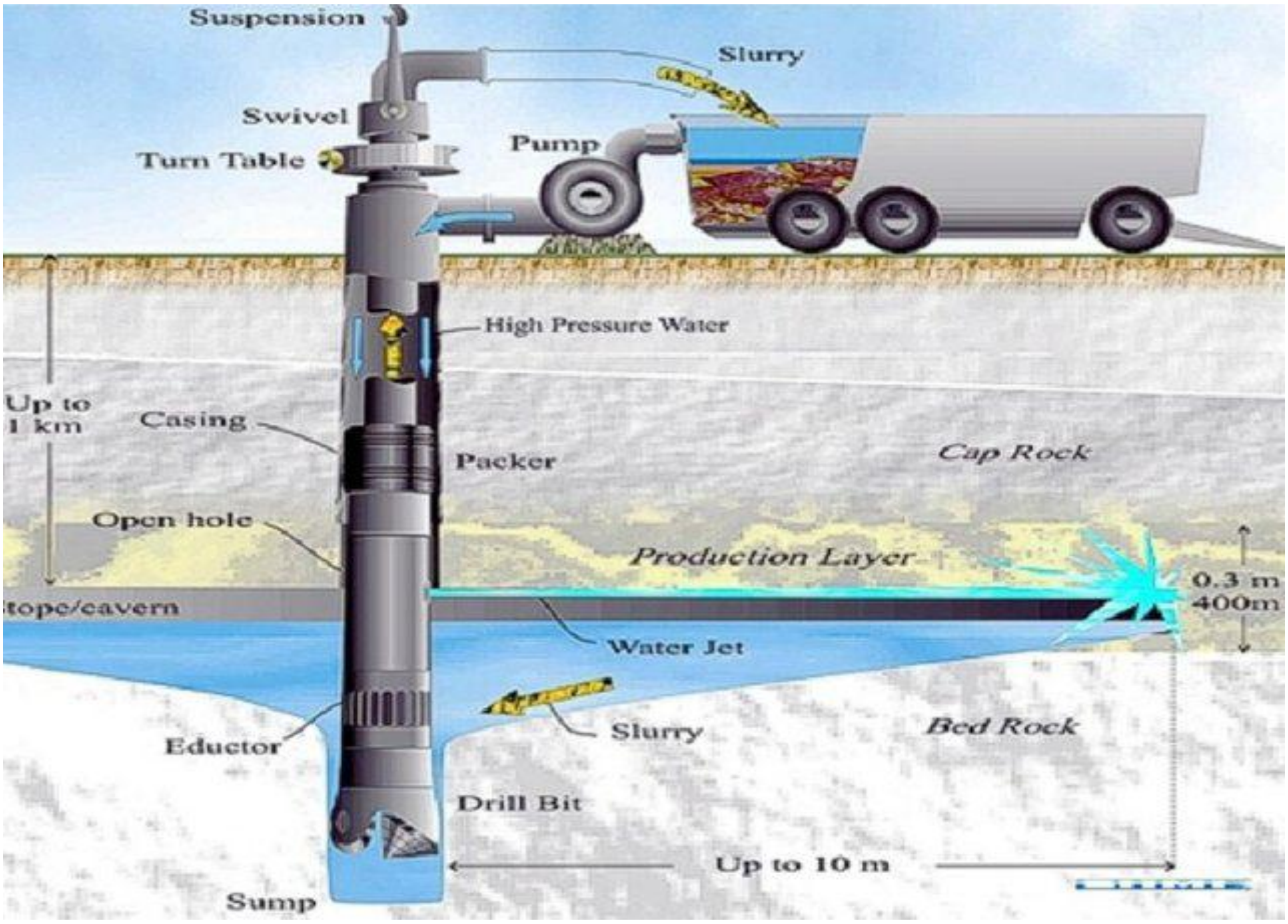

Figure 3.3: Jetting Equipment (Daniel Beck, 2016)

3.3.3 Sludging

This method, which may be described as reverse jetting, involves a pipe (bamboo has successfully being employed) being lowered into the hole and moved up and down. A one-way valve provides pumping action as water is fed into the hole and returns (with debris) up the drill pipe. There may be simple metal teeth at the cutting end of the pipe, and a small reservoir is required at the top of the hole for re-circulation.

Figure 3. 4: Sludging (Kerstin Danert, 2015)

3.3.4 Percussion drilling

Drilling by percussion is done by simply dropping a heavy cutting tool, 50kg or more, repeatedly in the hole. This may well be the original method of drilling for water, pioneered by Chinese 3000 years ago or more. The drilling tools are normally suspended by a rope or cable and depending on the weight of the drill string, which, for manual operation, is obviously limited. It is possible to drill to considerable depths in both soft and hard formations.

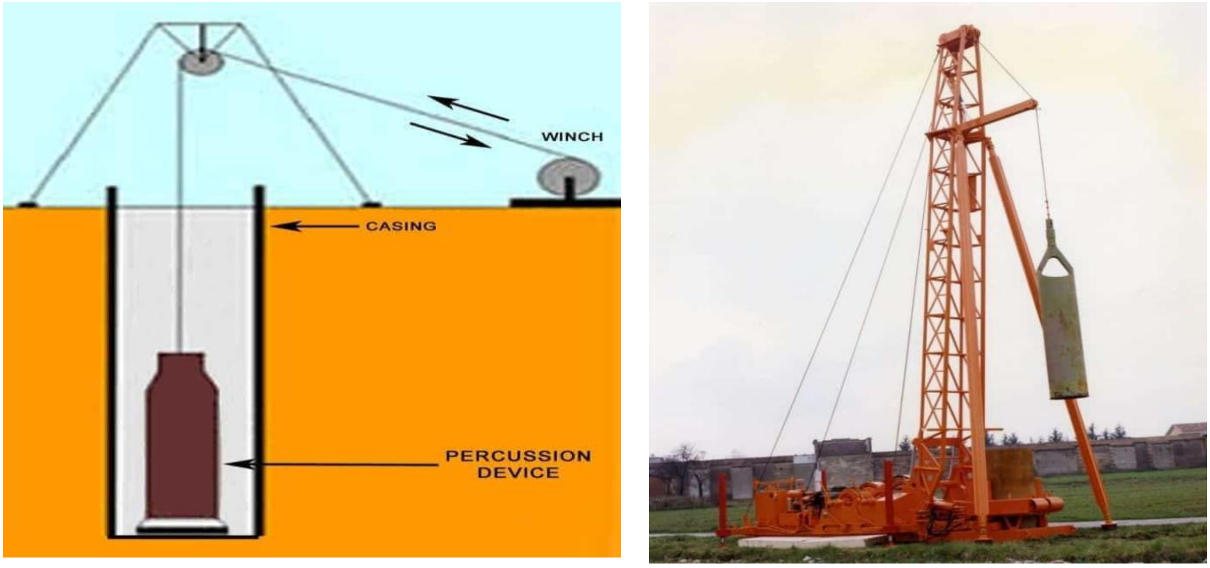

Figure 3.5: Percussion Equipment (Massenza Drilling Rigs)

3.3.4 Rotary drilling

Most borehole applications in the field will require rotary drilling. True rotary techniques allow much deeper boreholes to be constructed, and use circulating fluids to cool and lubricate the cutting tools and to remove debris from the hole. Circulating fluids usually take the form of compressed air or of pumped water with additives

The above methods are the recommended method of borehole drilling with Hand-auger as the most commonly used in Benin City due to the shallowness of the groundwater level. Site formation is very crucial as well as determination of level of groundwater level before determining the method of drilling to be used (Nigeria Industrial Standard, 2010).

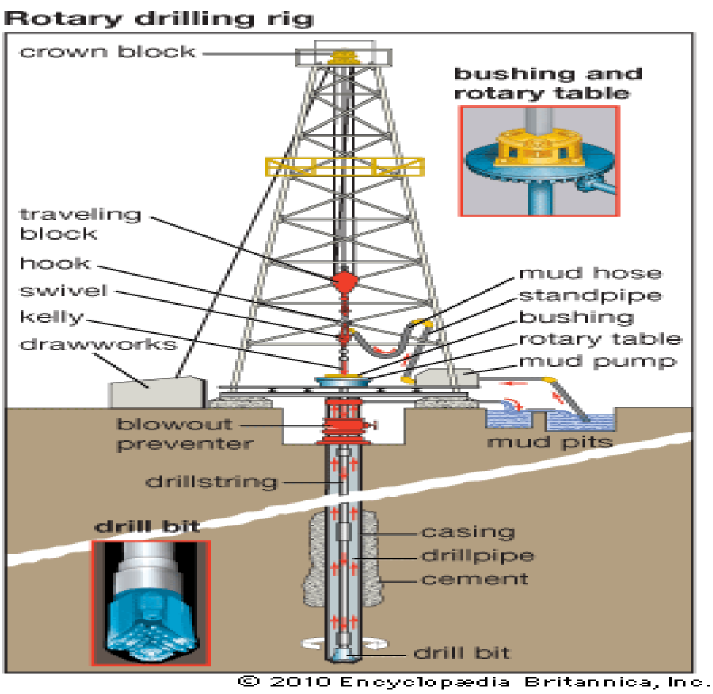

Figure 3.6: Rotary Drilling Rig (Mahmoud Khalifeh and Arild Saasen, 2020)

3.3.5 Borehole Drilling Processes

Borehole drilling process is a systematic process that is to be followed in order to have access to clean and suitable water for consumption purposes. This study aim at focusing on the processes to be followed, ensuring that all drilling procedures according to standards are effectively followed by drillers. The followings are the vital borehole drilling process that must be followed for the purpose of accessing clean water:

1. **Site Selection**

   Site selection is based on the geological surveys. It is important that proper surveys are carried out on that site area to ensure it is suitable for drilling in order to access clean and accessible water. Geological survey must be done to avoid guessing and trial and error work. With geological survey adequate information can be obtained before drilling is commenced on such sited location (Driscoll, 1986)

2. **Drilling preparation**

This process involves setting up equipment and ensuring safety measures. It is important that all equipment to be used are set-up and following standard of operation (Occupational Safety and Health Administration, 2020).

3. **Drilling**

Drilling is the process of boring hole into the earth surface using the appropriate as discussed in the methods of borehole drilling above. Drilling is done using different methods depending on the geological formation of such area being cited for borehole drilling (International Committee of the Red Cross, 2010).

4. **Casing and Cementing**

Casing is very important in preventing water contamination as well as cementing. This process must be done according to standards and codes. Casing and cementing should follow the specification as stated in (Nigeria Industrial Standard, 2010), to prevent water contamination why improving access to clean water.

5. **Well Development**

Well development involves cleaning and developing the well for optimal water flow quality. Well development should be done in accordance with standards to prevent water contamination (Driscoll, 1986).

6. **Testing and Completion**

At this stage, pump tests are conducted to ensure efficient pumping processes and also other assessments to determine the well's yield and sustainability. Pumping should be carried out based on the specification of (Nigeria Industrial Standard, 2010).

These are the drilling process that must be followed in accordance to guidelines and specifications to ensure access to clean and safe water for consumption.

2.3 Water Quality

The reason well drilling codes and standards should be followed and observed is to ensure quality water free from contaminants that may poses serious risk to public health. It is important that all guidelines for well drilling are not compromised and by-passed. According to (Nigeria Industrial Standard, 2010), water sample should be collected from each well and analyzed with the requirements of the Nigeria Standard for Drinking Water Quality NIS 55: 2007. The water quality analysis report should be certified by registered appropriate water analyst.

It is important that, the quality of water is ensured to prevent any related water borne diseases.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents various formats for the representation and discussion of the collected data as well as soil classification of each borehole log. These formats include both tabular, graphical and diagrammatic representations, which are used to compare the results obtained from different experiments.

4.2 BOREHOLE 1

Borehole one consist of 32 logs of soil sample for the first study area of Utekon (6.559497 latitude and 5.621047 longitude), at different depth before water table level. Sieve analysis were done for each log of soil in order to obtain D_{10} which was used to calculate the permeability constant "k" at each depth from 0-320fts of well depth. The tables below are the different sieve analysis values obtained for each soil log including their respective depth, permeability and soil classification. The formula used in calculating for permeability "K" using Hazen William's formula;

$$K=C(D_{10})^2. \quad (4.1)$$

K= Coefficient of permeability (m/s)

C= Constant, typically between 0.01mm

D_{10}= Effective grain size (in mm)

From this formula we obtained the permeability for each soil log for Borehole 1.

The effective size D_{10} is determined by finding the particle size corresponding to 10% cumulative passing on the curve.

4.2.1 CONSTANT OF PERMEABILITY FOR BOREHOLE 1 LOG 1-32

Table 4.1: Coefficient of permeability

BOREHOLE 1, LOGS	PERMEABILITY, K (in cm/s)	Soil Type	Drainage
Log 1	1.4x10-6	Silty clayey	Poor
Log 2	2.56x10-6	Silty clayey	Poor
Log 3	5.625x10-7	Silty clayey	Poor
Log 4	4x10-6	Silty clayey	poor
Log 5	4x10-6	Silty clayey	Poor
Log 6	5.29x10-6	Silty clayey	Poor
Log 7	5.76x-6	Silty clayey	Poor
Log 8	1x10-6	Silty clayey	Poor
Log 9	5.29x10-6	Silty clayey	Poor
Log 10	6.25x10-6	Silty clayey	Poor
Log 11	5.29x10-6	Silty clayey	Poor
Log 12	4x10-6	Silty clayey	Poor
Log 13	4.41x10-6	Silty clayey	Poor
Log 14	4x10-6	Silty clayey	Poor
Log 15	6.25x10-6	Silty clayey	Poor
Log 16	4.84x10-6	Silty clayey	Poor
Log 17	4x10-6	Silty clayey	Poor
Log 18	5.29x10-6	Silty clayey	Poor
Log 19	8.1x10-7	Clayey	Very poor
Log 20	8.41x10-6	Silty clayey	Poor
Log 21	5.29x10-6	Silty clayey	Poor
Log 22	4.41x10-6	Silty clayey	Poor
Log 23	4.41x10-6	Silty clayey	Poor
Log 24	2.25x10-6	Silty clayey	Poor
Log 25	4.9x10-7	Clayey	Very poor
Log 26	4x10-6	Silty clayey	Poor
Log 27	4.5x10-6	Silty clayey	Poor
Log 28	4x10-6	Silty clayey	Poor
Log 29	4.9x10-7	Clayey	Very Poor
Log 30	7.84x10-6	Silty clayey	Poor
Log 31	4.9x10-7	Clayey	Very poor
Log 32	1.6x10-5	Fine sand	poor

From the permeability obtained for each log it was observed that most of the soil samples at different depth were silty clayey which retains water and has a poor drainage to allow water to flow in and out of it. Also few logs were homogenous clay and clay has very poor drainage and therefore does not allow water in and out easily, if the drilling terminated at such depth, the amount of water that will be harvested using a pump may not be sufficient enough. At log 32, the point at which fine sand was encountered became the depth at which the screen was installed. Each soil has being classified based on their permeability values above.

Below are the sieve analysis for each soil sample used in obtaining D_{10} in obtaining permeability constant values;

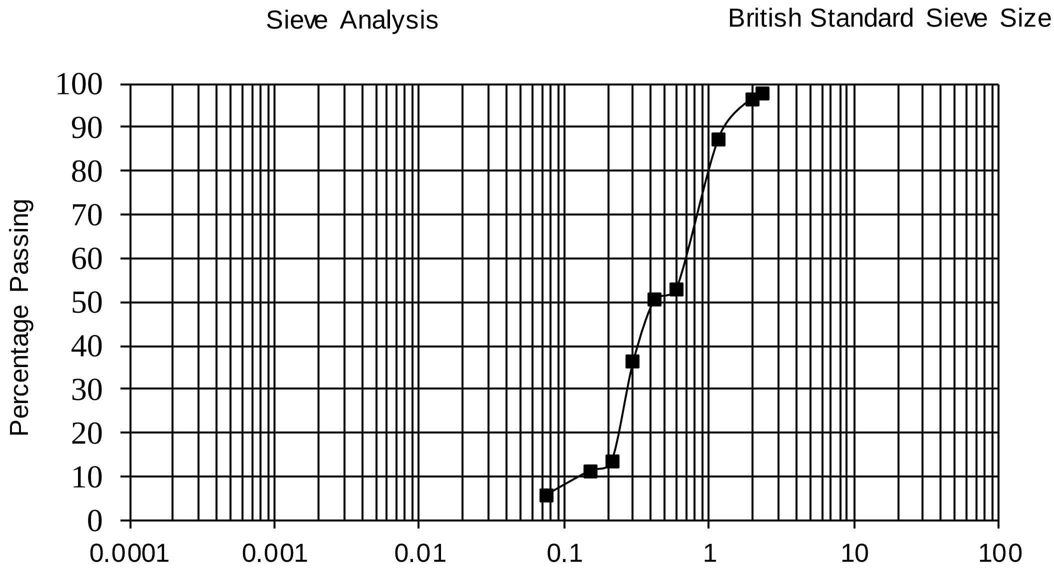

Figure 4.1: Sieve Analysis Graph for BH 1, Log 1.

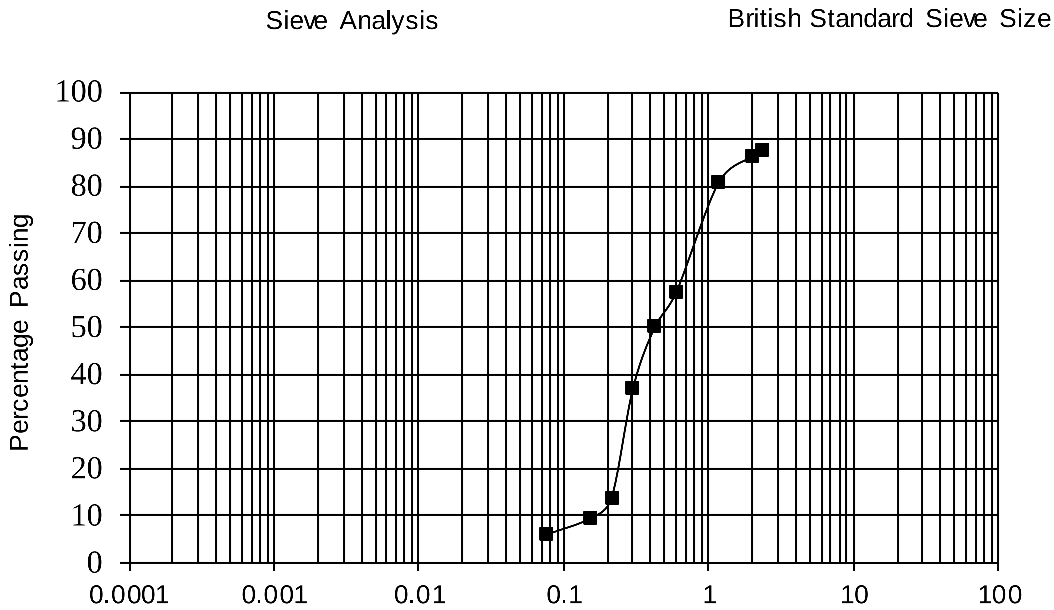

Figure 4.2: Sieve Analysis for BH 1, Log 2.

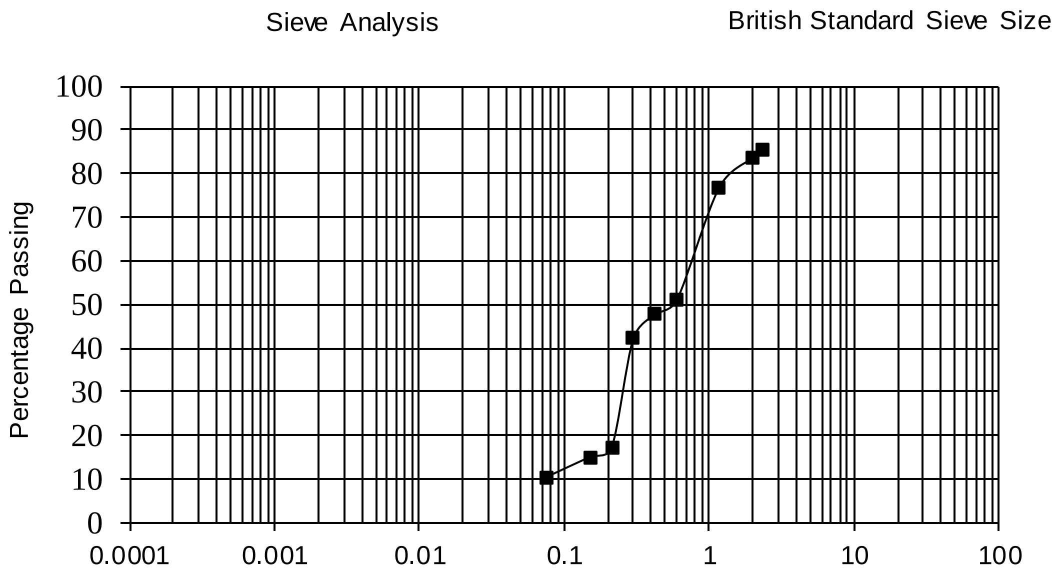

Figure 4.3: Sieve Analysis for BH 1, Log 3.

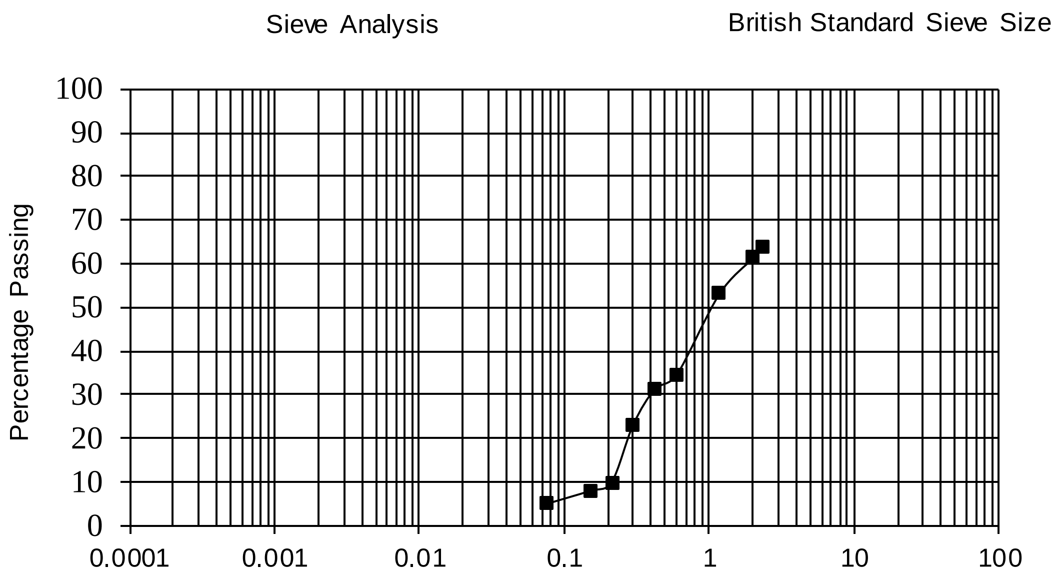

Figure 4.4: Sieve Analysis for BH 1, Log 4.

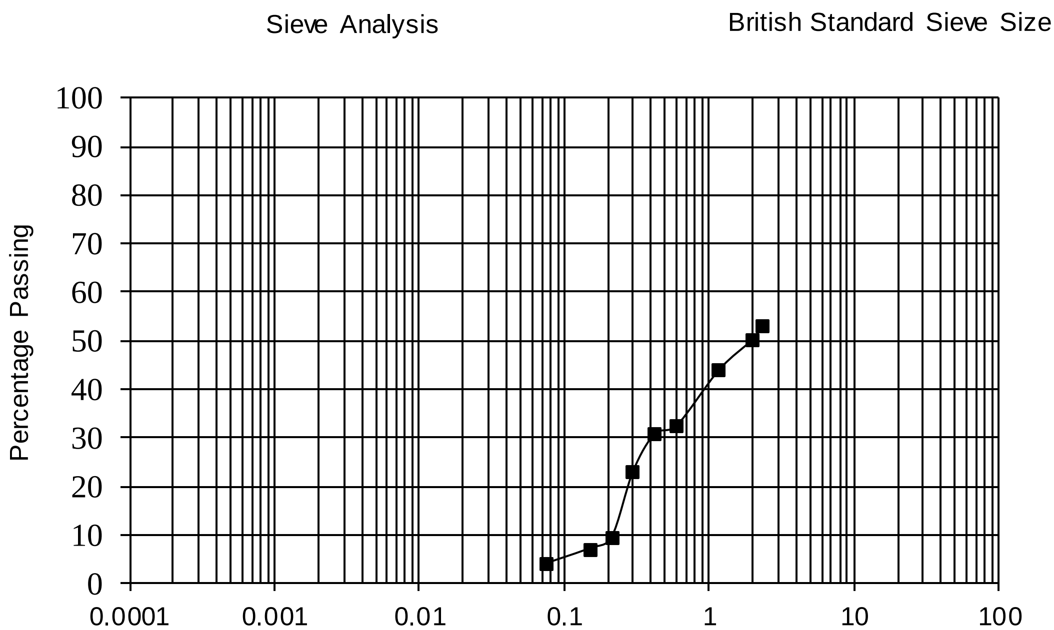

Figure 4.5: Sieve Analysis for BH 1, Log 5.

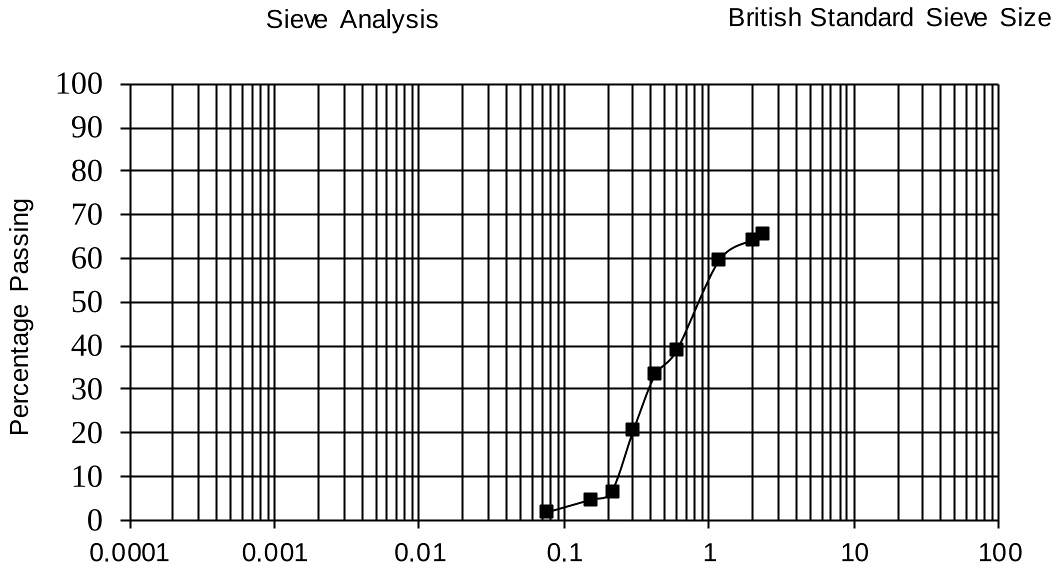

Figure 4.6: Sieve Analysis for BH 1, Log 6

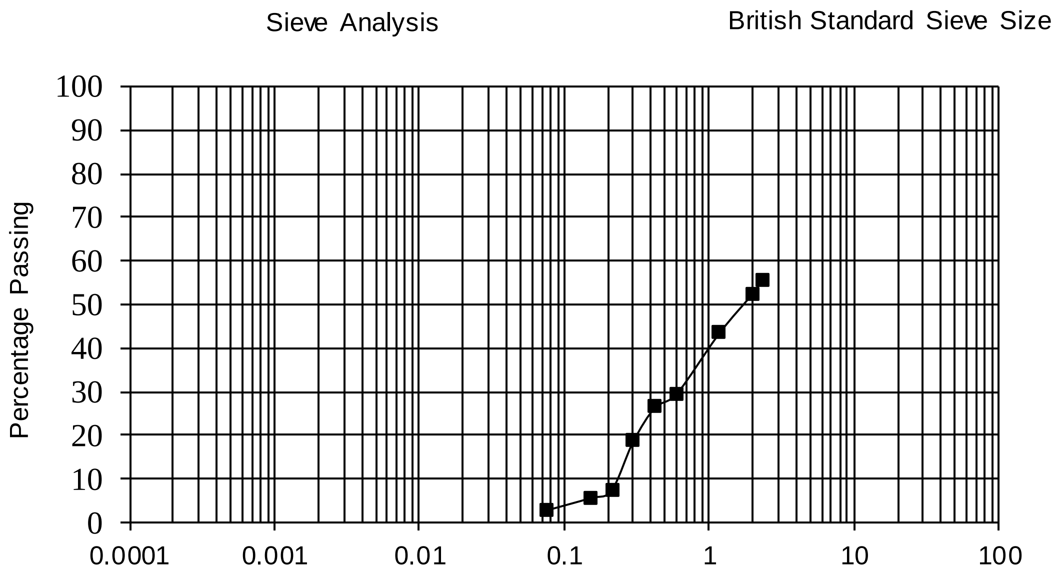

Figure 4.7: Sieve Analysis for BH 1, Log 7

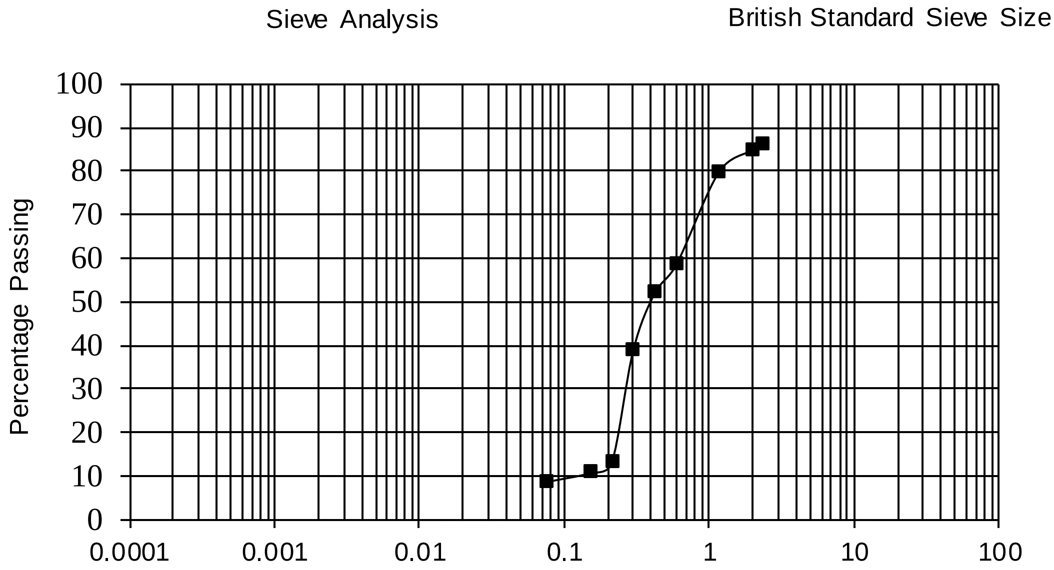

Figure 4.8: Sieve Analysis for BH 1, Log 8

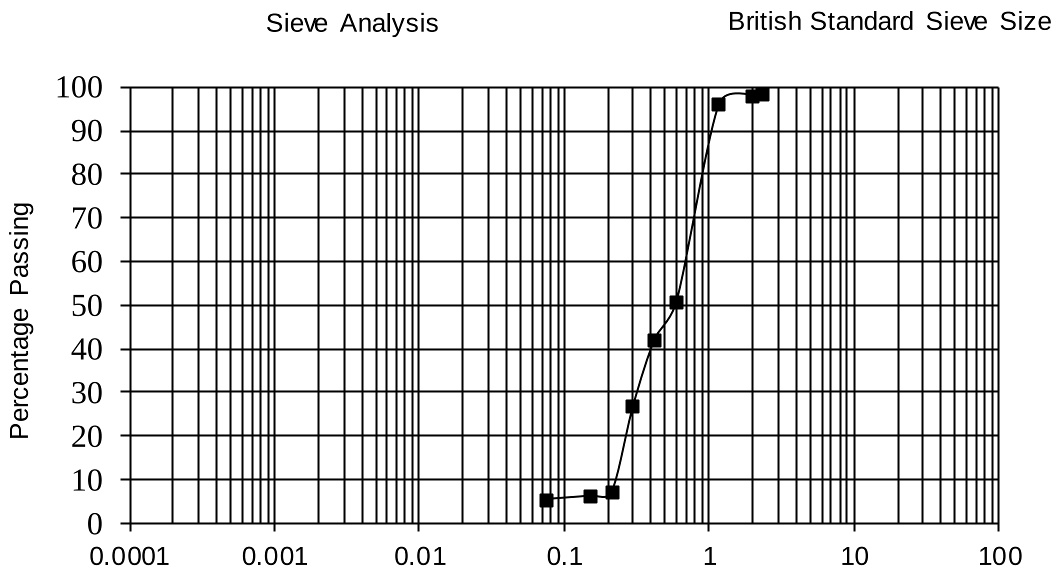

Figure 4.9: Sieve Analysis for BH 1, Log 9.

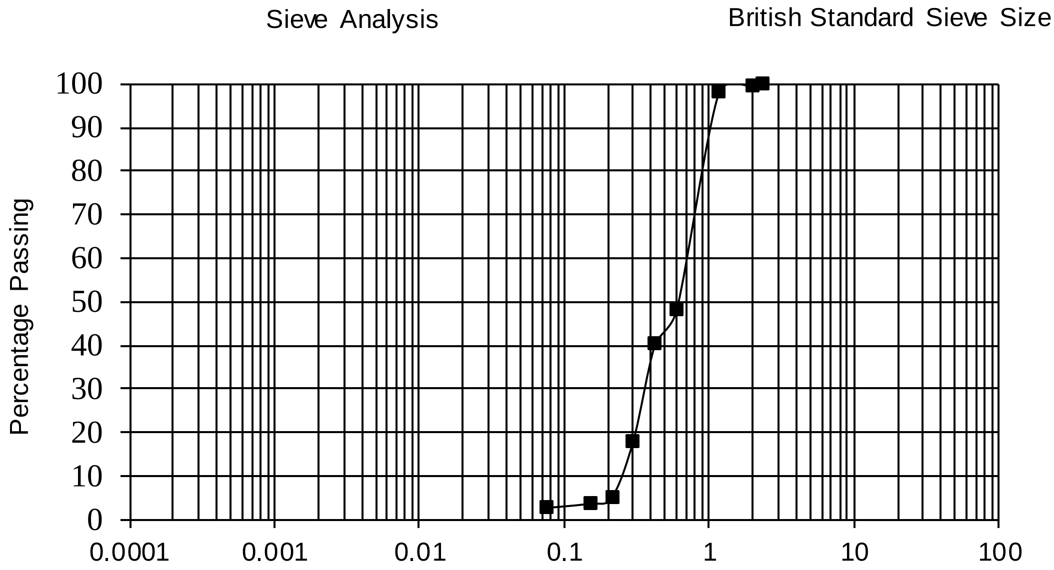

Figure 4.10 : Sieve Analysis for BH 1, Log 10

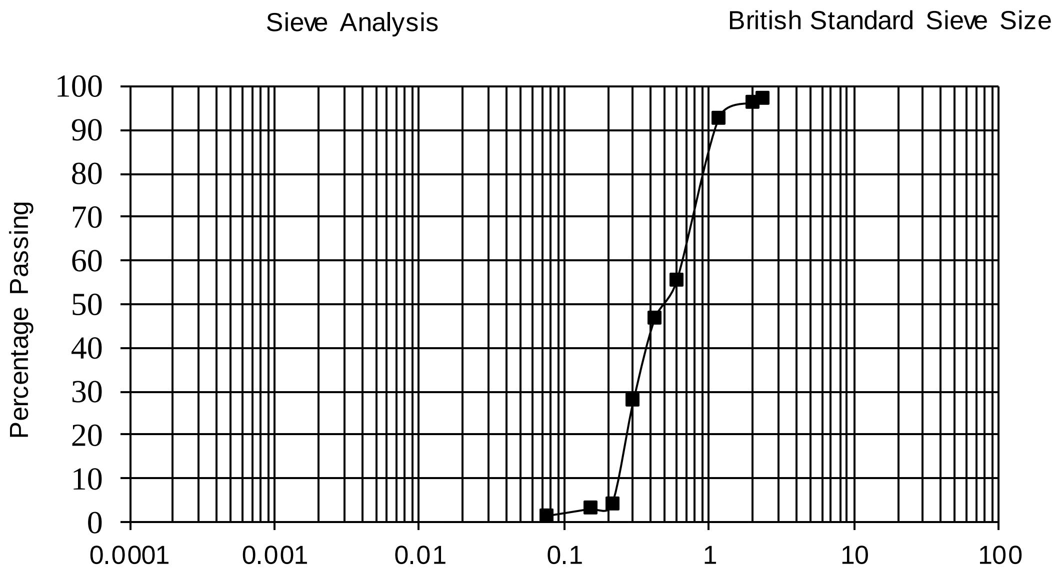

Figure 4.11: Sieve Analysis for BH 1, Log 11.

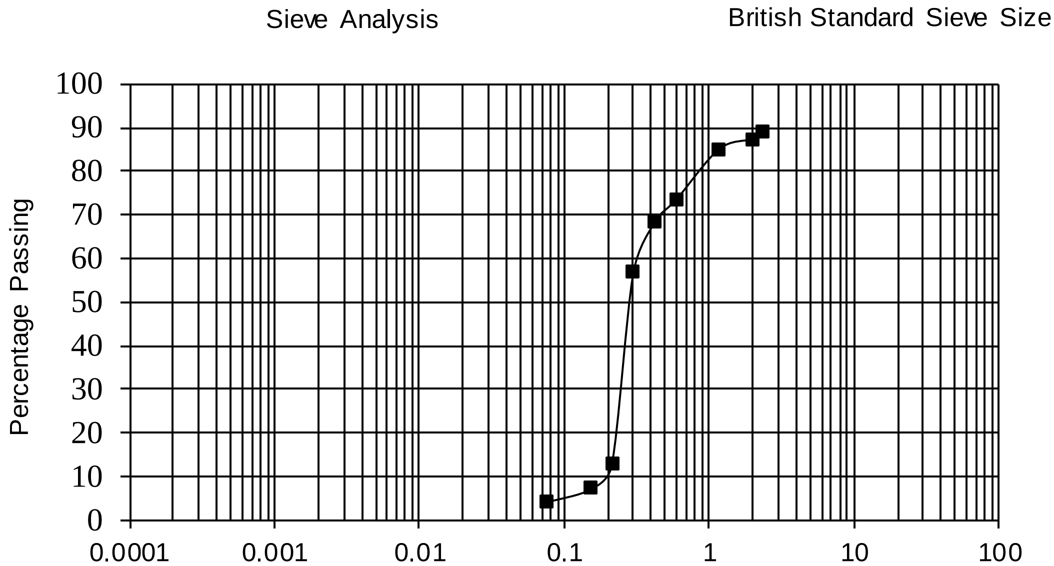

Figure 4.12: Sieve Analysis for BH 1, Log 12

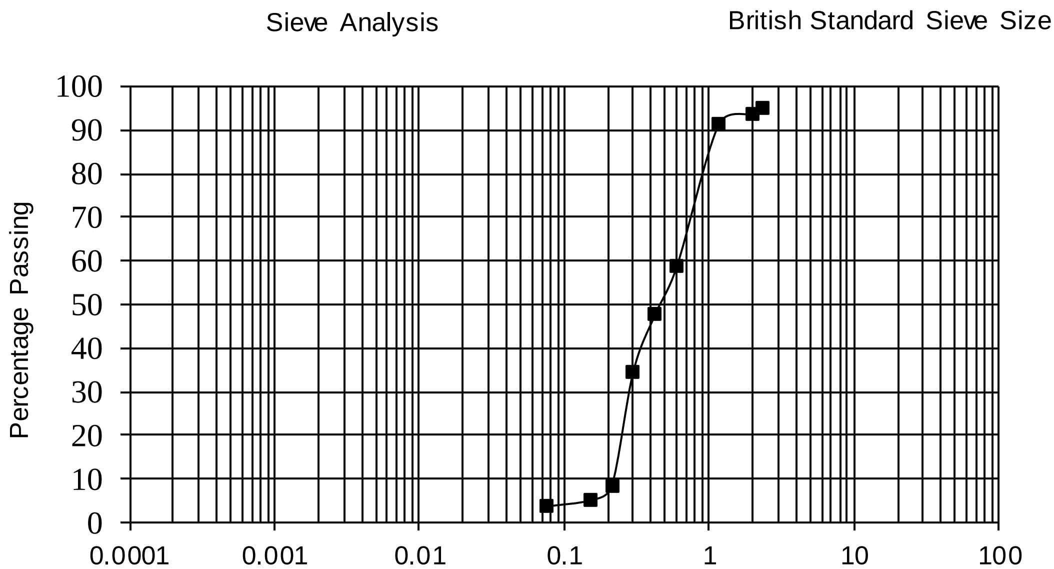

Figure 4.13: Sieve Analysis for BH 1, Log 13.

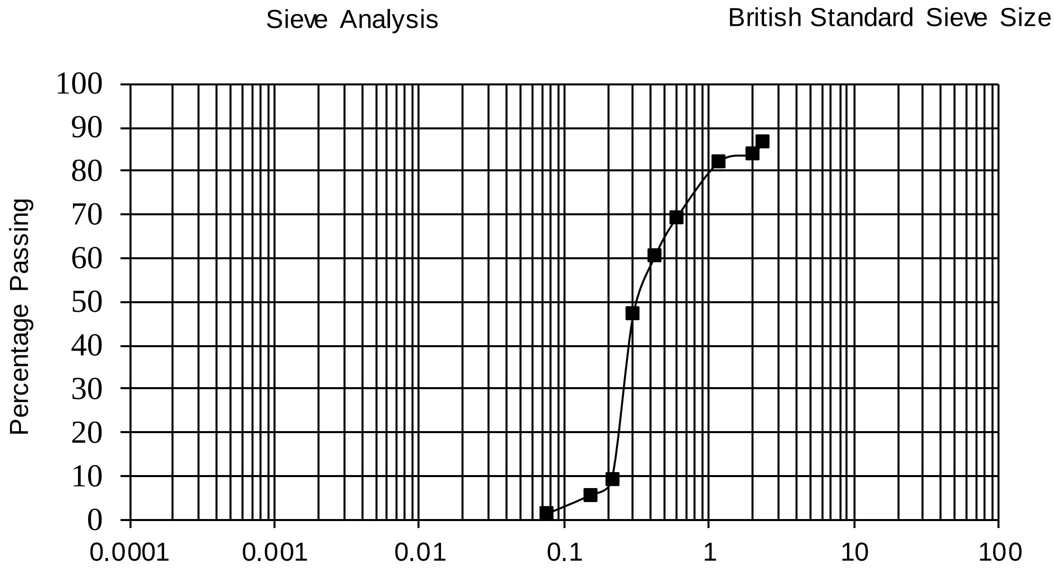

Figure 4.14: Sieve Analysis for BH 1, Log 14.

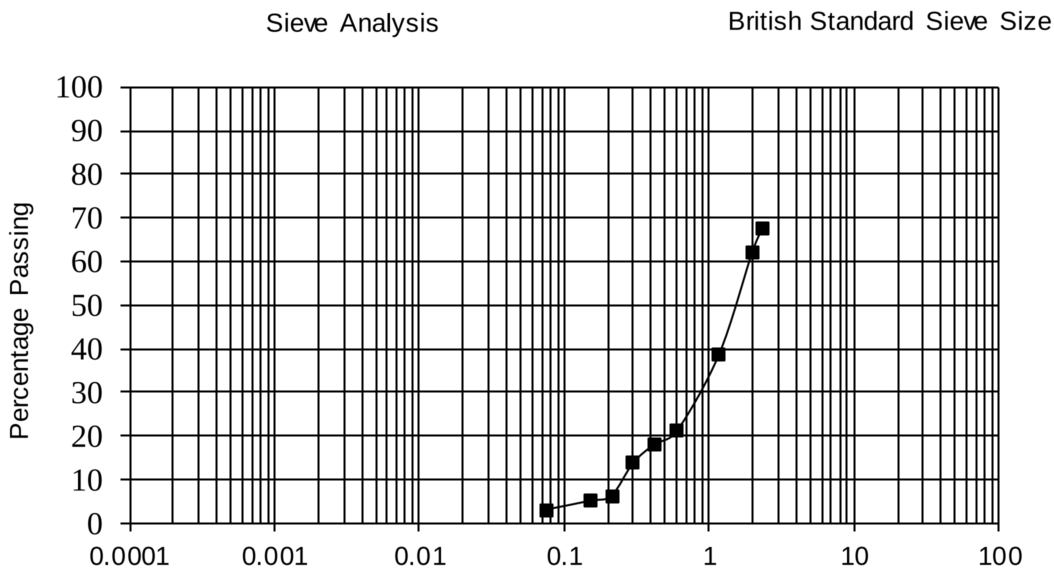

Figure 4.15: Sieve Analysis for BH 1, Log 15.

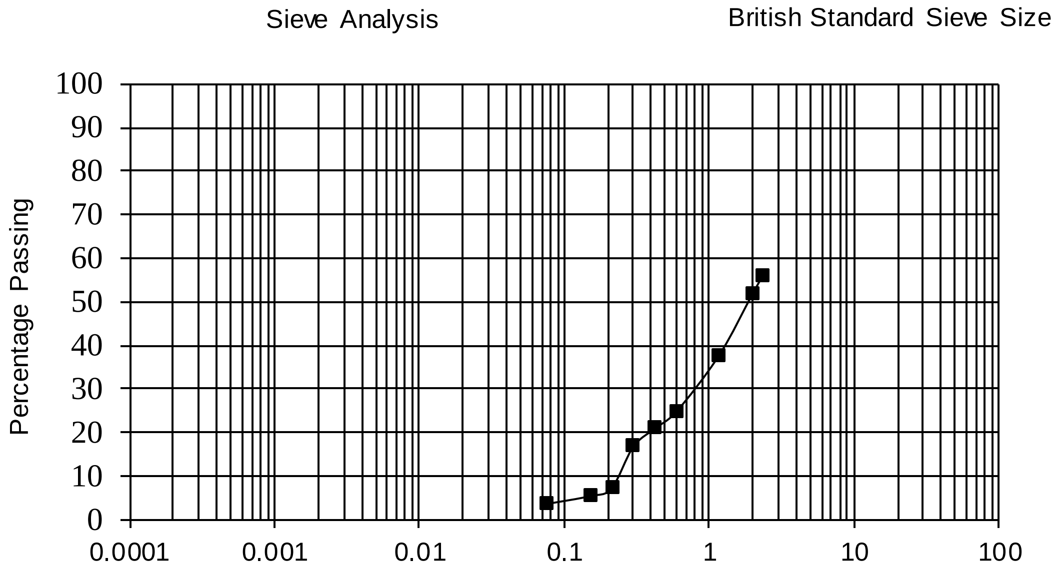

Figure 4.16: Sieve Analysis for BH 1, Log 16.

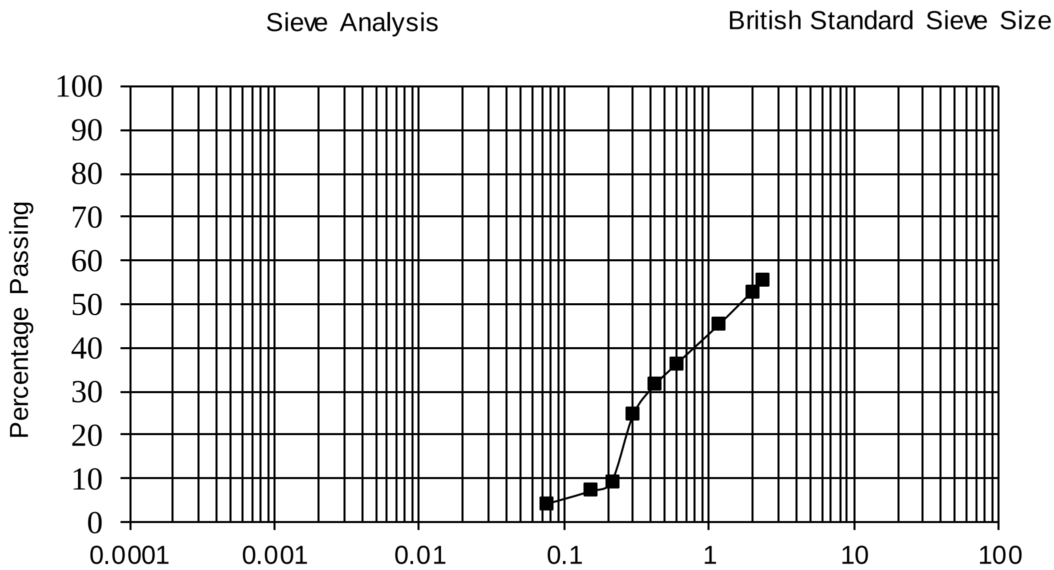

Figure 4.17: Sieve Analysis for BH 1, Log 17.

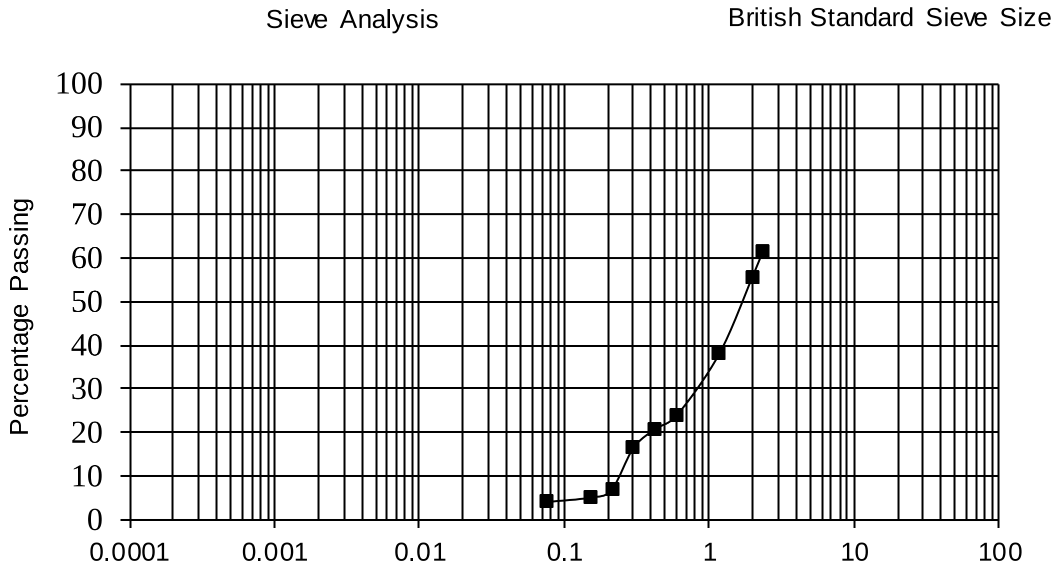

Figure 4.18: Sieve Analysis for BH 1, Log 18.

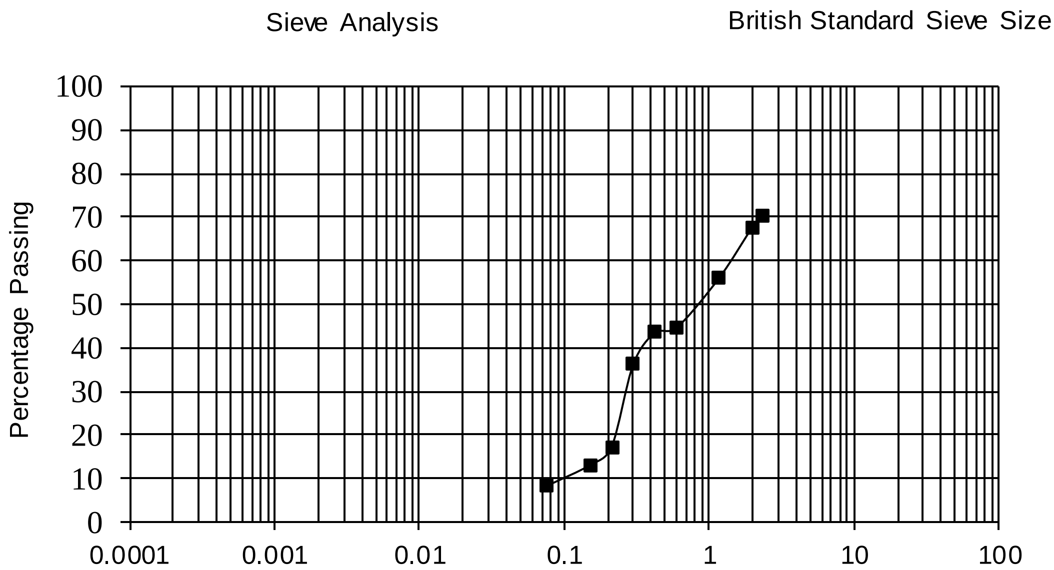

Figure 4.19: Sieve Analysis for BH 1, Log 19.

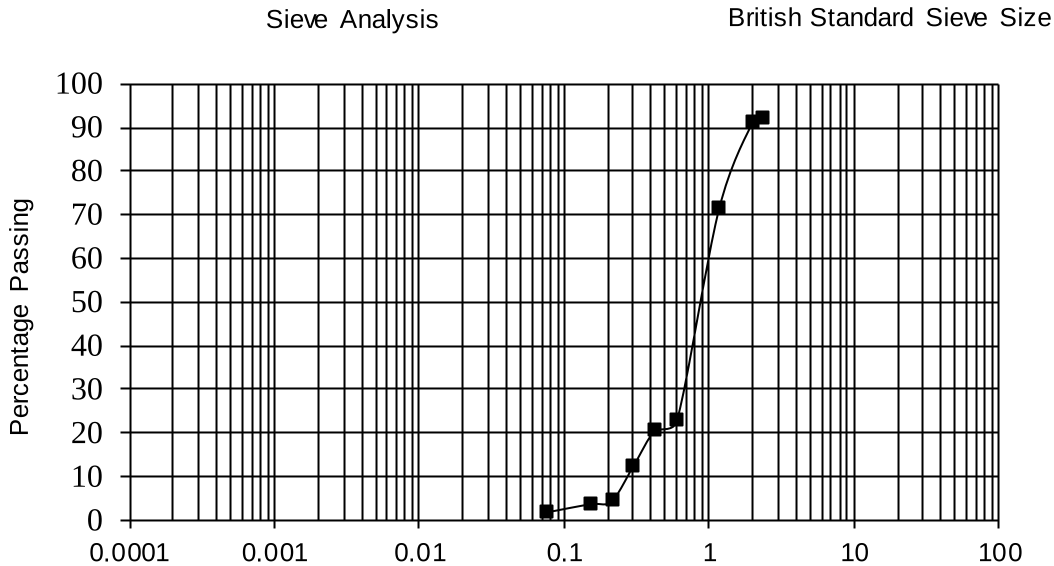

Figure 4.20: Sieve Analysis for BH 1, Log 20.

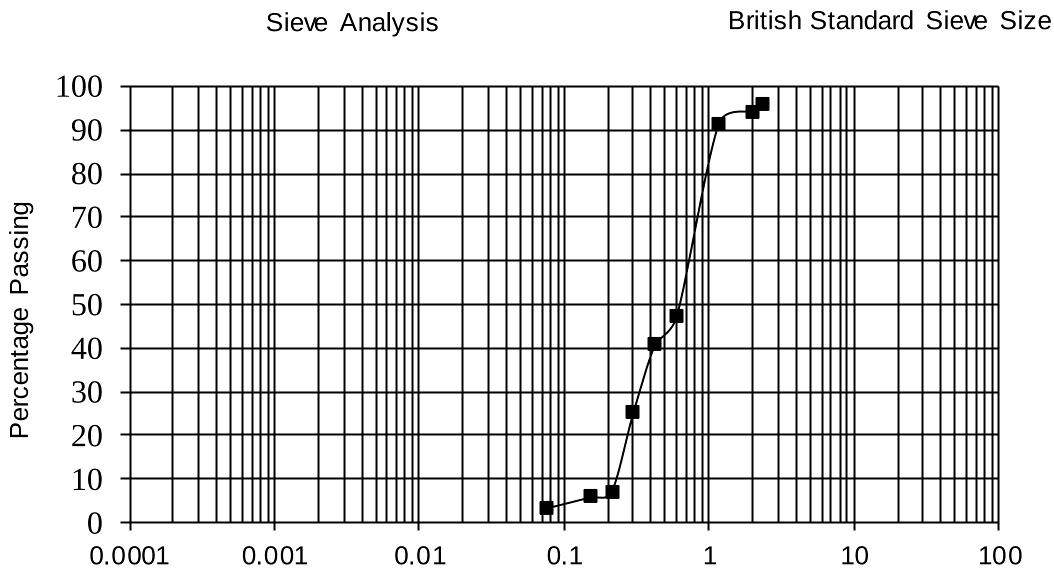

Figure 4.21: Sieve Analysis for BH 1, Log 21.

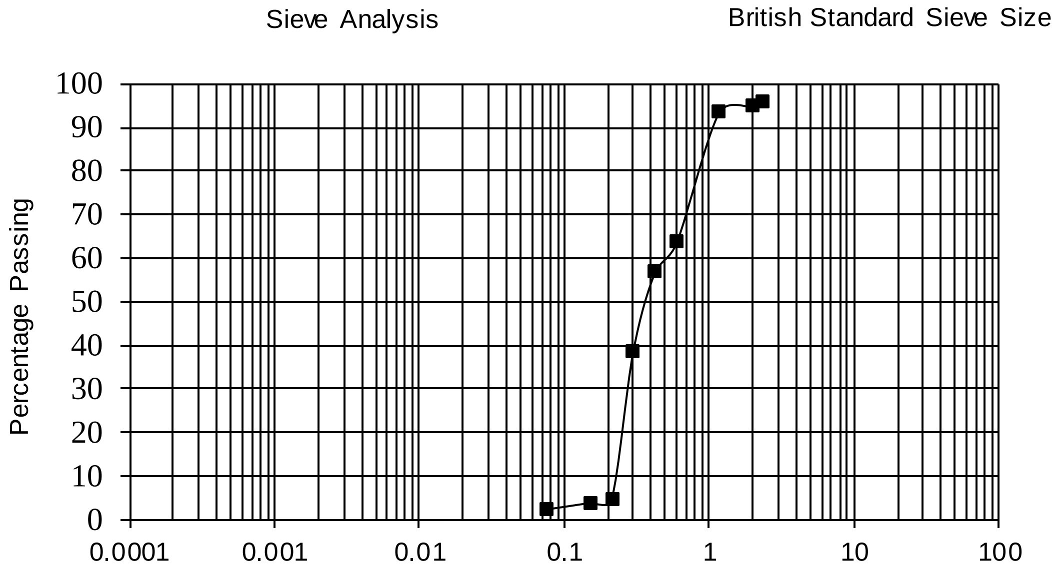

Figure 4.22: Sieve Analysis for BH 1, Log 22.

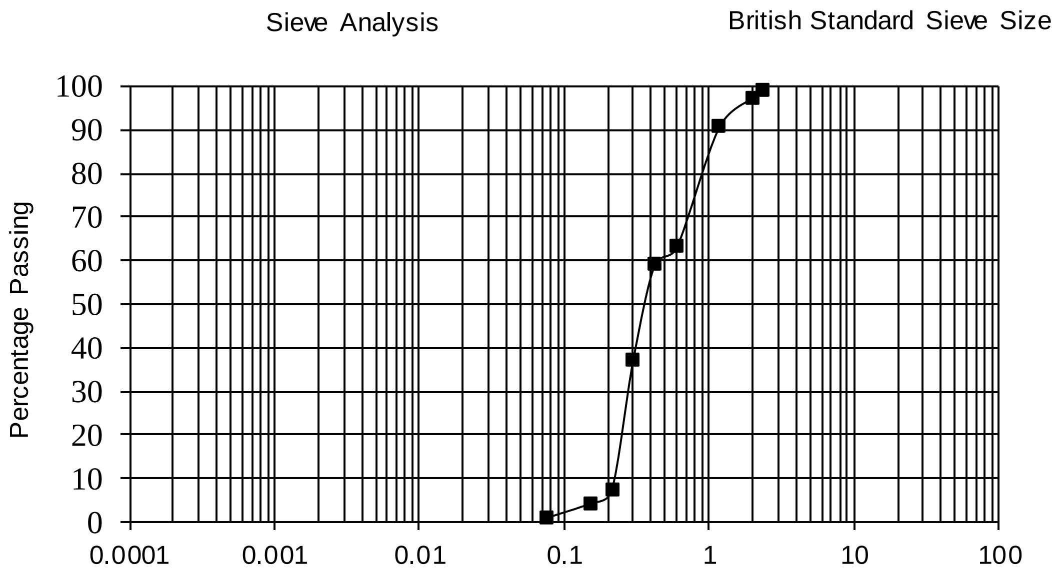

Figure 4.23: Sieve Analysis for BH 1, Log 23.

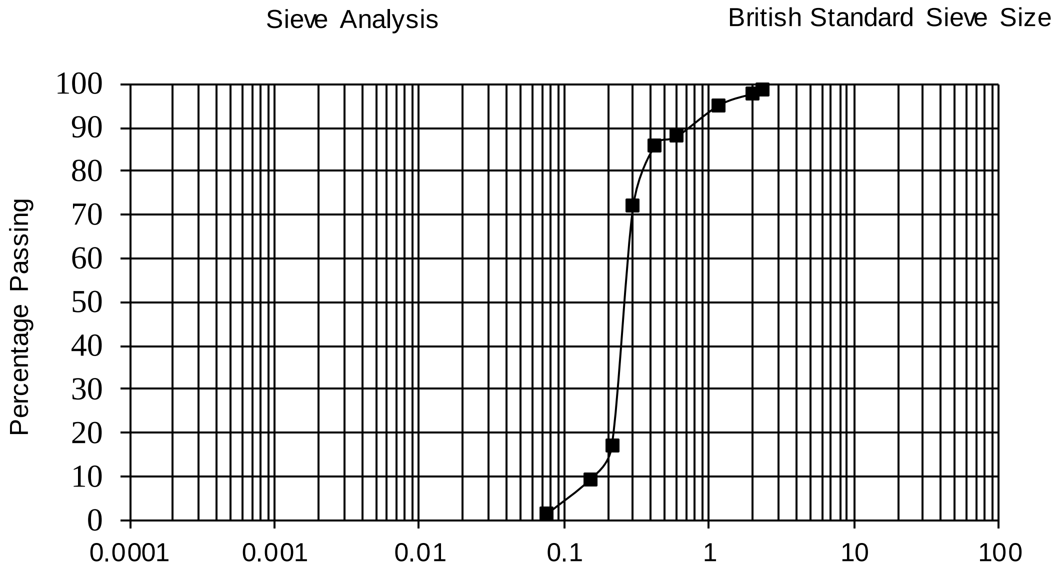

Figure 4.24: Sieve Analysis for BH 1, Log 24.

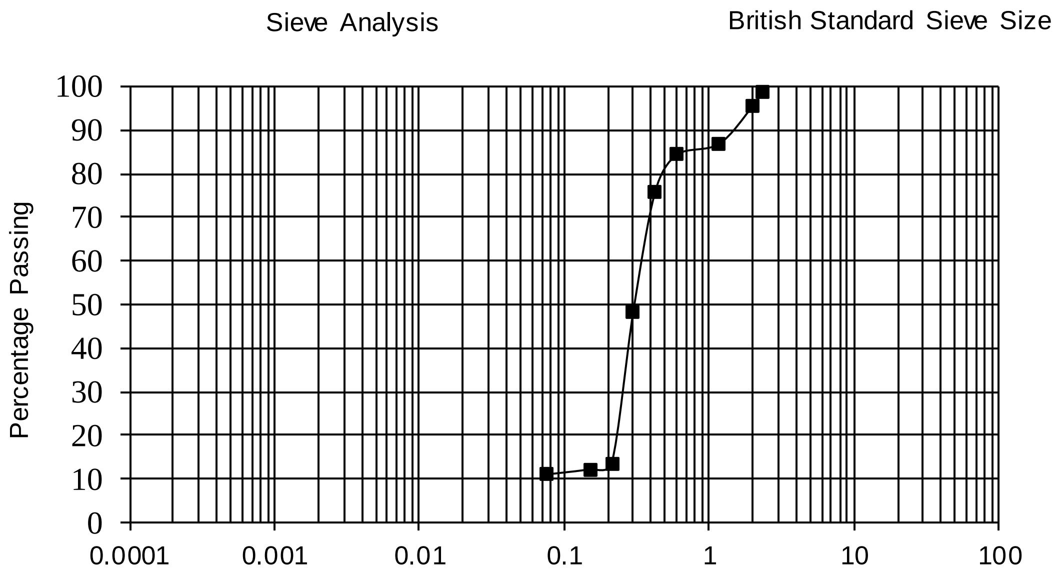

Figure 4.25: Sieve Analysis for BH 1, Log 25.

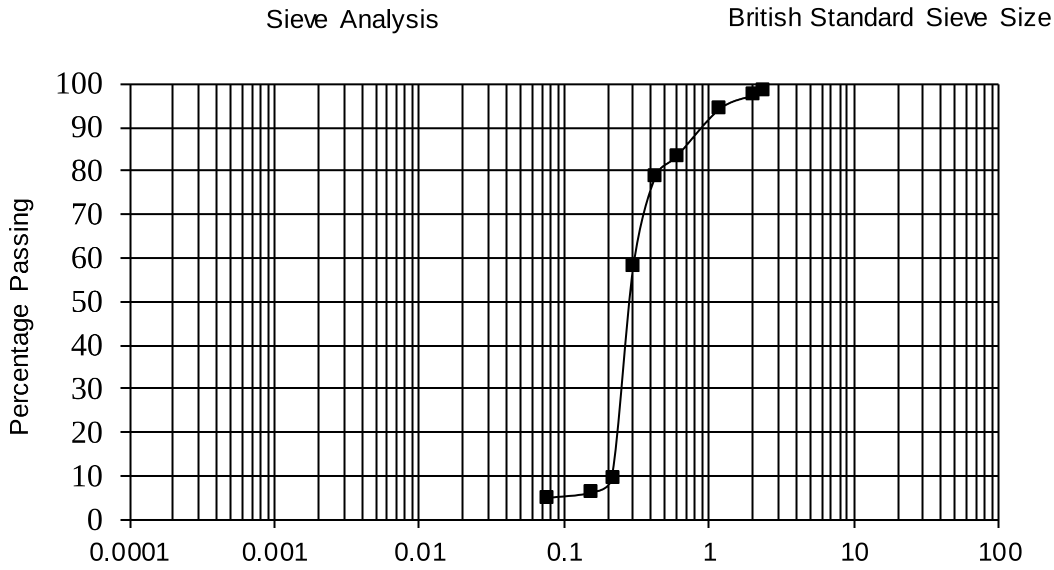

Figure 4.26: Sieve Analysis for BH 1, Log 26.

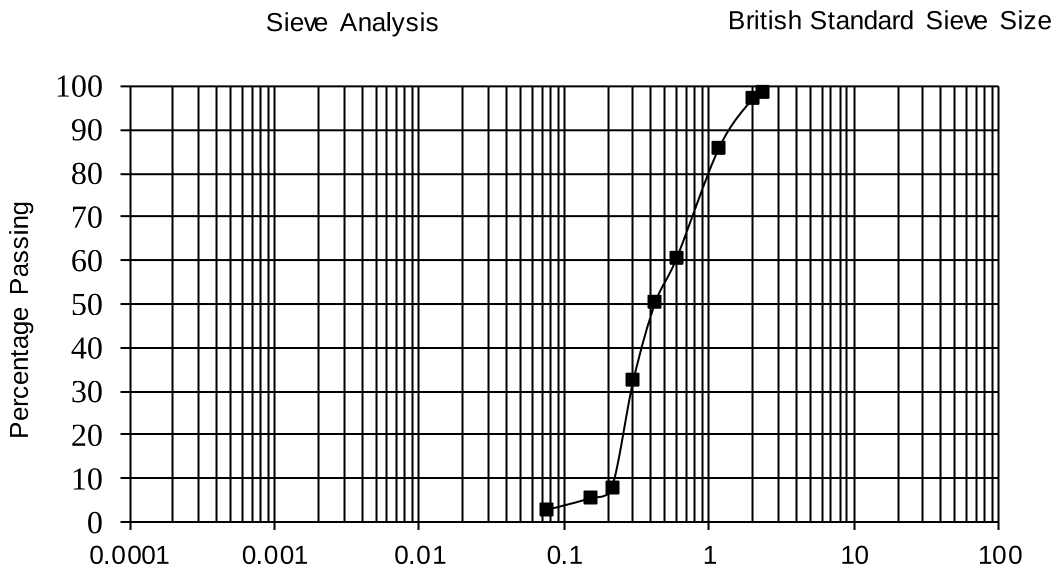

Figure 4.27: Sieve Analysis for BH 1, Log 27.

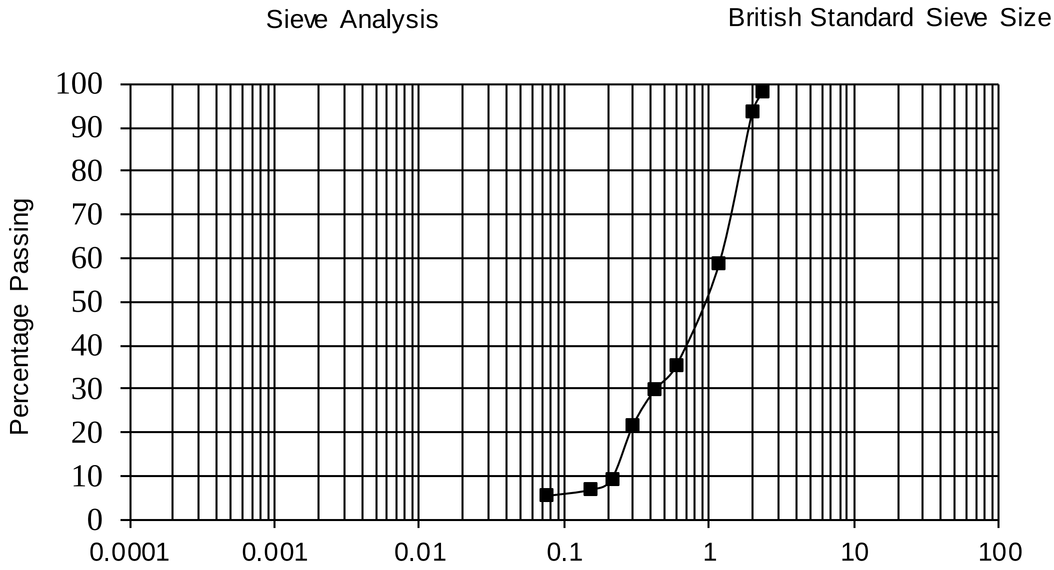

Figure 4.28: Sieve Analysis for BH 1, Log 28.

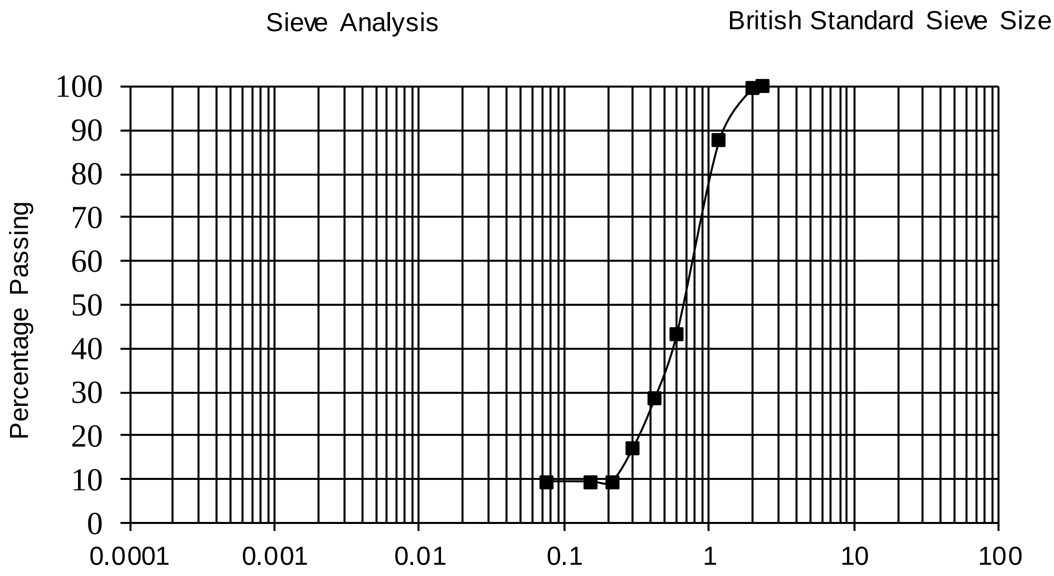

Figure 4.29: Sieve Analysis for BH 1, Log 29.

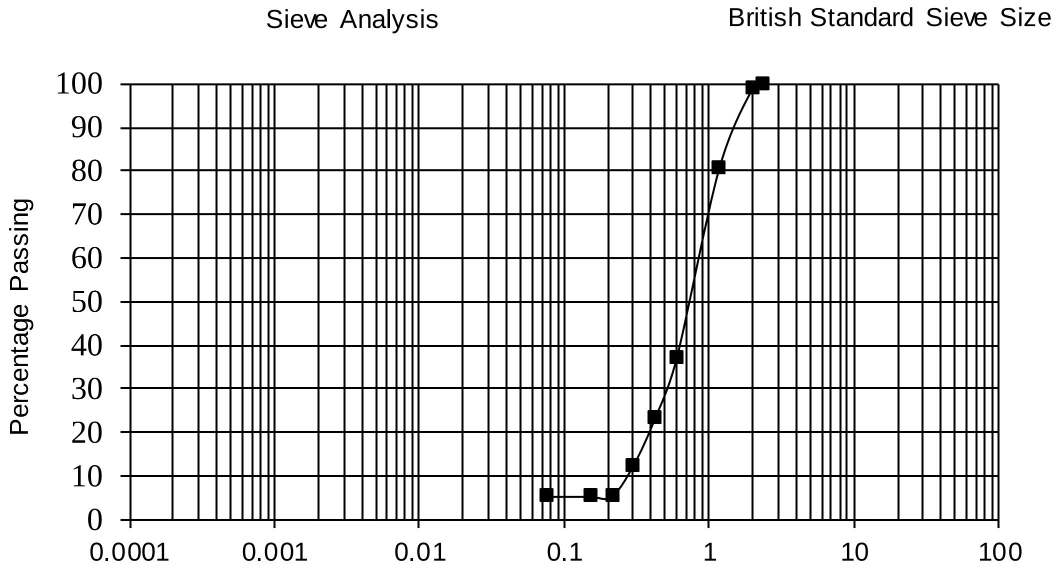

Figure 4.30: Sieve Analysis for BH 1, Log 30.

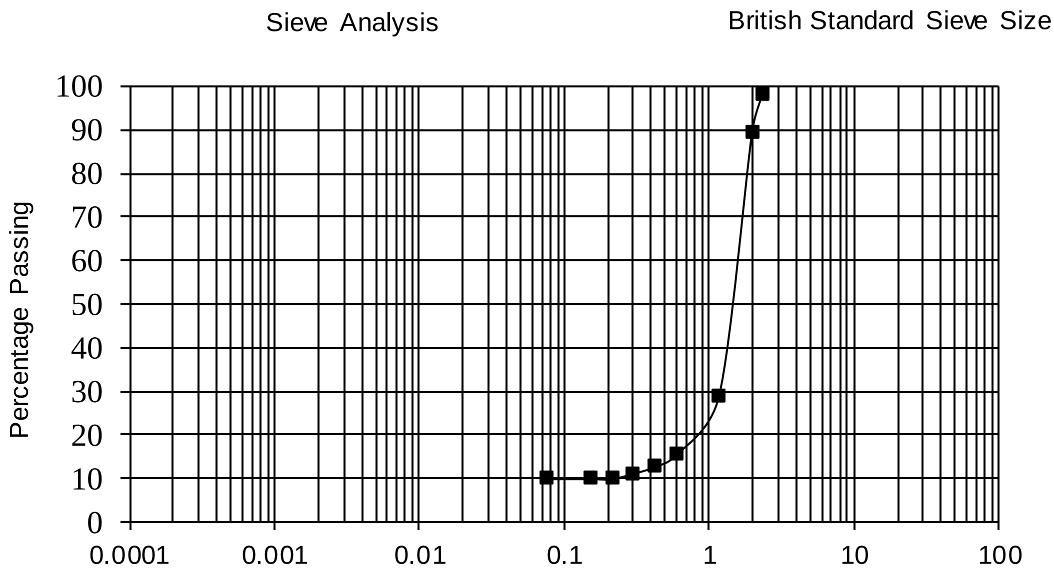

Figure 4.31: Sieve Analysis for BH 1, Log 31.

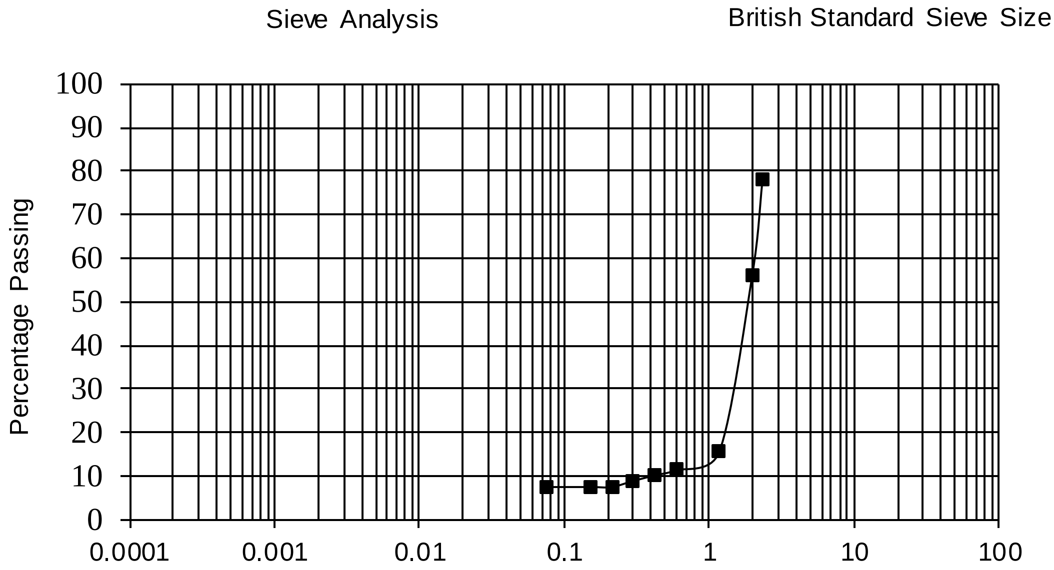

Figure 4.32: Sieve Analysis for BH 1, Log 32

4.2.2 BOREHOLE 1 SOIL STRATA

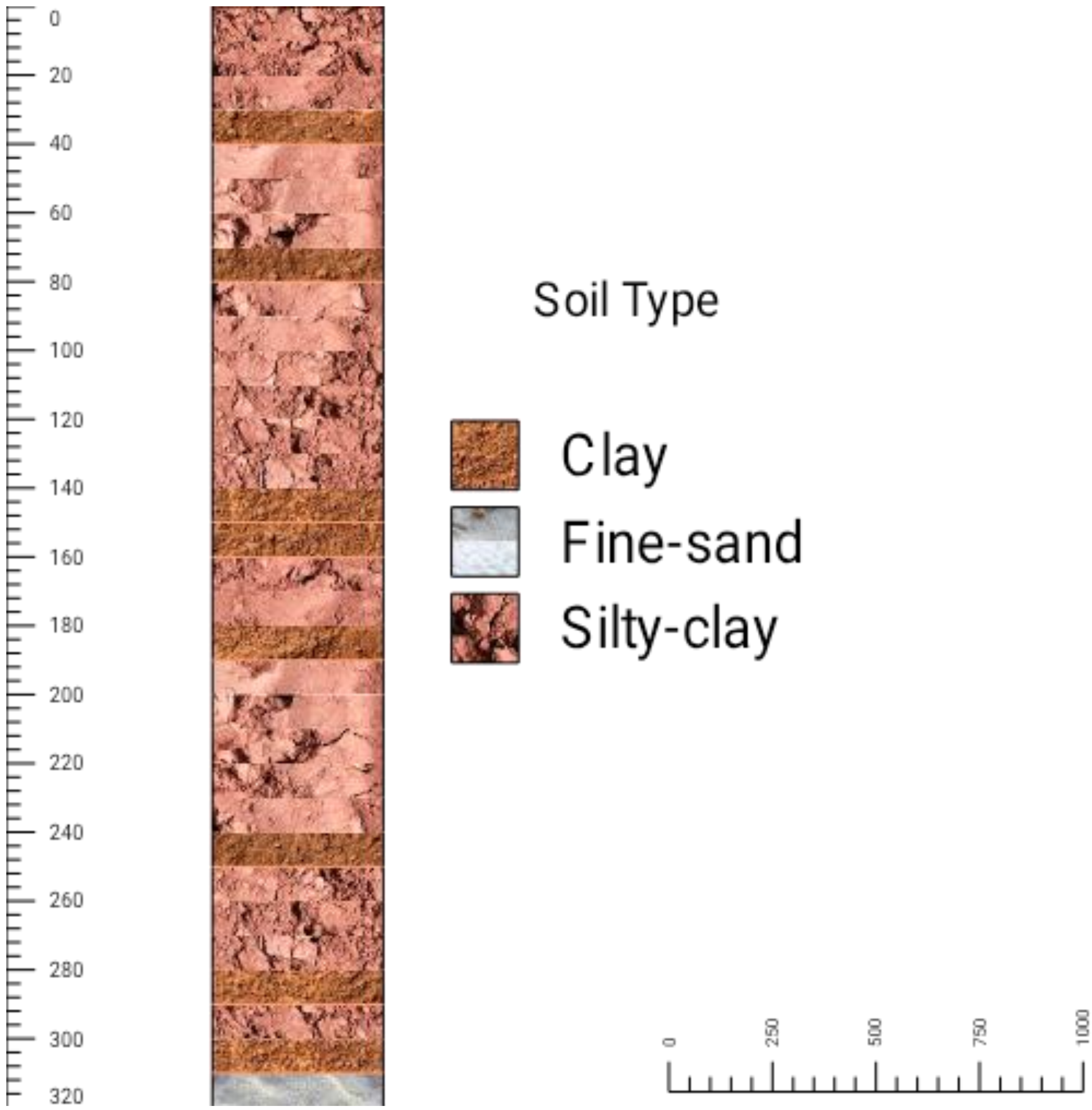

Figure 4.33: Soil Strata

Above is the soil strata for borehole one having a total of 32 logs of total depth of 320fts, it can be observed that a majority of the soil strata are silty-clay soil and few which are clay and fine sand. This is a typical borehole strata for my first study area.

4.2.3 SCREEN LOCATION

Screen was installed at 320fts (97.54metres), at the level of sharp sand formation. At this position, submersible pump was also installed at this same depth. Screen thickness was about 12mm. The drill bit size was about 4 inches (101.6mm).

4.3 BOREHOLE 2

Borehole two consist of 29 logs of soil sample for the second study area of and Oluku (River Road with latitude 6.437528 and longitude 5.601228), at different depth before water table level. Sieve analysis were done for each log of soil in order to obtain D_{10} which was used to calculate the permeability constant "k" at each depth from 0-290fts of well depth. The tables below are the different sieve analysis values obtained for each soil log including their respective depth, permeability and soil classification. The formula used in calculating for permeability "K" using Hazen William's formula;

$$K=C(D_{10})^2. \qquad (4.1')$$

K= Coefficient of permeability (cm/s)

C= Hazen's coefficient 0.01mm

D_{10}= Effective grain size (in mm)

From this formula we obtained the permeability for each soil log for Borehole 1.

The effective size D_{10} is determined by finding the particle size corresponding to 10% cumulative passing on the curve.

4.3.1 CONSTANT OF PERMEABILITY FOR BOREHOLE 2 LOG 1-29

Table 4.2: Coefficient of permeability

BH 2, LOGS	Permeability, K (in cm/s)	Soil Type	Drainage
Log 1	3.61x10-6	Silty clayey	Poor
Log 2	4.41x10-6	Silty clayey	Poor
Log 3	4x10-6	Silty clayey	Poor
Log 4	4.84x10-6	Silty clayey	Poor

BH 2, LOGS	Permeability, K (in cm/s)	Soil Type	Drainage
Log 5	6.25x10-6	Silty clayey	Poor
Log 6	4x10-6	Silty clayey	Poor
Log 7	4x10-6	Silty clayey	Poor
Log 8	5.29x10-6	Silty clayey	Poor
Log 9	4.4x10-6	Silty clayey	Poor
Log 10	3.24x10-6	Silty clayey	Poor
Log 11	4.41x10-6	Silty clayey	Poor
Log 12	4x10-6	Silty clayey	Poor
Log 13	4.5x10-6	Silty clayey	Poor
Log 14	9x10-6	Silty clayey	Poor
Log 15	9x10-6	Silty clayey	Poor
Log 16	6.25x10-6	Silty clayey	Poor
Log 17	4x10-6	Silty clayey	Poor
Log 18	4x10-6	Silty clayey	Poor
Log 19	3.24x10-6	Silty clayey	Poor
Log 20	2.25x10-6	Silty clayey	Poor
Log 21	2.89x10-6	Silty clayey	Poor
Log 22	4x10-6	Silty clayey	Poor
Log 23	3.24x10-6	Silty clayey	Poor
Log 24	4.41x10-6	Silty clayey	Poor
Log 25	4.41x10-6	Silty clayey	Poor
Log 26	1.44x10-4	Silty sand	Poor
Log 27	4.9x10-5	silty	Poor
Log 28	4.9x10-7	clayey	Very poor
Log 29	1x10-4	Fine sand	Poor

Below are the sieve analysis for each soil sample;

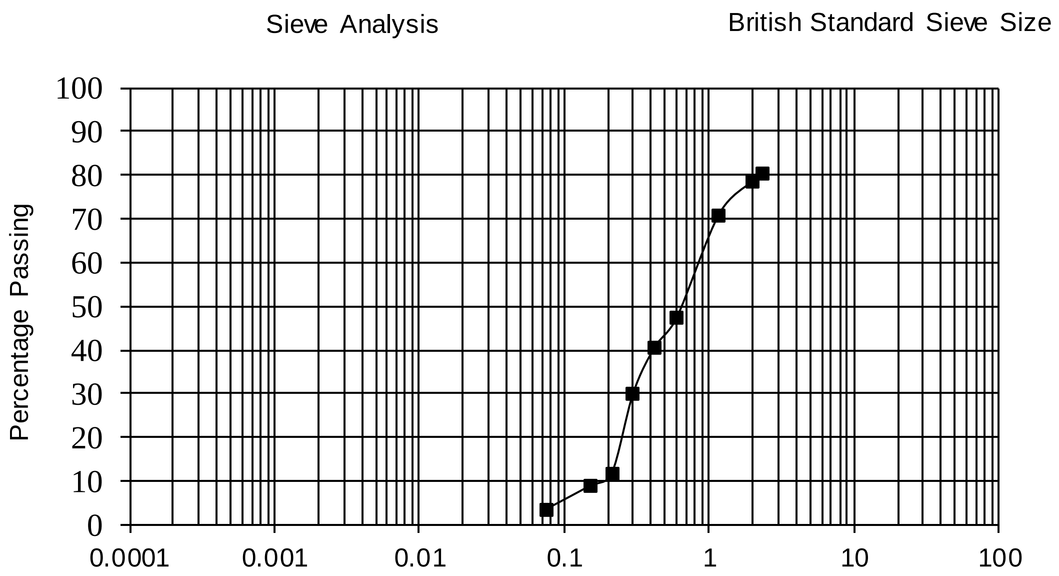

Figure 4.34: Sieve Analysis for BH 2, Log 1.

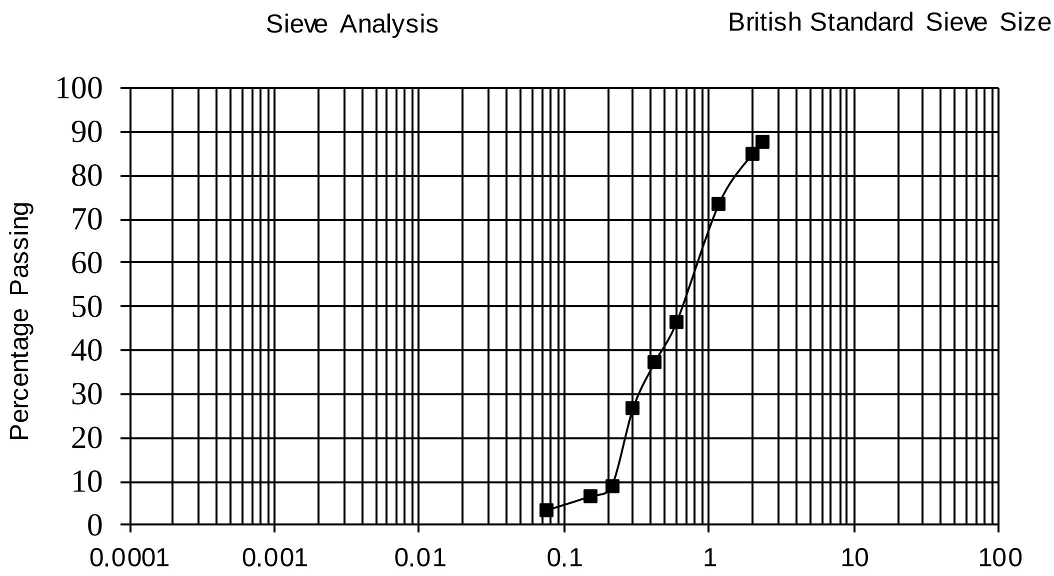

Figure 4.35: Sieve Analysis for BH 2, Log 2.

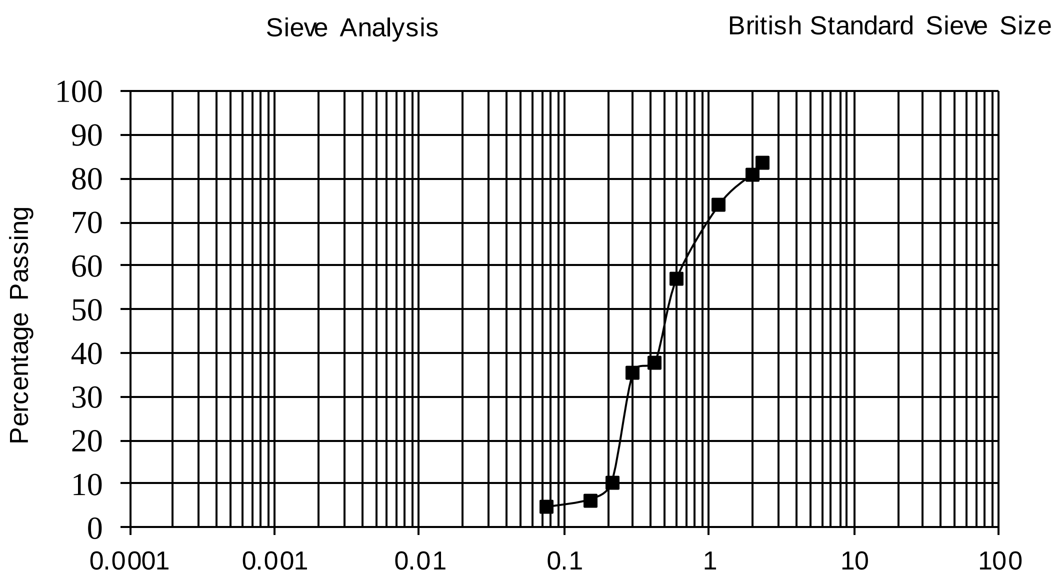

Figure 4.36: Sieve Analysis for BH 2, Log 3.

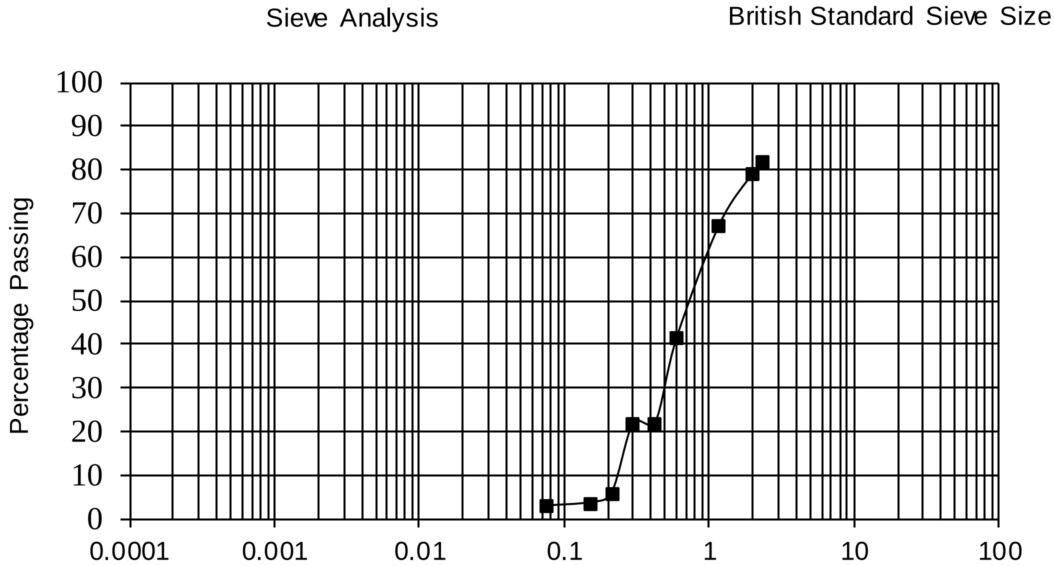

Figure 4.37: Sieve Analysis for BH 2, Log 4.

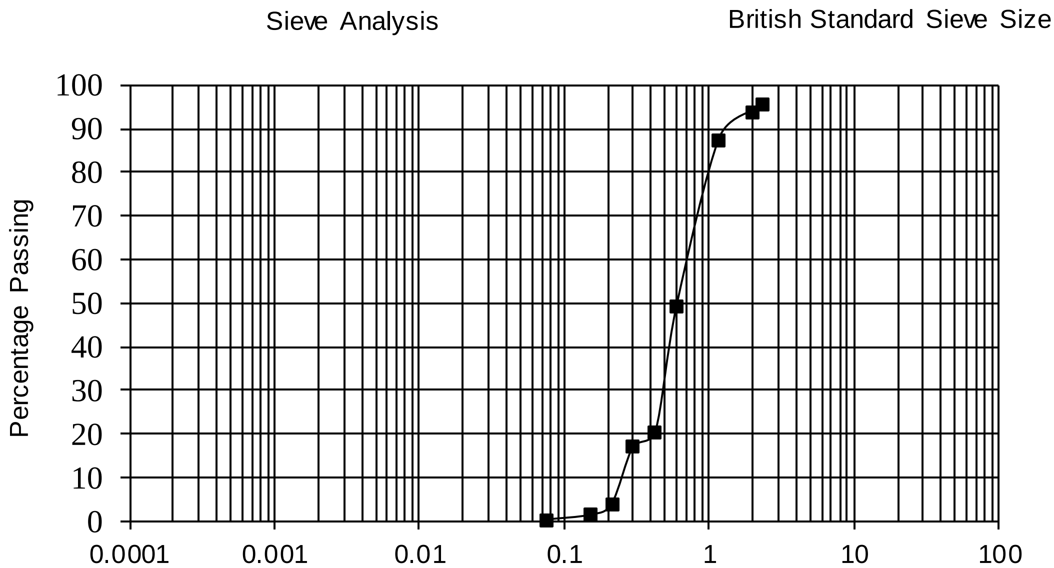

Figure 4.38: Sieve Analysis for BH 2, Log 5.

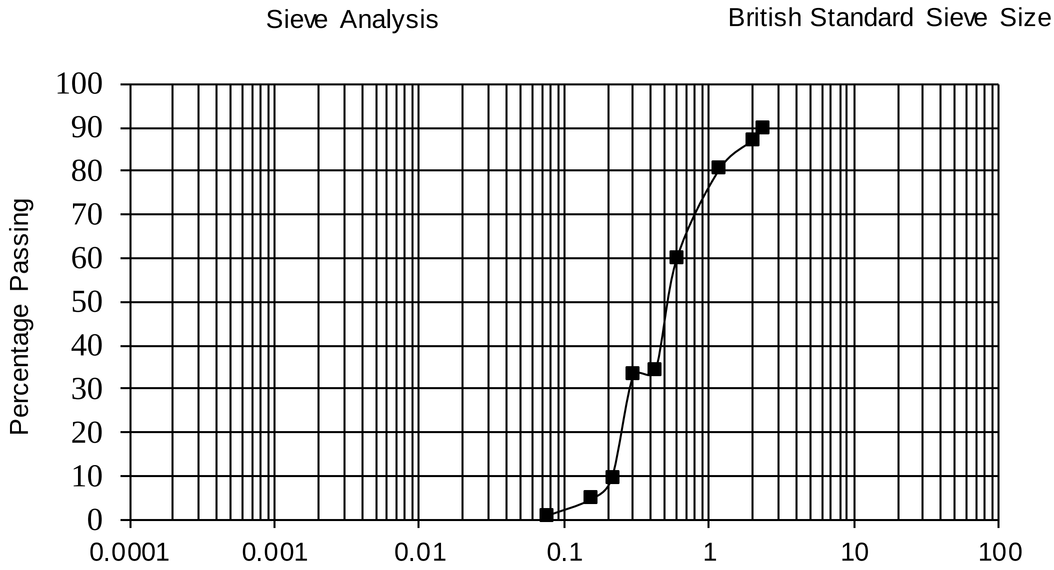

Figure 4.39: Sieve Analysis for BH 2, Log 6.

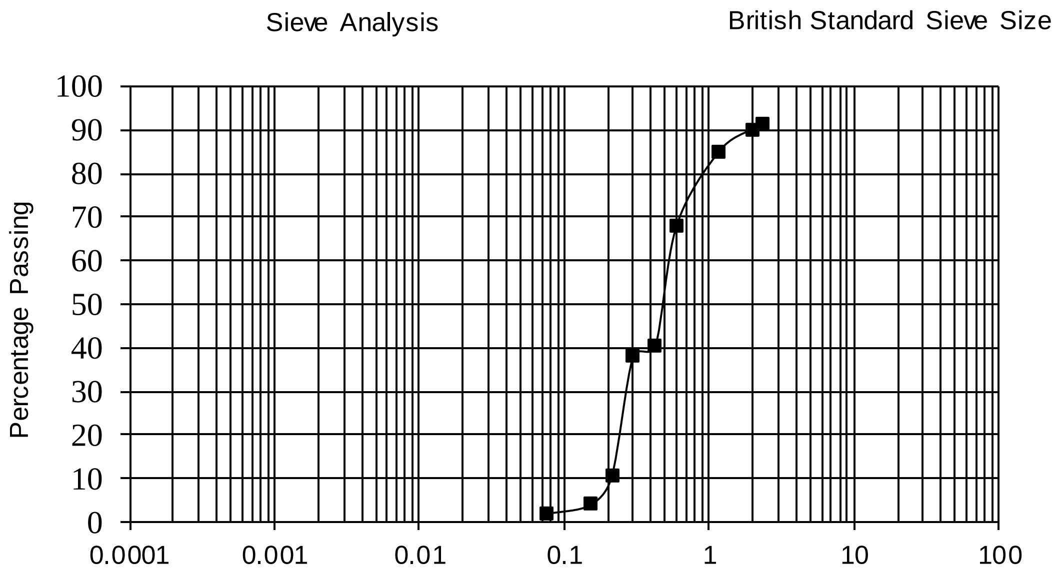

Figure 4.40: Sieve Analysis for BH 2, Log 7.

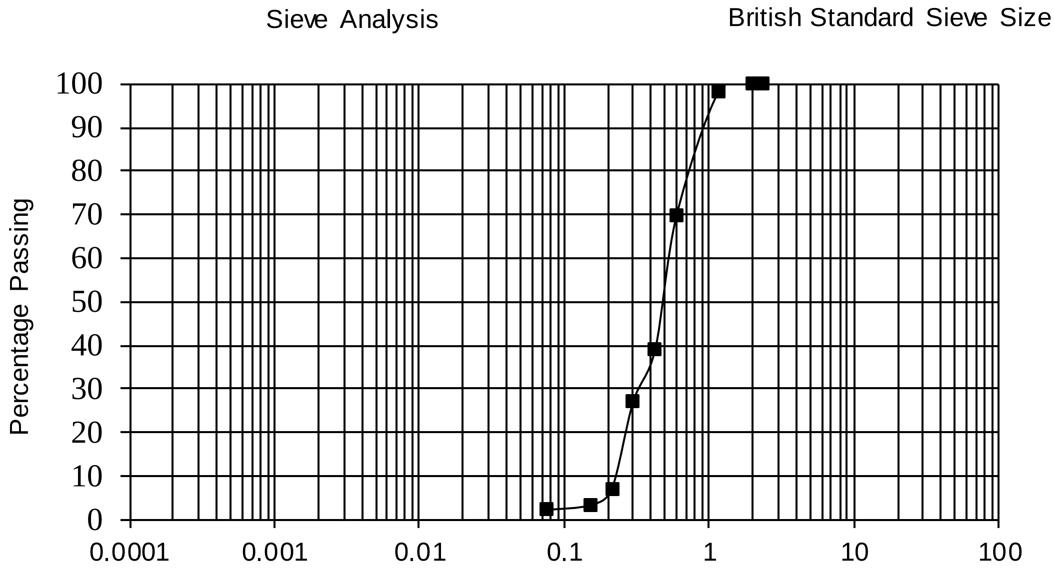

Figure 4.41: Sieve Analysis for BH 2, Log 8.

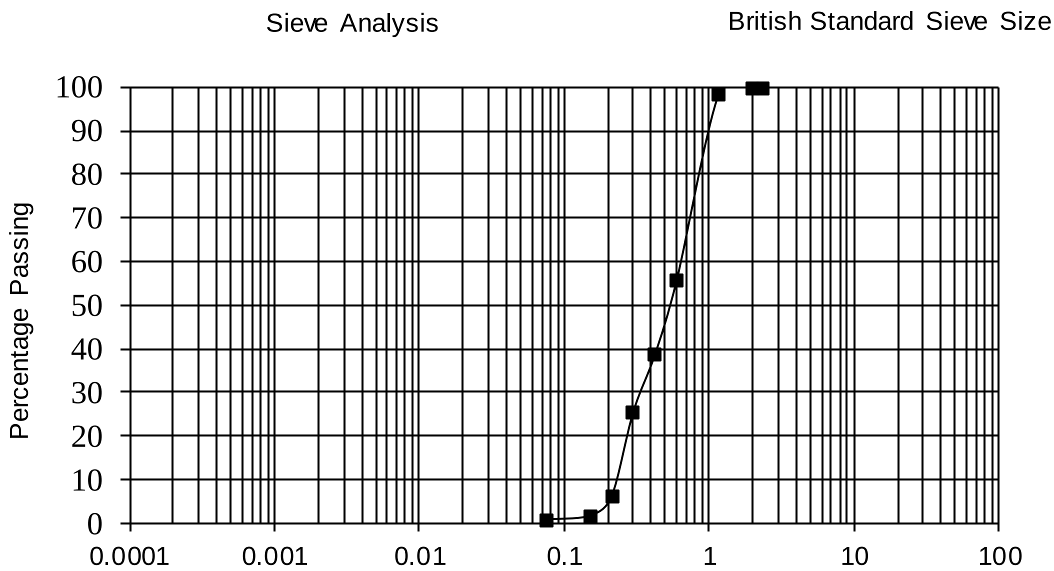

Figure 4.42: Sieve Analysis for BH 2, Log 9.

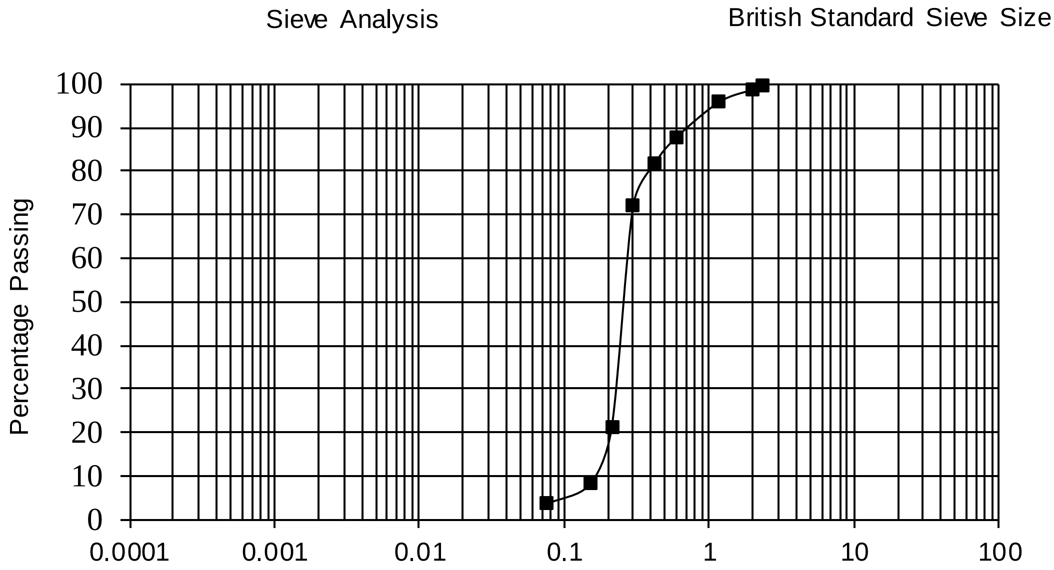

Figure 4.43: Sieve Analysis for BH 2, Log 10.

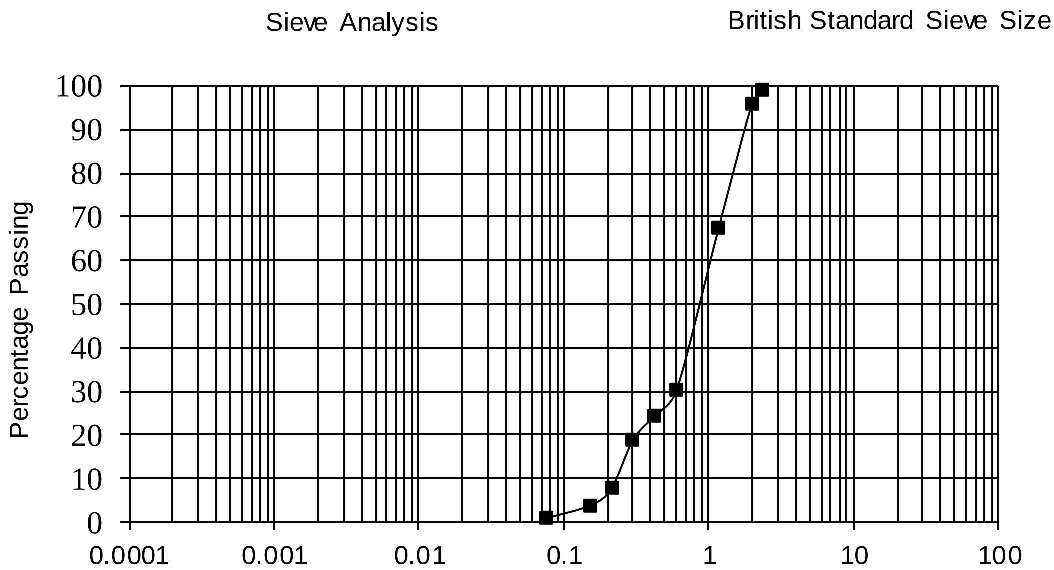

Figure 4.44: Sieve Analysis for BH 2, Log 11.

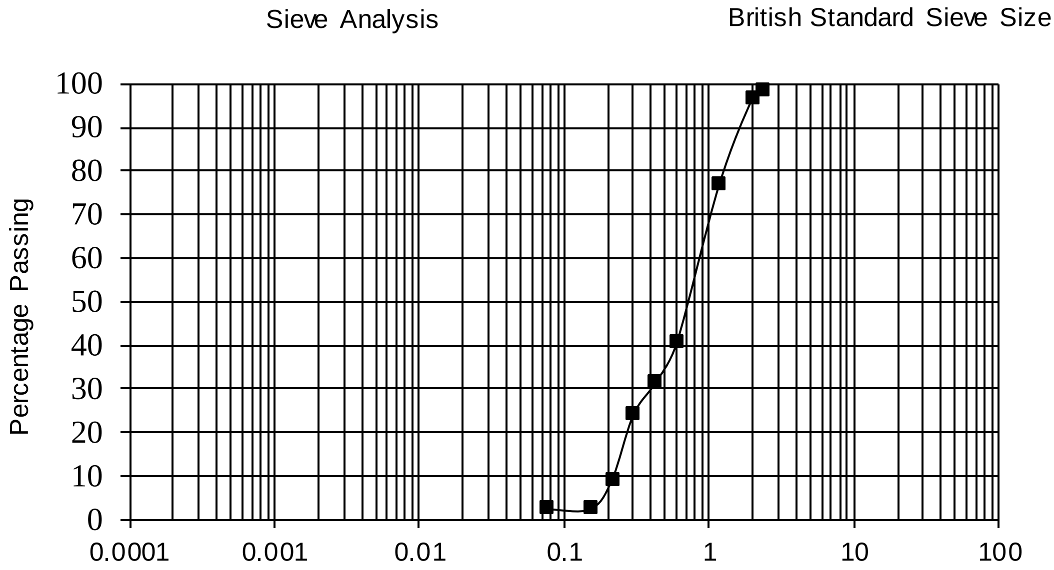

Figure 4.45: Sieve Analysis for BH 2, Log 12.

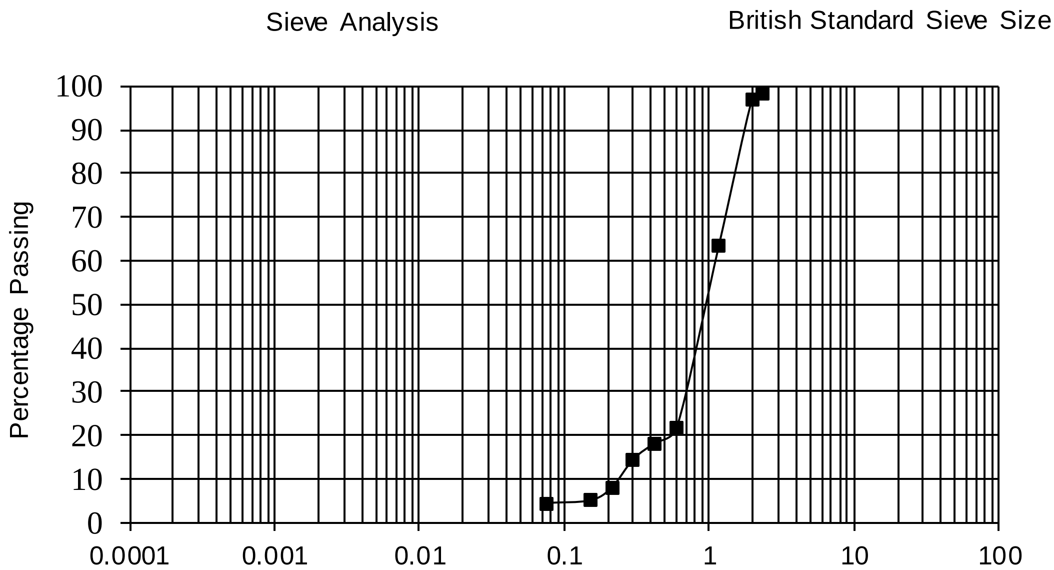

Figure 4.46: Sieve Analysis for BH 2, Log 13.

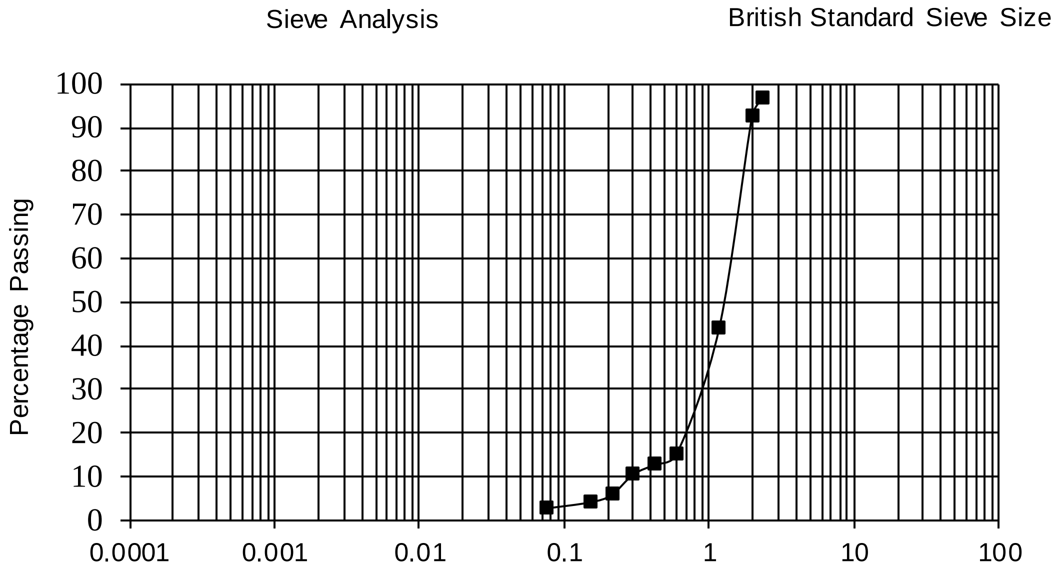

Figure 4.47: Sieve Analysis for BH 2, Log 14.

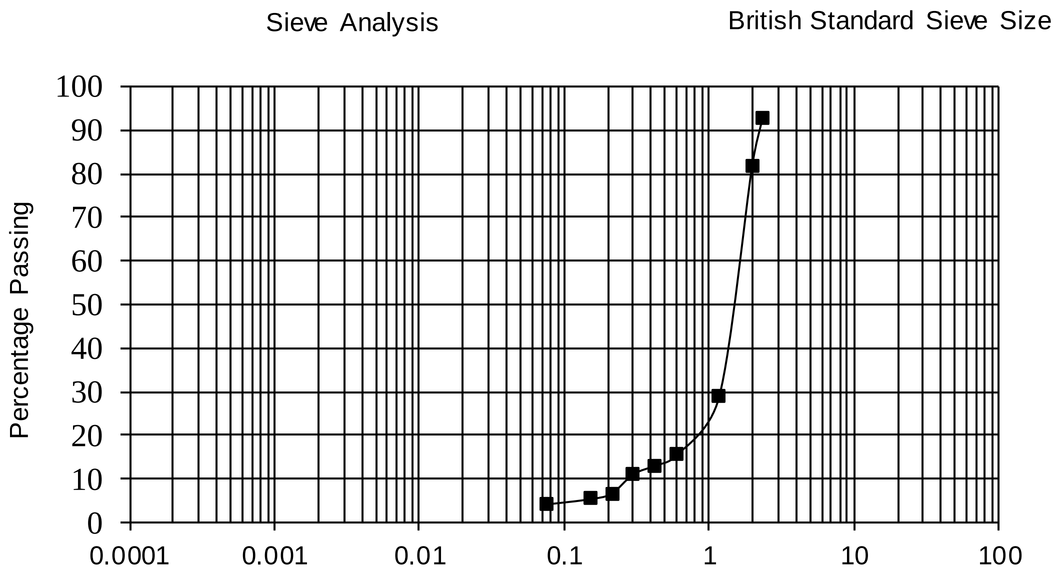

Figure 4.48: Sieve Analysis for BH 2, Log 15.

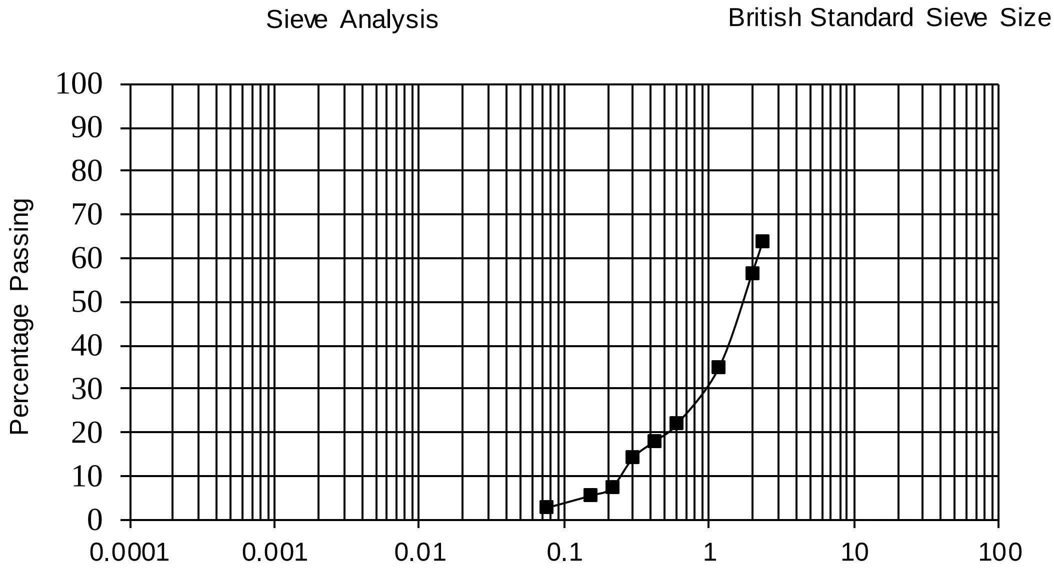

Figure 4.49: Sieve Analysis for BH 2, Log 16.

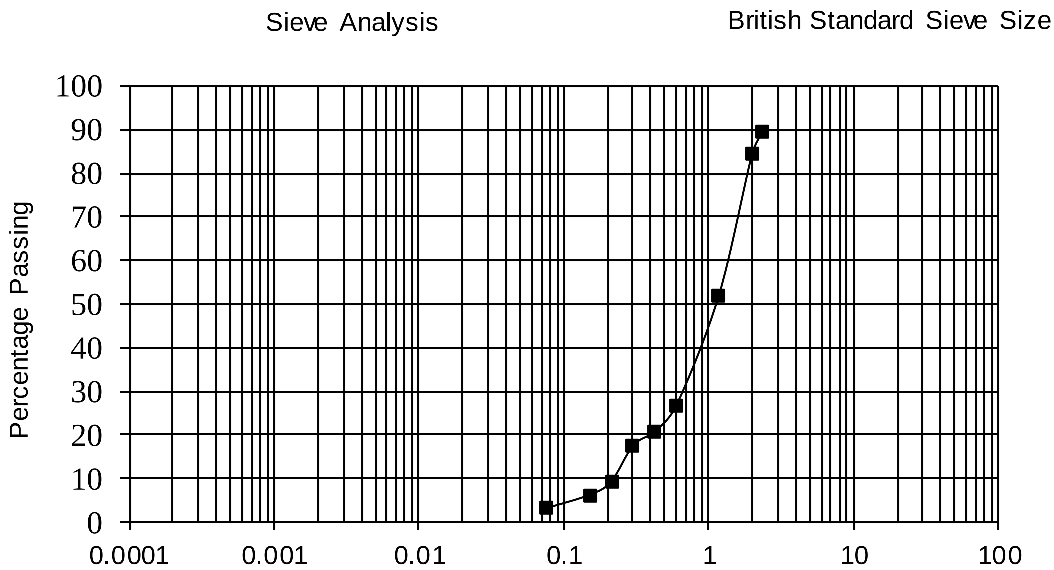

Figure 4.50: Sieve Analysis for BH 2, Log 17.

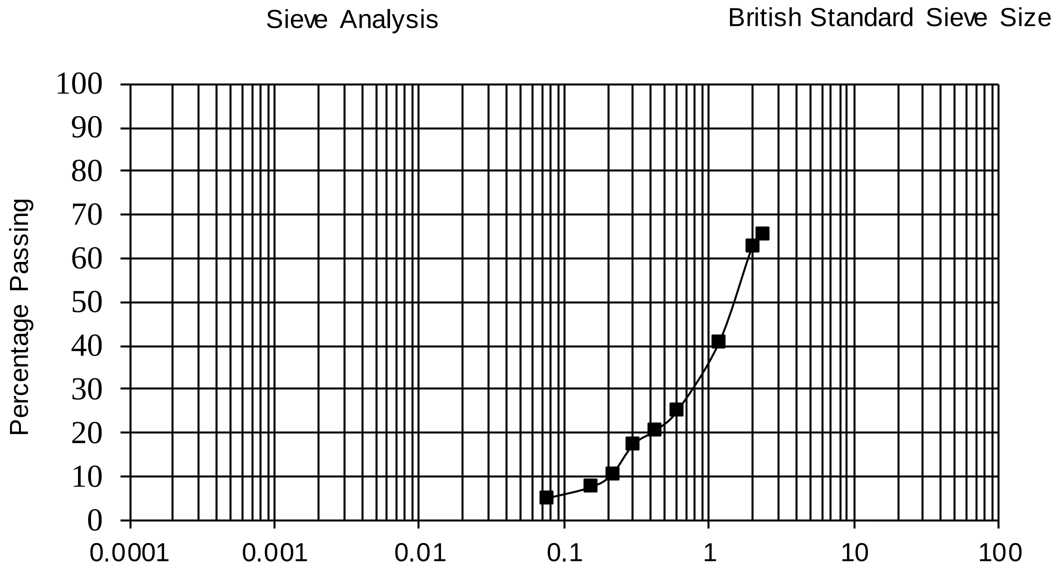

Figure 4.51: Sieve Analysis for BH 2, Log 18.

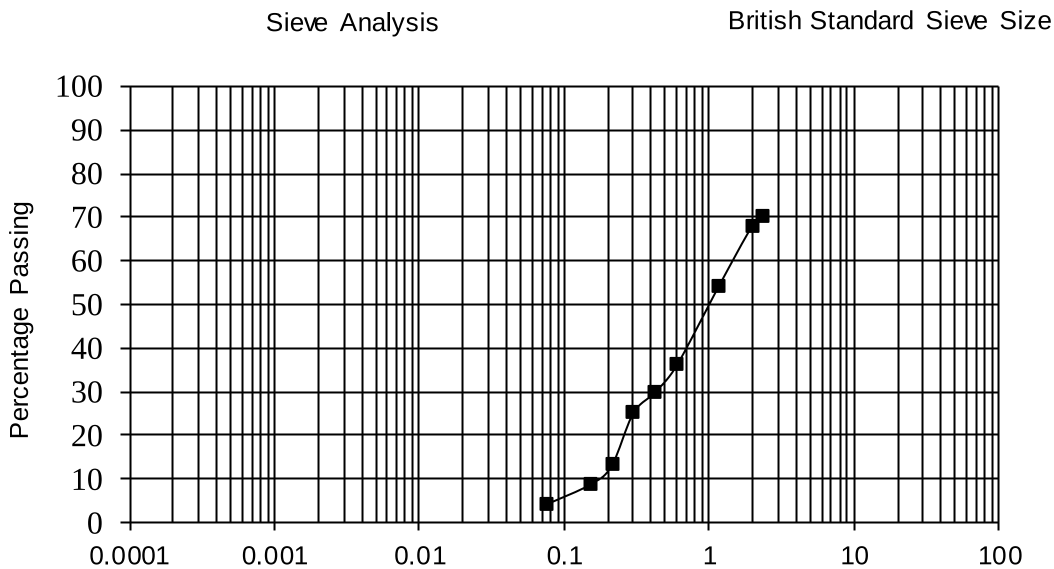

Figure 4.52: Sieve Analysis for BH 2, Log 19.

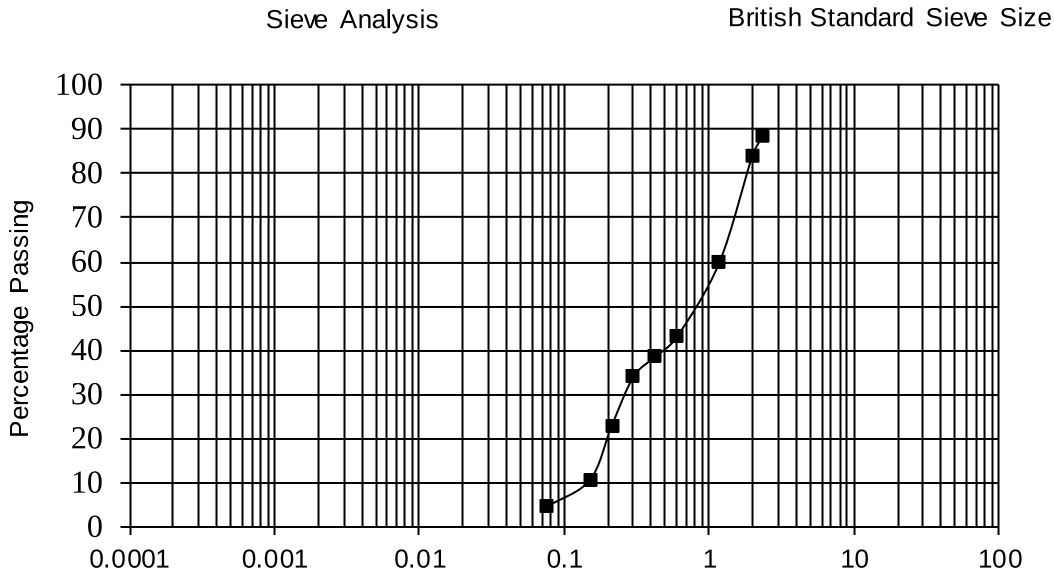

Figure 4.53: Sieve Analysis for BH 2, Log 20.

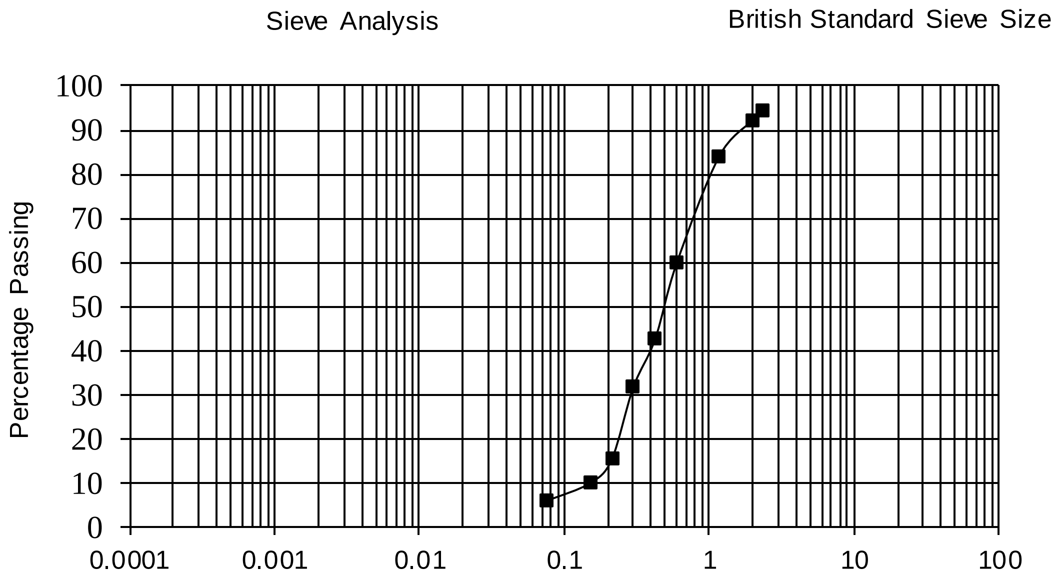

Figure 4.54: Sieve Analysis for BH 2, Log 21.

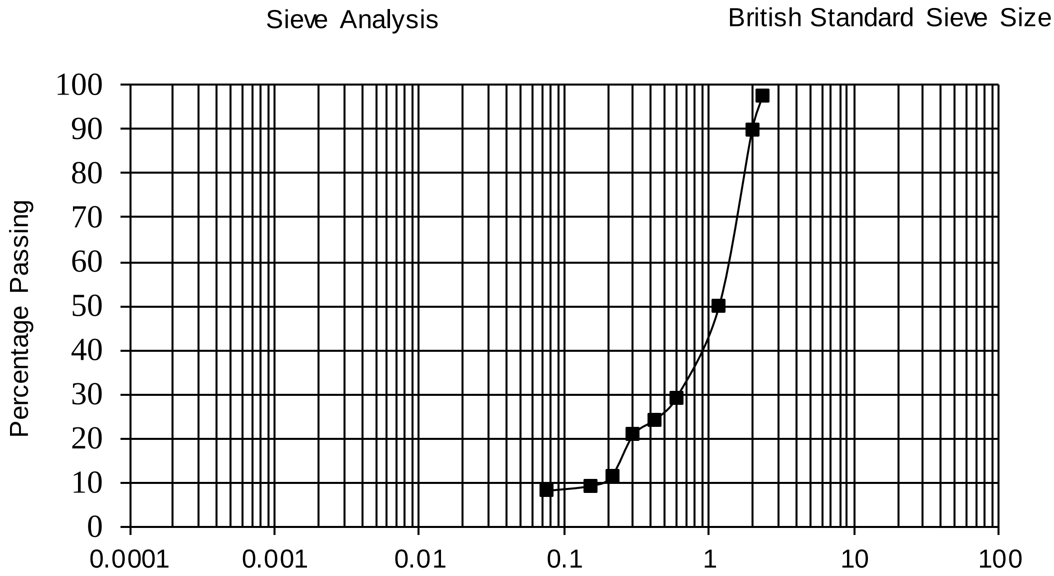

Figure 4.55: Sieve Analysis for BH 2, Log 22.

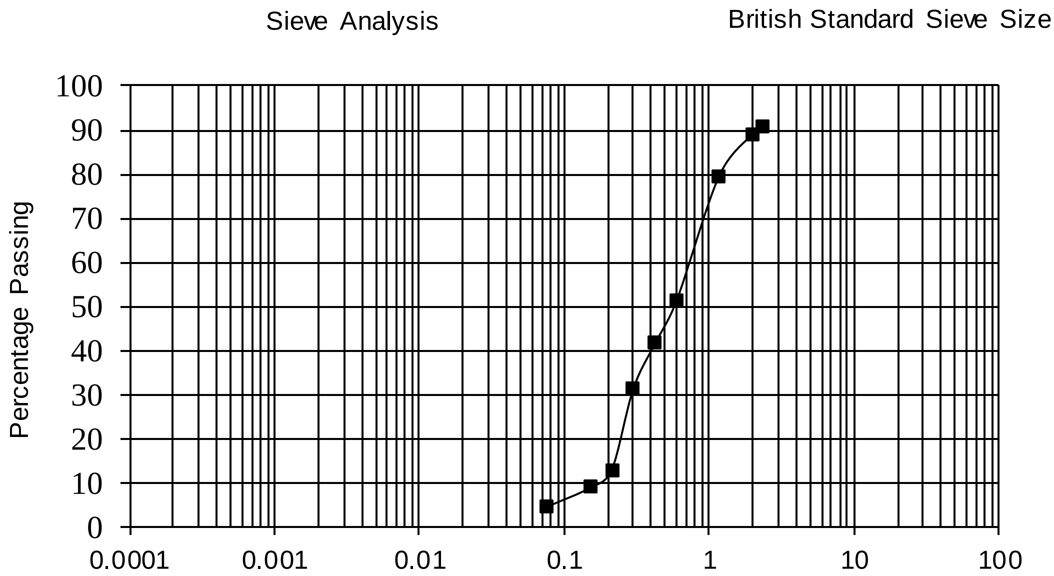

Figure 4.56: Sieve Analysis for BH 2, Log 23.

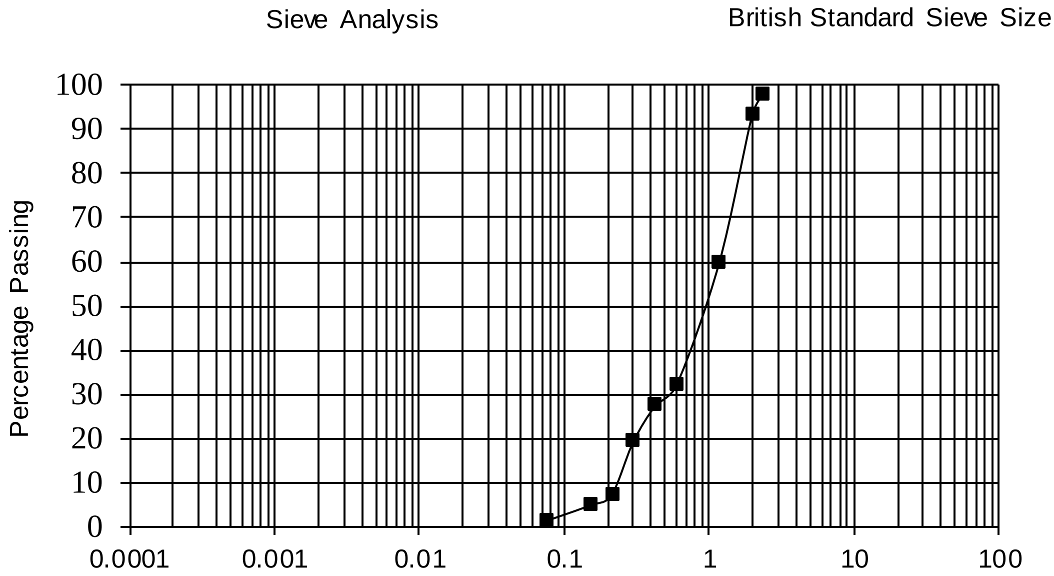

Figure 4.57: Sieve Analysis for BH 2, Log 24.

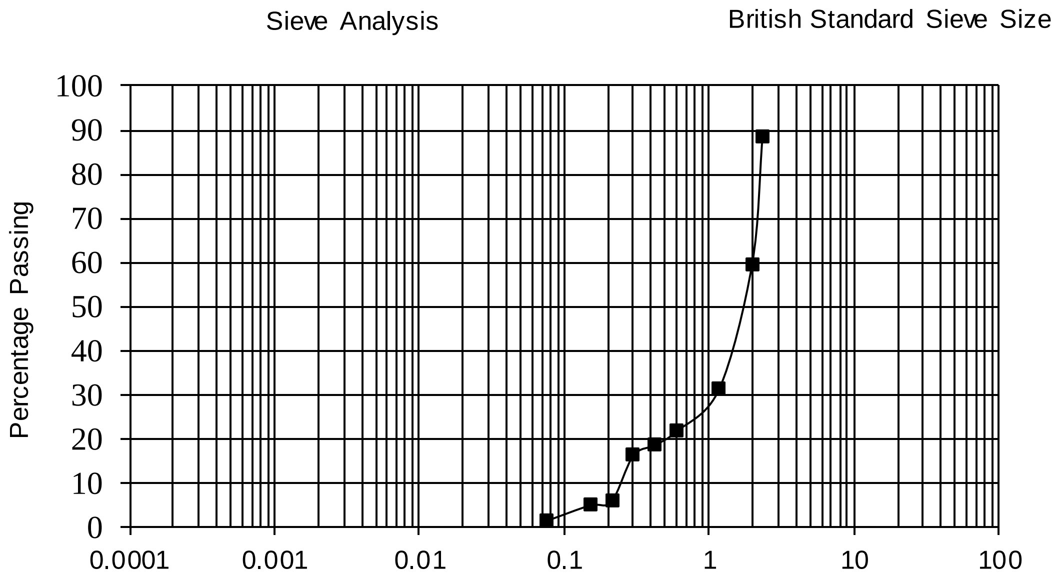

Figure 4.58: Sieve Analysis for BH 2, Log 25.

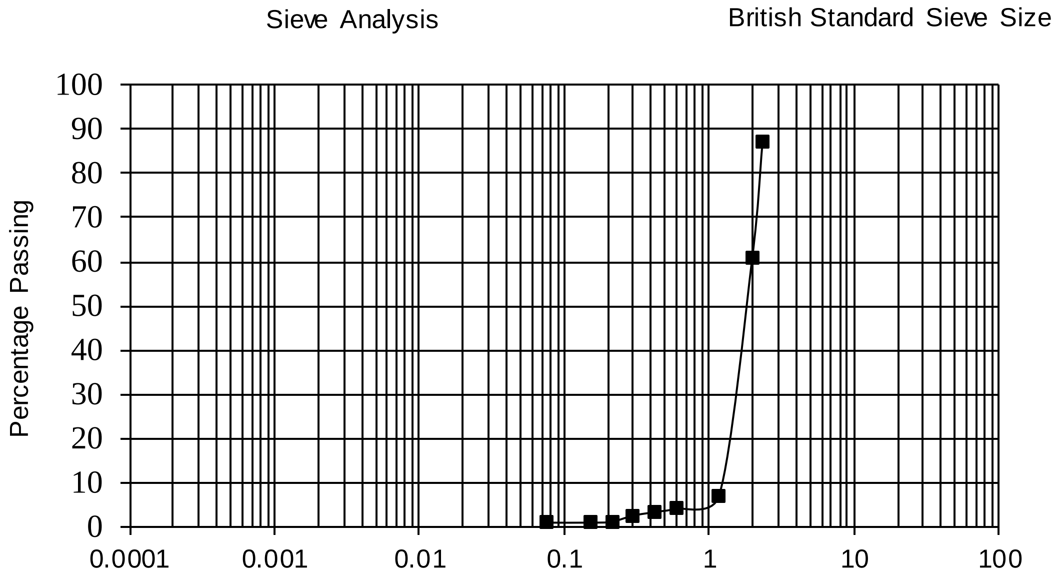

Figure 4.59: Sieve Analysis for BH 2, Log 26.

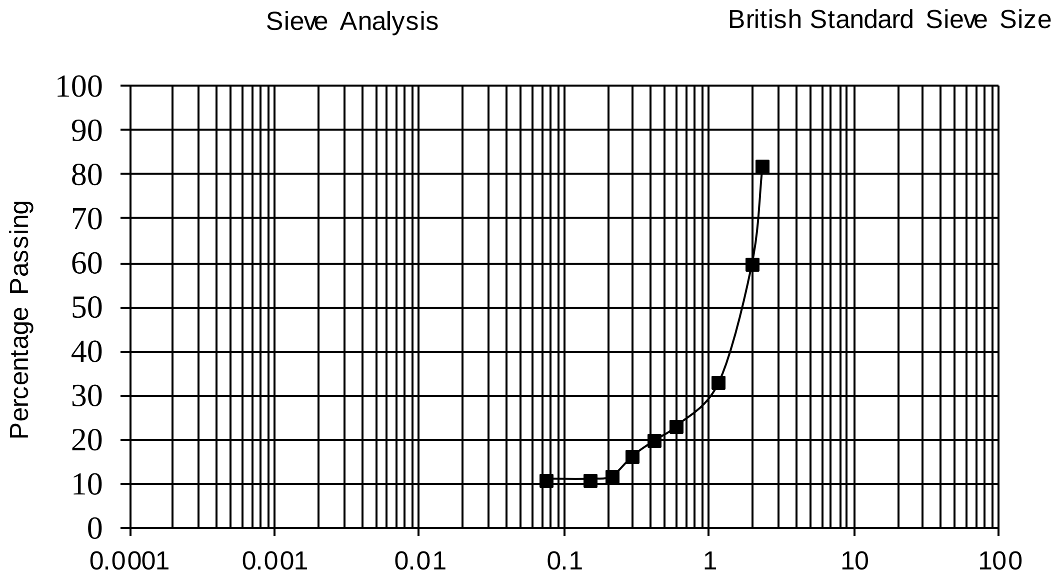

Figure 4.60: Sieve Analysis for BH 2, Log 27.

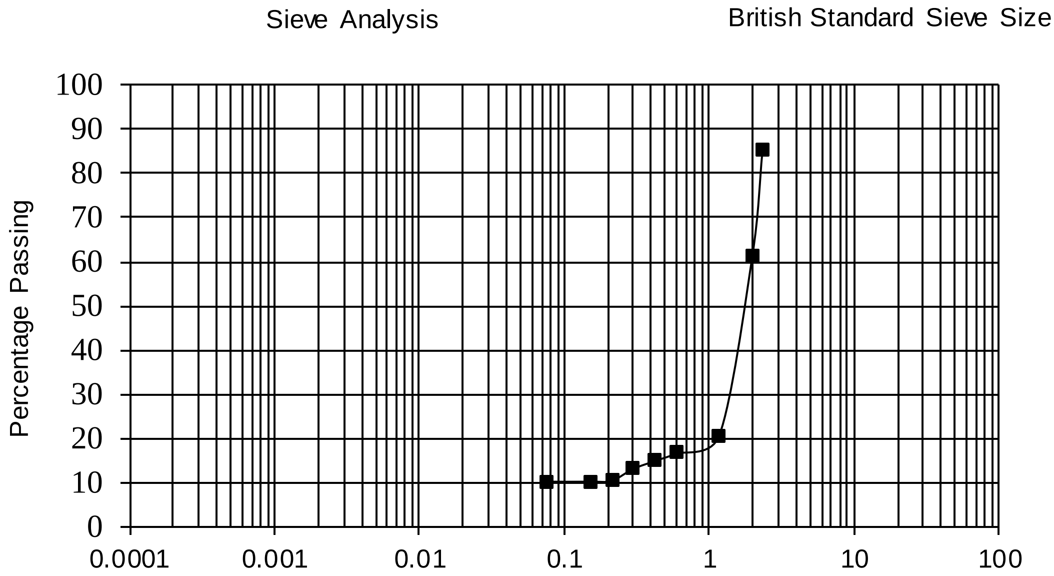

Figure 4.61: Sieve Analysis for BH 2, Log 28.

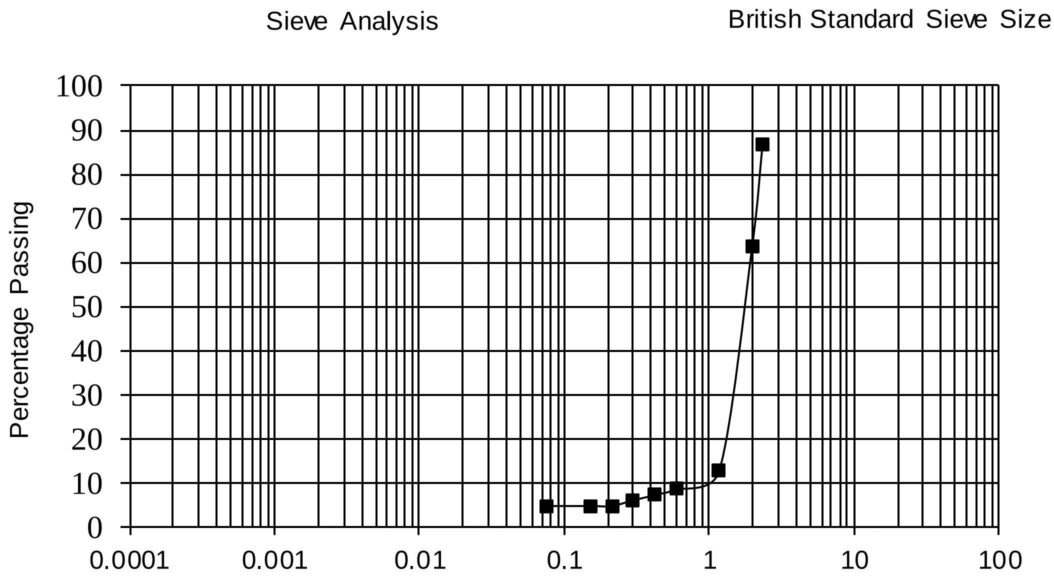

Figure 4.62: Sieve Analysis for BH 2, Log 29.

These sieve analysis values were strictly used in obtaining D_{10} values.

4.3.2 BOREHOLE 2 SOIL STRATA

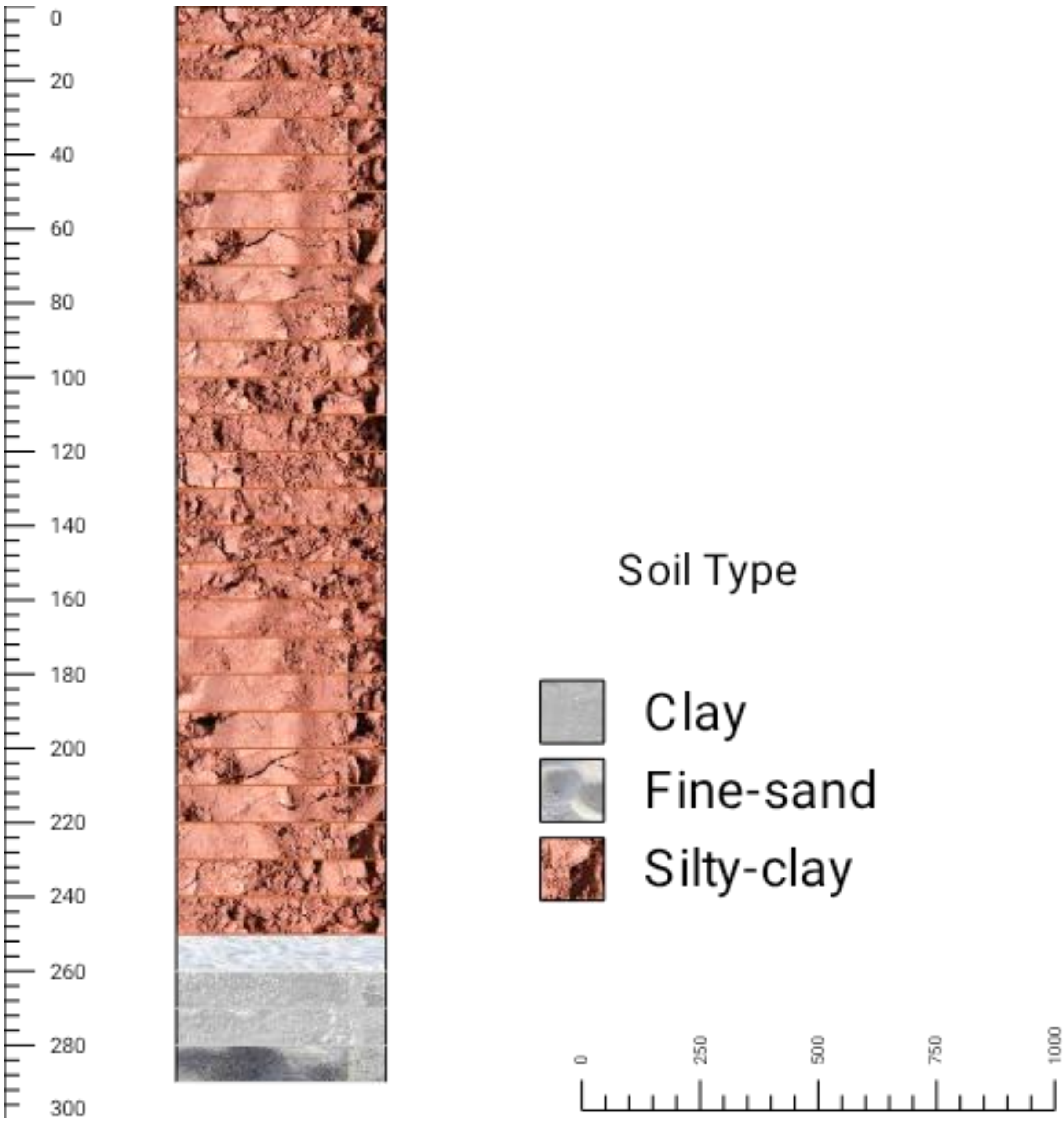

Figure 4.63: Soil strata

4.3.3 SCREEN LOCATION

A double Screen was installed at 290fts (88.39metres) and 280fts (85.34metre), at the level of Fine sand formation. At this position, submersible pump was also installed at 290fts. Screen thickness was about 12mm. The drill bit size was about 4 inches (101.6mm).

4.4 BOREHOLE 3

Borehole two consist of 28 logs of soil sample for the second study area of at Oluku (River Road with Lat/Long 6.436648/5.601393)at different depth before water table level. Sieve analysis were done for each log of soil in order to obtain D_{10} which was used to calculate the permeability constant "k" at each depth from 0-280fts of well depth. The tables below are the different sieve analysis values obtained for each soil log including their respective depth, permeability and soil classification. The formula used in calculating for permeability "K" using Hazen William's formula;

$$K=C(D_{10})^2. \qquad (4.1'')$$

K= Coefficient of permeability (m/s)

C= Constant, typically between 0.01mm

D_{10}= Effective grain size (in mm)

From this formula we obtained the permeability for each soil log for Borehole 1.

The effective size D_{10} is determined by finding the particle size corresponding to 10% cumulative passing on the curve.

4.4 .1 CONSTANT OF PERMEABILITY FOR BOREHOLE 2 LOG 1-28

Table 4.3: Coefficient of permeability

BH 3, LOGS	Permeability, K (in m/s)	Soil Type	Drainage
Log 1	4.41x10-6	Silty clayey	Poor
Log 2	4x10-6	Silty clayey	Poor
Log 3	1x10-6	Silty clayey	Poor

BH 3, LOGS	**Permeability, K (in m/s)**	**Soil Type**	**Drainage**
Log 4	4.9x10-7	Silty clayey	Poor
Log 5	2.25x10-6	Silty clayey	Poor
Log 6	4x10-6	Silty clayey	Poor
Log 7	4.41x10-6	Silty clayey	Poor
Log 8	4.9x10-7	Clayey	Very poor
Log 9	5.29x10-6	Silty clayey	Poor
Log 10	6.25x10-6	Silty clayey	Poor
Log 11	4x10-6	Silty clayey	Poor
Log 12	4x10-6	Silty clayey	Poor
Log 13	3.24x10-6	Silty clayey	Poor
Log 14	4x10-6	Silty clayey	Poor
Log 15	6.4x10-7	Clayey	Very poor
Log 16	6.4x10-7	Clayey	Poor
Log 17	2.9x10-6	Silty clayey	Poor
Log 18	4x10-6	Silty clayey	Poor
Log 19	6.4x10-5	Fine sand	poor
Log 20	7.84x10-6	Silty clayey	Poor
Log 21	4.41x10-6	Silty clayey	Poor
Log 22	4.41x10-6	Silty clayey	Poor
Log 23	4x10-6	Silty clayey	Poor
Log 24	4.9x10-7	Clayey	Very poor
Log 25	9x10-6	Silty clayey	Poor
Log 26	3.6x10-5	Fine sand	Poor
Log 27	1.44x10-4	Fine sand	Poor
Log 28	1.21x10-4	Fine sand	Poor

Below are the sieve analysis for each soil sample;

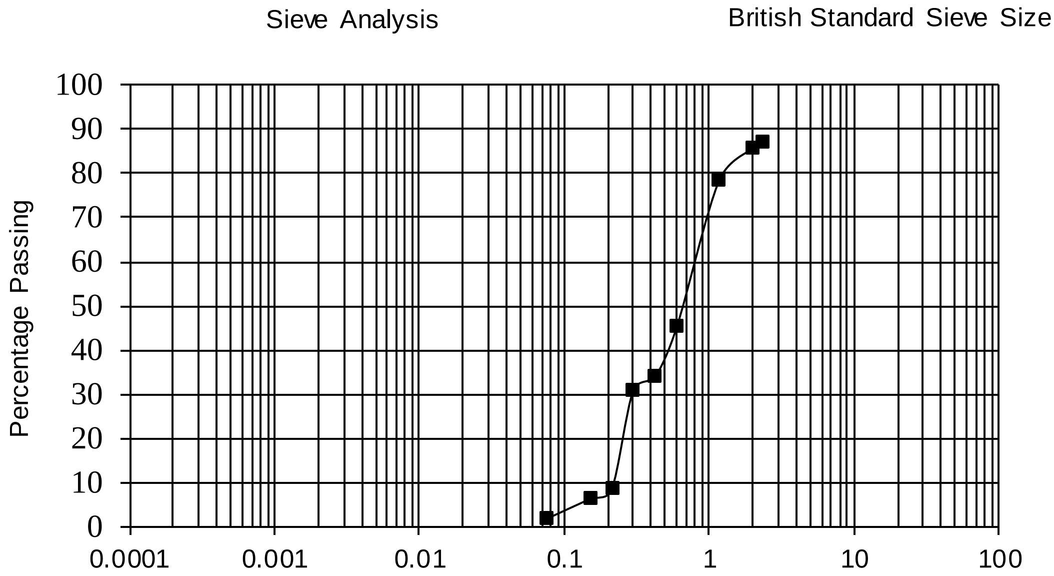

Figure 4.64: Sieve Analysis for BH 3, Log 1.

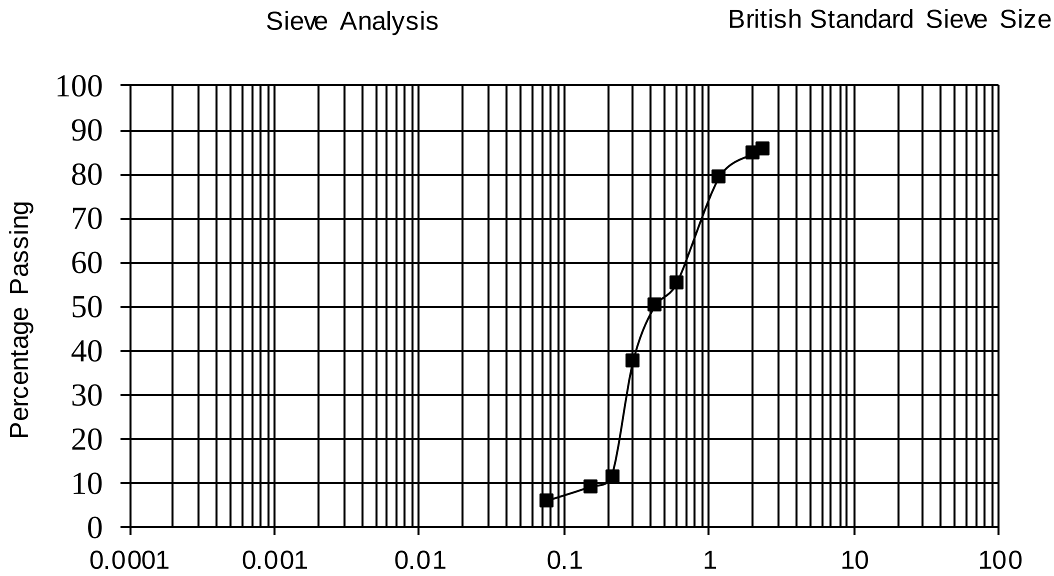

Figure 4.65: Sieve Analysis for BH 3, Log 2

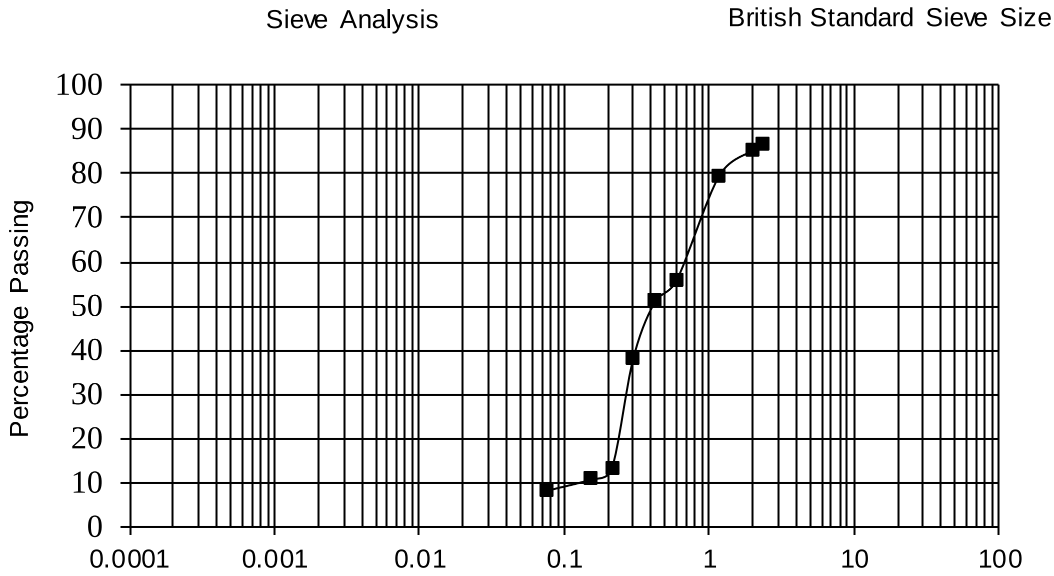

Figure 4.66: Sieve Analysis for BH 3, Log 3.

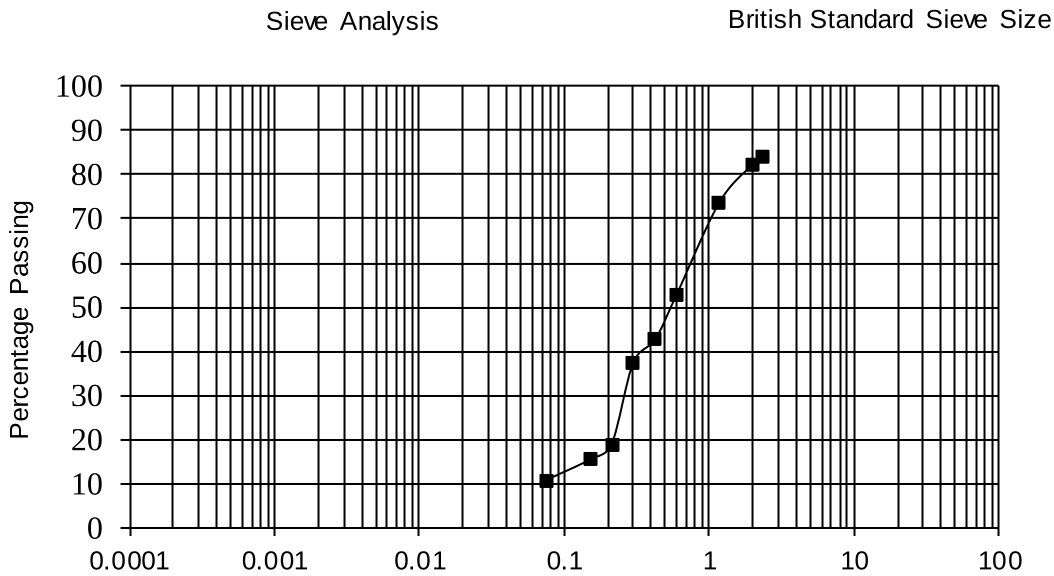

Figure 4.67: Sieve Analysis for BH 3, Log 4.

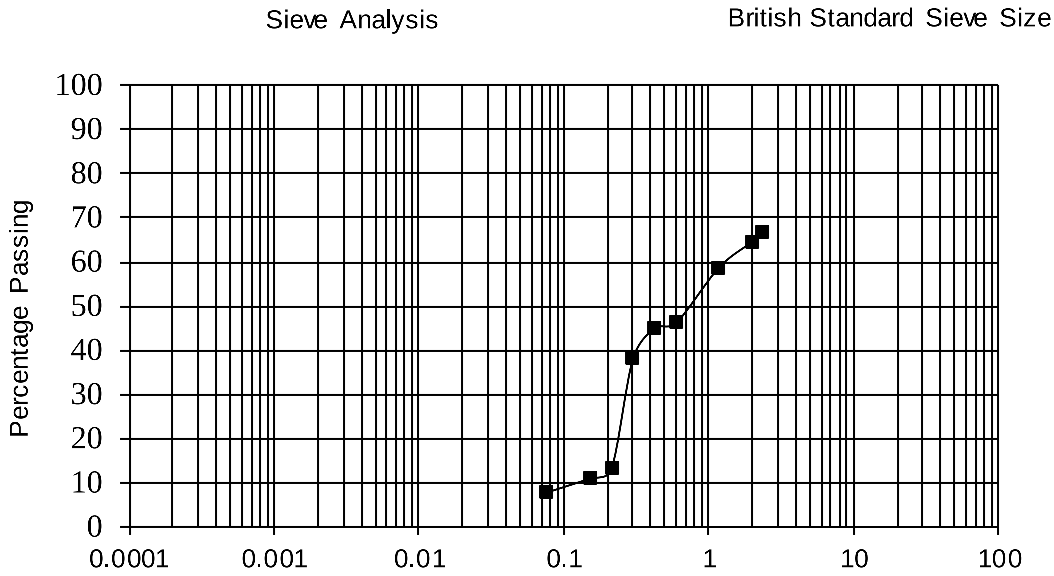

Figure 4.68: Sieve Analysis for BH 3, Log 5.

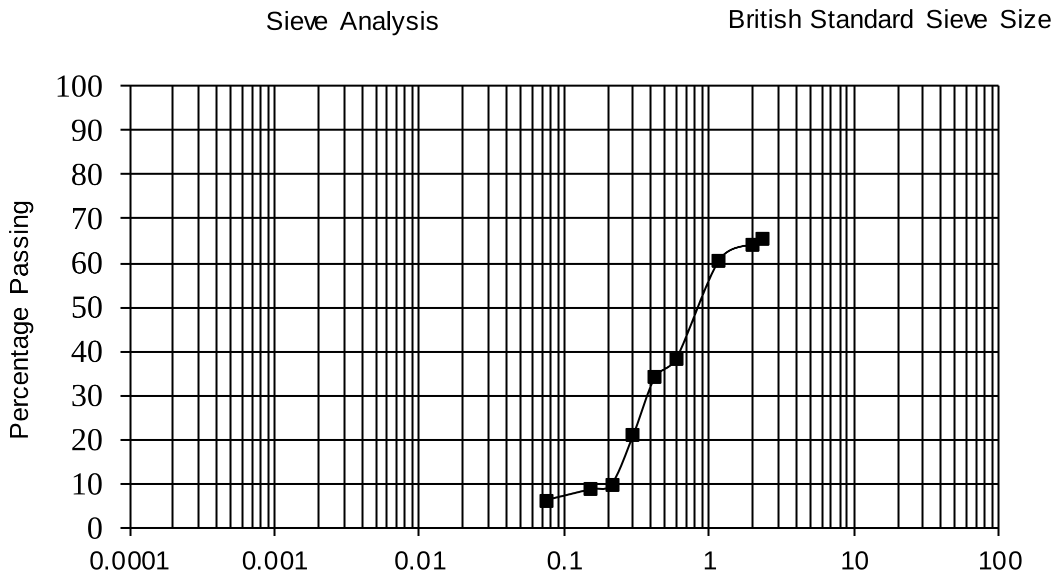

Figure 4.69: Sieve Analysis for BH 3, Log 6.

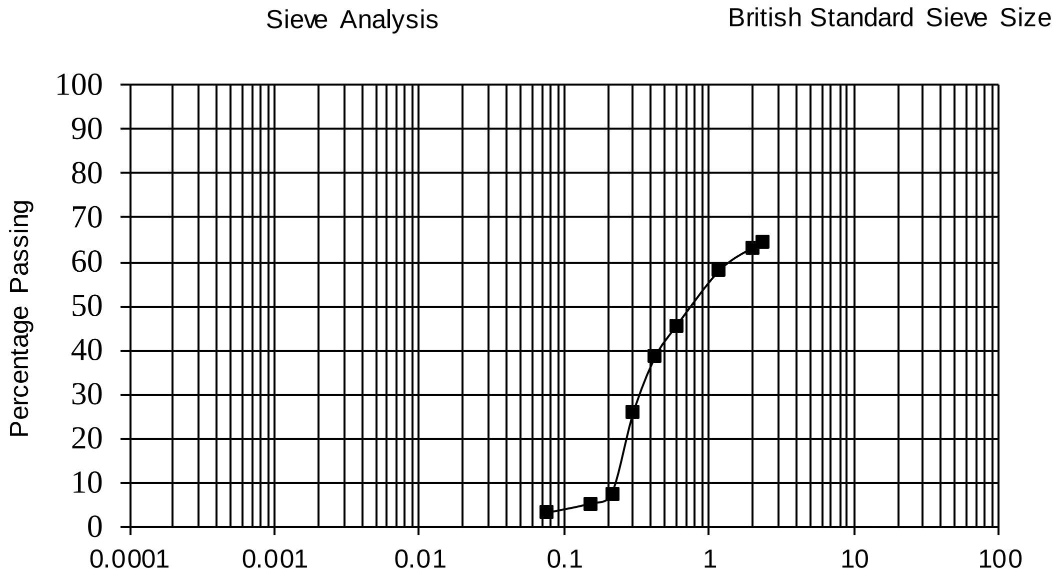

Figure 4.70: Sieve Analysis for BH 3, Log 7.

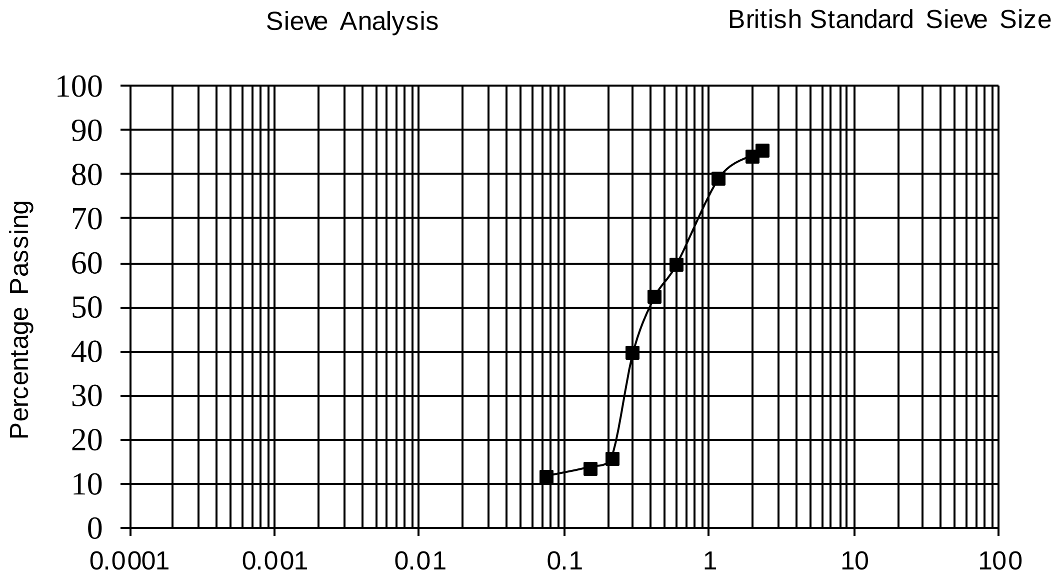

Figure 4.71: Sieve Analysis for BH 3, Log 8.

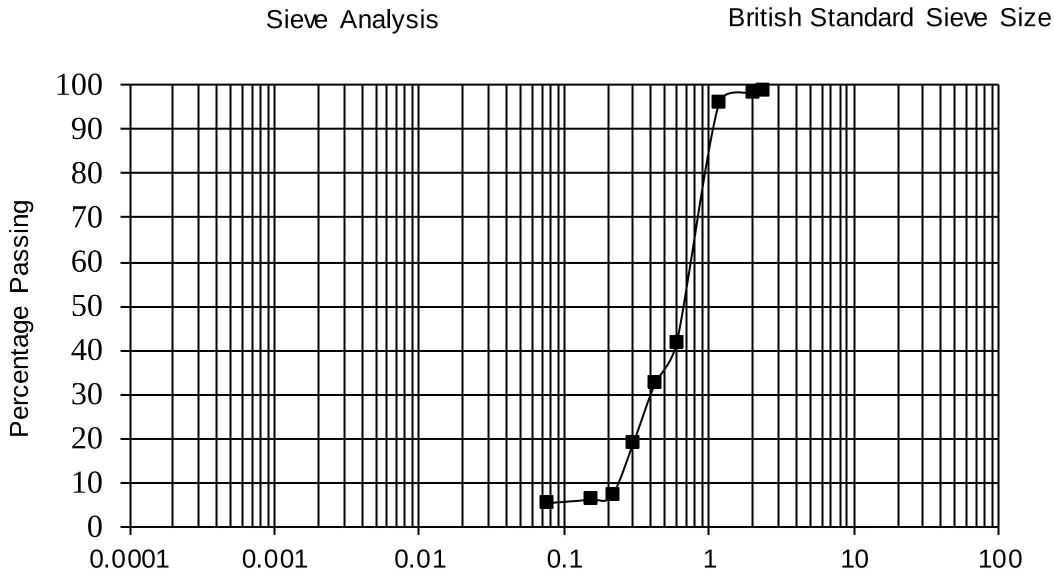

Figure 4.72: Sieve Analysis for BH 3, Log 9.

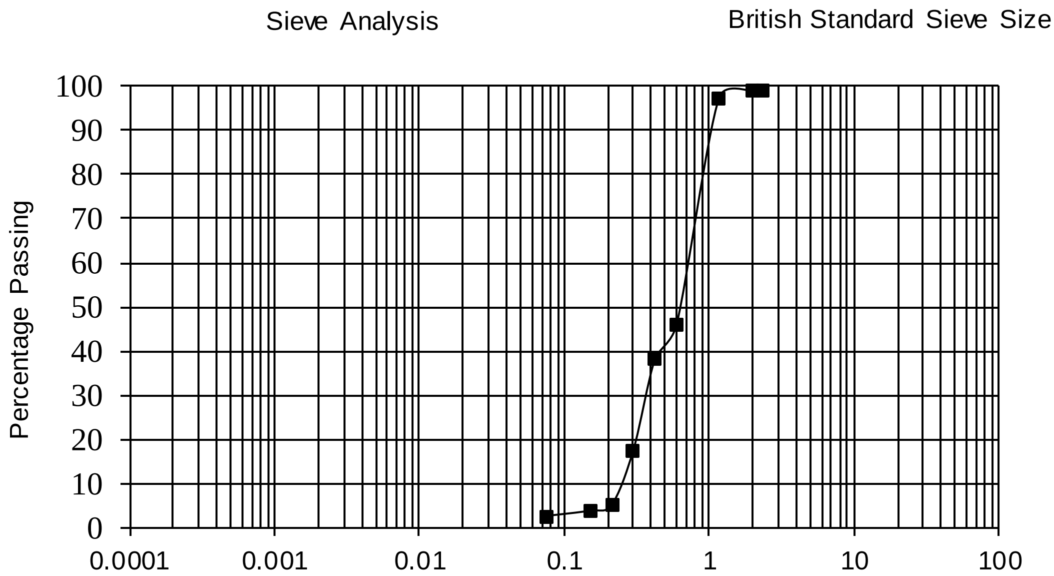

Figure 4.73: Sieve Analysis for BH 3, Log 10.

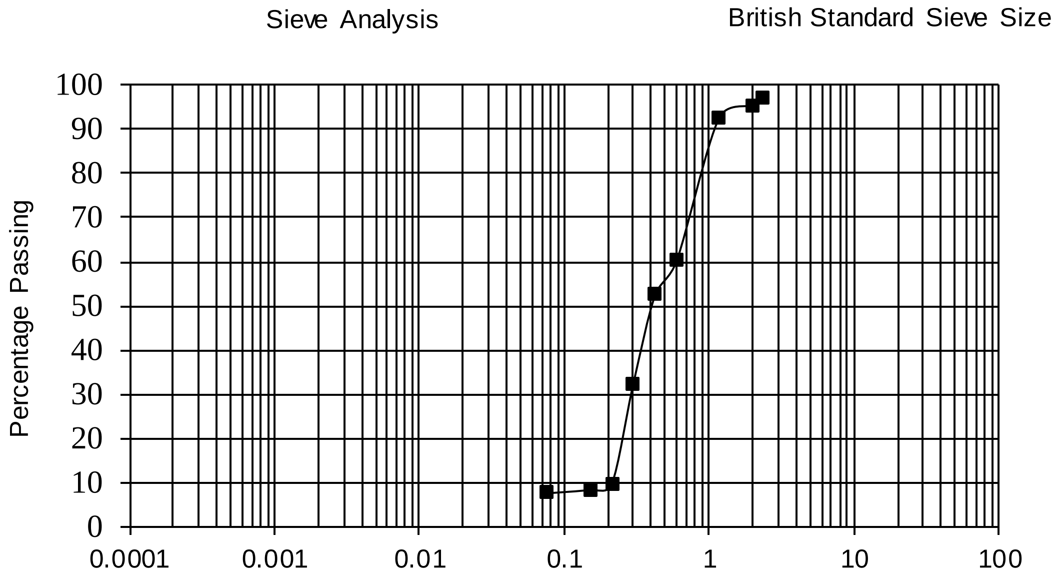

Figure 4.74: Sieve Analysis for BH 3, Log 11.

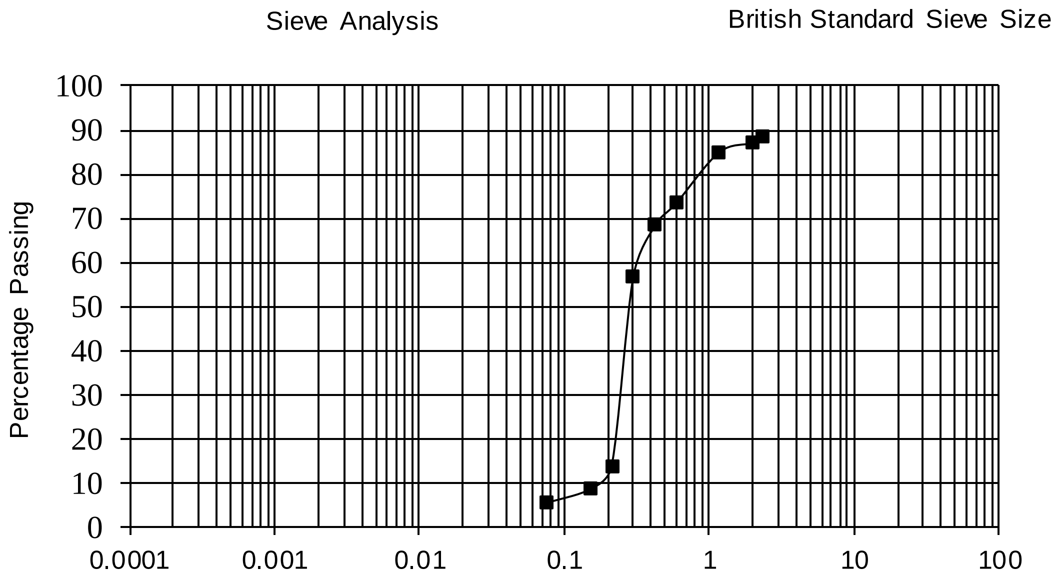

Figure 4.75: Sieve Analysis for BH 3, Log 12.

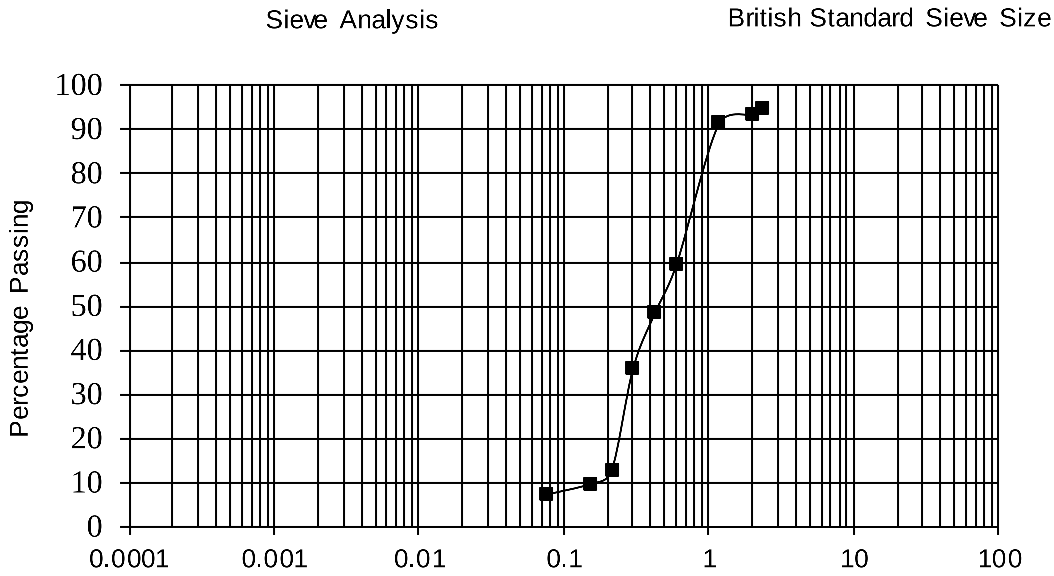

Figure 4.76: Sieve Analysis for BH 3, Log 13.

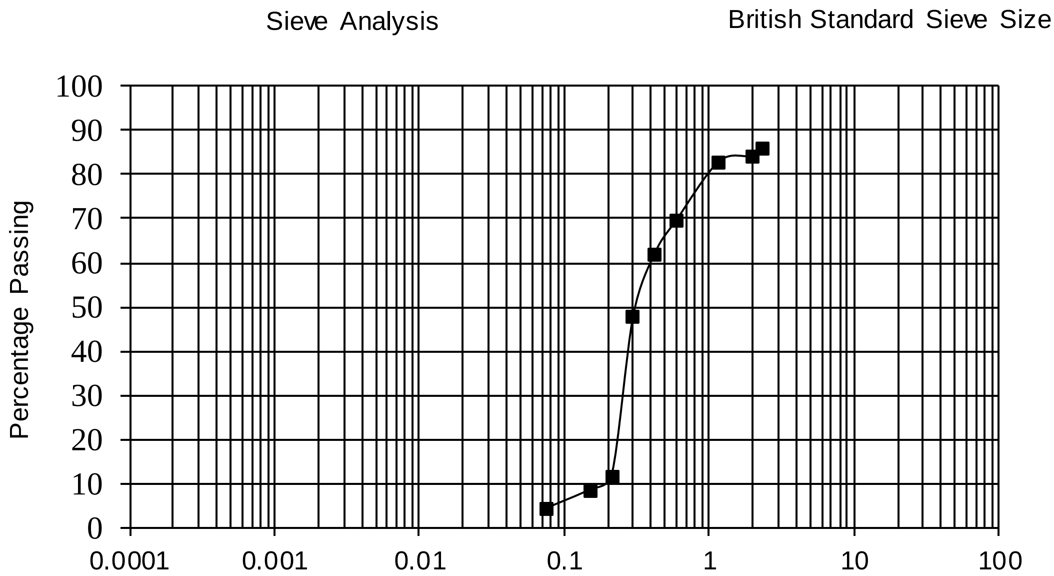

Figure 4.77: Sieve Analysis for BH 3, Log 14.

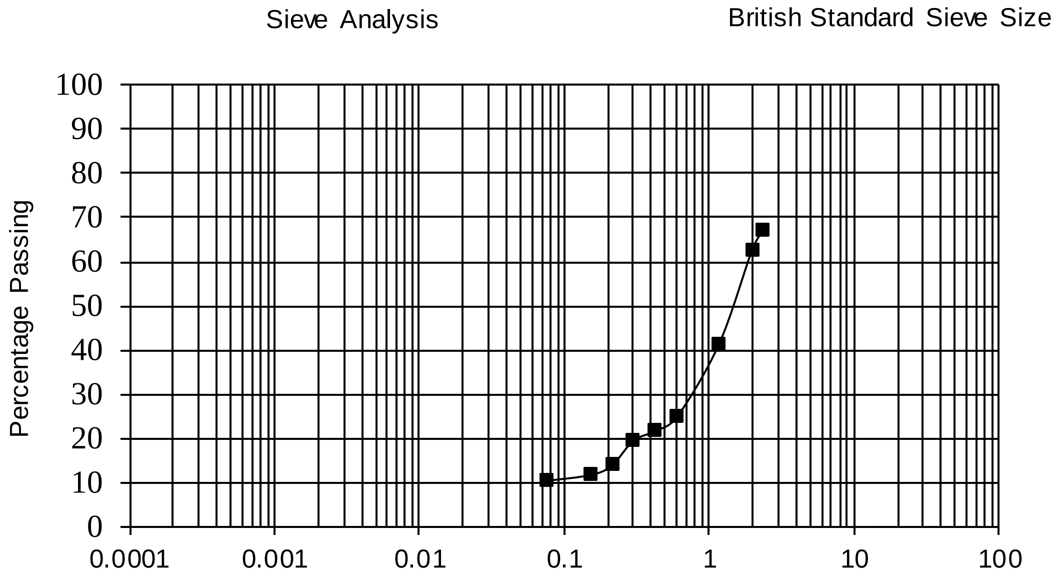

Figure 4.78: Sieve Analysis for BH 3, Log 15.

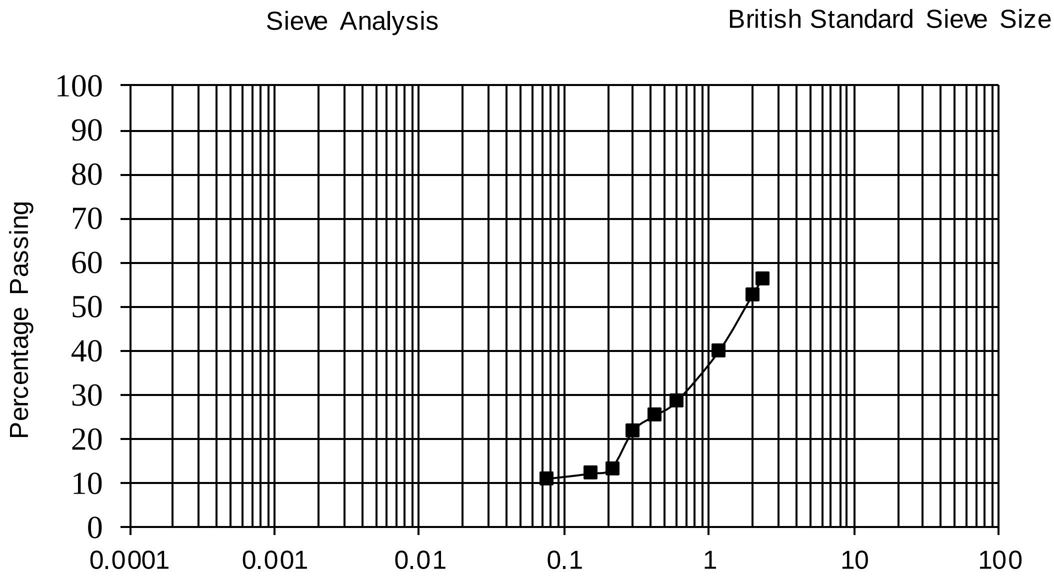

Figure 4.79: Sieve Analysis for BH 3, Log 16.

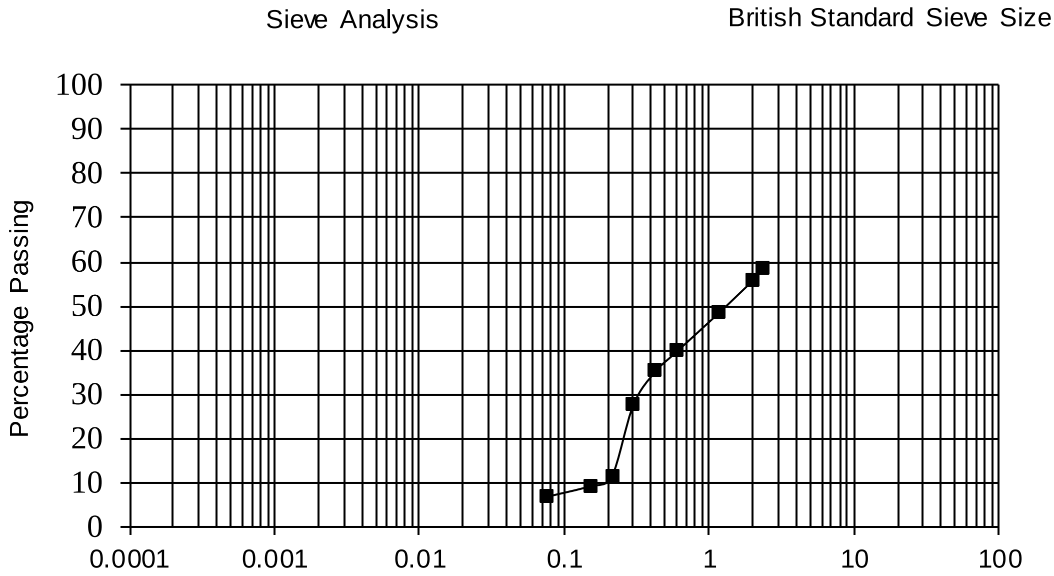

Figure 4.80: Sieve Analysis for BH 3, Log 17.

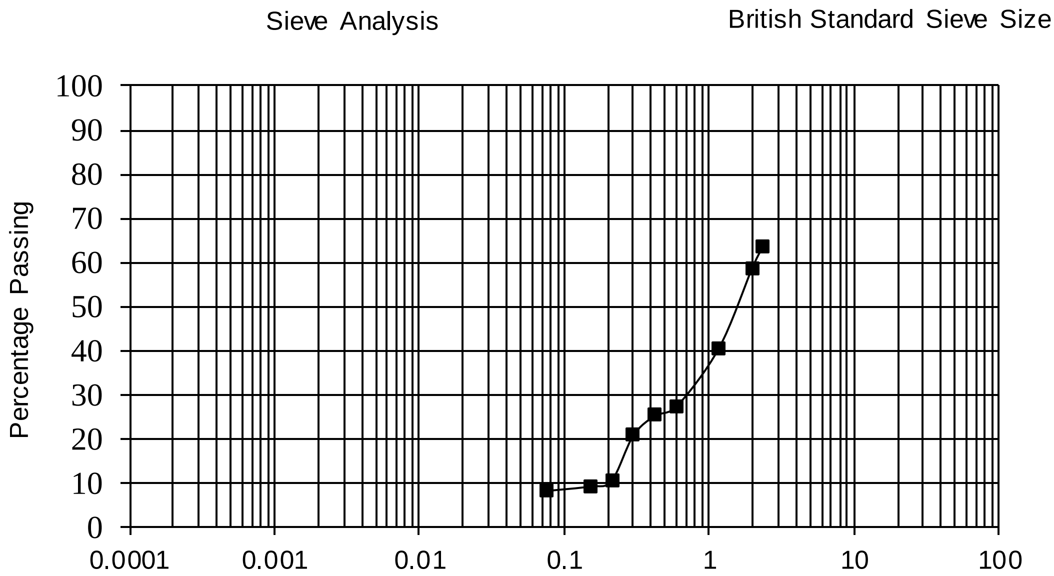

Figure 4.81: Sieve Analysis for BH 3, Log 18.

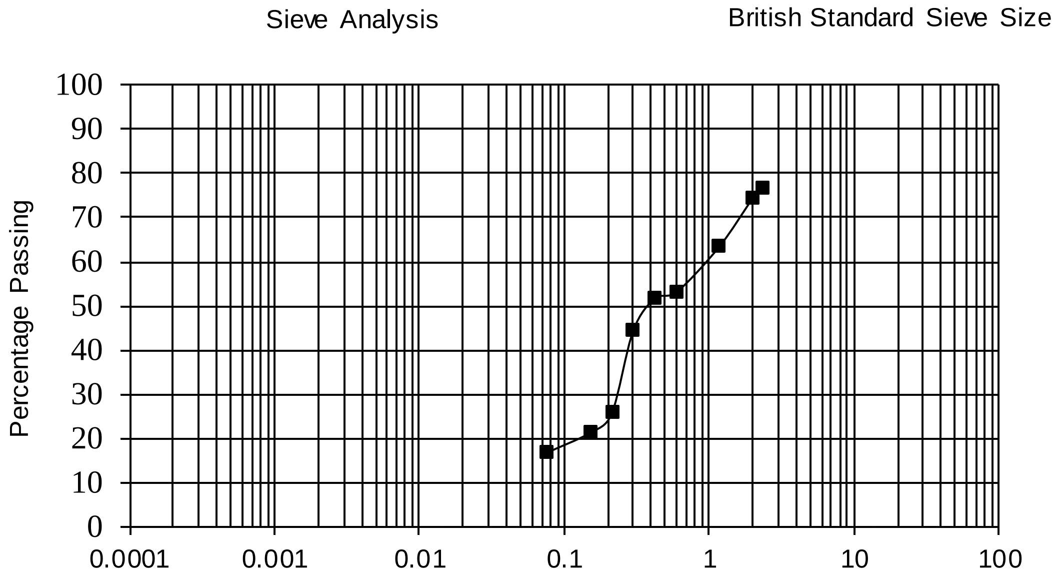

Figure 4.82: Sieve Analysis for BH 3, Log 19.

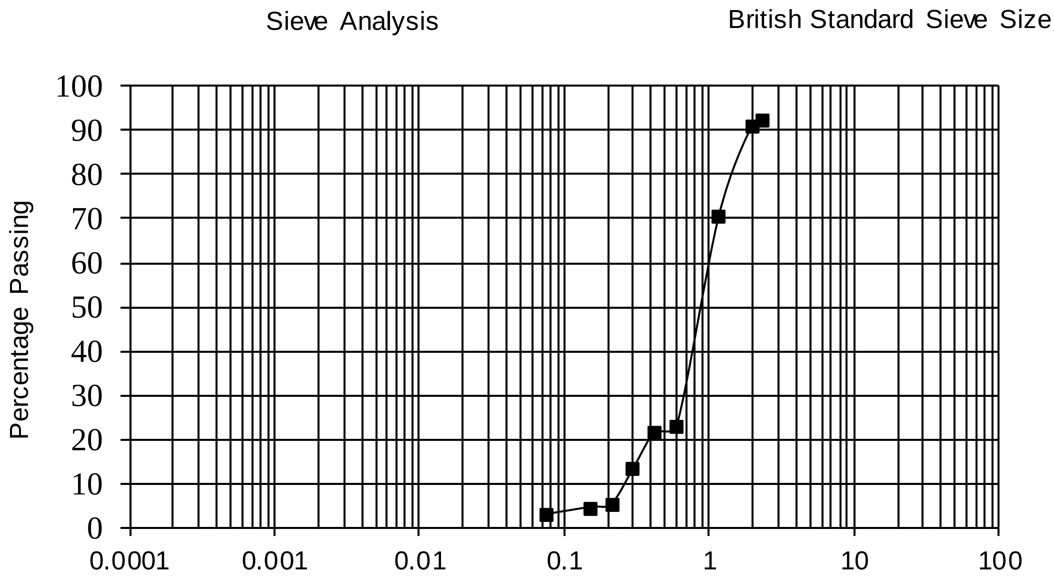

Figure 4.83: Sieve Analysis for BH 3, Log 20.

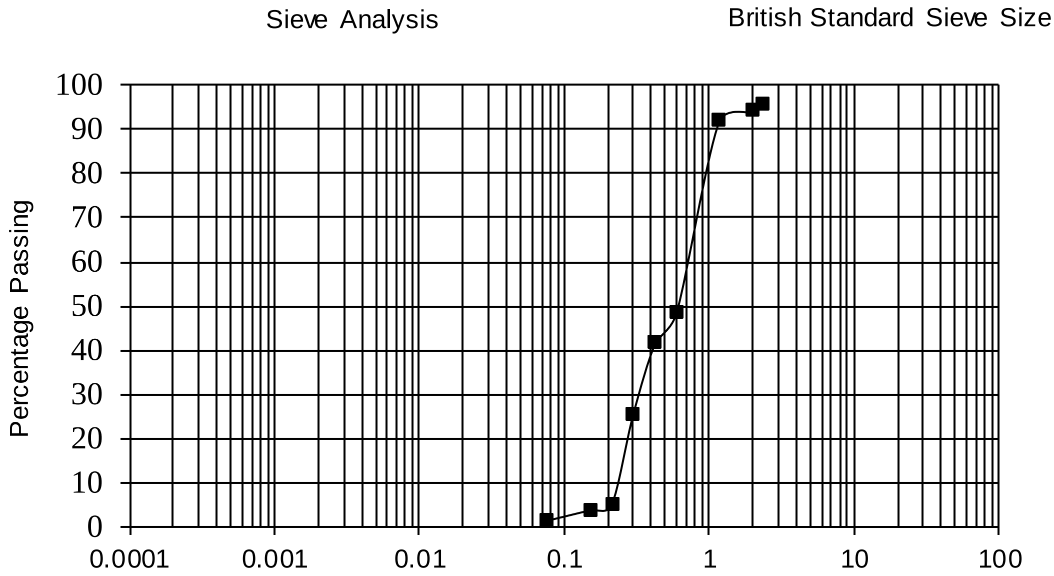

Figure 4.84: Sieve Analysis for BH 3, Log 21.

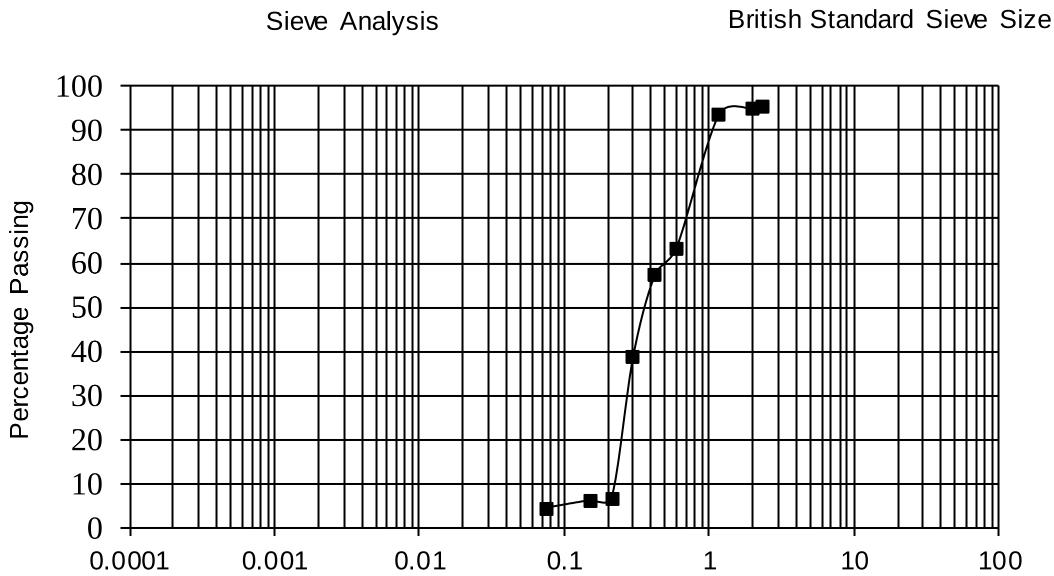

Figure 4.85: Sieve Analysis for BH 3, Log 22.

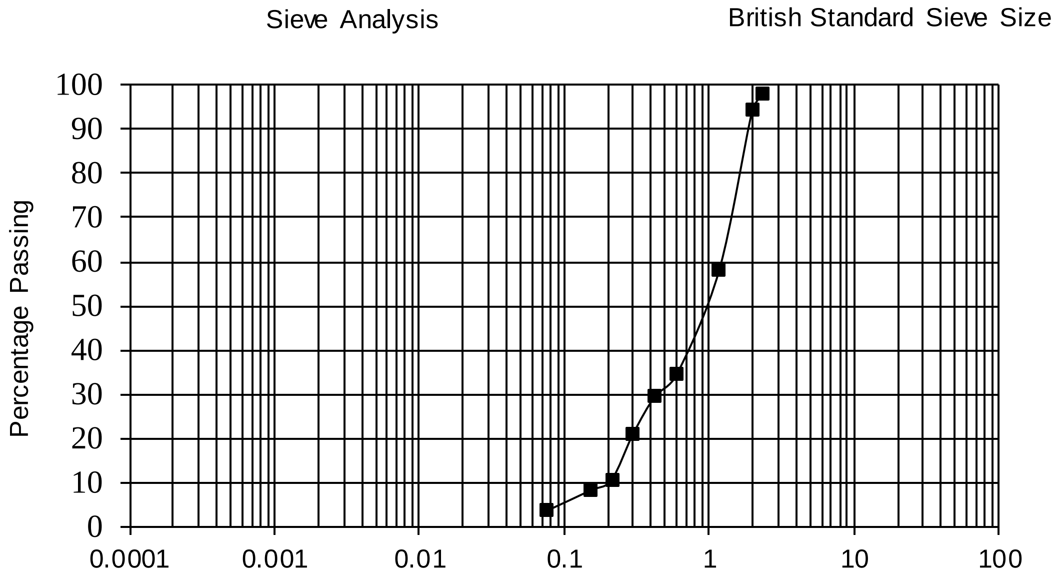

Figure 4.86: Sieve Analysis for BH 3, Log 23.

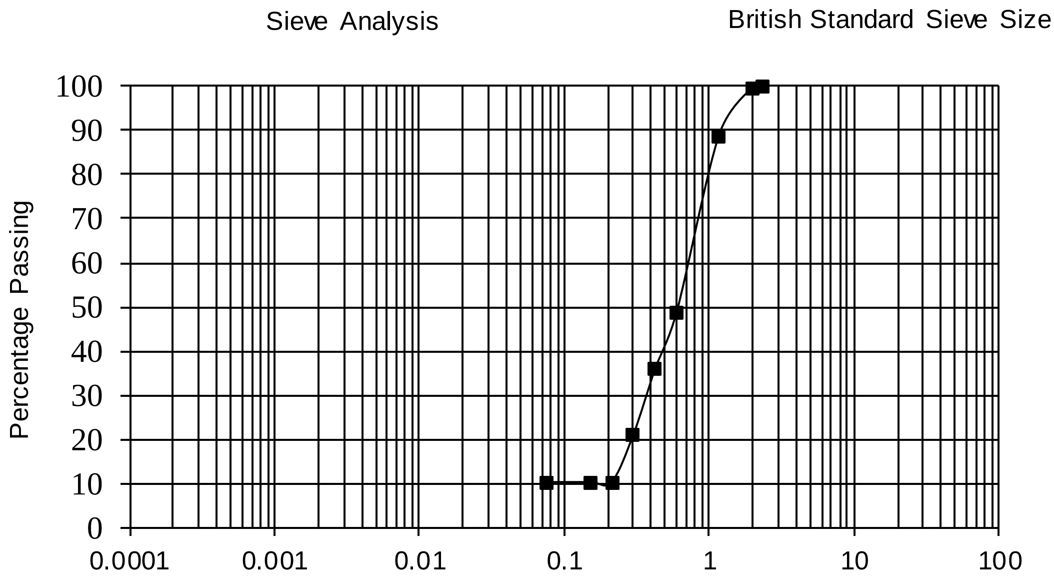

Figure 4.87: Sieve Analysis for BH 3, Log 24.

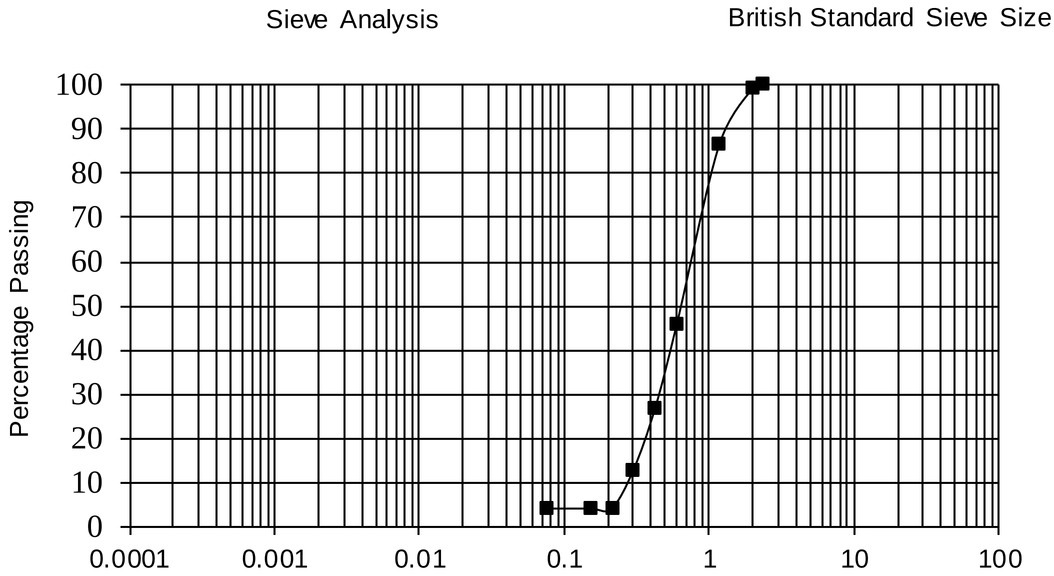

Figure 4.88: Sieve Analysis for BH 3, Log 25.

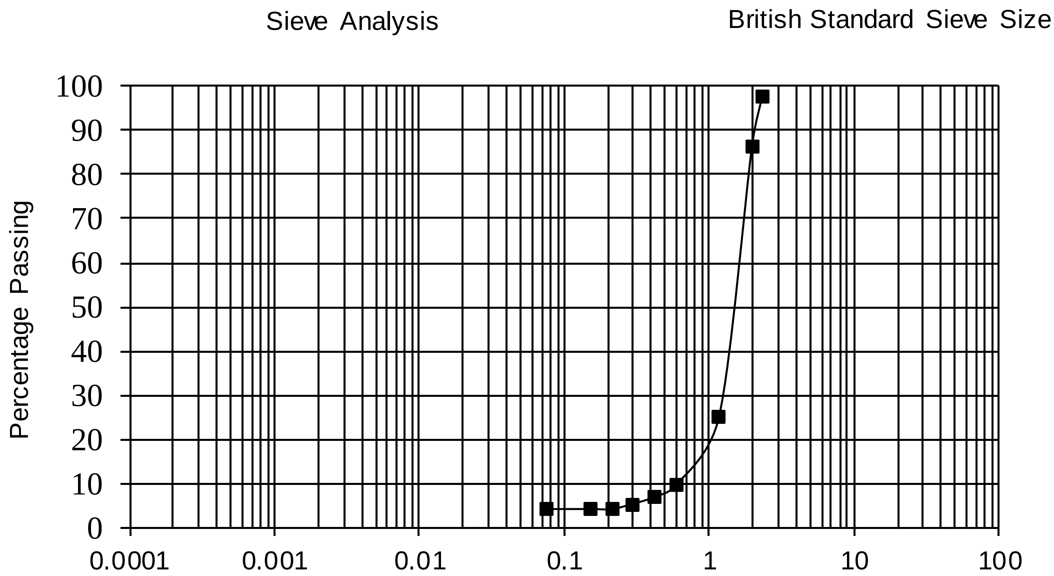

Figure 4.89: Sieve Analysis for BH 3, Log 26.

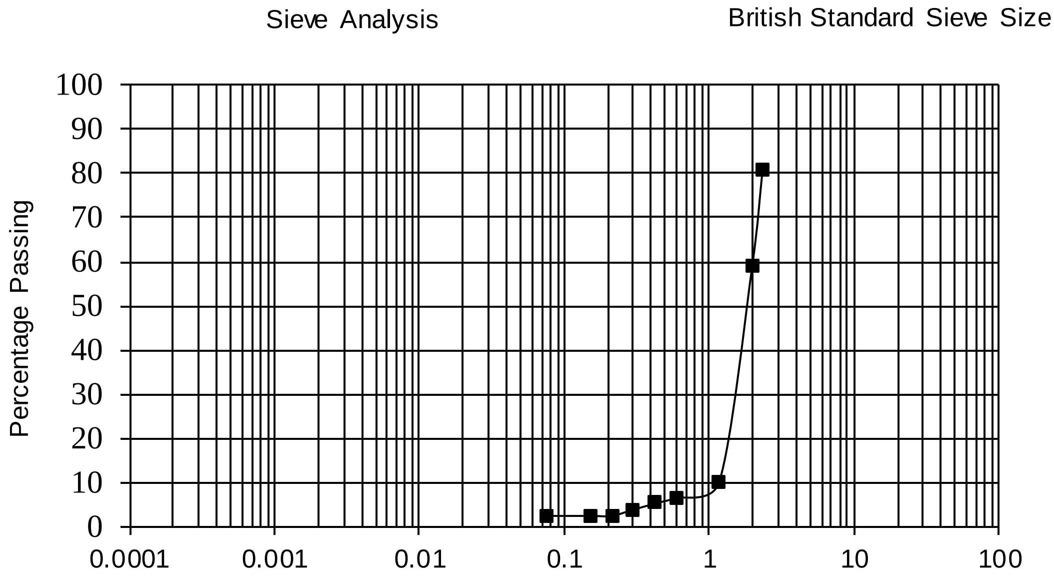

Figure 4.90: Sieve Analysis for BH 3, Log 27.

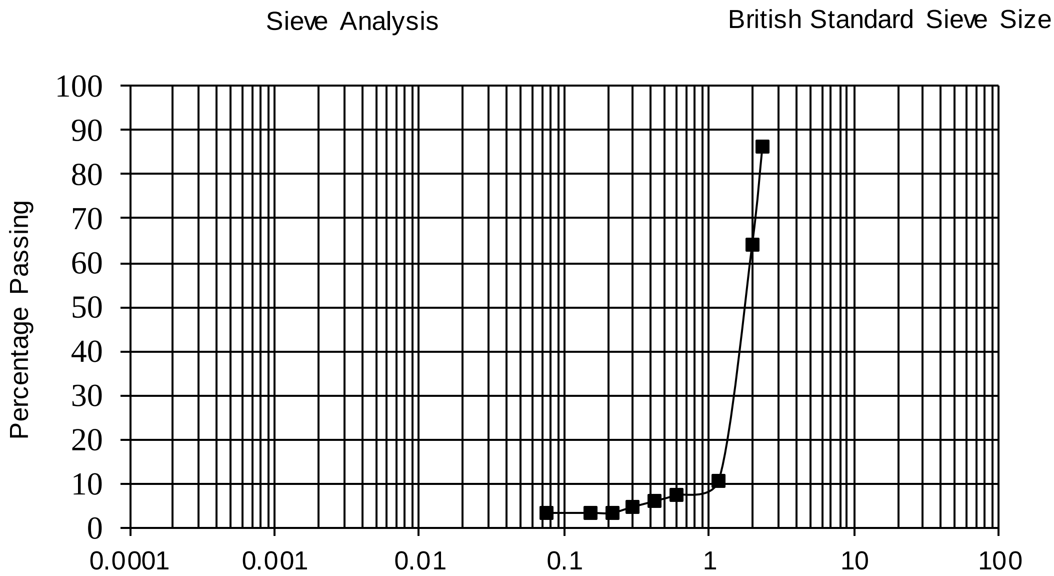

Figure 4.91: Sieve Analysis for BH 3, Log 28.

4.4.2 BOREHOLE 3 SOIL STRATA

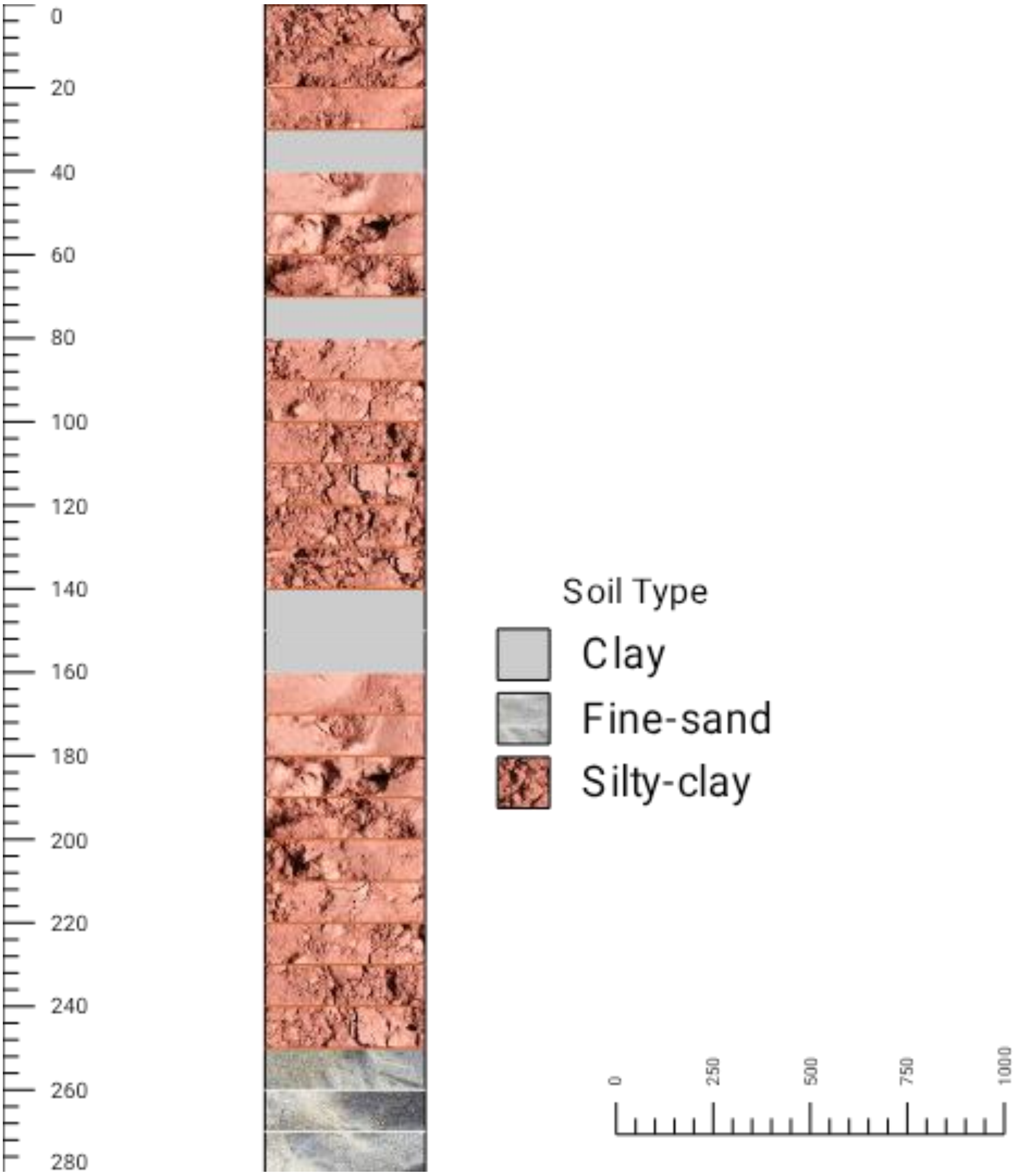

Figure 4.92: Soil Strata

This strata typically shows the different stratum of soil at different depth.

It is important to note that for each of this borehole, there was no conformance to hydrological standards. All drilling procedures for these three study areas were done based on personal experience and decisions without consulting professional personnel before embarking on the drilling of these boreholes used in this project. Results obtained, are strictly based on the data collected on these study areas.

4.4.3 SCREEN LOCATION

Screen was installed at 280fts (85.34metres), at the level of Fine sand formation. At this position, submersible pump was also installed at this same depth. Screen thickness was about 12mm. The drill bit size was about 4 inches (101.6mm).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study investigated the assessment of groundwater based on hydro-logical standards in preventing water contamination. This study focused on observation of the different stages of groundwater assessment based on hydro-logical standard in preventing water contamination and also soil stratification, classification and determination of permeability constant (k). From all investigation, during the course of this project, groundwater assessment procedures carried out were not all based on hydro-logical standard. This is because all drilling procedures were based on personal experiences and assumptions without proper investigation before drilling and the application of chemicals such as bentonites were not measured. Due to this observation, it can be concluded that the rate of water contamination for the different drilled wells will be high and these wells will also be subjected to collapse over a short period of time.

5.2 RECOMMENDATION

This study contributes to the existing body of knowledge on borehole drilling practices and groundwater management in Nigeria. From my investigation, during the course of this project, I will like to recommend that the government should enforce strict policies that is functional to guide the assessment of groundwater by different well drilling companies. Also there should be a permit and government inspection with adequate test of borehole water in in order to help control indiscriminate borehole drilling by nonprofessionals. Proper survey of area should be provided by qualified personnel before the commencement of any drilling process. This will help reduce the risk of water contamination as well as reduce the risk of collapse or even future earth quake which may result from too many drilled wells.

I will also like to recommend that the government should enforce the provision of public water system to reduce unnecessary drilling of wells which may result to groundwater contamination.

The recommendations arising from this study can inform policy decisions and guide the development of effective strategies to improve borehole drilling practices and ensure the sustainability of groundwater resources in the study area and beyond.

REFERENCES

Adebowale, N. (2018, January 30). One in three Nigerian households consume contaminated water. The Punch Newspaper.

Agheyisi, E.J. (2007). Spatial Variation In Borehole Depth And Drilling Cost In Benin Metropolis. Journal of Environmental Studies, 13(2), pp. 1-7.

Anyanwu, S. (2024, February 20). Indiscriminate BoreholesDrilling, Threat To Underground Water And Sustainable

Development. Federal Ministry of Information and National Orientation.

Van Der Wal, A. (2010, June). Understanding Groundwater And Wells in manual drilling (pp. 49). PRACTICAFoundation.

ASTM D1785-21a. (2021, October 28). StandardSpecification for Poly(Vinyl Chloride) (PVC) Plastic Pipe (pp. 1-11). ASTM International

Misstear, B., Banks, D. & Clark, L. (2006). Water Wells And Boreholes (Chapter 5, pp. 181-235). Wiley, ISBN: 0-470-84989-8.

Akujieze, C.N. & Oteze, G.E. (2006). Groundwater quality ofBenin City urban aquifer of the Pleistocene-Oligocene Benin Formation, Nigeria. Vol.7.

Ogbeifun, D.E., Archibong, U., Chinedu, I.E. & Ikpe, E. (2019). Assessment Of Water Quality Of Borehole In Selected Areas In Benin City, Edo State, Nigeria. Chemical Science International Journal, 28(2), DOI: 10.9734/CSJI/2019/v28i230133.

Beck, D. (2016). Applicability of hydraulic borehole mining to diamondiferous deposit. DOI: 10.13140/RG.2.214111.56485.

Driscoll, F.G. (1986). Groundwater and wells (6th ed., Chapter 10, pp. 277-333). ISBN: 0-9616456-0-1.

Driscoll, F.G. (1986). Groundwater and wells (6th ed., pp. 413-461). ISBN: 9780961645601.

Driscoll, F.G. (1986). Groundwater and wells (6th ed., Chapter 14, pp. 464-492). ISBN: 9780961645601.

Fetter, C.W. (2011). Applied Hydrogeology (4th ed., p. 3). ISBN: 9780130882394.

International Committee of the Red Cross. (2010). Technical Review: Borehole Drilling An Rehabilitation Under Field Conditions (Chapter 4, pp. 31-36).

Kerstin Danert (2015). Manual Drilling Compendium 2015 (pp. 31-36). DOI: 10.13140/RG.2.2.13210.67529, January.

Mahmoud Khalifeh and Arild Saasen (2020). Different Categories of Working Units (pp. 73-82). DOI:10.1007/978-3-030-39970-2-5.

Walker, M. (2024, November 26). Water conservation. Build a Stash.

Nigeria Industrial Standard (2010). Code of practice for water well construction (NCP 027:2010). 1st edition. Standards Organisation of Nigeria. pp. 1-15.

NOIpolls. (2020). Access to water; Borehole main source of drinking water for households. Nigeria.https://www.noi-polls.com/post/access-to-water-bore hole-water-remains-source-of-drinking-water-for-households

Occupational Safety and Health Administration (2020). Drilling Operations Safety Standards. OSHA Publication No. 3149-04R.

Harter, T. (2003). Basic Concepts Of Groundwater Hydrology. University of California, Davis. pp. 1-6. ISBN 978-1-60107-258-0.

Vahit, I. (2023, 19 June). Bentonite For Drilling Wells. Journal of Drilling Engineering, 10(2).

Alley, W.M., Reilly, T.E. and Franke, O.L. (1999). Sustainability Of Ground-Water Resources. U.S. Geological Survey Circular 1186. pp. 1-2. ISBN 0-607-93040-3.

World Health Organization (2011). Guidelines For Drinking water Quality. 4th ed. WHO Press. ISBN 9789241548151.

World Health Organization (2019). Guidelines For Drinking water Quality. 4th ed. WHO Press. ISBN 9789241550109.

APPENDIX A

Figure A-1: SCREEN

Figure B-1: WEIR HEAD CASTING

Figure C-1: ROTARY EQUIPMENT

Figure D-1: SITE WORK

Figure E-1: DRILL BIT

Plate F-1: BENTONITE MIXED WITH MUD

APPENDIX B

GROUNDWATER WELL CHECKLIST

Project Name:			
Reviewed By:		Date:	

General Information	
Location (NAD 83) Latitude Longitude	
Construction Class	
Depth	
Yield and Drawdown	

Duration: Sustained pumping rate:	
Well Pumping Rate	gpm ft TDH
Well control scheme (describe):	

Location and Construction of Well (also see 12 VAC 5-590-840)	
Well site inspected by ODW personnel and approved? Date of approval:	Yes ☐ No ☒
Well located in a Groundwater Management Area? If yes, and production may exceed 300,000 gallons per month, has a groundwater withdrawal permit been obtained, or are efforts underway to obtain a groundwater withdrawal permit?	Yes ☐No ☐ Yes ☐ No ☐N/A ☐
Community well lot (12VAC5-590-840 D)	
• Provide a distance of at least 50 feet from the well to all property lines? • Future expansion considered? • Access road provided and easement recorded if not adjacent to public road? • graded to divert surface runoff away from the well and to prevent ponding on the well lot? • final plat plan and dedication document prepared and recorded as described in 12VAC5-590-200? (or non-community if field office requires)	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐
Minimum well location requirements (12VAC5-590-840 E)	
• The horizontal distance from the well to any septic tank, sanitary drainfield, pit privy, cesspool, barnyard, animal feed lot, cemetery, geothermal well or source of similar contamination, and all surface runoff from actual or potential sources of contamination is at least 50 feet? • The horizontal distances from the well to any pipe carrying sewage or pipe in which sewage can back up is at least 50 feet?	Yes ☐ No ☐

● A separation of least 50 feet is between a fuel storage tank and a well; however, a lesser distance may be allowed if the fuel is propane or natural gas, or if it is liquid fuel meeting the following requirements: ○ Liquid fuel tanks shall be located above grade. ○ Liquid fuel tanks shall be double-walled with an inner wall leak-detection alarm or single-walled with a full-capacity containment system constructed of compatible material. ○ Liquid fuel lines shall be located above grade or enclosed in a protective casing if below grade, and liquid fuel tanks shall be provided with a paved and curbed parking pad at the tank filling location. ● A spill response plan is provided if the fuel is stored within 50 feet of the well?	Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ N/A ☐
Well construction, materials and development (12VAC5-590-840 F and G)	
Class II well construction or better? ● Borehole Diameter (at least 3 in greater than casing couplings) ● Casing Depth (min 50 ft (II), 100 ft (I)) ● Casing terminates in solid rock ● Casing Material, Diameter and Thickness:___________________ ● Steel casing and liner pipe meet dimensions in Table 840.1? ● Steel casing and liner pipe meet applicable ASTM, NSF/ANSI/CAN or AWWA standards? ● Plastic well casing is PVC meeting ASTM F480-14, NSF/ANSI/CAN Standard 61-2020 or AWWA A100-20? ● Plastic well casing depth does not exceed published resistance to hydraulic collapse, taking into account the installation techniques and grouting methods. ● Lining Pipe Material: __________________________ ● Grout Type, Depth, and Installation:_________________________ ● Neat Cement Grout? ● Grouted to a depth of 50 ft (Class II) or 100 ft (Class I) ● Screen zones: ____	Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐

● Outer Casing material, depth, thickness:______________________ ● Screens when required: o Constructed of material that will not be damaged by chemical action of groundwater or future cleaning operations o Size of openings is based on sieve analysis of the formation to be screened and adequate to pass flows af 0.1 ft/sec or less o Installed so that exposure above the pumping level will not occur ● Packers or other well construction materials are of material that will not impart taste, odors, toxic substances, or bacterial contamination to the water in the well.	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐
Uniform Water Well Completion Report, Form GW-2 completed, submitted and accurate? (12VAC5-590-840 F)	Yes ☐ No ☐
Well yield and drawdown test (12VAC5-590-840 H)	
Results of yield and drawdown test submitted? Drawdown test minimum pumping interval of 48 hours? Noncommunity system pumping interval reduced to $\geq$ 12 hours? ODW approved the reduced pumping interval in advance of the test? Nearby wells simultaneously tested or monitored if required by the well site approval? Aquifer test plan for a well in a GWMA includes yield and drawdown test? Aquifer test plan protocol approved by ODW in advance of testing?	Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐
Water Quality Tests (12VAC5-590-840) K	

A new, modified, or reconditioned well or spring? Samples analyzed by DCLS or a laboratory certified by DCLS for each method/analyte? Analytical methods conform to requirements in 12VAC5-590-440? TNCs - nitrate and nitrite only SOCs tests waived by ODW? Community and NTNC: inorganics, metals, radiological, VOCs, nitrate/nitrite, cyanide and SO's collected (unless SOCs waived)? Summarize sample results in the table on the last page of this checklist?	Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐
If any MCL exceedances, VOC detects, etc., are there adequate plans to treat? Summarize:	Yes ☐ No ☐ N/A ☐
New or deepened well (if yes, requirements follow)? 20 MPNs collected, 30 min apart, during the last 10 hr. of yield and drawdown? Geometric mean total coliform: E. Coli detections: GWUDI determination/Date: Disinfection required? Modified or reconditioned well (if yes, requirements follow)? At least two MPN samples collected at least 30 minutes apart, while the pump is in continuous operation. Summarize sample results:	Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐
Well Appurtenances (12VAC5-590-840 I)	
● Sanitary seal or water tight well cap (pitless adapter)? ● Well casing extends at least 12 inches above the concrete floor or well apron? ● Screened downward-facing vent, or suitable alternative? ● Suitable raw water sampling tap available? ● Totalizing flow meter (upstream of blowoff)? (12VAC5-590-1065 D 2)	Yes ☐ No ☐ Yes ☐ No ☐ Yes ☐ No ☐

● Equipment and appurtenances for measuring water level provided, corrosion resistant, and firmly supported by the drop pipe or pump column and in a manner to prevent entrance of foreign materials? ● Allpitlesswell units, adapters, and watertight caps listed by the Water Systems Council as certified products or approved by ODW? ● Apron 6 in thick x 6 ft x 6 ft centered on well	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐
Piping, valves, and meters (also see 12 VAC 5-590-1065)	
Discharge Piping ● Accessible check valve and gate valve provided? ● Control valves above floor? ● Standard pressure gauge displays under all conditions? ● Blowoff provided for pumping to waste away from source? ○ Erosion protection at point of waste discharge? (recommended) ○ Not cross connected? ○ Discharge capped or screened? ● Protected against freezing?	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐

Well House (if applicable)	
Locking entrance?	Yes ☐ No ☐ N/A ☐
Overhead access provided & adequately secured?	Yes ☐ No ☐ N/A ☐
Light & heat provided? (12 VAC 5-590-1040)	Yes ☐ No ☐ N/A ☐
Well Pump	
Pump capacity	gpm
Is pump capacity less than or equal to the well yield, or adequately throttled?	Yes ☐ No ☐
Velocity through screen ≤ 0.1 ft/s	Yes ☐ No ☐ N/A ☐
Pump operation scheme adequate?	Yes ☐ No ☐
GWMA Only requirements (12VAC5-590-840 B)	
Not constructed with screens in multiple aquifers?	Yes ☐ No ☐ N/A ☐
Geophysical logging and formation sampling and Uniform Water Well Completion Report, Form GW-2, submitted?	Yes ☐ No ☐ N/A ☐
Observation and production wells constructed with gravel packs and grout in a manner that prevents movement between aquifers?	Yes ☐ No ☐ N/A ☐
Pump intake setting documented, and the pump intake not set below the top of a confined aquifer or the bottom of an unconfined aquifer that supplies water to the well?	Yes ☐ No ☐ N/A ☐
All zones containing water of undesirable quality or zones to be protected but excluded from final completion are grouted at least five feet above the zone to at least five feet below the zone. (12VAC5-590-840 M)	Yes ☐ No ☐ N/A ☐
Gravel Packed Wells (12VAC5-590-840 N)	
• The gravel utilized is free of foreign material, properly sized, washed, and then disinfected before or during placement. • The gravel refill pipes, when used, are incorporated within the pump foundation or concrete apron and terminated with screwed or welded caps at least 12 inches above the pump house floor or concrete apron. • The gravel refill pipes in the grouted annular opening shall be surrounded by a minimum of 1-1/2 inches of grout. • A means for the prevention of leakage of grout into the gravel pack of the screen shall be provided. • The minimum protective casing and grouted depth shall be acceptable to the department. • Wells located in a GWMA shall have gravel packing installed in accordance with 12VAC5-590-840 B 3.	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐

	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐
Flowing artesian wells (12VAC5-590-840 P)	
● Flowing artesian wells located outside a GWMA will be considered on an individual basis by the department. ● The well is equipped with a pitless adapter specifically designed for pressurized artesian wells? ● Contacted field office to determine special well construction, casing, and sealing for flowing artesian wells? ● If yes, describe requirements:	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐
Disinfection (12VAC5-590-840 J)	
New, modified, or reconditioned groundwater well or spring is disinfected after placement of the final pumping equipment?	Yes ☐ No ☐ N/A ☐
Wells are disinfected in accordance with AWWA Standard C654-13?	Yes ☐ No ☐ N/A ☐
Capacities of Wells (12VAC5-590-840 Q)	
Wells used for community waterworks meet the daily water demand?	Yes ☐ No ☐ N/A ☐
Capacity of wells located in consolidated rock formations is determined from the lesser of: ● (A x 1440 min/day) / 1.8 = gpd well sustainable yield, where A = well yield (gpm) determined by the yield and drawdown test ● Installed well pump capacity. Capacity of wells located in unconsolidated formations is determined from the lesser of: ● well yield ● Installed well pump capacity.	Well Yield: ________________(gpd) Well sustainable yield: ________________(gpd) Well Pump Capacity: ________________(gpd) Well Capacity: ________________(gpd)
Waterworks serving 50 or more residential connections (12VAC5-590-840 R)	
● Waterworks serving 50 or more residential connections employing only wells providing the source water include at least two wells?	Yes ☐ No ☐ N/A ☐

• If only two wells are provided, then the second well is rated for at least 30% of the waterworks permit capacity.	Yes ☐ No ☐ N/A ☐
Waterworks serving fewer than 50 residential connections (12VAC5-590-840 S)	
• A waterworks serving fewer than 50 residential connections with a single well providing the source water shall provide or have ready access to a replacement pump and other components and materials needed for pump replacement. • Alternatively, the owner may provide 48 hours of total finished water storage volume based on the maximum daily water demand.	Yes ☐ No ☐ N/A ☐ Yes ☐ No ☐ N/A ☐